CO2 Mass transfer model for carbonic anhydrase-enhanced aqueous MDEA solutions

In this study a CO2 mass transfer model was developed for carbonic anhydrase-enhanced MDEA solutions based on a mechanistic kinetic enzyme model. Four different enzyme models were compared in their ability to predict the liquid side mass transfer coefficient at temperatures in the range of 298 to 328 K, solvent concentrations in the range 15 to 50 wt%, CO2 partial pressures up to 50 kPa, solvent loading between 0 and 0.5 mole CO2 per mole MDEA and enzyme concentrations up to 8.5 g/L. The reversible Michaelis Menten model (MR) and the simplified model with product inhibition by the bicarbonate ion (SP) were able to predict the mass transfer with an absolute average relative deviation of less than 15%. The MR model could account for every influence (solvent concentration, temperature, solvent loading, CO2 partial pressure) of the different process conditions on the mass transfer, whereas the SP model is limited to applications with low CO2 partial pressure such as CCS from coal burning power plants. Two other models that were also investigated are not suitable for implementation into an absorber column simulation, as they cannot describe the influence of changing solvent loading on the mass transfer.

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A generic methodology for processing route synthesis and design based on superstructure optimization

In this paper, a systematic framework for novel and sustainable synthesis-design of processing routes is presented along with the associated computer-aided methods and tools. In Stage 1, superstructure optimization is used to determine the optimal processing route(s). In Stage 2, the design issues are resolved and targets for improvement are identified through the use of integrated tools. In Stage 3, new alternatives are generated using the selected route and the previously identified targets. In addition to the various computer-aided tools, two special tools are presented: (1) a database employing a specially developed knowledge representation system, and (2) Super-O, a software interface that guides users through the formulation and solution of synthesis problems. Super-O transfers data between the different tools, including a library of generic models, representing a wide range of processing options. Application of the synthesis and design stages is highlighted through two case studies (biorefinery and carbon capture-utilization).

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Organisations: Department of Chemical and Biochemical Engineering, KT Consortium, CAPEC-PROCESS, Technical University of Denmark
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A Reaction Database for Small Molecule Pharmaceutical Processes Integrated with Process Information
This article describes the development of a reaction database with the objective to collect data for multiphase reactions involved in small molecule pharmaceutical processes with a search engine to retrieve necessary data in investigations of reaction-separation schemes, such as the role of organic solvents in reaction performance improvement. The focus of this reaction database is to provide a data rich environment with process information available to assist during the early stage synthesis of pharmaceutical products. The database is structured in terms of reaction classification of reaction types; compounds participating in the reaction; use of organic solvents and their function; information for single step and multistep reactions; target products; reaction conditions and reaction data. Information for reactor scale-up together with information for the separation and other relevant information for each reaction and reference are also available in the database. Additionally, the retrieved information obtained from the database can be evaluated in terms of sustainability using well-known “green” metrics published in the scientific literature. The application of the database is illustrated through the synthesis of ibuprofen, for which data on different reaction pathways have been retrieved from the database and compared using “green” chemistry metrics.

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Automated Determination of Oxygen-Dependent Enzyme Kinetics in a Tube-in-Tube Flow Reactor
Enzyme-mediated oxidation is of particular interest to synthetic organic chemists. However, the implementation of such systems demands knowledge of enzyme kinetics. Conventionally collecting kinetic data for biocatalytic oxidations is fraught with difficulties such as low oxygen solubility in water and limited oxygen supply. Here, we present a novel method for the collection of such kinetic data using a pressurized tube-in-tube reactor, operated in the low-dispersed flow regime to generate time-series data, with minimal material consumption. Experimental development and validation of the instrument revealed not only the high degree of accuracy of the kinetic data obtained, but also the necessity of making measurements in this way to enable the accurate evaluation of high K_MO enzyme systems. For the first time, this paves the way to integrate kinetic data into the protein engineering cycle.

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Bioprocess intensification for the effective production of chemical products

The further implementation of new bioprocesses, using biocatalysts in various formats, for the synthesis of chemicals is highly dependent upon effective process intensification. The need for process intensification reflects the fact that the conditions under which a biocatalyst carries out a reaction in nature are far from those which are optimal for industrial processes. In this paper the rationale for intensification will be discussed, as well as the four complementary approaches used today to achieve bioprocess intensification. Two of these four approaches are based on alteration of the biocatalyst (either by protein engineering or metabolic engineering), resulting in an extra degree of freedom in the process design. To date, biocatalyst engineering has been developed independently from the conventional process engineering methodology to intensification. Although the integration of these two methodologies has now started, in the future synergistic integration should enable many new opportunities for bioprocesses for the production of chemicals.

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Characterization of a continuous agitated cell reactor for oxygen dependent biocatalysis

Biocatalytic oxidation reactions employing molecular oxygen as the electron acceptor are difficult to conduct in a continuous flow reactor because of the requirement for high oxygen transfer rates. In this paper, the oxidation of glucose to glucono-1,5-lactone by glucose oxidase was used as a model reaction to study a novel continuous agitated cell reactor (ACR). The ACR consists of ten cells interconnected by small channels. An agitator is placed in each cell, which mixes the content of the cell when the reactor body is shaken by lateral movement. Based on tracer experiments, a hydrodynamic model for the ACR was developed. The model consisted of ten tanks-in-series with back-mixing occurring within and between each cell. The back-mixing was a necessary addition to the model in order to explain the observed phenomenon that the ACR behaved as two continuous stirred tank reactors (CSTRs) at low flow rates, while it at high flow rates behaved as the expected ten CSTRs in series. The performance of the ACR was evaluated by comparing the steady state conversion at varying residence times with the conversion observed in a stirred batch reactor of comparable size. It was found that the ACR could more than double the overall reaction rate, which was solely due to an increased oxygen transfer rate in the ACR caused by the intense mixing as a result of the spring agitators. The volumetric oxygen transfer coefficient, kL a, was estimated to be 344 h⁻¹ in the 100mL ACR, opposed to only 104 h⁻¹ in a batch reactor of comparable working volume. Interestingly, the large deviation from plug flow behavior seen in the tracer experiments was found to have little influence on the conversion in the ACR, since both a plug flow reactor (PFR) model and the backflow cell model described the data sufficiently well. Biotechnol. Bioeng. 2017;9999: 1-9. © 2017 Wiley Periodicals, Inc.

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Computational chemical product design problems under property uncertainties

Three different strategies of how to combine computational chemical product design with Monte Carlo based methods for uncertainty analysis of chemical properties are outlined. One method consists of a computer-aided molecular design (CAMD) solution and a post-processing property uncertainty propagation through the considered process. It is demonstrated for an industrial case study on identification of a suitable working fluid in a thermodynamic cycle for waste heat recovery. The results show that including property uncertainties gives an additional criterion for the fluid ranking in working fluid design. While the higher end of the uncertainty range of the process model output is similar for the best performing fluids, the lower end of the uncertainty range differs largely.

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Design and simulation of rate-based CO₂ capture processes using carbonic anhydrase (CA) applied to biogas

Today the mix of the energy sector is changing from reduction of CO₂ emission from fossil fueled power industry into a general focus on renewable industry which is emitting less greenhouse gases. Renewable fuels like biomass for electricity production or biogas for bio-methane production have a potential to create negative emissions using bio-energy carbon capture and storage (BECCS).

All sectors are still in the need for applying more sustainable carbon capture and storage (CCS) technologies which result in lower energy consumption while reducing the impact on the environment. Recently several promoters have been developed for solvent based technologies, but there is still a need to develop new approaches which can potentially reduce energy consumption even further. Solvents typically used for CCS have the tendency to form carbamate. They are characterized by the speed at which they react with CO₂. Advantageous kinetics results in smaller equipment size. But this is not the only benefit.

In this study we deliberately apply a slow reacting solvent, MDEA (methyl-diethanolamine). It is in the category of noncarbamate forming tertiary amines, for the same reason it binds less hard to CO₂. The advantage is a noticeably lower regeneration energy compared to primary and secondary amines. As a result the cost for stripping is significantly lower. Reactivated slow tertiary amines are applied in this study with the aim of reducing energy consumption. This is achieved by using carbonic anhydrase (CA) enzymes as additives in the slow solvent. The aim of this work is to develop a rate-based model for tertiary MDEA mixed with various amounts of CA. The results show that the properties for biogas are significantly different compared to air and may need to be treated accordingly accurate. This work proves that the typical mass transfer resistance observed in the biogas gas phase is low compared to the resistance in the liquid phase. The consequence is a reduced requirement for accurate properties for the biogas and the biogas can easily be modelled as being similar to air. In this work we create a calculation engine which is capable of BECCS, thereby enabling prevention of CO₂ emissions from renewable technologies giving a potential for zero-emission scenarios which can help to reach the new low emission CO₂ target set up by COP21.
Development of a thiol-ene based screening platform for enzyme immobilization demonstrated using horseradish peroxidase

Efficient immobilization of enzymes on support surfaces requires an exact match between the surface chemistry and the specific enzyme. A successful match would normally be identified through time consuming screening of conventional resins in multiple experiments testing individual immobilization strategies. In this study we present a versatile strategy that largely expands the number of possible surface functionalities for enzyme immobilization in a single, generic platform. The combination of many individual surface chemistries and thus immobilization methods in one modular system permits faster and more efficient screening, which we believe will result in a higher chance of discovery of optimal surface/enzyme interactions. The proposed system consists of a thiol-functional microplate prepared through fast photochemical curing of an off-stoichiometric thiol-ene (OSTE) mixture. Surface functionalization by thiol-ene chemistry (TEC) resulted in the formation of a functional monolayer in each well, whereas, polymer surface grafts were introduced through surface chain transfer free radical polymerization (SCT-FRP). Enzyme immobilization on the modified surfaces was evaluated by using a rhodamine labeled horseradish peroxidase (Rho-HRP) as a model enzyme, and the amount of immobilized enzyme was qualitatively assessed by fluorescence intensity (FI) measurements. Subsequently, Rho-HRP activity was measured directly on the surface. The broad range of utilized surface chemistries permits direct correlation of enzymatic activity to the surface functionality and improves the determination of promising enzyme-surface candidates. The results underline the high potential of this system as a screening platform for synergistic immobilization of enzymes onto thiol-ene polymer surfaces. This article is protected by copyright. All rights reserved.
Development of in-situ product removal strategies in biocatalysis applying scaled-down unit operations

An experimental platform based on scaled-down unit operations combined in a plug-and-play manner enables easy and highly flexible testing of advanced biocatalytic process options such as in-situ product removal (ISPR) process strategies. In such a platform it is possible to compartmentalize different process steps while operating it as a combined system, giving the possibility to test and characterize the performance of novel process concepts and biocatalysts with minimal influence of inhibitory products. Here the capabilities of performing process development by applying scaled-down unit operations are highlighted through a case study investigating the asymmetric synthesis of 1-methyl-3-phenylpropylamine (MPPA) using ω-transaminase, an enzyme in the sub-family of amino transferases (ATAs). An on-line HPLC system was applied to avoid manual sample handling and to semi-automatically characterize ω-transaminases in a scaled-down packed-bed reactor (PBR) module, showing MPPA as a strong inhibitor. To overcome the inhibition, a two-step liquid-liquid extraction (LLE) ISPR concept was tested using scaled-down unit operations combined in a plug-and-play manner. Through the tested ISPR concept, it was possible to continuously feed the main substrate benzylacetone (BA) and extract the main product MPPA throughout the reaction, thereby overcoming the challenges of low substrate solubility and product inhibition. The tested ISPR concept achieved a product concentration of 26.5 g MPPA L⁻¹, a purity up to 70% g MPPA L⁻¹, and a recovery in the range of 80% mol-mol⁻¹ of MPPA in 20 hours, with the possibility to increase the concentration, purity and recovery further. This article is protected by copyright. All rights reserved
Effect of Water Clustering on the Activity of Candida antarctica Lipase B in Organic Medium

The effect of initial water activity of MTBE (methyl tert-butyl ether) medium on CALB (Candida antarctica lipase B) catalyzed esterification reaction is investigated using experimental methods and classical molecular dynamics (MD) simulations. The experimental kinetic studies show that the initial reaction rate of CALB-catalyzed esterification reaction between butyric acid and ethanol decreases with increasing initial water activity of the medium. The highest rate of esterification is observed at the lowest water activity studied. MD simulations were performed to gain a molecular insight on the effect of initial water activity on the rate of CALB-catalyzed reaction. Our results show that hydration has an insignificant effect on the structure and flexibility of CALB. Rather, it appears that water molecules bind to certain regions ("hot spots") on the CALB surface and form clusters. The size of the water clusters at these hot spot regions gradually increase and expand with increasing water activity. Consequently, the surface area of CALB covered by the water molecules also increases. Specifically, our results indicate that a particular water cluster located close to the active site partially cover the binding pocket of substrate at high water activity. As a consequence, the effective concentration of substrate at the catalytic site decreases. Therefore, the reaction rate slows down with increasing water activity, which correlates well with the observed decrease in the experimentally determined initial reaction rate.
Experimental and computational evaluation of area selectively immobilized horseradish peroxidase in a microfluidic device

A microreactor with a square shaped reactor chamber was developed with the aim to correlate enzyme positioning with biocatalytic activity. The enzyme position as an important parameter to improve the contribution of the individual enzymes towards the overall reactor efficacy was therefore evaluated experimentally and by computational fluid dynamics (CFD) simulations. Ultimately, such a correlation would lead to faster development through computational pre-screening and optimized experimental design. In this proof-of-concept study, microreactors were prepared in a 2-step curing process of an off-stoichiometric thiol-ene-epoxy (OSTE+) mixture employing both a thiol-ene (TEC) and a thiol-epoxy curing reaction. Subsequent surface functionalization of the remaining thiol groups on the reactor surface through stenciled photoinitiated TEC enabled the preparation of specific surface patterns in the reactor. Patterns were visualized using an allyl-functional disperse red dye, illustrating the successful preparation of a fully reacted surface, a half covered surface and 2 checkerboard patterns. Similarly, allyl glycidyl ether was exploited to functionalize the microreactor surface with epoxide groups, which were used for covalent immobilization of horseradish peroxidase (HRP) in the same patterns. Biocatalytic activity measurements confirmed a clear dependency of the overall reactor performance depending on the spatial distribution of the immobilized enzymes, where specifically the two checkerboard motifs were identified as being particularly effective compared to enzymes covering homogeneously the entire reactor surface. The performance of the same configurations was additionally determined by 3-dimensional CFD simulations. The computational model predicted the same tendencies for the overall reactor performance as obtained from experimental determination. This good agreement between the obtained experimental and computational results confirmed the high potential of CFD models for predicting and optimizing the biocatalytic performance of such a reactor.
Influence of temperature and solvent concentration on the kinetics of the enzyme carbonic anhydrase in carbon capture technology

In this study the effect of carbonic anhydrase addition on the absorption of CO₂ was investigated in a wetted wall column apparatus. Four different solvents: the primary amine monoethanolamine (MEA), the sterically hindered primary amine 2-amino-2-methyl-1-propanol (AMP), the tertiary amine N-methyl-diethanolamine (MDEA) and the carbonate salt solution K₂CO₃ were compared in concentrations from 5 to 50 wt% in a temperature range of 298–328 K with and without enzyme. Necessary mass transfer parameters such as liquid side mass transfer coefficient and solvent and enzyme reaction rates were determined and benchmarked to a 30 wt% MEA solution. The study reveals that the addition of the enzyme carbonic anhydrase (CA) dramatically increases the liquid side mass transfer coefficient for MDEA, and K₂CO₃; AMP has a moderate increase whereas MEA was unchanged. The results confirm that just bicarbonate forming systems benefit from CA. The influence of temperature on the enzyme kinetics and mass transfer coefficients is different for different solvent types. A temperature increase resulted in lower liquid side mass transfer coefficient for MDEA and K₂CO₃ but in a higher coefficient for AMP. The overall first order enzyme reaction rate (s⁻¹) was linearly dependent on enzyme concentration for MDEA and K₂CO₃ at 313 K. Temperature and concentration did increase the enzymatic rate constant slightly in the concentration range of 5–15 wt% K₂CO₃ and significantly between 15 and 20 wt%. The enzymatic reaction rate constant for MDEA decreased with temperature, the solvent concentration had a negligible on it. The enzymatic reaction rate for AMP rose with temperature and was higher for lower solvent concentration.

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Integrated computer-aided framework for chemical product and process application design and optimization for waste heat recovery

This contribution presents an integrated framework for product-process design. The framework integrates the two design problems into one and finds the optimal solution through simultaneous optimization. The framework consists of four hierarchical steps and uses a set of methods, tools and databases for property prediction, novel fluid design and mathematical programming. The application of the framework is targeted for waste heat recovery design systems, where the sensitivity of product and process design variables is high and the simultaneous design is necessary. The sustainable design solutions are showcased in this paper for mixed refrigeration design.

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Integrated working fluid-thermodynamic cycle design of organic Rankine cycle power systems for waste heat recovery

Today, some established working fluids are being phased out due to new international regulations on the use of environmentally harmful substances. With an ever-increasing cost to resources, industry wants to converge on improved sustainability through resource recovery, and in particular waste heat recovery. In this paper, an organic Rankine cycle process and its pure working fluid are designed simultaneously for waste heat recovery of the exhaust gas from a marine diesel engine. This approach can overcome design issues caused by the high sensitivity between the fluid and cycle design variables and otherwise high resource demands, which through conventional methods cannot be addressed. The global optimal design was a 1.2MW cycle with 2,2,3,3,4,4,5,5-octafluorohexane as the new fluid. The fluid has no ozone depletion potential and a global warming potential under the regulatory limit. By using the simultaneous design approach the optimum solution was found in 5.04 s, while a decomposed approach found the same solution in 5.77 h. However, the decomposed approach provided insights on the correlation between the fluid and cycle design variables by analyzing all possible solutions. It was shown that the high sensitivity between the fluid and cycle design variables was overcome by using the simultaneous approach. Correlation between net power output and the product of the overall heat transfer coefficient and the heat transfer area could further be addressed by employing a new solution strategy including maximum constraints for this product. The use of such constraints resulted in the design of a new fluid (5-chloro-4,5,5-trifluoro-2,3-dimethylpent-2-ene) with a 1.25 MW net power output. Finally, a comparison with conventional fluids was shown where 2,2,3,3,4,4,5,5-octafluorohexane offered an improvement on net power output and economic and environmental metrics.
Model-based design and analysis of glucose isomerization process operation

The application of model-based methods for design and analysis of operational improvements of an industrial glucose isomerization (GI) process is highlighted. First, a multi-scale mathematical model representing important phenomena encountered in the reaction system of a glucose isomerization reactor is developed. Next, model analysis, model identification and model validation based on available reactor operational data are performed. The reactor model is found to describe accurately important phenomena, such as, reaction kinetics, enzyme decay and internal diffusion of the substrate in the enzymatic pellet as a function of the temperature, thereby confirming that the model is ready for use in design-analysis studies. Operation of the GI process is then analyzed in a single reactor and based on this, the reactor model is used as a building block to represent the operation of a GI reactor plant consisting of 10–20 reactors in parallel. The design of the GI plant operation is evaluated through the analysis of simulated results of different operational scenarios.

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Online Measurement of Oxygen-Dependent Enzyme Reaction Kinetics

As the application of biocatalysis to complement conventional chemical and catalytic approaches continues to expand, an increasing number of reactions involve poorly-water soluble substrates. At required industrial concentrations necessary for industrial implementation, this frequently leads to heterogeneous reaction mixtures composed of multiple phases. Such systems are challenging to sample and therefore it is problematic to measure representative component concentrations. In this work we demonstrate and validate an online method for following the progress of oxygen-dependent reactions through accurate measurement of the oxygen mass balance in the gas-phase of a reactor. The method was successfully validated and demonstrated using two model reactions: firstly the oxidation of glucose by glucose oxidase and secondly the Baeyer-Villiger oxidation of macrocyclic ketones to lactones. Initial reaction rate constants and time-course progressions calculated from the oxygen mass balance were validated against conventional online methods of dissolved oxygen tension and pH titration measurements. A feasible operating window as well as the sensitivity to dynamic changes of reaction rates was established by controlling oxygen transfer via the operating parameters of the reactor. Such kinetic data forms the basis for reaction characterisation, from which bottlenecks may be made evident and directed improvement strategies can be identified and implemented.
Operating considerations of ultrafiltration in enzyme enhanced carbon capture

Today, enzyme enhanced carbon capture and storage (CCS) is gaining interest, since it can enable the use of energy efficient solvents, and thus potentially reduce the carbon footprint of CCS. However, a limitation of this technology is the high temperatures encountered in the stripper column, which can deactivate the enzymes. One solution to this challenge is the use of ultrafiltration to retain the enzyme in the absorber unit. In this report, a base case of a CCS facility is used to model the impact of such membranes for use in a full scale CCS commercial plant. The base case has an approximate capture capacity of 1 MTonn CO₂/year, and is here operated for one year continuously. This publication compares soluble enzymes dissolved in a capture solvent with and without the use of ultrafiltration membranes. The membranes used here have an enzyme retention of 90%, 99% and 99.9%. Enzyme retention is the amount of enzyme that is retained in the absorption column in each cycle. These membranes were modeled with five stripper temperatures 60 °C, 70 °C, 80 °C, 90 °C and above 100 °C. Enzyme deactivation follows a 1st order rate and increases with increasing temperatures. It was found that for all stripper temperatures used in this model, deactivation rates were too high for continuous operation over 1 year, without adding additional enzyme, if an activity of at least 50% should be maintained. With increasing stripper temperatures the membrane retention requirement increased. To retain over 50% activity over a whole year at 70 °C stripper temperature required a membrane of 90% or higher enzyme retention, at stripper temperatures of 90 °C a membrane of 99.9% retention was required for the same result. Finally, it was investigated if stripper temperatures over 100 °C, where instant deactivation was modeled could be used. It was found that with enzyme retention of 99.9%, with instant deactivation, after 1 month 50% of the activity is lost. Thus the use of membranes in enzyme enhanced CCS might be restricted to temperatures below 100 °C, or temperatures the enzyme can withstand for shorter time periods.

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Operating_considerations_of_ultrafiltration.pdf
Pilot absorption experiments with carbonic anhydrase enhanced MDEA

Mass transfer experiments were carried out on DTU’s pilot absorber unit, a 10 m high column packed with 250 Y Mellapak structured packing. The influence of temperature, solvent loading, column height and liquid flow rates on absorption performance were determined for a 30 wt% N-methyl-diethanolamine (MDEA) solvent, with and without the enzyme carbonic anhydrase (CA). The absorption experiments were performed at atmospheric pressure and gas phase carbon dioxide mole fraction of 0.13. During experiments liquid samples were withdrawn at each meter of column height and the solvent loading was determined by both a density method and the BaCl2 method. After the solvent was loaded to equilibrium it was heated up and reintroduced into the column, where CO2 was stripped off using air as stripping gas. The addition of CA increased the mass transfer significantly in all experiments. Lower absorption temperatures resulted in higher mass transfer in absorption, when 28 and 40 ºC inlet temperature were chosen. The absorption performance decreased with lower solvent flow. The enzyme was also capable of enhancing the desorption process, where higher desorption rates were measured at 45 and 50 ºC with CA enhanced solvent compared to 55 ºC without CA.
Prediction of properties of new halogenated olefins using two group contribution approaches

The increasingly restrictive regulations for substances with high ozone depletion and global warming potentials are driving the search for new sustainable fluids with low environmental impact. Recent research works have pointed out the great potential of fluorine- and chlorine-based olefins as refrigerants and solvents, due to their environmentally-friendly features. However there is a lack of experimental data of their thermophysical properties. In this work we present two models based on a group contribution method, using a classical approach and neural networks, to predict the critical temperature, critical pressure, normal boiling temperature, acentric factor, and ideal gas heat capacity of organic fluids containing chlorine and/or fluorine. The accuracy of the prediction capacity of the two models is analyzed, and compared with equivalent methods in the literature. The models showed an average reduction of the absolute relative deviation for all the studied properties of more than 50%, compared to other methods. In addition, it was observed that the neural-network-based model yielded a better accuracy than the classical approach in the prediction of all the properties, except for the acentric factor, due to the lack of experimental data for this property.

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Organisations: Department of Mechanical Engineering, Thermal Energy, Department of Chemical and Biochemical Engineering, CAPEC-PROCESS
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Rate-based modelling and validation of a pilot absorber using MDEA enhanced with carbonic anhydrase (CA)

The great paradox of the 21st century is that we must meet the increasing global demand for energy and products while simultaneously mitigating the climate change. If both these criteria are to be met, carbon capture and storage is an imperative technology for sustainable energy infrastructure development. Post-combustion capture is a mature capture technology, however, to make it economically attractive, design of innovative solvents and process optimization is of crucial importance. An example for promising solvent is MDEA enhanced with carbonic anhydrase (CA), due to its fast kinetics and low solvent-regeneration energy demand. The focus of this work is to develop a rate-based model for CO₂ absorption using MDEA enhanced with CA and to validate it against pilot-scale absorption experiments. In this work, we compare model predictions to measured temperature and CO₂ concentration profiles for different L/G ratios, lean CO₂ loadings, gas CO₂ content and packing height. We show that the developed model is suitable for CO₂ capture simulation and optimization using MDEA and MDEA enhanced with CA. Furthermore, we investigate the accuracy of the General Method (GM) enhancement factor model for CO₂ absorption/desorption using wetted-wall column data: 0 to 0.5 CO₂ loading and temperatures between 298 and 328 K. The present study represents a first step towards developing and optimizing a CA promoted MDEA CO₂ capture process.
Reaction Equilibrium of the ω-Transamination of (S)-Phenylethylamine: Experiments and ePC-SAFT Modeling
This work focuses on the thermodynamic equilibrium of the ω-transaminase-catalyzed reaction of (S)-phenylethylamine with cyclohexanone to acetophenone and cyclohexylamine in aqueous solution. For this purpose, the equilibrium concentrations of the reaction were experimentally investigated under varying reaction conditions. It was observed that the temperature (30 and 37 °C), the pH (between pH 7 and pH 9), as well as the initial reactant concentrations (between 5 and 50 mmol·kg⁻¹) influenced the equilibrium position of the reaction. The position of the reaction equilibrium was moderately shifted toward the product side by either decreasing temperature or decreasing pH. In contrast, the initial ratio of the reactants showed only a marginal influence on the equilibrium position. Further experiments showed that increasing the initial reactant concentrations significantly shifted the equilibrium position to the reactant side. In order to explain these effects, the activity coefficients of the reacting agents were calculated and the activity-based thermodynamic equilibrium constant $K_{th}$ of the reaction was determined. For this purpose, the activity coefficients of the reacting agents were modeled at their respective experimental equilibrium concentrations using the equation of state electrolyte PC-SAFT (ePC-SAFT). The combination of the concentrations of the reacting agents at equilibrium and their respective activity coefficients provided the thermodynamically consistent equilibrium constant $K_{th}$. Unexpectedly, the experimental $K_m$ values deviated by a factor of up to four from the thermodynamic equilibrium constant $K_{th}$. The observed concentration dependency of the experimental $K_m$ values could be explained by the influence of concentration on activity coefficients. Further, these activity coefficients were found to be strongly temperature dependent, which is important for the determination of standard enthalpy of reactions, which in this work was found to be $+7.7 \pm 2.8$ kJ·mol⁻¹. Using the so-determined $K_{th}$ and activity coefficients of the reacting agents (ePC-SAFT), the equilibrium concentrations of the reaction were predicted for varying initial reactant concentrations, which were found to be in good agreement with the experimental behavior. These results showed a non-negligible influence of the activity coefficients of the reacting agents on the equilibrium position and, thus, on the product yield. Experiments and ePC-SAFT predictions showed that the equilibrium position can only be described accurately by taking activity coefficients into account.

General Information
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Role of Biocatalysis in Sustainable Chemistry

Based on the principles and metrics of green chemistry and sustainable development, biocatalysis is both a green and sustainable technology. This is largely a result of the spectacular advances in molecular biology and biotechnology achieved in the past two decades. Protein engineering has enabled the optimization of existing enzymes and the invention of entirely new biocatalytic reactions that were previously unknown in Nature. It is now eminently feasible to develop enzymatic transformations to fit predefined parameters, resulting in processes that are truly sustainable by design. This approach has successfully been applied, for example, in the industrial synthesis of active pharmaceutical ingredients. In addition to the use of protein engineering, other aspects of biocatalysis engineering, such as substrate, medium, and reactor engineering, can be utilized to improve the efficiency and cost-effectiveness and, hence, the sustainability of biocatalytic reactions. Furthermore, immobilization of an enzyme can improve its stability and enable its reuse multiple times, resulting in better performance and commercial viability. Consequently, biocatalysis is being widely applied in the production of pharmaceuticals and some commodity chemicals. Moreover, its broader application will be further stimulated in the future by the emerging biobased economy.
Shape optimization as a tool to design biocatalytic microreactors

Reactor design is commonly constrained to already well-known reactor shapes. This article presents an innovative application of shape optimization techniques to design biocatalytic microreactors. Currently, the optimization of reactor performance is often done by considering solely the process conditions. However, common reactor types used in (bio)chemical processes do not always give the optimal conditions for executing the reaction, and it is therefore necessary to look into new approaches to further improve the performance of reactors. The new application of shape optimization described in this paper has as its main goal the design of a reactor by compensating for the limitations of the reaction system by modifying the reactor configuration. Random search was the optimization method chosen for transforming the initial reactor configuration to a more optimal one.

The case study presented here investigates the impact of a change to the microreactor shape on the active mixing of two parallel streams (one containing an enzyme, amino transaminase, and the other the substrates, acetophenone and isopropylamine) and consequently its influence on the reaction yield. Compared to the original reactor configuration, the shape optimization resulted in changes of the microreactor wall surfaces leading to an 8.4 fold improvement of the reactor yield. This innovative optimization also offers the opportunity to obtain new structures which can later be tested experimentally.

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Simple preparation of thiol-ene particles in glycerol and surface functionalization by thiol-ene chemistry (TEC) and surface chain transfer free radical polymerization (SCT-FRP)

Thiol-ene (TE) based polymer particles have traditionally been prepared via emulsion polymerization in water (using surfactants, stabilizers and co-solvents). Here, we present a green and simple alternative with excellent control over particle size, while avoiding the addition of stabilizers. Glycerol is applied as a dispersing medium for the preparation of offstoichiometric TE (OSTE) microparticles, where sizes in the range of 40 to 400 µm are obtained solely by changing the mixing speed of the emulsions prior to cross-linking. Control over surface chemistry is achieved by surface functionalization of excess thiol groups via photochemical thiol-ene chemistry (TEC) resulting in a functional monolayer. In addition, surface chain transfer free radical polymerization (SCT-FRP) was used for the first time to introduce a thicker polymer layer on the particle surface. The application potential of the system is demonstrated by using functional particles as a support for immobilized enzymes in a continuous plug-flow reactor.
Ultrasound-assisted production of biodiesel FAME from rapeseed oil in a novel two-compartment reactor

Ultrasoundication has been proposed as a promising technique for enzymatic transesterification. In contrast, excess ultrasonication causes an enzyme inactivation. This paper presents enzymatic transesterification to produce fatty acid methyl ester (FAME) from rapeseed oil using Callera Trans L™ using a an original two-compartment reactor. The reactor was composed of a mechanically stirred compartment (ST) and ultrasound irradiation compartment (US). The reaction solution was recirculated between the ST and the US. The enzyme was only exposed by ultrasonication in the US. The reactor system has the option to control the direct irradiation period of ultrasonication to soluble enzyme, regulated by the mean residence time in the US.

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Upscaling of enzyme enhanced CO2 capture

Fossil fuels are the backbone of the energy generation in the coming decades for USA, China, India and Europe, hence high greenhouse gas emissions are expected in future. Carbon capture and storage technology (CCS) is the only technology that can mitigate greenhouse gas emissions from fossil fuel fired power by selectively capturing CO2 from flue gases. High capital and high operational costs of this process are the major obstacles of industrial implementation. In the field of CCS the chemical absorption process is the most mature technology. The use of kinetic rate promoters that enhance the mass transfer of CO2 with slow-capturing but energetically favorable solvents can open up a variety of new process options for this technology. The ubiquitous enzyme carbonic anhydrase (CA), which enhances the mass transfer of CO2 in the lungs by catalyzing the reversible hydration of CO2, is one very promising mass transfer rate promoter for CCS. This process has been previously been tested successfully in lab scale and in some rare cases in pilot scale, but no validated process model for this technology has been published yet.

This PhD thesis presents an investigation of the feasibility of enzyme enhanced CO2 capture technology by identifying the potentials and limitations in lab and in pilot scale and benchmarking the process against proven technologies. The main goal was to derive a realistic process model for technical size absorbers with a wide range of validity incorporating a mechanistic enzyme kinetic model and validating it against in-house pilot plant experiments. The work consisted of identifying a suitable enzyme-solvent system and the ideal process conditions by comparing mass transfer rates of different solvents and enzyme enhanced solvents in a lab scale wetted wall column. A kinetic model for the mechanistic enzyme reactions was developed for MDEA (N-methyl-diethanolamine) solutions capable of describing the mass transfer of CO2 for absorption and desorption. It incorporates the influence of all relevant process conditions for technical absorbers, such as: temperature, solvent concentration, enzyme concentration, CO2 concentration in the gas and liquid phase, as well as bicarbonate concentration in the liquid phase. The process with enzyme enhanced MDEA was scaled up, and absorption experiments were carried out on a 10 m high pilot absorber column. The influence of enzyme concentration, column height, as well as solvent flow rates were determined for 30 wt% MDEA in over 50 runs and compared to over 30 pilot plant runs with the industrial standard solvent 30 wt% MEA (monoethanolamine) under the same process conditions. The mass transfer performance of enzyme enhanced solutions was found to be close to the industrial standard.

The pilot plant experiments could be accurately predicted with the in-house absorber column model CAPCO2 after the kinetic enzyme model from the lab experiments was implemented. The model can very accurately simulate the influence of each process parameter tested. For targeting the thermal stability of the enzyme in desorption, an alternative low temperature process without reboiler was presented. A stripping gas carrier is utilized in this process to avoid thermal deactivation of the enzymes in the solvent regeneration; its technical feasibility was successfully tested in pilot scale desorption experiments. The experiments at lab and pilot scale have clearly proven CA’s potential in CCS. The presented validated absorber column model together with the low temperature regeneration process can be used to simulate and optimize the enzyme enhanced CO2 capture process and benchmark this novel technology against conventional processes.

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A Correlation between the Activity of Candida antarctica Lipase B and Differences in Binding Free Energies of Organic Solvent and Substrate

The ability of enzymes to operate in organic solvent is now widely accepted and is the basis for extensive research in enzymology. The challenge is to select the solvent media that allows the modulation of enzyme activity. For a rational selection of a solvent, it is necessary to understand the effect of organic solvent molecules on enzyme structure and the enzymatic reaction on a molecular level. To gain such insight, we combined experimental kinetics studies with full atomic molecular dynamics simulations and found a correlation between the activity of Candida antarctica lipase B (CALB) [for the esterification reaction between butyric acid and ethanol at a fixed water activity] and the binding of the solvent/substrate molecules in the active site region of CALB. We have investigated the influence of four organic solvents hexane (HEX), methyl tertiary butyl ether (MTBE), acetonitrile (ACN), and tertiary butanol (TBU)-on the catalytic activity of CALB for the esterification reaction. The solvents have been chosen on the basis of different polarity/functional groups. Our study shows that these organic solvents do not alter the overall conformation of CALB; rather, the solvent effects on the performance of the enzyme may be ascribed to binding of solvent molecules to the enzyme active site region and the solvation energy of substrate molecules in the different solvents. Polar solvent molecules interact strongly with CALB and compete with the substrate to bind to the active site region, resulting in an inhibitory effect which is also confirmed by the binding free energies for the solvent and substrate molecules estimated from the simulations. Consequently, the catalytic activity of CALB decreases in polar solvents. This effect is significant, and CALB is over 10 orders of magnitude more active in nonpolar solvents (HEX and MTBE) than in the polar solvents (ACN and TBU). TBU molecules show an exceptional behavior because the solvent molecule forms an extensive hydrogen bond network within the CALB active site region suggesting that solvent molecules rich on hydrogen bond acceptors and donors are poor solvents when used for lipase-catalyzed esterification reactions.
A microfluidic toolbox for the development of in-situ product removal strategies in biocatalysis

A microfluidic toolbox for accelerated development of biocatalytic processes has great potential. This is especially the case for the development of advanced biocatalytic process concepts, where reactors and product separation methods are closely linked together to intensify the process performance, e.g., by the use of in-situ product removal (ISPR). This review provides a general overview of currently available tools in a microfluidic toolbox and how this toolbox can be applied to the development of advanced biocatalytic process concepts. Emphasis is placed on describing the possibilities and advantages of the microfluidic toolbox that are difficult to achieve with conventional batch-process-based technologies. Application of this microfluidic toolbox will potentially make it possible to intensify biocatalytic reactions and thereby facilitate the development towards novel and advanced biocatalytic processes, which in many cases have proven too difficult in conventional batch equipment.

Application of NAD(P)H oxidase for cofactor regeneration in dehydrogenase catalyzed oxidations

Biocatalytic oxidations can offer clear advantages compared to chemically catalyzed oxidations in terms of chemo, regio and stereoselectivity as well as a reduced environmental impact. One of the most industrially important reactions is the oxidation of alcohols, which can be carried out using alcohol dehydrogenases. However, their effective use requires an effective regeneration of the oxidized nicotinamide cofactor (NAD(P)⁺), which is critical for the economic feasibility of the process. NAD(P)H oxidase is an enzyme class of particular interest for this cofactor regeneration since it enables the use of molecular oxygen as a substrate, generating either water or hydrogen peroxide as a by-product. The use of these enzymes is now gaining an increased interest, and several different enzymes of both types have been applied for proof-of-concept. In this review, we give an overview of the state-of-the-art, and discuss several important issues for future implementation in a production process.
NADH(P)H oxidase, Co-factor regeneration, Biooxidation, Oxidoreductase

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A Rapid Selection Procedure for Simple Commercial Implementation of omega-Transaminase Reactions

A stepwise selection procedure is presented to quickly evaluate whether a given omega-transaminase reaction is suitable for a so-called "simple" scale-up for fast industrial implementation. Here "simple" is defined as a system without the need for extensive process development or specialized equipment. The procedure may be used when investment in intensive process development cannot be justified or when rapid execution is paramount, for applications such as small singular batches. The three step evaluation procedure consists of: (1) thermodynamic assessment, (2) biocatalyst activity screening, and (3) determination of product inhibition. The method is exemplified with experimental work focused on two products: 1-(4-bromophenyl)ethylamine and (S)-(+)3-amino-1-Boc-piperidine, synthesized from their corresponding prochiral ketones each with two alternative amine donors, propan-2-amine, and 1-phenylethylamine. Each step of the method has a threshold value, which must be surpassed to allow "simple" implementation, helping select suitable combinations of substrates, enzymes, and donors. One reaction pair, 1-Boc-3-piperidone with propan-2-amine, met the criteria of the three-step selection procedure and was subsequently run at 25 mL scale synthesizing (S)-(+)3-amino-1-Boc-piperidine at concentrations up to 75 g/L. However, the highest product yield (70%) was obtained at a lower substrate concentration of 50 g/L.

General information
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Benchmarking of Processes for the Biosynthesis of Natural Products

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Bioinspired Multifunctional Membrane for Aquatic Micropollutants Removal
Micropollutants present in water have many detrimental effects on the ecosystem. Membrane technology plays an important role in the removal of micropollutants, but there remain significant challenges such as concentration polarization, membrane fouling, and variable permeate quality. The work reported here uses a multifunctional membrane with rejection, adsorption, and catalysis functions to solve these problems. On the basis of mussel-inspired chemistry and biological membrane properties, a multifunctional membrane was prepared by applying "reverse filtration" of a laccase solution and subsequent "dopamine coating" on a nanofiltration (NF) membrane support, which was tested on bisphenol A (BPA) removal. Three NF membranes were chosen for the preparation of the multifunctional membranes on the basis of the membrane properties and enzyme immobilization efficiency. Compared with the pristine membrane, the multifunctional membrane exhibited significant improvement of BPA removal (78.21 ± 1.95%, 84.27 ± 7.30%, and 97.04 ± 0.33% for NT103, NF270, and NF90, respectively), all of which are clearly superior to the conventional Fenton treatment (55.0%) under similar conditions and comparable to soluble laccase coupled with NF270 membrane filtration (89.0%). The
Improvement would appear to be due to a combination of separation (reducing the enzymatic burden), adsorption (enriching the substrate concentration as well as prolonging the residence time), and lastly, catalysis (oxidizing the pollutants and breaking the "adsorption saturation limits"). Furthermore, the synergistic effect of the polydopamine (PDA) layer on the enzymatic oxidation of BPA was confirmed, which was due to its enhanced adsorption and electron transfer performance. The multifunctional membrane could be reused for at least seven cycles with an acceptable activity loss, demonstrating good potential for removal of micropollutants.
Carbonic Anhydrase Enhanced Carbon Capture: Kinetic Measurements and Pilot Plant Trials

In this study the effect of carbonic anhydrase addition on the absorption of CO₂ was investigated in a wetted wall column apparatus. Four different solvents: MEA (a primary amine), AMP (a sterically hindered primary amine), MDEA (a tertiary amine) and K₂CO₃ a carbonate salt solution were tested in concentrations from 5 to 50 wt%. Necessary mass transfer parameters such as liquid side mass transfer coefficient and solvent and enzyme reaction rates were determined in a temperature range from 298 to 328 K and benchmarked to a 30 wt% MEA solution.

The study reveals that the addition of the enzyme carbonic anhydrase (CA) dramatically increases the liquid side mass transfer coefficient for 30 wt% MDEA and 15 wt% K₂CO₃. 30 wt% AMP has a moderate increase whereas 30 wt% MEA was unchanged. The results confirm that bicarbonate forming solvent which does not produce carbamate benefit from CA. The results reveal the impact of temperature in relation to CA. A temperature increase resulted in lower liquid side mass transfer rate for 30 wt% MDEA and 15 wt% K₂CO₃ but in higher rate for 30 wt% AMP. The overall first order enzyme reaction rate (s⁻¹) was linearly dependent on enzyme concentration for 30 wt% MEA and 15 wt% K₂CO₃ at 313 K. The derived enzymatic reaction rate constant kenz (m⁻³ kg⁻¹ s⁻¹) for 15 wt% K₂CO₃ at 313 K was about 9 times higher than for 30 wt% MDEA and 10 times higher than for 30 wt% AMP. Temperature and concentration did not observably influence the enzymatic rate constant in the concentration range of 5 to 15 wt% K₂CO₃. The higher solvent concentration only led to a slightly higher reaction rate. A solution with 20 wt% K₂CO₃ had almost 3 times higher enzyme reaction rate compared to 15 wt% at 328 K. The enzymatic reaction rate for MDEA decreased with both temperature and solvent concentration from 15 to 30 wt%. An increase to 50 wt% resulted in a decrease in reaction rate due to less water present.

Pilot plant campaigns were carried out for different solvents and conditions and the results were successfully modelled using intrinsic data obtained from the wetted-wall column experiments.

Characterization of water-forming NADH oxidases for co-factor regeneration

Traditional chemical methods for alcohol oxidation are often associated with issues such as high consumption of expensive oxidizing agents, formation of metal waste and the use of environmentally undesirable organic solvents. Developing green, selective catalysts is therefore important from an environmental and economic perspective [1].

Alcohol dehydrogenases (ADH) offer one such alternative. However, the reaction requires the oxidized nicotinamide co-factor (NAD⁺) that must be recycled due to its high cost contribution. One regeneration method that offers certain advantages is the oxidation of NADH using water forming NADH oxidases (NOX-2). The implementation of the ADH/NOX system for alcohol oxidation, however, requires consideration of several different issues. Enzyme activity and stability at relevant pH and temperature conditions, but also the tolerance to the substrates and products present (alcohols and aldehydes) are important properties to characterize. Importantly, inactivation by gas-liquid interfaces has been reported for some enzymes, such as the NOX from Lactococcus lactis [2]. Thus, investigating the sensitivity to bubbling is also highly important from a process development perspective.

General information

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Authors: Seita, C. S. (Intern), Rehdorf, J. (Ekstern), Woodley, J. (Intern)
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Authors: Rehn, G. (Intern), Pedersen, A. T. (Intern), J. Charnock, S. (Ekstern), Woodley, J. (Intern)
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Continuous production of chitooligosaccharides by an immobilized enzyme in a dual-reactor system

A chitosanolytic activity found in a commercial α-amylase from Bacillus amylolyquefaciens (BAN) was covalently immobilized onto glyoxal agarose beads (25% recovery of activity) and assessed for the continuous production of chitooligosaccharides (COS). The immobilization did not change the reaction profile (with chitotriose and chitobiose as major products, using chitosans of different polymerization and deacetylation degrees), but significantly increased the enzyme thermostability. A two-step process was proposed, in which chitosan was first hydrolyzed in a batch reactor to a viscosity that could flow through a packed-bead reactor (PBR), thus avoiding clogging of the column. The relationship between hydrolysis degree of chitosan (1% w/v) and viscosity of the solution was assessed in a batch reactor. A 50% hydrolyzed chitosan did not cause any clogging of the PBR. Under these conditions, the productivity of the PBR at the lowest dilution rate was 37 gCOS L\(^{-1}\) h\(^{-1}\), with a conversion yield of 73%. In contrast, at the highest dilution rate, the productivity was nearly 200 gCOS L\(^{-1}\) h\(^{-1}\), but the conversion yield dropped to around 40%.

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Organisations: Department of Chemical and Biochemical Engineering, CAPEC-PROCESS, Instituto de Catálisis y Petroleoquímica
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Enhanced Oil Recovery with Application of Enzymes

Enzymes have recently been reported as effective enhanced oil recovery (EOR) agents. Both laboratory and field tests demonstrated significant increase in the ultimate oil production. Up to 16% of additional oil was produced in the laboratory conditions and up to 269 barrels of additional oil per day were recovered in the field applications. The following mechanisms were claimed to be responsible for the enhancement of the oil production due to enzymes: wettability improvement of the rock surface; formation of the emulsions; reduction of oil viscosity; and removal of high molecular weight paraffins. However, the positive effect of enzymes on oil recovery is not that obvious. In most of the studies commercial enzyme products composed of enzymes, surfactants and stabilisers were used. Application of such samples makes it difficult to assign a positive EOR effect to a certain compound, as several components of commercial mixture might possess surface-active properties. Hence, the main goals of the present study were to establish whether enzymes alone can improve oil production and to identify mechanisms that might underlie enzymatic EOR (EEOR), especially, under conditions of the North Sea petroleum reservoirs.

At the first stage of the work enzyme samples that might have potential for EOR applications were selected. Wettability tests such as measurements of contact angles and determination of adhesion behaviour were applied as screening tools. The group of lipases/esterases demonstrated strong ability to detach oil from the calcite surface and was identified as the most promising group for further investigations. Wettability improvement due to protein adsorption on to the mineral was proposed as the main mechanism for EEOR. It was also proved that the enzyme molecules themselves caused change of the wetting state of calcite, while presence of stabilising ingredients did not interfere the results. Implementation of such a mechanism of enzymatic action under reservoir conditions might be limited by retention of the protein molecules in the porous medium. In order to verify this hypothesis, adsorption behaviour of enzymes/proteins on the reservoir rocks was studied by application of the static adhesion tests and adsorption experiments on powders, as well as of dynamic flow-through experiments. It was established that enzymes are indeed significantly lost during the transport in the porous medium due to the irreversible adsorption. The adsorption capacity of carbonate material was found to be much higher compared to sandstone. Various methods (for example, change of ionic strength and pH of the enzyme solution and displacing fluid) were applied in order to desorb attached protein molecules, but no desorption was observed. Another possible mechanism that might underlie EEOR is formation of enzyme-stabilised emulsions. Similar to the wettability screening, lipases/esterases demonstrated the best surface active properties; they formed the most stable emulsions with rather small drops. Light fractions of the crude oil participated mostly in formation of the protein-stabilised emulsions. Incubation of the oil-[enzyme + sea water] systems was found to be important in order to obtain high stability of emulsions. Combined application of enzymes and solid particles was an alternative way to increase emulsion stability.

Other crude oil-brine interaction tests revealed additional problems that can arise during the application of enzymatic EOR. Interaction of the enzyme solution with the crude oil can induce gelation/emulsification of the propylene glycol (the main component of the enzyme productstabilisers). Moreover, when purified enzyme containing almost no stabilisers was used, a highly viscous oil-in-water emulsion was formed.

Finally, assessment of enzymes as EOR agents under conditions similar to the conditions of the petroleum reservoirs was carried out in core flooding experiments. Two types of enzymes (lipase and amylase) were selected based on the results from the wettability and emulsion studies. They were only tested in tertiary mode, employing various injection schemes.
Application of enzymes in sandstone core samples resulted in increase of the ultimate oil production by 0.23-1.69% relative to original oil in place, while no additional oil due to enzymes was produced from chalk. Wettability change was confirmed to be the main EOR mechanism, while emulsification plays less significant role.

Overall, enzymes have possessed low potential for EOR applications at least in sandstone and chalk reservoirs containing light crude oils. An alternative technique that will shift adsorption balance towards reversible adsorption should be established in order to make enzymatic EOR an effective and economically feasible oil recovery method.

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Enzymatic network for production of ether amines from alcohols
We constructed an enzymatic network composed of three different enzymes for the synthesis of valuable ether amines. The enzymatic reactions are interconnected to catalyze the oxidation and subsequent transamination of the substrate and to provide cofactor recycling. This allows production of the desired ether amines from the corresponding ether alcohols with inorganic ammonium as the only additional substrate. To examine conversion, individual and overall reaction equilibria were established. Using these data, it was found that the experimentally observed conversions of up to 60% observed for reactions containing 10mM alcohol and up to 280mM ammonia corresponded well to predicted conversions. The results indicate that efficient amination can be driven by high concentrations of ammonia and may require improving enzyme robustness for scale-up.

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Enzymatic pretreatment of low-grade oils for biodiesel production

The alkaline process for making biodiesel (fatty acid methyl esters, or FAME) is highly efficient at the transesterification of glycerides. However, its performance is poor when it comes to using oil that contain significant amounts of free fatty acids (FFA). The traditional approach to such feed stocks is to employ acid catalysis, which is slow and requires a large excess of methanol, orto evaporate FFA and convert that in a separate process. An attractive option would be to convert the FFA in oil feedstocks to FAME, before introducing it into the alkaline process. The high selectivity of enzyme catalysis makes it a suitable basis for such a pretreatment process. In this work, we present a characterization of the pretreatment of high-FFA rapeseed oil using immobilized *Candida antarctica* lipase B (Novozym 435), focused on the impact of initial FFA and
methanol concentration. Based on experimental results, we have identified limitations for the process in terms of FFA concentration in the feedstock and make suggestions for process operation. It was found that, using 5% catalyst and 4% methanol at 35°C, the FFA concentration could be reduced to 0.5% within an hour for feedstock containing up to 15% FFA. Further, the reaction was observed to be under kinetic control, in that the biocatalyst converts FFA (and FAME) at a much higher rate than glyceride substrates. There is thus, both a minimum and a maximum reaction time for the process to achieve the desired concentration of FFA. Finally, an assessment of process stability in a continuous packed bed system indicates that as much as 15m³ oil could potentially be pretreated by 1 kg of biocatalyst at the given process conditions.

**General information**

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Organisations: Department of Chemical and Biochemical Engineering, CAPEC-PROCESS, Novozymes A/S
Authors: Nordblad, M. (Intern), Pedersen, A. K. (Intern), Rancke-Madsen, A. (Ekstern), Woodley, J. M. (Intern)
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Scopus rating (2008): SJR 1.238 SNIP 1.288
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Enzyme Characterization in Microreactors by UV-Vis Spectroscopy

In protein engineering mutants are often selected solely on the basis of activity [1], simplifying the analysis and enabling high throughput screening. At a later stage of development, several mutants show comparable performance and this basis for selection becomes indistinct. The basis for selection can at this point be improved by characterization of the enzyme performance where also inhibition and toxicity effects are taken into account. Enzyme characterization is here defined as the effect on initial rate of reaction with respect to pH, enzyme, substrate, co-substrate, product and co-product concentration [2]. From this investigation, it will be possible to determine whether the enzyme meets the criteria for process requirements or not. The development of the process will determine the requirements and this can also reach a state of maturity that resolves obstacles, lowers criteria and paves the way for implementation. As an example ω-transaminase is here investigated, which facilitates the exchange of an amine- and keto-group stereoselectively. The characterization will be carried out in a microreactor [3], this size is currently the only concept that can facilitate this thorough analysis, as the enzyme resource is scarce at this point of development. In the case where the reaction operates with UV active components, UV can be used to detect compounds with high sensitivity supplemented by multivariate data analysis. The spectra are here decorrelated and regressed to yield concentrations of individual compounds. HPLC systems are built for handling small quantities of liquids and the UV detectors for these proves to be fitting excellent. Enzyme characterization is therefore carried out by a combination of a microreactor with a diode array detector from an HPLC system.
Generic Model-Based Tailor-Made Design and Analysis of Biphasic Reaction Systems

Biphasic reaction systems are composed of immiscible aqueous and organic liquid phases where reactants, products, and catalysts are partitioned. These biphasic conditions point to novel synthesis paths, higher yields, and faster reactions, as well as facilitate product separation. The biphasic systems have a broad range of application, such as the manufacture of petroleum-based chemicals, pharmaceuticals, and agro-bio products. Major considerations in the design and analysis of biphasic reaction systems are physical and chemical equilibria, kinetic mechanisms, and reaction rates.

The primary contribution of this thesis is the development of a systematic modeling framework for the biphasic reaction system. The developed framework consists of three modules describing phase equilibria, reactions and mass transfer, and material balances of such processes. Correlative and predictive thermodynamic models, including newly developed group-contribution electrolyte model (e-KT-UNIFAC), have been implemented to predict the partitioning and equilibria of electrolyte and non-electrolyte species for a wide variety of reacting substances. Reaction kinetics and mass transfer are described by non-elementary reaction rate laws. Extents of reaction are used to calculate the species material balances. The resulting mathematical model contains temperature dependent reaction rate parameters, equilibrium constants, and partition coefficients; where only the reaction rates are to be regressed to a minimum of time-dependent data. The application of the framework is made to five distinct cases in order to highlight the performance of the model for correlating the data and predicting the overall rates, the ultimate amounts of product formation, the ultimate impurities amount, and the optimum operating condition using different organic solvents leading to an improved and innovative design of the system.
Integrated Process Design, Control and Analysis of Intensified Chemical Processes

Process design and control problems have been considered as independent problems for many years. In this context, a sequential approach is used where the process is designed first, followed by the control design. However, this sequential approach has its limitations related to dynamic constraint violations, for example, infeasible operating points, process overdesign or under-performance. Therefore, by using this approach, a robust performance is not always guaranteed. Furthermore, process design decisions can influence process control and operation. To overcome these limitations, an alternative approach is to tackle process design and controllability issues simultaneously, in the early stages of process design. This simultaneous synthesis approach provides optimal/near-optimal operation and more efficient control of conventional (non-reactive binary distillation columns) as well as complex chemical processes; for example, intensified processes such as reactive distillation. Most importantly, it identifies and eliminates potentially promising design alternatives that may have controllability problems later. To date, a number of methodologies have been proposed and applied on various problems to address the interactions between process design and control, and they range from optimization-based approaches to model-based methods.

In this work, integrated process design and control of reactive distillation processes is considered through a computer-aided framework. To assure that design decisions give the optimum operational and economic performance, operability and controllability issues are considered simultaneously with the process design issues. Operability issues are addressed to ensure a stable and reliable process design at pre-defined operational conditions whereas controllability is considered to maintain desired operating points of the process at imposed disturbances in the feed under normal operating conditions. First, a set design methods, similar in concept to design of non-reactive distillations, such as McCabe-Thiele and driving force approach are selected to design the reactive distillation column. Next, these design methods are extended using element concept to also include ternary as well as multicomponent reactive distillation processes. The element concept is used to translate a ternary system of compounds (A + B ↔ C) to a binary system of elements (WA and WB). When only two elements are needed to represent the reacting system of more than two compounds, a binary element system is identified. In the case of multi-element reactive distillation processes (where more than two elements are encountered) the equivalent element concept is used to translate such systems (A + B ↔ C + D) to a binary system of key elements (elements WHK and WLK). For an energy-efficient design, non-reactive driving force (for binary non-reactive distillation), reactive driving force (for binary element systems) and binary-equivalent driving force (for multicomponent reactive distillation) were employed. For both the McCabe-Thiele and driving force method, vapor-liquid equilibrium data are based on elements. It has been demonstrated that designing a reactive distillation column at the maximum driving force will result in the minimum energy consumption. Note, that the same principles that apply to a binary non-reactive compound system are valid also for a binary-element or a multi-element system. Therefore, it is advantageous to employ the element based method for multicomponent reaction-separation systems.

It is shown that the same design-control principles that apply to a non-reacting binary system of compounds are also valid for a reactive binary system of elements or multi-elements for distillation columns. Application of this framework shows that designing the reactive distillation process at the maximum driving force results in a feasible and reliable design of the process as well as the controller structure. Through analytical, steady-state and closed-loop dynamic analysis it is verified that the control structure, disturbance rejection and energy requirement of the reactive distillation column is better than any other operation point that is not at the maximum driving force. Furthermore, it is shown that the design at the maximum driving force can be both controlled using simple controllers such as PI as well as advanced controllers such as MPC.
Measurement of oxygen transfer from air into organic solvents: Oxygen transfer from air into organic solvents
Background: The use of non-aqueous organic media is becoming increasingly important in many biotechnological applications in order to achieve process intensification. Such media can be used for example to directly extract poorly water-soluble toxic products from fermentations. Likewise many biological reactions require the supply of oxygen, most normally from air. However, reliable on-line measurements of oxygen concentration in organic solvents (and hence oxygen transfer rates from air to the solvent) has to date proven impossible due limitations in the current analytical methods.
Results: For the first time, we demonstrate on-line oxygen measurements in non-aqueous media using a novel optical sensor. The sensor was used to measure oxygen concentration in various organic solvents including toluene, THF, isooctane, DMF, heptane and hexane (which have all been shown suitable for several biological applications). Subsequently, we measured the oxygen transfer rates from air into these organic solvents.
Conclusion: The measurement of oxygen transfer rates from air into organic solvents using the dynamic method was established using the solvent resistant optical sensor. The feasibility of online oxygen measurements in organic solvents has also been demonstrated, paving the way for new opportunities in process control.

General information
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Modelling and synthesis of pharmaceutical processes: moving from batch to continuous

Research in pharmaceutical process development has gained a lot of interest over the last years. Long development times, increasing R&D costs, increasing competition, and short patent duration are some of the driving forces for the increased research efforts in the field. Increased process understanding of the pharmaceutical process has resulted in major improvements in the field. Process systems engineering (PSE) approaches, which have been successfully applied in the design, analysis and optimization of chemical and petrochemical processes, might be also important for the improvement of pharmaceutical processes by providing systematic and structured solutions for the stages of the pharmaceutical process development.

In this PhD thesis, the objective is to systematize the pharmaceutical process development in order to enhance process understanding by creating a data-rich environment and to investigate/evaluate opportunities for continuous operation. To achieve the mentioned objectives the use of an integrated framework based on systematic model-based methods and tools is proposed. Computer-aided methods and tools are used to generate process knowledge and to evaluate different operational scenarios.

The developed framework is divided into four main sections: the reaction pathway, reaction analysis, separation synthesis and process evaluation-operation based on evaluation. In the first section, the selection of the reaction pathway to produce a desired active ingredient is examined. A reaction database for small pharmaceutical molecules, including information for reactions, the solvent role and processing information, has been developed to assist the reaction pathway selection. In the second section, the reaction analysis, the identified individual reactions during the reaction pathway selection are analysed. The objective of the reaction analysis section is to collect reaction data and by using model-based methods to investigate possibilities of reaction improvement by evaluating the reaction conditions, the operating mode, the solvent role, and the reactor design. In the third section, alternatives for the separation of the reaction mixture are generated based on the driving force principles and evaluated based on performance criteria, such as mass and energy utilization. Finally, the overall process is simulated and evaluated in terms of productivity and environmental impact.

Process optimization studies are performed by defining optimization target based on the process analysis. The application of the developed integrated framework is highlighted through four case studies. In the first case study, the overall use of the framework is highlighted using the synthesis of ibuprofen as a motivating example. The second case study focuses on the application of the developed solvent selection methodology for solvent swap problems. The third
case study focused on multiphase reaction systems and improvements through the combination of reaction-separation. Finally, model-based analysis-design is performed for the operation improvement of a glucose isomerization plant.

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**Process Evaluation Tools for Enzymatic Cascades Welcome Message**

Biocatalysis is attracting significant attention from both academic and industrial scientists due to the excellent capability of enzyme to catalyse selective reactions. Recently, much interest has been shown in the application of enzymatic cascades as a useful tool in organic synthesis to synthesize valuable compounds (e.g. chiral molecules) especially as pharmaceutical intermediates and to assist complex reactions that otherwise has problems as single step system. Despite this interest, process evaluation of many enzymatic cascades has only rarely been reported in the search for process improvement and implementation. Hence, the goal of this thesis is to evaluate the process concepts in enzymatic cascades in a systematic manner, using tools such as thermodynamic and kinetic analysis. Three relevant case studies have been used to exemplify the approach.

In the first case study, thermodynamic and kinetic studies were used to evaluate the favourability of a redox neutral cascade for the asymmetric amination of alcohols to their corresponding chiral amines. This synthetic cascade is potentially attractive since it synthesizes valuable chiral molecule from cheap raw materials as well as maximising the atom economy. The scheme consists of two primary enzymes (alcohol dehydrogenase and ω-transaminase) that are directly involved in the main synthesis. Alanine dehydrogenase was introduced as a secondary enzyme to regenerate the co-factor NAD⁺ and co-substrate alanine in situ as well as to shift the equilibrium positions in the main syntheses. In principle, this strategy could successfully achieve high conversion, using ammonia as the sole reagent used in excess to drive the conversion. The findings herein indicate that quantitatively the possibilities for improving the conversion of thermodynamically limited reactions are not only via application of enzyme coupling reactions (coupling the unfavourable reaction with an energetically favourable reaction) but also by matching the relative reaction rates between the interconnecting enzymes.

When the reaction steps are independent in a cascade, the kinetics can be controlled in a highly efficient way to achieve a sufficiently favourable conversion to a given target product. This is exemplified in the second case study, in the kinetic modelling of the formation of 2-ketoglutarate from glucoronate, the second case study. This cascade consists of 4 enzymes (uronate dehydrogenase, glucarate dehydratase, keto-deoxy-d-galactarate dehydratase and α-ketoglutaric semialdehyde dehydrogenase) run in that order to successfully achieve high conversion.

Finally, a third case study was used to explore the effect of activity-coefficients in enzyme-catalysed reactions. Frequently, the ‘apparent’ or (concentration-based) equilibrium constant (K'), instead of activity-based equilibrium constant, was used to describe reaction equilibria of biological systems. It is assumed that the reactant activity is equal to the respective reactant molar concentration at equilibrium since many reactions operate in dilute aqueous solutions and thus neglect the activity coefficient effect. The effect of such assumption was therefore tested with the cyclohexanone amination with (S)-1-phenylethylamine catalysed by ω-transaminase. The findings showed that the activity coefficients of the components significantly deviate from unity, indicating its non-ideal behaviour in the reaction medium.

Hence, thermodynamic and kinetic analyses are powerful tools to evaluate and to achieve workable cascades for non-natural pathways. Additionally, more meaningful equilibrium data from enzyme-catalysed reactions can be a useful way to determine the effectiveness of a given cascade strategy.
Process limitations of a whole-cell P450 catalyzed reaction using a CYP153A-CPR fusion construct expressed in *Escherichia coli*

Cytochrome P450s are interesting biocatalysts due to their ability to hydroxylate non-activated hydrocarbons in a selective manner. However, to date only a few P450-catalyzed processes have been implemented in industry due to the difficulty of developing economically feasible processes. In this study, we have used the CYP153A heme domain from Marinobacter aquaeolei fused to the reductase domain of CYP102A1 from Bacillus megaterium (BM3) expressed in *Escherichia coli*. This self-sufficient protein chimera CYP153A-CPRBM3 G307A mutant is able to selectively hydroxylate medium and long chain length fatty acids at the terminal position. ω-Hydroxylated fatty acids can be used in the field of high-end polymers and in the cosmetic and fragrance industry. Here, we have identified the limitations for implementation of a whole-cell P450-catalyzed reaction by characterizing the chosen biocatalyst as well as the reaction system. Despite a well-studied whole-cell P450 catalyst, low activity and poor stability of the artificial fusion construct are the main identified limitations to reach sufficient biocatalyst yield (mass of product/mass of biocatalyst) and space-time yield (volumetric productivity) essential for an economically feasible process. Substrate and product inhibition are also challenges that need to be addressed, and the application of solid substrate is shown to be a promising option to improve the process.

Economic analysis, allied to process systems engineering tools, can provide useful insights about process techno-economic feasibility. More interestingly, rather than being used to evaluate specific process conditions, this techno-economic analysis can be turned upside down to achieve target values for the main process metrics, providing feedback to the research and development team and setting goals for experimental efforts. The present study proposes a methodology for performing such a "retro" techno-economic analysis. It consists of choosing the most important variables of the process and finding their threshold values and the correlation between them. To demonstrate the capabilities of the methodology, the production of succinic acid from sucrose was assessed. Through the use of this methodology, an infeasible region was identified and threshold values for the process variables were obtained. Although applied to a biochemical process, the methodology is general and can be applicable to all types of chemical processes.
Scale-up of industrial biodiesel production to 40 m$^3$ using a liquid lipase formulation

In this work, we demonstrate the scale-up from an 80 L fed-batch scale to 40 m$^3$ along with the design of a 4 m$^3$ continuous process for enzymatic biodiesel production catalysed by NS-40116 (a liquid formulation of a modified *Thermomyces lanuginosus* lipase). Based on the analysis of actual pilot plant data for the transesterification of used cooking oil and brown grease, we propose a method applying first order integral analysis to fed-batch data based on either the bound glycerol or free fatty acid content in the oil. This method greatly simplifies the modelling process and gives an indication of the effect of mixing at the various scales (80L to 40m3) along with the prediction of the residence time needed to reach a desired conversion in a CSTR.

Suitable process metrics reflecting commercial performance such as the reaction time, enzyme efficiency and reactor productivity were evaluated for both the fed-batch and CSTR cases. Given similar operating conditions, the CSTR operation on average, has a reaction time which is 1.3 times greater than the fed-batch operation.

We also showed how the process metrics can be used to quickly estimate the selling price of the enzyme. Assuming a biodiesel selling price of 0.6 USD/kg and a one-time use of the enzyme (0.1% (w/w) oil) enzyme dosage; the enzyme can then be sold for 30 USD/kg which ensures that that the enzyme cost is not more than 5% of the biodiesel revenue. This article is protected by copyright. All rights reserved

## General information

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The application of reaction engineering to biocatalysis

Biocatalysis is a growing area of synthetic and process chemistry with the ability to deliver not only improved processes for the synthesis of existing compounds, but also new routes to new compounds. In order to assess the many options and strategies available to an engineer developing a new biocatalytic process, it is essential to carry out a systematic evaluation to progress rapidly and ensure decisions are made on firm foundations. In this way, directed development can be carried out and the chances of implementation of a commercially successful process can be much improved. In this review, we outline the benefits of reaction engineering in this development process, with particular emphasis on reaction kinetics. Future research needs to focus on rapid methods to collect such data at sufficient accuracy that it can be used for the effective design of new biocatalytic processes.
The effect of cultivation media and washing whole-cell biocatalysts on monoamine oxidase catalyzed oxidative desymmetrization of 3-azabicyclo[3,3,0]octane

It is well known that washing whole-cells containing enzyme activities after fermentation, but prior to biocatalysis can improve their activity in the subsequent reaction. In this paper, we quantify the impact of both the fermentation media and cell washing on the performance of whole-cell biocatalysis. The results are illustrated using a recombinant monoamine oxidase (expressed in Escherichia coli, used in resting state) for the oxidative desymmetrization of 3-azabicyclo[3,3,0]octane. It was shown that the need for washing biocatalyst prior to use in a reaction is dependent upon growth medium. Unlike cells grown in LB medium, washing of the cells was essential for cells grown on TB medium. With TB media, washing the cells improved the final conversion by approximately a factor of two. Additionally, over 50-fold improvement was achieved in initial activity. A potential reason for this improvement in activity was identified to be the increase in transfer of substrates across the cell membrane as a result of cell washing. (C) 2015 Elsevier Inc. All rights reserved.
Amine donor and acceptor influence on the thermodynamics of ω-transaminase reactions

In recent years biocatalytic transamination using ω-transaminase has become established as one of the most interesting routes to synthesize chiral amines with a high enantiomeric purity, especially in the pharmaceutical sector where the demand for such compounds is high. Nevertheless, one limitation for successful implementation and scale-up is that the thermodynamics of such conversions are frequently found unfavourable. Herein we report experimental measurements of apparent equilibrium constants for several industrially relevant transamination reactions in a systematic manner to better understand the effect of amine acceptor and donor choice. For example, we have found that ortho-substitution of acetophenone like molecules, had a significant impact on the thermodynamic equilibrium. Likewise, the effect of cyclic amine acceptors was evaluated and compared to similar non-cyclic structures. It was found that an aliphatic six membered ring was favourable and a conjugated bicyclic five membered ring structure, unfavourable. Finally, we evaluated and
compared the use of five different donor molecules, and calculated their ΔGapp values. This is particularly important in the further implementation of such reactions because it may be used to help select suitable donor/acceptor combinations. The results presented here give guidance, with respect to thermodynamics, in order to further extend the application of biocatalytic transamination.

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A Model-Based Methodology for Integrated Design and Operation of Reactive Distillation Processes

Process intensification is a new approach that has the potential to improve existing processes as well as new designs of processes to achieve more profitable and sustainable production. However, many issues with respect to their implementation and operation is not clear; for example, the question of operability and controllability. Traditionally process design and process control are considered as independent problems and are solved sequentially. The process design problem is usually solved to achieve the design objectives, and then, the operability and process control issues are identified, analyzed and resolved. A new approach is to tackle process intensification and controllability issues in an integrated manner, in the early stages of process design. This integrated and simultaneous synthesis approach provides optimal operation and more efficient control of complex intensified systems that suffice the process design objectives. Furthermore, it may also suggest innovative process alternatives which are more economical and environmentally sustainable. In this work, a systematic model-based methodology for integrated design and operation of reactive distillation operations is presented. Issues related to operation are addressed to ensure a stable and reliable process design at predesigned operational conditions whereas controllability is considered to maintain desired operating points of the process at any kind of imposed disturbance under normal operating conditions. The methodology employs a decomposition-based method so that the complexity of the problems is reduced into a set of sub-problems that are solved sequentially. The method consists of four hierarchical stages: (1) pre-analysis, (2) steady state analysis, (3) dynamic analysis, and (4) evaluation stage. To illustrate the application of the proposed methodology, production of methyl-tert-butyl-ether (MTBE) using an active distillation column (RDC) is considered. Simple graphical design methods that are similar in concept to non-reactive distillation processes are used. The methods are based on the element concept, which is used to translate a ternary system of compounds (methanol, isobutene and MTBE) to a binary system of elements (elements A and B). For a binary element system, a simple reactive McCabe-Thiele-type method (to determine the number of reactive stages) has been used. The reactive equilibrium curve is constructed through sequential calculation of reactive bubble points. For an energy-efficient design, the driving-force approach (to determine the optimal feed location) for a reactive system has been employed. For both these reactive McCabe-Thiele and driving force method, vapor-liquid equilibrium data are based on elements. Thereactive bubble point algorithm is used to compute the reactive vapor-liquid equilibrium data set. The operation of the RDC at the highest driving force and other candidate points is compared through open-loop and closed-loop analysis. By application of this methodology it is shown that designing the process at the maximum driving force results in an energy efficient and operable design. It is verified that the reactive distillation design option is less sensitive to the disturbances in the feed at the highest driving force and has the inherent ability to reject disturbances.

Application of A Microfluidic Tool for the Determination of Enzyme Kinetics

Biocatalysis offers the ability to carry out important synthesis and production of valuable chemicals at benign conditions. In the development of new processes, enzymes are being engineered towards specific products with great success. Currently, mutations are introduced into enzymes, and mutants are formed thereof and a search among these is conducted. High throughput screening can deliver screening of mutants in the order of millions a day. Enzyme mutants with increased performance are therefore likely to be found. Here, the enzyme amine transaminases is evaluated since it offers a unique way of producing chiral amines. These amines are important as building blocks for pharmaceuticals and
agrochemicals. A promising enzyme has been found, but it has been a problem to assess its performance and give process development direction. Common limitations are substrate and product solubility, unfavourable thermodynamics, inhibition and stability. It is a difficult task to assess where the current bottle neck is for a desired process. Moreover, it cannot be expected that a single solution to the limitations can be found and rather an integrated solution of all of the problems should be the future aim. All the limitations surround the reactor of a process, and with the performance of this being unknown, it is almost impossible to direct development. A focal point must therefore lie in the determination of kinetic models and how kinetic data can be obtained in a robust and generic way. Models for many enzymes already exist and can be found in common text books. These models do however require mutant specific data and must be collected with the target reaction. In this thesis a novel way of collecting kinetic data is created, this is carried out by combining existing technology and enables the analysis of aqueous solutions on-line. Furthermore, the use of a size exclusion column enables the simultaneous detection of enzymes and UV/VIS active compounds. The size exclusion chromatography does not provide baseline separated results, nor is this required. The application of chemometric tools enable detection of compounds in the collected retention time wavelength data. A major improvement over traditional techniques is the quantification of enzyme concentration and this makes it possible to use specific activities for model fitting. The setup takes advantage of microfluidic features and delivers semi-automatic experimentation, overall reducing both consumption of precious materials and costly labor.

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**Application of Enzyme Coupling Reactions to Shift Thermodynamically Limited Biocatalytic Reactions**
In recent years, much interest has been shown in the use of multi-enzyme cascades as a tool in organic synthesis. Such enzymatic cascades can provide added value to a synthetic scheme by starting from cheaper raw materials or making more valuable products. Additionally, they can be used to help shift the equilibrium of otherwise thermodynamically unfavourable reactions to give a higher conversion of the target product. By coupling an energetically unfavourable reaction with a more favourable one, the multi-enzyme cascade mimics the approach taken in nature in metabolic pathways. Nevertheless, it can be challenging to combine several engineered enzymes in vitro for the conversion of non-natural substrates. In this mini-review we focus on enzyme coupling reactions as a tool to alleviate thermodynamic constraints in synthetically useful biocatalytic reactions. The implications of thermodynamic parameters such as the equilibrium constant on the multienzyme cascades and the conventional methods of equilibrium shifting are also discussed in addition to methods used to estimate such values.

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Application of microfluidics for the development of intensified aminotransferase (ATA) processes

Development of biocatalytic processes is greatly dominated by well-established batch process based screening technologies, e.g. glass vials (mL) and microtiter plates (μL). However, there is still a need for improvement of currently available technologies and for new technologies enabling relatively easy screening and characterization of different process options. For example, small-scale microfluidic platforms enable testing of complex process options, by combining multiple process steps in a plug-and-play manner, that are difficult to assess with conventional methods. Early in the development of biocatalytic processes, most attention is given to developing and modifying the biocatalyst to reach required process targets. However, it is important to consider the downstream processing (DSP) early in the process development as well, i.e. the downstream costs and limitations to the separation steps will greatly influence the economic viability due to the constraints placed on the required process metrics. This thesis will therefore emphasise product recovery limitations and requirements in combination with the biocatalyst performance and limitations. Here the focus is mainly related to biocatalytic processes where it is found beneficial/necessary to implement in-situ co-product/product removal (IScPR/ISPR). For example, through combined operation of reactor and separation modules, as such applications require selective separation and sufficient driving force to influence the process significantly.

In recent years, many microfluidic applications have proven useful for process and synthesis development within the area of organic synthesis, i.e. flow chemistry. For example, the unique characteristics of the small scale enable safer and efficient handling and production of explosive and/or toxic compounds. Furthermore, development based on applying microfluidic platforms potentially enables easier introduction of continuous process aspects, when suitable. The motivation for this project is to investigate the potential of applying microfluidic technologies in the development and testing of biocatalytic processes. Within this thesis, microfluidic modules are applied as tools to screen, characterize, and test reactor and separation process options. Furthermore, multiple microfluidic modules are combined in order to test complex process configurations, i.e. reactor modules combined with separation modules, as a means of narrowing down and optimizing the most promising process options.

Throughout this thesis the applicability of microfluidics, as an integrated part of biocatalytic process development, is evaluated based on case studies focusing on the asymmetric synthesis of chiral amines using aminotransferases (ATAs). Chiral amines are valuable building blocks for many pharmaceuticals and precursors. The application of ATAs for asymmetric synthesis has many advantages, but it is also common that there are some challenges. In many cases it is found beneficial/necessary to apply various process engineering strategies, e.g. IScPR and ISPR, to overcome the challenges and ensure the economic feasibility of such processes. With economic process feasibility in mind, it can be extremely useful to apply microfluidic platforms to enable fast screening and characterization of various process options in order to overcome the challenges. Due to the physicochemical properties of the compounds involved in the case studies in this thesis, the focus will be on the application/development of liquid-liquid extraction modules to operate in combination with reactor modules. The main outcome of this PhD thesis is knowledge on the potential of applying microfluidics, in combination with conventional methods, for the development of biocatalytic processes. More specifically, microfluidics will enable testing of complex process options and strategies, which are very difficult to test with conventional methods, by combining microfluidic modules representing different process steps in a plug-and-play manner. The advantages and technology constraining disadvantages of microfluidics for biocatalytic process development are both identified in this thesis. Novel applications of microfluidic development of ATA processes are investigated in detail, i.e. first by
characterization of single microfluidic process steps (reactor and liquid-liquid extraction modules) and afterwards by testing of complex processes by combining multiple microfluidic process steps. This is realized by putting in place a microfluidic demonstration system, a plug-and-play combination of a reactor module with two liquid-liquid extraction modules and settlers. Another novelty of this thesis, is the application of the integrated liquid-liquid extraction steps to both recover the product, using in-situ product removal (ISPR), and at the same time feed the main substrate, i.e. in-situ substrate supply (ISSS). Furthermore, guidelines for identifying suitable ISPR/IScPR options – and, importantly, for eliminating unfeasible options – for ATA processes are proposed.

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**A Practical and Fast Method To Predict the Thermodynamic Preference of omega-Transaminase-Based Transformations**

A simple, easy-to-use, and fast approach method is proposed and validated that can predict whether a transaminase reaction is thermodynamically unfavourable. This allowed us to de-select, in the present case, at least 50% of the reactions because they were thermodynamically unfavourable as confirmed by experiment. Once a larger data base is established, in silico screening of several new reactions (new target molecules) can easily be performed each day.

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A Practical and Fast Method To Predict the Thermodynamic Preference of ω-Transaminase-Based Transformations

A simple, easy-to-use, and fast approach method is proposed and validated that can predict whether a transaminase reaction is thermodynamically unfavourable. This allowed us to de-select, in the present case, at least 50% of the reactions because they were thermodynamically unfavourable as confirmed by experiment. Once a larger data base is established, in silico screening of several new reactions (new target molecules) can easily be performed each day.

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A Systematic Computer-Aided Framework for Integrated Design and Control of Chemical Processes

Chemical processes are conventionally designed through a sequential approach. In this sequential approach, first, a steady-state process design is obtained and then, control structure synthesis that, in most of the cases, is based on heuristics is performed. Therefore, process design and process control and operation considerations have been studied independently. Furthermore, this sequential approach does not adequately answer this question, “How process design decisions influence process control and operation?”. In order to answer this question, it is necessary to consider process controllability and operability issues together with process design tasks (Seferlis and Georgiadis, 2004). In this way, it can be assured that design decisions give the optimum operational and economic performance. Operability issues are addressed to ensure a stable and reliable process design at pre-defined operational conditions whereas controllability is considered to maintain desired operating points of the process at any kind of imposed disturbance under normal operating conditions.

In this work, a systematic hierarchical computer-aided framework for integrated process design and control of chemical processes including process intensification is proposed. Note however, because of integration of functions/operations into one system the controllability region of intensified equipment may become smaller (Nikačević et al., 2012). The methodology developed in this work, employs a decomposition-based approach so that the complexity of the problem is reduced into a set of sub-problems that are solved sequentially. The production of methy-tert-butyl-ether (MTBE) is used to demonstrate the application of the framework. First, optimal design-control solution is presented for MTBE production via a reactor-separator-recycle (RSR) system. Next, it will be shown that the RSR system can be replaced by an intensified unit operation, a reactive distillation column (RDC) which optimal design-control solution is also presented. The operation and control of the RSR and RDC at the optimal designs is compared with other candidate designs compared through open-loop and closed-loop analysis. By application of this methodology it is shown that the optimal design obtained from this methodology, it is not only the best from an economic steady-state design point of view, but also from control and operation point view. It is verified that the optimal design options for RSR and RDC are less sensitive to the disturbances in the feed at the optimal design.

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Design of a process template for amine synthesis

A conceptual nitro reduction process template that should be generic such that it can handle a series of substrates with similar molecular functionality has been designed. The reduction process is based on a continuos plug-flow slurry reactor. The process template aims at speeding up the process development for new substrates by being easily adapted for a range of substrates as well as easily scaled by numbering-up. The potential saving in process development time could make it a particularly powerful experimental tool for early delivery campaigns in the pharmaceutical industry for the production of Kg amounts of material for clinical trials.
Economic Considerations for Selecting an Amine Donor in Biocatalytic Transamination

The industrial implementation of biocatalysis for production of pharma and fine chemicals has grown substantially over recent years. An upcoming application is that of chiral synthesis of optically pure amines, a technology known for many years but that is now seeing a renewed and wider interest in industry. The technology has been demonstrated in a few selected cases, but widespread implementation and for a broader range of target molecules requires a deeper understanding of the underlying thermodynamic as well as economic constraints for the different choices that can be made in designing the process, in particular the choice of amine donor. This paper discusses these constraints and demonstrates, through simple thermodynamic and economic models, the process targets that need to be set and achieved for a process dependent on allowed process costs and quality targets.
In this paper, we use mechanistic modelling to guide the development of a continuous enzymatic process that is performed as a fed-batch operation. In this work, we use the enzymatic biodiesel process as a case study. A mechanistic model developed in our previous work was used to determine the reactor operating conditions for a desired conversion. However, in using a detailed mechanistic model, given the large number of parameters and few experimental data points, the parameters were found not identifiable. The model is then only applicable within the limited operating range for which the model was validated. We hypothesize that fitting this model to fed-batch and continuous stirred tank reactor (CSTR) data together will enable us to use the model for determination of residence times to reach a specified conversion in a CSTR. With this approach, the model fits the experimental data for the five measured components (triglycerides, diglycerides, monoglycerides, free fatty acid and fatty acid methyl esters (biodiesel)) much better than using fed-batch data alone given the smaller residuals. We also observe a reduction in the correlation between the parameters. The model was then used to predict that five reactors are required (with a combined residence time of 30 hours) to reach a final biodiesel concentration within 2% of the 95.6 mass % achieved in a fed-batch operation, for 24 hours.
Guidelines for development and implementation of biocatalytic P450 processes

Biocatalytic reactions performed by cytochrome P450 monoxygenases are interesting in pharmaceutical research since they are involved in human drug metabolism. Furthermore, they are potentially interesting as biocatalysts for synthetic chemistry because of the exquisite selectivity of the chemistry they undertake. For example, selective hydroxylation can be undertaken on a highly functionalized molecule without the need for functional group protection. Recent progress in the discovery of novel P450s as well as protein engineering of these enzymes strongly encourages further development of their application, including use in synthetic processes. The biological characteristics of P450s (e.g., cofactor dependence) motivate the use of whole-cell systems for synthetic processes, and those processes implemented in industry are so far dominated by growing cells and native host systems. However, for an economically feasible process, the expression of P450 systems in a heterologous host with sufficient biocatalyst yield (g/g cdw) for non-growing systems or space-time yield (g/L/h) for growing systems remains a major challenge. This review summarizes the opportunities to improve P450 whole-cell processes and strategies in order to apply and implement them in industrial processes, both from a biological and process perspective. Indeed, a combined approach of host selection and cell engineering, integrated with process engineering, is suggested as the most effective route to implementation.
Immobilisation of ω-transaminase for industrial application: Screening and characterisation of commercial ready to use enzyme carriers

Despite of the advantages that enzyme immobilisation can bring to industrial biocatalysis, its utilisation is still limited to a small number of enzymes and processes. Transaminase catalysed processes are a good example where immobilisation can be of major importance and even decisive for economic feasibility. This work presents results obtained for screening of enzyme carriers for immobilisation of ω-transaminase for industrial application. A total of 6 commercial enzyme carriers (polymeric resins) were screened and two suitable enzyme carriers were selected for immobilisation of both (S)- and (R)-selective ω-transaminases. These carriers allowed the re-use of the immobilised enzyme for 8 cycles of 24 h each, under relevant process conditions, corresponding to approximately 250 h of operation, with more than 50% of the initial activity retained. Likewise the stability towards higher temperatures and possibility to store the biocatalyst for more than 70 days (at room temperature) were obtained as result of the immobilisation on the selected supports.
Integrated Process Design and Control of Reactive Distillation Processes

In this work, integrated design and control of reactive distillation processes is presented. Simple graphical design methods that are similar in concept to non-reactive distillation processes are used, such as reactive McCabe-Thiele method and driving force approach. The methods are based on the element concept, which is used to translate a system of compounds into elements. The operation of the reactive distillation column at the highest driving force and other candidate points is analyzed through analytical solution as well as rigorous open-loop and closed-loop simulations. By application of this approach, it is shown that designing the reactive distillation process at the maximum driving force results in an optimal design in terms of controllability and operability. It is verified that the reactive distillation design option is less sensitive to the disturbances in the feed at the highest driving force and has the inherent ability to reject disturbances.

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Integrated Process Design and Control of Reactive Distillation Processes

In this work, integrated process design and control of reactive distillation processes is presented. Simple graphical design methods that are similar in concept to non-reactive distillation processes are used, such as reactive McCabe-Thiele method and driving force approach. The methods are based on the element concept, which is used to translate a system of compounds into elements. The operation of the reactive distillation column at the highest driving force and other candidate points is analyzed through analytical solution as well as rigorous open-loop and closed-loop simulations. By application of this approach, it is shown that designing the reactive distillation process at the maximum driving force results in an optimal design in terms of controllability and operability. It is verified that the reactive distillation design option is less sensitive to the disturbances in the feed at the highest driving force and has the inherent ability to reject disturbances.

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Kinetic modeling of multi-component crystallization of industrial-grade oils and fats
Transient crystallization kinetics is investigated for complex, industrial-grade vegetable oils consisting of more than ten triacylglycerols (TAG). The classical nucleation model has been used to describe primary nucleation, while secondary nucleation has been described by a semi-empirical approach. Growth is modeled using a modified Burton-Cabrera-Frank (BCF) model. Surface tensions and growth constants have been determined using focused-beam-reflectance measurements (FBRM). The required adjustable parameters in the model have been fitted to overall crystallization curves obtained by solid-fat content (SFC) measurements for a given oil at different cooling rates and degrees of dilution. The developed model can accommodate more polymorphs simultaneously and performs well with respect to predicting crystallization onset, rate of crystallization and final SFC value. It can also qualitatively describe how higher cooling rates lead to formation of more meta-stable crystals and smaller mean-crystal sizes. The model provides a good starting point for developing more realistic, transient models for TAG crystallization with the ability to accommodate processing conditions and complex chemical compositions. Such a predictive model may provide a powerful tool to screen and optimize oil formulations in industrial processes and allow product developers to evaluate recrystallization events.

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Microscale technology and biocatalytic processes: Opportunities and challenges for synthesis

Despite the expanding presence of microscale technology in chemical synthesis and energy production as well as in biomedical devices and analytical and diagnostic tools, its potential in biocatalytic processes for pharmaceutical and fine chemicals, as well as related industries, has not yet been fully exploited. The aim of this review is to shed light on the strategic advantages of this promising technology for the development and realization of biocatalytic processes and subsequent product recovery steps, demonstrated with examples from the literature. Constraints, opportunities, and the future outlook for the implementation of these key green engineering methods and the role of supporting tools such as mathematical models to establish sustainable production processes are discussed.

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Model-Based Analysis and Efficient Operation of a Glucose Isomerization Reactor Plant

The application of computer-aided model based methods within an integrated systematic framework is illustrated with the objective to assist the multi-purpose pharmaceutical/biochemical industry to systematically solve the complex problems that are experienced when aiming at improving the process efficiency. The objective of this study is the application of the developed framework on an industrial case study of a glucose isomerization (GI) reactor plant that is part of a corn refinery, with the objective to improve the productivity of the process. Therefore, a multi-scale reactor model is developed for use as a building block for the GI reactor plant simulation. An optimal operation strategy is proposed on the basis of the simulation results.
Oxygen transfer rates and requirements in oxidative biocatalysis

Biocatalytic oxidation reactions offer several important benefits such as regio- and stereoselectivity, avoiding the use of toxic metal based catalysts and replacing oxidizing reagents by allowing the use of oxygen. However, the development of biocatalytic oxidation processes is a complex task which requires simultaneous consideration of several issues regarding the process design and operation. In this work, the oxygen requirements are analysed for different process scenarios, considering different biocatalyst formats and variation of the desired productivity. Also, the applicability of two different oxygen supply methods (bubbling and membrane aeration) is considered. The results indicate that growing cells could be used to reach productivities up to 3.5 g L\(^{-1}\) h\(^{-1}\) without oxygen supply being limiting. Also, membrane contactors can provide a feasible oxygen supply method when bubble-less aeration is desired. However, in order to support high productivity the oxygen flux using air may be insufficient, thus requiring the use of oxygen.

Oxygen transfer rates and requirements in oxidative biocatalysis

Biocatalytic oxidation reactions offer several important benefits such as regio- and stereoselectivity, avoiding the use of toxic metal based catalysts and replacing oxidizing reagents by allowing the use of oxygen. In this contribution the oxygen requirements are analysed for different process scenarios, considering different biocatalyst formats and variation of the desired productivity. Also, the applicability of two different oxygen supply methods (bubbling and membrane aeration) is investigated. Hollow fibre membrane contactors present an interesting alternative for reactor aeration, creating large specific areas (area/volume) of the gas/liquid interface. The modular design of membrane contactors, scaling-up is relatively straightforward (Gabelman and Hwang, 1999), and membrane contactors are implemented for various industrial applications (Klaassen et al., 2005).
**Process Alternatives for Second Generation Ethanol Production from Sugarcane Bagasse**

In ethanol production from sugarcane juice, sugarcane bagasse is used as fuel for the boiler, to meet the steam and electric energy demand of the process. However, a surplus of bagasse is common, which can be used either to increase electric energy or ethanol production. While the first option uses already established processes, there are still many uncertainties about the techno-economic feasibility of the second option. In this study, some key parameters of the second generation ethanol production process were analyzed and their influence in the process feasibility assessed. The simulated process includes the enzymatic hydrolysis of sugarcane bagasse pretreated with liquid hot water, and the analyzed parameters were the solid consistency in the hydrolysis and pretreatment reactors and the hydrolysis reaction time. The solid consistency in the hydrolysis reactor had the highest influence on the economic feasibility of the process. For the economic scenario considered in this study, using bagasse to increase ethanol production yielded higher ethanol production costs compared to using bagasse for electric energy production, showing that further improvements in the process are still necessary.

**General information**

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**Process considerations for use of galactose oxidase as an industrial biocatalyst**

In nature galactose oxidase (GOase, EC.1.1.3.9) catalyses the oxidation of the C6 hydroxyl group of D-galactose to the corresponding aldehyde, while reducing molecular oxygen to hydrogen peroxide. In recent years a great effort has been made to broaden the substrate scope, enabling GOase to oxidize C6-OH of glucose and fructose, as well as secondary alcohols to ketones. The widened substrate scope of GOase opens up many important industrial applications, such as synthesis of industrially relevant compounds containing aldehydes and ketones (e.g. the oxidation of 5-hydroxymethylfurfural to diformylfuran), deracemization of secondary alcohols, and modification of a wide range of naturally occurring polysaccharides [1,2]. Despite these promising characteristics of GOase, application at industrial scale has not been achieved so far. This can in part be ascribed to the process challenges experienced when performing
Process development for the production of 15β-hydroxy-cyproterone acetate using *Bacillus megaterium* expressing CYP106A2 as whole-cell biocatalyst

**Background:** CYP106A2 from *Bacillus megaterium* ATCC 13368 was first identified as a regio- and stereoselective 15 beta-hydroxylase of 3-oxo-Δ4-steroids. Recently, it was shown that besides 3-oxo-Δ4-steroids, 3-hydroxy-Δ5-steroids as well as di- and triterpenes can also serve as substrates for this biocatalyst. It is highly selective towards the 15β position, but the 6β, 7α/β, 9α, 11α and 15α positions have also been described as targets for hydroxylation. Based on the broad substrate spectrum and hydroxylation capacity, it is an excellent candidate for the production of human drug metabolites and drug precursors.

**Results:** In this work, we demonstrate the conversion of a synthetic testosterone derivative, cyproterone acetate, by CYP106A2 under *in vitro* and *in vivo* conditions. Using a *Bacillus megaterium* whole-cell system overexpressing CYP106A2, sufficient amounts of product for structure elucidation by nuclear magnetic resonance spectroscopy were obtained. The product was characterized as 15β-hydroxy-cyproterone acetate, the main human metabolite. Since the product is of pharmaceutical interest, our aim was to intensify the process by increasing the substrate concentration and to scale-up the reaction from shake flasks to bioreactors to demonstrate an efficient, yet green and cost-effective production. Using a bench-top bioreactor and the recombinant *Bacillus megaterium* system, both a fermentation and a transformation process were successfully implemented. To improve the yield and product titers for future industrial application, the main bottlenecks of the reaction were addressed. Using 2-hydroxypropyl-β-cyclodextrin, an effective bioconversion of 98% was achieved using 1 mM substrate concentration, corresponding to a product formation of 0.43 g/L, at a 400 mL scale.

**Conclusions:** Here we describe the successful scale-up of cyproterone acetate conversion from shake flasks to bioreactors, using the CYP106A2 enzyme in a whole-cell system. The substrate was converted to its main human metabolite, 15β-hydroxy-cyproterone acetate, a highly interesting drug candidate, due to its retained antiandrogener activity but significantly lower progestogen properties than the mother compound. Optimization of the process led to an improvement from 55% to 98% overall conversion, with a product formation of 0.43 g/L, approaching industrial process requirements and a future large-scale application.
Biocatalytic oxidation reactions have the potential to substitute many chemically catalyzed oxidations in the pharmaceutical and fine chemical industry due to their superior regio- and stereoselectivity and low environmental impact. Galactose oxidase (GOase) has been shown to be a promising biocatalyst for the oxidation of primary and secondary alcohols to their corresponding aldehydes and ketones, respectively. However, GOase requires a number of additives to sustain its catalytic function, such as the enzyme catalase for degradation of the byproduct hydrogen peroxide as well as single-electron oxidants to reactivate the enzyme upon loss of the amino acid radical in its active site. In this work, the addition of catalase, single-electron oxidants, and copper ions was investigated systematically in order to find the minimum concentrations required to obtain a fully active GOase. Furthermore, it was found that the concentration and type of buffer is essential for the activity of GOase, which was significantly more active in sodium phosphate buffer than in other...
buffers investigated. Enzyme stability and oxygen requirements are of crucial importance for the implementation of oxidase based processes. GOase was shown to be completely stable for 120 h in buffer with stirring at 25 °C, and the activity even increased 30% if the enzyme solution was also aerated in a similar experiment. The high $K_m$ for oxygen of GOase (>5 mM) relative to the solubility of oxygen in water reveals a trade-off between supplying oxygen at a sufficiently high rate and ensuring a high degree of enzyme utilization (i.e., ensuring the highest possible specific rate of reaction). Nevertheless, the good stability and high activity of GOase bode well for its future application as an industrial biocatalyst.

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BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.114 SNIP 0.97
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Real-Time Model Based Process Monitoring of Enzymatic Biodiesel Production

In this contribution we extend our modelling work on the enzymatic production of biodiesel where we demonstrate the application of a Continuous-Discrete Extended Kalman Filter (a state estimator). The state estimator is used to correct for mismatch between the process data and the process model for Fed-batch production of biodiesel. For the three process runs investigated, using a single tuning parameter, \( q_x = 2 \times 10^{-2} \) which represents the uncertainty in the process model, it was possible over the entire course of the reaction to reduce the overall mean and standard deviation of the error between the model and the process data for all of the five measured components (triglycerides, diglycerides, monoglycerides, fatty acid methyl esters, and free fatty acid). The most significant reduction for the three process runs, were for the monoglyceride and free fatty acid concentration. For those components, there was over a ten-fold decrease in the overall mean error for the state estimator prediction compared with the predictions from the pure model simulations. It is also shown that the state estimator can be used as a tool for detection of outliers in the measurement data. For the enzymatic biodiesel process, given the infrequent and sometimes uncertain measurements obtained we see the use of the Continuous-Discrete Extended Kalman Filter as a viable tool for real time process monitoring.
Rules for biocatalyst and reaction engineering to implement effective, NAD(P)H-dependent, whole cell bioreductions

Access to chiral alcohols of high optical purity is today frequently provided by the enzymatic reduction of precursor ketones. However, bioreductions are complicated by the need for reducing equivalents in the form of NAD(P)H. The high price and molecular weight of NAD(P)H necessitate in situ recycling of catalytic quantities, which is mostly accomplished by enzymatic oxidation of a cheap co-substrate. The coupled oxidoreduction can be either performed by free enzymes in solution or by whole cells. Reductase selection, the decision between cell-free and whole cell reduction system, coenzyme recycling mode and reaction conditions represent design options that strongly affect bioreduction efficiency. In this paper, each option was critically scrutinized and decision rules formulated based on well-described literature examples. The development chain was visualized as a decision-tree that can be used to identify the most promising route towards the production of a specific chiral alcohol. General methods, applications and bottlenecks in the set-up are presented and key experiments required to “test” for decision-making attributes are defined. The reduction of o-chloroacetophenone to (S)-1-(2-chlorophenyl)ethanol was used as one example to demonstrate all the development steps. Detailed analysis of reported large scale bioreductions identified product isolation as a major bottleneck in process design.

General information
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Shape and topology optimization of enzymatic microreactors

Structural optimization methods have been used by mechanical and civil engineers over the years to find the optimal structures. Structural optimization is a series of computational techniques which include shape and topology optimization. Shape optimization is directly applied to the boundaries of a structure and results in the deformation of the configuration. Topology optimization contributes to the improvement of the layout of the material in a domain. The mechanical performance of a structure is evaluated by an objective function which can be for example maximizing its stiffness. The need for effective and cost-efficient reactors for pharmaceutical processes forces the industry to search for better technologies. In biochemical engineering, the used reactor design in a given process is usually limited to a range of well-established configurations and layouts. Usually, the implemented reactors in a chemical process do not always yield in the best reaction conditions. This thesis develops an innovative application of topology and shape optimization methods to a chemical engineering problem. The main goal is to design a reactor according to the limitations of the reaction system by modifying the reactor configuration. In this thesis structural optimization methods were exclusively applied to enzymatic microreactors. The case studies were chosen such that they can be experimentally tested afterwards. In this way, the design of the reactor is customized to the reaction system and it contributes to the reduction of extensive experimental work to find the best reactor configuration. Shape optimization has been applied to an YY-microreactor with a rectangular cross-section with the intention to investigate the shape influence on the active mixing of substances and consequently in the reaction yield. The inlet and the outlet are located at the respective ends of the reactor. Both inlet and outlet have a Y shape where two streams meet at the entrance of the reaction chamber and two streams are split again at the exit. The optimization routine focuses on the modification of the microreactor shape parameters such as height and width. This is achieved by a computational fluid dynamic (CFD) simulation study, which investigates a biocatalytic reaction for the production of optically pure chiral amines in the reactor system. The routine implements kinetic models into a CFD framework (ANSYS CFX®), which is coupled with a self-programmed MATLAB® code. ANSYS CFX® performs the discretization of the microreactor into finite volume elements and calculates the main reactor outputs. The MATLAB® routine performs the optimization by changing the geometry. Furthermore, it includes the evaluation of the objective function, the new definition and execution of the next simulation for each new microreactor shape. Afterwards, the performance of the system is evaluated by comparing the objective function (reaction yield) with the previous best configuration. If the geometry changes result in a better reaction yield, this geometry is selected as the best and the old configuration is discarded. The optimization routine continues until a constraint is fulfilled or the optimization converges. The changes of the geometry are performed by a gradient-free method named random search. The random search modifies the design variables by sampling in an arbitrary manner from a vector which sets the variation limits. Subsequently, the same coupled routine between ANSYS CFX® and MATLAB® is applied to topology optimization. The method was used as a novel technique to computationally discover the best spatial distribution of an enzyme inside a microreactor. Usually, the enzyme is uniformly distributed inside a reactor, which can mean either at a wall surface or in a packed bed reactor or free in solution. Therefore, these three applications are studied. The aim is to improve the product formation per same amount of enzyme in the reactor. The Evolutionary Structural Optimization (ESO) method is adapted to perform the optimization. The ESO method removes inefficient elements from a structure by a gradual and iterative procedure according to a rejection criterion which determines the elements that should be removed every iteration. The MATLAB® routine features the adaptation of the ESO method to the biocatalytic reactor. The two-dimensional topology optimization is applied to a microreactor with immobilized enzyme on the wall surface. The selected reactor geometry is an adaptation of a previously scientific documented shape used in topology optimization of microreactors. The three-dimensional topology is computationally applied to the distribution of enzyme in a miniaturized packed bed reactor as well as to a microreactor with free enzyme in the volume. In the last part of the thesis, the topology of microreactors is the experimentally studied. This is achieved by using the peroxidase-catalyzed oxidation of 2,2'-azino-bis(3-ethylbenzthiazoline-6-sulfonic acid) (ABTS) to its radical form by reduction of hydrogen peroxide. The determination of the kinetic mechanism is required in order to validate the optimized microreactors. Two microreactor shapes are topology optimized for posterior experimental validation. The first shape corresponds to the shape with immobilized peroxidase on the wall surface. The experimental validation was attempted by using a photochemical reaction. The reaction attaches linkage molecules to a masked surface, which has an immobilization pattern. The linkage molecules will thereafter react with the enzyme molecules binding them covalently to the surface. The second microreactor configuration corresponds to a square shaped cross section microchannel with free enzyme in solution. For this case study, a well-mixed solution of enzyme and substrate is considered to enter the microreactor. The experimental comparison is performed by comparing an improved inlet configuration with a reference system. The configurations were selected and fabricated as a compromise considering the outcome of the topology optimization and the limitations of the fabrication process.
Study of wettability of calcite surfaces using oil-brine-enzyme systems for enhanced oil recovery applications

Enzymes have recently been considered as possible agents for enhanced oil recovery (EOR) acting at the liquid-solid interface. One way to assess this is via measuring the wettability of calcite surfaces, important for EOR methods in carbonaceous reservoirs. In the present work, we have experimentally investigated the effect of enzymes on the wettability of calcite mineral surfaces with oil-brine systems. The action of various enzymes, including esterases/lipases, carbohydrates, proteases and oxidoreductases (along with two commercial mixtures) was studied by contact angle measurements and adhesion behaviour tests. Comparative studies with a surfactant, protein, purified enzyme, enzyme stabiliser using n-decane (as a model for the oil) have also been carried out in order to verify experimental results. The enzymes that have the highest effect on the wettability have been identified. Those enzymes, which were found the most promising from a practical perspective, have shown the ability to fully detach oil from the surface, even at very low enzyme concentrations. For example, esterases/lipases were found to strongly affect the wettability and to remove adhesion at concentrations as low as 0.1% of the enzyme product (corresponding to 0.002-0.005% protein). Likewise, proteases could also improve wettability, although the effect was not consistent and was dependent on impurities. Other enzymes had no effect on the wettability of calcite at the concentration studied. The main mechanism of enzymatic action has been found to be replacement of oil at the solid surface by the enzyme. Other mechanisms (modification of the surface tension or catalytic modification of hydrocarbons resulting in reducing the oil viscosity) have shown to be much less pronounced from the measurements reported here.
Sustainable process synthesis–intensification

Chemical industry is facing global challenges such as the need to find sustainable production processes. Process intensification as part of process synthesis has the potential to find truly innovative and more sustainable solutions. In this paper, a computer-aided, multi-level, multi-scale framework for synthesis, design and intensification of processes, for identifying more sustainable alternatives is presented. Within the framework, a three stage work-flow has been implemented where, in the first “synthesis” stage an optimal processing route is synthesized through a network superstructure optimization approach and related synthesis tools. In the second, “design” stage, the processing route from the first stage is further developed and a base case design is established and analyzed. In the third, “innovation” stage, more sustainable innovative solutions are determined. The application of the framework is illustrated through a case study related to the production of di-methyl carbonate, which is an important bulk chemical due to its multiplicity of uses.

General information
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Synthesis of 5-hydroxymethylfurfural (HMF) by acid catalyzed dehydration of glucose-fructose mixtures

Synthesis of 5-hydroxymethylfurfural (HMF) from hexoses has been studied extensively in the scientific literature. However, a process has yet to be implemented at industrial scale. In this paper the simultaneous dehydration of glucose and fructose was investigated, in order to develop a process allowing the use of the cheapest available source of fructose: high fructose corn syrup. The dehydration was catalyzed by hydrochloric acid and conducted in acetone-water mixtures, which ensured good selectivity towards HMF and eliminated precipitation of polymer by-products (insoluble humins). Through a detailed experimental investigation a reaction network was proposed, and subsequently the corresponding kinetic model was fitted to experimental data in order to obtain estimates of the reaction kinetic parameters. The kinetic model is capable of predicting the formation of HMF along with the important by-products: soluble humins, glucose dimers, anhydroglucose, and formic acid. The reaction conditions in four different reactor configurations were optimized and compared using the kinetic model. It was found that a recirculating reactor setup is preferable, where the equilibrium controlled by-products (anhydroglucose and glucose dimers) are recirculated to the dehydration reactor. The model predicts an HMF selectivity of close to 70% in a recirculating reactor at conditions where HMF degradation is avoided.

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Synthesis of biorefinery networks using a superstructure optimization based approach

Petroleum is currently the primary raw material for the production of fuels and chemicals. Consequently, our society is highly dependent on fossil non-renewable resources. However, renewable raw materials are recently receiving increasing interest for the production of chemicals and fuels, so a new industrial system based on biomass, an inexpensive, abundant and renewable raw material, is being established with sustainability as the main driving force [1]. The processing facilities for the production of multiple products (including biofuels and chemicals) from biomass are referred as biorefineries [2]. The optimal synthesis of biorefinery networks problem is defined as: given a set of biomass derived feedstock and a set of desired final products and specifications, determine a flexible, sustainable and innovative processing network with the targets of minimum cost and sustainable development taking into account the available technologies, geographical location, future technological developments and global market changes. The problem of optimal design of biorefinery networks is solved in this work through three different stages: (i) synthesis stage, (ii) design stage, and (iii) innovation stage. At the synthesis stage, the considered alternatives are represented in a superstructure, from which a mixed-integer linear or nonlinear programming (MILP or MINLP) problem is derived and solved in order to find the optimal processing network for a pre-defined objective function. Next, at the design stage, the selected processing network is simulated and analyzed and targets for improvement are identified. Finally, a more sustainable design is achieved at the innovation stage by generating innovative solutions that satisfy the targets from the design stage. This work is concerned with the first stage: the synthesis stage. Various biorefinery processing alternatives are represented in a superstructure and the associated data is collected and stored in a database. Once a specific biorefinery synthesis problem is formulated, the superstructure is reduced in order to include only the relevant alternatives. The superstructure is reduced based on constraints from the problem formulation, such as location or raw material. The reduced superstructure is then represented using mathematical models - the modelling approach by Quaglia et al. [3] is used - and solved to find the optimal network. The applicability of the proposed approach is shown through a practical case study for the production of valuable products (i.e. lysine and lactic acid) from sugarcane molasses; these alternatives are considered with respect to availability and demands in Mexico [4].
a mathematical model as a tool for the simulation and potential design of such a process for the production of a range of chiral amines. The mathematical model developed considers that each reaction is performed in a single ideally mixed isothermal reactor operating sequentially in fed batch–batch mode. Both reactors are interconnected through a semi-permeable membrane, where multicomponent intra-membrane transport takes place by diffusion and viscous flow. The kinetic modeling of both reactions has been carried out and model simulations show that in this way a significant increase in the yield of the chiral amine product may be obtained. Finally, the role of the different parameters involved in the process model has been analyzed.

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**Thermodynamic Calculations for Systems Biocatalysis**

'Systems Biocatalysis' is a term describing multi-enzyme processes in vitro for the synthesis of chemical products. Unlike in-vivo systems, such an artificial metabolism can be controlled in a highly efficient way in order to achieve a sufficiently favourable conversion for a given target product on the basis of kinetics. However, many of the most interesting non-natural chemical reactions which could potentially be catalysed by enzymes, are thermodynamically unfavourable and are thus limited by the equilibrium position of the reaction. A good example is the enzyme ω-transaminase, which catalyses the transamination of a pro-chiral ketone into a chiral amine (interesting in many pharmaceutical applications). Here, the products are often less energetically stable than the reactants, meaning that the reaction may be thermodynamically unfavourable. As in nature, such thermodynamically-challenged reactions can be altered by coupling with other reactions. For instance, in the case of ω-transaminase, such a coupling could be with alanine dehydrogenase. Herein, the aim of this work is to identify thermodynamic bottlenecks within a multi-enzyme process, using group contribution method to calculate the Gibbs free energy change, $\Delta G^O_r$, of the overall cascade. The findings show that unfavourable reactions in the cascade can be improved by coupling to a favourable reaction giving more energetically stable products.

**Thermodynamic Modeling of Multi-phase Solid–Liquid Equilibria in Industrial-Grade Oils and Fats**

Compositional thermodynamic phase separation is investigated for industrial-grade vegetable oils with complex compositions. Solid–liquid equilibria have been calculated by utilizing the Margules 2-suffix activity-coefficient model in combination with minimization of the Gibb's free energy of the system. On the basis of quasi-equilibrium solid-fat content (SFC) measurements, a new approach to the estimation of the interaction parameters, needed for the activity-coefficient model, has been developed. The parameters are fitted by matching the SFC of two oils at various degrees of dilution and isothermal temperatures. Subsequently, the parameters are successfully validated against three oils, rich in asymmetric and symmetric triacylglycerols (TAG), respectively. The new approach developed is shown to be very flexible, allowing incorporation of additional TAG and polymorphic states. It thereby provides a simple way to dealing with multi-component, multi-phase TAG mixtures without having the required binary interaction parameters at hand a priori. This ultimately provides a powerful, predictive tool which may serve as a starting point for laboratory screening and creation of tailor-made products because many different oil mixtures can be evaluated quickly with respect to specific properties, prior to more time-consuming experimental evaluation.
Topology optimization for biocatalytic microreactor configurations

The aim of this study is to present an innovative strategy for selecting a reactor for a specific process. Instead of adapting the process to a well-known reactor shape, a topology optimization method is used to obtain the best reactor configuration, and is applied to a biocatalytic reaction system as a case study. The Evolutionary Structure Optimization (ESO) method is applied using an interface between Matlab® and the computational fluid dynamic simulation software ANSYS CFX®. In the case study, the ESO method is applied to optimize the spatial distribution of immobilized enzyme inside a microreactor. The results allow evaluating which regions in the microreactor have more importance for the product formation. In fact, it was possible to simulate the improvement of the outlet product concentration per same amount of enzyme by modifying the spatial distribution of the immobilized enzyme.

Use of operating windows for assessment of continuous plug flow slurry reactor

General information
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Achieving More Sustainable Designs through a Process Synthesis-Intensification Framework

More sustainable process designs refer to design alternatives that correspond to lower values of a set of targeted performance criteria. In this paper, a multi-level framework for process synthesis-intensification that leads to more sustainable process designs is presented. At the highest level of aggregation, process flowsheets are synthesized in terms of a sequence of unit operations that correspond to acceptable values for a set of targeted performance criteria. This defines the upper-bound of the performance criteria and the design is called the base-case design. At the next lower level, tasks representing unit operations are identified and analyzed in terms of means-ends to find more flowsheet alternatives that improve the base-case design and correspond to lower values of the set of targeted performance criteria. At the lowest level, phenomena employed to perform the specific tasks are identified and manipulated to find intensified operations leading to more flowsheets that further improve the base-case design and correspond to even lower values of the set of target performance criteria. An overview of the framework is presented together with a case study that highlights the key concepts and application workflow.
Application of environmental and economic metrics to guide the development of biocatalytic processes

The increasing industrial interest in biocatalytic processes is predominantly driven by the need for selective chemistry, with high reaction yield (Y-reaction) and few side reactions, as well as the need for optically pure chiral molecules (in particular in the pharmaceutical industry). Interestingly, it is often argued that the mild conditions frequently used in biocatalytic reactions (ambient temperature and pressure, neutral pH and aqueous-based media) automatically lead to environmentally-friendly and cost-effective production processes. However, such a conclusion is not justified without the use of adequate tools to evaluate the performance of a process, in particular during process development. Nevertheless, at the early development stage, evaluation of biocatalytic processes is not a trivial task, not only due to the lack of data, but also because at this stage many of the biocatalytic processes are not yet fully optimized. Hence, in this paper we propose the use of a range of tools which can be used to guide process development, research tasks and support decision-making. Three sets of metrics are identified, each for use at different stages of process development (route selection, early development and late development), each with different objectives.

Application of Uncertainty and Sensitivity Analysis to a Kinetic Model for Enzymatic Biodiesel Production

This paper demonstrates the added benefits of using uncertainty and sensitivity analysis in the kinetics of enzymatic biodiesel production. For this study, a kinetic model by Fedosov and co-workers is used. For the uncertainty analysis the Monte Carlo procedure was used to statistically quantify the variability in the model outputs due to uncertainties in the parameter estimates; showing the model is most reliable in the start (first 5 hours) of the reaction. To understand which input parameters are responsible for the output uncertainty, two global sensitivity methods (Standardized Regression Coefficients, and Morris screening) were used. The results from both sensitivity analyses identified that only 10 of the 32 parameters are influential to the model outputs. The model was then simplified by removing the non-influential parameters. A parity plot of the simplified model vs. the full model gave a R2 value of over 0.95 for all the model outputs.
Applying Enzymatic Cascades for ISCPR in ω-transaminase Systems

Biocatalysis complements the classical organic synthesis, and in many cases the superior selectivity of a biocatalyst is a strong driver explaining why there are an increasing number of processes where traditional organic synthesis has been replaced or combined with biocatalytic industrial process steps. An important fact is also that different types of selectivity make biocatalysis an excellent tool for overcoming difficulties typically associated with organic synthesis. Regioselectivity of the biocatalysts offers potential process simplification compared to the organic synthesis routes (reduction of the number of protective/deprotective steps), and stereoselectivity of the biocatalyst enables production of the desired chiral compounds, which often are building blocks of APIs. Currently there are many established processes in the industry using biocatalysis (= 300), e.g. the usage of lipases, esterases, ketoreductases and proteases and many more emerging biocatalysts such are monoamine oxidases, transaminases and P450 monoxygenases to name a few. The focus of this thesis is the biocatalytic synthesis of small molecule pharmaceuticals (Mw<1000), and in particular the production of optically pure amines via ω-transaminases, which is an interesting class of reactions for the pharmaceutical industry. There are many challenges related to the realization and implementation of these technologies, and attempts of tackling them have been numerous. In some cases ω-transaminase catalyzed reactions are thermodynamically challenged and equilibrium shifting strategies are required. The proposed equilibrium shifting strategies are selection of an amino donor, excess of an amino donor, in-situ product removal (ISPR) and in-situ co-product removal. (ISCPR). For severely thermodynamically challenged reactions ISCPR by enzymatic cascades often provides the only viable option as equilibrium shifting strategy. In the literature several enzymatic cascades have been reported as an ISCPR for the ω-transaminase systems, however in most cases no process considerations have been made and the consequences of using a givens cascade in an industrial process context have thus not been considered properly. In this research lactate dehydrogenase (LDH) (E.C. 1.1.1.27), alanine dehydrogenase (E.C. 1.4.1.1) (AlaDH) and yeast alcohol dehydrogenase (E.C. 1.1.1.1) (YADH) have been researched as co-product degrading enzymes and glucose dehydrogenase (GDH) (E.C. 1.1.1.47) and formate dehydrogenase (E.C. 1.2.1.2) (FDH) as co-factor regeneration enzymes. Additionally pyruvate decarboxylase (E.C. 4.1.1.1) (PDC) and acetolactate synthase (E.C. 2.2.1.6) (ALS) have been considered as co-product degrading options. This work presents a procedure for cascade selection based on process considerations: thermodynamics, selectivity and operational stability while the final selection is further supported by the use of kinetic models. From the above presented cascade system options, the selection procedure identified the LDH/FDH cascade system as the system that is most promising for future industrial implementation. Furthermore, the required improvements of the ω-transaminase have been identified as a function of the added cascade enzymes and for the case γLDH = 11 g L-1, γFDH = 11 g L-1 and cNADH = 0.1 mmol L-1, it was found that the ω-transaminase activity expressed as Vmax_f,r is required to be 55.33 mmol min-1 L-1 to achieve 95 % conversion within 24 h. Further investigation concluded that a significant LDH concentration reduction is possible if inhibition by lactate is alleviated (preferably by protein engineering). This thesis identified the UFMR (UltraFiltration Membrane Reactor) as a viable process design option and charge analysis showed that ISPR is possible via ion exchange resins or electrodialysis. An ISPR example showed that process intensification could yield significant reductions in the required ω-transaminase activity improvement (up to five fold improvement) needed to achieve a viable industrial process, as well as reduction of required tolerance toward product inhibition. Although this thesis has been based on a specific case of a severely thermodynamically challenged ω-transaminase reaction (Keq = 4.03×10^-5), the selection framework can be transferred to any thermodynamically challenged reaction where the use of ISCPR by enzymes is considered to shift the equilibrium. Therefore, this work delivers: a) a method for initial investigation of thermodynamic limitations and viability of one or more equilibrium shifting strategies; b) a method for selecting a viable cascade option for ISCPR based on industrial conditions; c) information on the required enzyme performance e.g. the activity of the ω-transaminase, and potentially required compromises using process intensification tools and methods.
A process synthesis-intensification framework for the development of sustainable membrane-based operations

In this paper a multi-level, multi-scale framework for process synthesis-intensification that aims to make the process more sustainable than a base-case, which may represent a new process or an existing process, is presented. At the first level (operation-scale) a conceptual base case design is synthesized through the sequencing of unit operations and subsequently analyzed for identifying process hot-spots using economic, life cycle and sustainability metrics. These hot-spots are limitations/bottlenecks associated with tasks that may be targeted for overall process improvement. At the second level (task-scale) a task-based synthesis method is applied where one or more tasks representing unit operations are identified and analyzed in terms of means-ends for generating intensified flowsheet alternatives. At the third level (phenomena-scale) a phenomena-based synthesis method is applied, where the involved phenomena in various tasks are identified, manipulated and recombined to generate new and/or existing unit operations configured into flowsheet alternatives that target the tasks associated with hot-spots. Every lower-scale or higher-level, generates more alternatives than their corresponding larger-scale. Those alternatives that are able to address the identified hot-spots therefore give innovative and more sustainable process designs that otherwise could not be found from the larger-scales. In this paper, membrane-based operations identified through this framework are highlighted in terms of extension of the combined intensification-synthesis method and its application to generate membrane-based operations. Also, application of the framework is illustrated through a case study involving the production of methyl acetate where membrane-based intensified operations play a major role in determining more sustainable process design alternatives.

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A systematic methodology for design of tailor-made blended products

A systematic methodology for design of tailor-made blended products has been developed. In tailor-made blended products, one identifies the product needs and matches them by blending different chemicals. The systematic methodology has four main tasks. First, the design problem is defined: the product needs are identified, translated into target properties and the bounds for each target property are defined. Secondly, target property models are retrieved from a property model library. Thirdly, a mixture/blend design algorithm is applied to obtain the mixtures/blends that match the design targets. The result is a set of blends that match the constraints, the composition of the chemicals present in the blend, and the values of the target properties. Finally, the mixture target property values are verified by means of rigorous models for the properties and the mixtures. In this paper, the methodology is highlighted through two case studies involving gasoline blends and lubricant base oils.

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Batch production of FAEE-biodiesel using a liquid lipase formulation

The application of lipase catalysis to the production of biodiesel has received much interest during the past several years. Although most of the previous work has involved the use of immobilized enzyme, more recent work has indicated that liquid formulations of lipase can provide a highly competitive option for the conversion of oils and fats to biodiesel. This study investigates the impact of several process parameters on the production of fatty acid ethyl esters from rapeseed oil in a pure batch process on the liquid lipase formulation Callera™ Trans L. Oil conversion in excess of 98% was achieved.
by combining a 50% stoichiometric excess of ethanol (1.5 equivalents) with 20% (w/w) water relative to the oil. The rate of reaction was directly proportional to the amount of lipase added in this system (500-2000 LU per gram oil). Addition of glycerol to the initial reaction mixture reduced the initial reaction rate, but also improved the final yield of biodiesel by suppressing hydrolysis. © 2014 Published by Elsevier B.V.
Biocatalytic process development using microfluidic miniaturized systems
The increasing interest in biocatalytic processes means there is a clear need for a new systematic development paradigm which encompasses both protein engineering and process engineering. This paper argues that through the use of a new microfluidic platform, data can be collected more rapidly and integrated with process modeling, can provide the basis for validating a reduced number of potential processes. The miniaturized platform should use a smaller reagent inventory and make better use of precious biocatalysts. The EC funded BIOINTENSE project will use ω-transaminase based synthesis of chiral amines as a test-bed for assessing the viability of such a high throughput biocatalytic process development, and in this paper, such a vision for the future is presented.

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Bioprocess engineering for the application of P450s
The highly specific hydroxylation performed by P450 monooxygenases is a very powerful tool for synthetic chemists, not only at laboratory scale, but potentially also at industrial scale. However, despite this potential, only in a few cases has this class of enzymes been implemented at an industrial scale. In the case of P450s, the requirements for cofactor and electron transporting redox partner, coupled with conversion of hydrophobic substrates to hydrophobic products already set some constraints. In order to enable focused and directed improvement of the biocatalyst (and process), such limitations need to be quantified via carefully designed experiments. In this presentation, we will report the results of a hypothesis driven experimental approach to characterization, with the aim of quantifying the limitations associated with cofactor regeneration, inhibition, toxicity and trans-membrane transport. Selected test reactions and biocatalysts made available within the EC FP7 research program P4FIFTY have been used for the study, including CYP153A[1], CYP102A1[2] expressed in Escherichia coli and CYP106A2[3] expressed in Bacillus megaterium. Common limitations
have been found to be the stability of the biocatalyst, as well as substrate inhibition and toxicity. These limitations will influence what we have reported as typical targets necessary to implement a commercially feasible process (reaction yield, biocatalyst yield, final product concentration and space-time yield). The analysis reveals that while further improvements are required to reach the targets, the remaining limitations should ultimately be possible to overcome. Such a process analysis tool can in principle be applied to many biocatalytic systems and it is hoped that in the future it will help to enable accelerated biocatalytic process development.
Biocatalysis encompasses the use of enzymes or whole cell systems for effecting the conversion of readily available, inexpensive starting materials to high value products. Enzymes are fully recyclable catalytic proteins that frequently display exquisite chemo-, enantio- and regioselectivity and operate under mild conditions of pH and temperature. These characteristics make them cost-effective and sustainable catalysts for a wide range of chemical transformations. Modern tools of protein discovery and engineering as well as advances in molecular biology and protein structure aid the development of biocatalysts and their tailor-designed integration into industrial processes. Consequently, they find wide application in the production of pharmaceutical intermediates, novel materials and diagnostics, as well as fine, performance and commodity chemicals. The Biocatalysis Gordon Research Conference highlights the best science, technologies and case studies to provide in-depth understanding of the development and practical use of biocatalysts around the world.
Engineering of Biocatalysts and Biocatalytic Processes
Discovering and developing new biocatalytic reactions and biocatalysts has been the major focus of the activities in the EC FP7 BIOTRAINS network. However, industrial implementation of these new reactions requires engineering of both the biocatalysts and the associated processes, to achieve the necessary targets for economic and sustainable feasibility of full-scale processes. The possible engineering solutions can most rapidly be identified using a series of tools and in this article we will describe some of these as well as giving a perspective on the future of this important element of process research and development.
Enzymatically Assisted CO₂ Removal from Flue-Gas

The enzyme carbonic anhydrase is an enzyme known to enhance CO₂ absorption rates. However, for economic viability in enzyme based absorption technology long term stability under process relevant conditions is needed. Thus, here enzyme stability for extended times are investigated with respect to pH, temperature and solvent. Temperatures and pH stability were tested for up to 100 hours incubation and the enzyme was temperature stable up to 60 °C and in the pH range from 7 to 11, with some residual activity between pH 5 and 12. Furthermore, enzyme stability was tested for 7 different capture solvents for 150 days, at 1 M or 3 M solvent concentrations, 40 °C and pH between 8-9 and 10. Residual activity was found with all samples ranging from 12 to 91 % of the initial activity. This study show that this enzyme can indeed be used for extended periods in process relevant conditions, and thus shows promise for industrial implementation as a catalyst in carbon capture.

General information
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Enzyme characterisation in microreactors by multivariate data analysis

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Fed-Batch Feeding Strategies for Enzymatic Biodiesel Production
In this work a kinetic model for the enzymatic transesterification of rapeseed oil using a solubilised lipase (Callera Trans L-Thermomyces lanuginos us) was developed from first principles. The model is based on a Ping-Pong Bi-Bi mechanism, with methanol inhibition, along with consideration of the differences in the interfacial and bulk concentrations of the enzyme. The model is then used to evaluate various feeding strategies to improve the enzymatic biodiesel production. The feeding strategies investigated, gave insight into how the methanol should be fed to potentially mitigate enzyme deactivation while improving the biodiesel yield. The best experimental results gave a yield of 703.76 g FAME L-1 and a reactor productivity of 28.12 g FAME L-1 h-1. In comparison, to reach the same yield, the optimised two step feeding strategy took 6.25 hours less, which equates to an increase in the reactor productivity of 36.9 %.

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Filamentous Fungi Fermentation

Filamentous fungi (including microorganisms such as Aspergillus niger and Rhizopus oryzae) represent an enormously important platform for industrial fermentation. Two particularly valuable features are the high yield coefficients and the ability to secrete products. However, the filamentous morphology, together with non-Newtonian rheological properties (shear thinning), result in poor oxygen transfer unless sufficient energy is provided to the fermentation. While genomic research may improve the organisms, there is no doubt that to enable further application in future it will be necessary to match such research with studies of oxygen transfer and energy supply to high viscosity fluids. Hence, the implementation of innovative solutions (some of which in principle are already possible) will be essential to ensure the further development of such fermentations.

Identification and use of an alkane transporter plug-in for application in biocatalysis and whole-cell biosensing of alkanes

Effective application of whole-cell devices in synthetic biology and biocatalysis will always require consideration of the uptake of molecules of interest into the cell. Here we demonstrate that the AlkL protein from Pseudomonas putida GPo1 is an alkane import protein capable of industrially relevant rates of uptake of C_{7-16} n-alkanes. Without alkL expression, native E.coli n-alkane uptake was the rate-limiting step in both the whole-cell bioconversion of C_{7-16} n-alkanes and in the activation of a whole-cell alkane biosensor by C_{10} and C_{12} alkanes. By coexpression of alkL as a transporter plug-in, specific yields improved by up to 100-fold for bioxidation of C_{10-16} alkanes to fatty alcohols and acids. The alkL protein was shown to be toxic to the host when overexpressed but when expressed from a vector capable of controlled induction, yields of alkane oxidation were improved a further 10-fold (8 g/L and 1.7 g/g of total oxidized products). Further testing of activity on n-octane with the controlled expression vector revealed the highest reported rates of 120 μmol/min/g and 1 g/L/h total oxidized products. This is the first time AlkL has been shown to directly facilitate enhanced uptake of C_{10-16} alkanes and represents the highest reported gain in product yields resulting from its use.
Identification of Critical Parameters in Liquid Enzyme-Catalyzed Biodiesel Production

Identification_and_use_of_an_alkane.pdf

Bibliographical note
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Identification of Critical Parameters in Liquid Enzyme-Catalyzed Biodiesel Production

Callera TM, Trans L, a liquid formulation of Thermomyces lanuginosus lipase, has recently shown great promise as a cost-efficient catalyst for methanolysis of triglyceride substrates, specifically in the BioFAME process. However, identifying the right combination of temperature and concentrations of catalyst, water and methanol to realize the full potential of the reaction system has remained a challenge. This study presents an investigation of the impact of temperature, enzyme and water concentration on the reaction, as well as the effect of methanol feed rate for the conversion of rapeseed oil in a fed-batch reaction system. It was observed that the reaction can be divided into two distinct parts. The first part of the reaction, during which primarily tri- and diglycerides are converted, proceeded at a high rate and thus required a high rate of methanol supply. The second part of the reaction, where the remaining di- and monoglycerides are converted, proceeded at a much lower rate. Consequently, it is necessary to reduce the methanol feed rate during the latter part of the reaction to avoid inhibition or even inactivation of the enzyme. Since the second part of the reaction occupied most of the 24-h reaction time, it was concluded that this is the part of the process where further development efforts should be targeted. This point was demonstrated by partially substituting the catalyst with a lipase with a different specificity, which enhanced the performance during the second phase of the reaction.

General information
State: Published
Inhibition of Gas Hydrate Nucleation and Growth: Efficacy of an Antifreeze Protein from the Longhorn Beetle *Rhagium mordax*

Antifreeze proteins (AFPs) are characterized by their ability to protect organisms from subfreezing temperatures by preventing tiny ice crystals in solution from growing as the solution is cooled below its freezing temperature. This inhibition of ice growth is called antifreeze activity, and in particular, certain insect AFPs show very high antifreeze activity. Recent studies have shown AFPs to be promising candidates as green and environmentally benign inhibitors for gas hydrate formation. Here we show that an insect antifreeze protein from the longhorn beetle, *Rhagium mordax* (RmAFP1), the most potent protein yet found for freezing inhibition, can inhibit methane hydrates as effectively as the synthetic polymeric inhibitor polyvinylpyrrolidone (PVP). In high pressure rocking cell experiments, onset hydrate nucleation temperatures and growth profiles showed repeatable results. RmAFP1 clearly showed inhibition of hydrates compared to amino acids (l-valine and l-threonine) and the protein bovine serum albumin (BSA). This indicates that proteins or amino acids do not generally inhibit hydrate formation. The promising performance of RmAFP1 as a new green kinetic hydrate inhibitor could further the development and increased production of green hydrate inhibitors.

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Organisations: Center for Energy Resources Engineering, Department of Chemical and Biochemical Engineering, CERE – Center for Energy Resources Engineering, CAPEC-PROCESS, Technical University of Denmark, University of Stavanger, Roskilde Universitet
Authors: Perfeldt, C. M. (Ekstern), Chua, P. C. (Ekstern), Daraboina, N. (Intern), Friis, D. (Ekstern), Kristiansen, E. (Ekstern), Ramløv, H. (Ekstern), Woodley, J. (Intern), Kelland, M. A. (Ekstern), von Solms, N. (Intern)
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Introducing an In Situ Capping Strategy in Systems Biocatalysis To Access 6-Aminohexanoic acid

The combination of two cofactor self-sufficient biocatalytic cascade modules allowed the successful transformation of cyclohexanol into the nylon-6 monomer 6-aminohexanoic acid at the expense of only oxygen and ammonia. A hitherto unprecedented carboxylic acid capping strategy was introduced to minimize the formation of the dead-end intermediate 6-hydroxyhexanoic acid. For this purpose, the precursor e-caprolactone was converted in aqueous medium in the presence of methanol into the corresponding methyl ester instead of the acid. Hence, it was shown for the first time that esterases—specifically horse liver esterase—can perform the selective ring-opening of e-caprolactone with a clear preference for methanol over water as the nucleophile.

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Organisations: Department of Chemical and Biochemical Engineering, CAPEC-PROCESS, University of Graz, Evonik Industries AG
Authors: Sattler, J. H. (Ekstern), Fuchs, M. (Ekstern), Mutti, F. G. (Ekstern), Grischek, B. (Ekstern), Engel, P. (Ekstern), Pfeffer, J. (Ekstern), Woodley, J. M. (Intern), Kroutil, W. (Ekstern)
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Introducing an In Situ Capping Strategy in Systems Biocatalysis To Access 6-Aminohexanoic acid

The combination of two cofactor self-sufficient biocatalytic cascade modules allowed the successful transformation of cyclohexanol into the nylon-6 monomer 6-aminohexanoic acid at the expense of only oxygen and ammonia. A hitherto unprecedented carboxylic acid capping strategy was introduced to minimize the formation of the deadend intermediate 6-
hydroxyhexanoic acid. For this purpose, the precursor e-caprolactone was converted in aqueous medium in the presence of methanol into the corresponding methyl ester instead of the acid. Hence, it was shown for the first time that esterases—specifically horse liver esterase—can perform the selective ring-opening of ε-caprolactone with a clear preference for methanol over water as the nucleophile.

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**Kinetic study on the enzymatic esterification of octanoic acid and hexanol by immobilized Candida antarctica lipase B**

This study investigates reaction kinetics of the esterification of octanoic acid and hexanol into hexyloctanoate, catalyzed by an immobilized Candida antarctica lipase (Novozym®435). The product is considered natural and used as a fresh vegetable and fruity flavour additive in food, cosmetic and pharmaceutical products. The reaction is performed in n-decane as the solvent, to improve enzyme stability and to increase the reaction yield. The influence of substrate concentration on hexyl octanoate synthesis is investigated over a wide range up to 2 M. The observed bi-substrate inhibition pattern follows a Ping-Pong bi-bi mechanism with dead-end inhibition by both substrates and, based on the proposed model, the kinetic constants of the esterification reaction are estimated. These parameters are verified to be intrinsic – neither external nor internal mass transfer resistances are significant for the examined reaction system – and are essential to extend analysis to a large-scale process and for a wide range of operating conditions. The progress of the reaction is also observed and the kinetic model is validated by fitting experimental progress curves with two different concentrations of biocatalyst. Effects of biphasicity of the reaction system, inhibition by the ester produced and the influence of the reverse reaction have been also evaluated.© 2014 Elsevier B.V. All rights reserved.

**General information**

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Organisations: Department of Chemical and Biochemical Engineering, CAPEC-PROCESS, University of Calabria
Authors: Lopresto, C. G. (Ekstern), Calabro, V. (Ekstern), Woodley, J. M. (Intern), Tufvesson, P. (Intern)
Mathematical Modeling of Vegetable-Oil Crystallization

In recent years the food sector has experienced a great boost in demand for tailor-made fats and oils to produce so-called functional foods, where ingredients have been carefully modified to yield products with specific, valuable properties. Depending on market segment and product, it may be desirable to enhance specific properties such as shelf life, viscosity, texture, sensory aspects and physical appearance.

Vegetable oils and fats constitute a considerable part of many food products such as chocolate, margarine, bread, spreads and ice cream. Several attractive properties found in these products, including flavor release, melting profile and appearance, are governed by the oils and fats added. Consequently, altering the fat phase may lead to enhanced properties of the products.

The primary focus of the present work is vegetable oils and fats originating from different sources covering the most abundant fatty-acid moieties encountered in industrial productions of food and confectionary products. The oils usually contain more than 95% triacylglycerols (TAGs), a family of molecules which is shown to govern many of the aforementioned properties of oils and fats. With few exceptions natural oils and fats comprise an abundant number of TAGs giving rise to complex chemical compositions. In this research the focus will mainly be on TAGs, disregarding minor components.

To date improvements of oils and fats have largely been based on empirical laboratory tests designed by skilled experts and specialists drawing on many years of experience and knowledge. With this in mind, the aim of the present project was to develop a transient mathematical model, describing crystallization of vegetable fats and oils, based on physicochemical phenomena. The model itself can provide the industry with a valuable tool to design and optimize products. It can also serve as a fundament for testing proposed hypotheses and facilitate realizations with respect to oil and fat crystallization.

The research carried out in this project is schematically described in Figure 2. The mathematical model is developed by combining the 5 sections. The actual work is primarily concerned with sections 2-4, while the outputs (section 5) are used as a measure of the model’s performance. Section 2 deals with the thermodynamic foundation needed to correctly understand and describe the driving force toward crystallization of TAGs from a liquid. As a consequence of the polymorphic nature of TAGs and their ability to mix non-ideally in the solid state, special measures are to be exercised to develop a versatile, predictive model describing multi-component, multi-phase solid-liquid equilibria.

With reference to research reported in literature, solid-liquid equilibria for complex systems are calculated by minimization of the Gibb’s free energy of the system. Possible phase splits are taken into account by employing the tangent-plane criterion. Non-ideal mixing leads to excess Gibb’s free energy, which can be described by an activity-coefficient model, in this case the Margules 2-suffix model. This model requires binary-interaction parameters for each pair of TAGs. Obtaining these parameters for pure binary mixtures would be extremely time-consuming, expensive and in some cases impossible due to unavailability of the pure TAGs. A new approach to simultaneously determine all interaction parameters for complex, industrial oils is developed. A series of solid-fat-content (SFC) measurements are performed for different oil blends and temperatures and the experimental SFC values are matched by the model by varying the interaction parameters. The final model with the fitted interaction parameters performs excellently and is validated against independent oil blends. This SLE model shapes the foundation needed in the following kinetic and mechanistic assessments.

Section 3 extends the developed SLE model to deal with TAG crystallization under non-isothermal conditions and deals with appropriate description of nucleation and growth phenomena. The developed model is fitted and tested against SFC curves recorded for various oil blends and temperature profiles while some necessary kinetic constants are obtained via focused-beam-reflectance measurements (FBRM). The model includes primary and secondary nucleation and growth being governed by both integration and diffusion kinetics. Both growth constants are temperature dependent and the integration constant is allowed to change value as a function of TAG type (tri-saturated, di-saturated, etc.) due to the different degrees of conformational order needed for integration to take place. The diffusion constant is related to the viscosity of the system which in turn is a function of the solid-volume fraction. In total five adjustable parameters are indentified and fitted to experimental SFC curves. Using the fitted parameters the transient model can describe the course of crystallization for a number of oil blends and accommodates the effect of varying the cooling rate.

Section 4 refines the model behavior by introducing a population balance (PB), keeping track of the chord-length distribution (CLD) (derived from particle-size distribution (PSD)) and providing a more realistic picture of the surface area available for growth. A discretized PB, based on the moving-pivot technique, is introduced. The PSD is divided into a number of segments and this approach is numerically easy to handle and well-behaved. The method proves fast, precise and flexible with respect to mechanistic dependencies. All particles are assumed to exhibit spherical geometry and nucleation, growth and aggregation events are accommodated in the PB. Five adjustable parameters are fitted by comparing the model output with experimental CLDs recorded using FBRM. Good results are obtained taking only nucleation and growth into account and disregarding aggregation. The model describes the experimental CLDs well, not only in terms of the overall shape but also with respect to trends. The model correctly describes broader distributions as the concentration of crystallizing TAGs is increased and more narrow distributions as the cooling rate is increased.

General Information

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Organisations: Department of Chemical and Biochemical Engineering
Authors: Hjorth, J. L. (Intern), Woodley, J. (Intern), Kil, S. (Intern), Leth-Miller, R. (Intern)
Number of pages: 191
Publication date: 2014
Mechanistic Modelling of Biodiesel Production using a Liquid Lipase Formulation

In this article, a kinetic model for the enzymatic transesterification of rapeseed oil with methanol using Callera™ Trans L (a liquid formulation of a modified Thermomyces lanuginosus lipase) was developed from first principles. We base the model formulation on a Ping-Pong Bi-Bi mechanism. Methanol inhibition, along with the interfacial and bulk concentrations of the enzyme was also modeled. The model was developed to describe the effect of different oil compositions, as well as different water, enzyme, and methanol concentrations, which are relevant conditions needed for process evaluation, with respect to the industrial production of biodiesel. The developed kinetic model, coupled with a mass balance of the system, was fitted to and validated on experimental results for the fed-batch transesterification of rapeseed oil. The confidence intervals of the parameter estimates, along with the identifiability of the model parameters were presented. The predictive capability of the model was tested for a case using 0.5% (wt. Enzyme/wt. Oil), 0.5% (wt. Water/wt. Oil) and feeding 1.5 times the stoichiometric amount of methanol in total over 24 h. For this case, an optimized methanol feeding profile that constrains the amount of methanol in the reactor was computed and the predictions experimentally validated. Monte-Carlo simulations were then used to characterize the effect of the parameter uncertainty on the model outputs, giving a biodiesel yield, based on the mass of oil, of 90.8 ± 0.55 mass %. © 2014 American Institute of Chemical Engineers
Mechanistic Modelling Of Enzymatic Biodiesel Production For Fed Batch Control

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Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Computer Aided Process Engineering Center
Authors: Price, J. A. (Intern), Nordblad, M. (Intern), Woodley, J. (Intern), Huusom, J. K. (Intern)
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Modelling and operation of reactors for enzymatic biodiesel production
In developing sustainable industrial processes, biochemical engineering, as a part of a broader field of chemical engineering is becoming an increasingly important as a tool in the chemical engineers toolbox. Its application is driven by consumer demand for new products and by industry wishing to increase profits while reducing operating cost, as well as meeting government and regulatory pressures for processes to be environmentally friendly and sustainable. Current applications of biocatalysts, more specifically, enzymes for large scale bulk production of chemicals have been successfully applied to the production of high fructose corn syrup, upgrading of fats and oils and biodiesel production to name a few. Despite these examples of industrial enzymatic applications, it is still not “clear cut” how to implement biocatalyst in industry and how best to optimize the processes. This is because
the processing strategy is usually different to most traditional catalytic processes. In nature, enzymes operate at much lower substrate and product concentrations compared to most industrial chemical processes. What this means is that the natural conditions for biocatalysts are normally much different from conventional process-relevant conditions. Also, the optimal process conditions can vary greatly from one biocatalyst to the next. Hence, to maximize product yields and reactor productivity then the type of reactor operation and downstream processing need to be able to address the aforementioned issues. One way to achieve this is through process modeling to help focus the experimental work needed for process understanding and to support further process development and optimization of the process. To address how the reactors should be operated; a strategy using mechanistic modeling by combining the biological aspects of the enzyme with reaction/reactor engineering is performed. This strategy is applied to a case study of biodiesel production catalysed by a liquid enzyme formulation. The use of enzymes for biodiesel production is still in its infancy with non-optimized process designs. Furthermore, it is unclear how the process should be operated to ensure optimal economics given the relatively high cost of the enzyme and the low value of the products.

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**Oxidase-based biocatalytic processes**
Biocatalytic processes are gaining significant focus in frontiers where they offer unique advantages (selectivity and mild operating conditions) over chemical catalysts. It is therefore not surprising that there have been many industrial biocatalytic processes implemented. Despite past successes, the implementation of a new biocatalytic process still presents some challenges (demands placed on the biocatalyst) in terms of the requirements to make a viable industrial process. In order for a biocatalytic process to be economically successful, it is necessary that certain a set of targetmetrics (product titre, biocatalyst yield or space time yield and reaction yield) are achieved. Hence, the biocatalyst must be able to work at high substrate and product concentrations. Such constraints that arise from the biocatalyst are classified as biocatalyst-related limitations. In addition, other limitations can arise from the reaction species (substrate and product volatility for example) and the process (such as oxygen supply, ability to control pH) and are classified as reaction-related and process-related constraints respectively. Although the development of biocatalyst and process engineering tools offers a number of solutions to overcome the limitations, it is often complicated to identify the key limitation of the system that prevents economic scale-up. Hence, development of a systematic method for identifying the limitations during early-stage development of a biocatalytic process and potentially the order in which they need to be tackled would offer a valuable tool for process development. Biocatalytic oxidations are potentially of great value because of the selective chemistry that they offer, resulting in higher yields compared to those achievable through chemical catalysis. Oxidases are particularly interesting biocatalysts because they use a mild oxidant (oxygen) as a substrate as opposed to their chemical counterparts which use strong oxidants such as permanganates. A class of oxidases called monooxygenases has been used as the central case study for the thesis. The rationale for choosing this system is that it has been shown to exhibit the potential for resolution of racemic amines, and is capable of producing industrially interesting imines which are rather difficult to synthesize by chemical routes. An important aspect for biocatalytic reactions would be the implementation of monitoring and control systems that allow for rapid data collection to gain process knowledge. For oxidase-based biocatalysis, oxygen is consumed in stoichiometric amounts for the reaction. Therefore, oxygen sensors which can measure the oxygen concentration can be a valuable tool for monitoring of the process. The thesis exemplifies the use of novel solvent-resistant oxygen sensors as supporting technology for oxidase-based reactions using a glucose oxidase reaction system as an example. Implementation of biocatalytic oxidation at scale still requires process knowledge which includes the limitations of the system and the knowledge about the potential solutions available to alleviate these limitations. This thesis presents a methodology for development of oxidase-based biocatalytic processes. Particularly important aspect of the methodology includes the use of in silico analysis where property prediction tools have been used to identify the potential limitations to the reaction system prior to experimentation. Such an analysis presents the opportunity to direct
experimental work and therefore reduce the time and effort spent on process development, by eliminating unfeasible
routes. The example chosen for the development of the methodology was a specific monoamine oxidase-based syntheses
for the production of a pharmaceutical intermediate. This particular reaction system was chosen because of the potential
use of the product of the biocatalytic reaction as a pharmaceutical intermediate. However, there was little information on the
reaction system in the literature for the use of this biocatalyst for the synthesis of chemicals. Therefore, early stage process
understanding was required. The chapters of the thesis identify the potential limitations for the reaction system by
systematic evaluation of the reaction system through the use of property prediction tools as well as experiments. The
results obtained from the experiments are then used to identify the bottleneck for the implementation at scale. Furthermore,
the discussion of the limitations and the order in which they need to be tackled is presented.

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Perspectives on Multienzyme Process Technology
There is little doubt that chemical processing of the future will involve an increasing number of biocatalytic processes using
more than one enzyme. There are good reasons for developing such innovative biocatalytic processes and interesting
new biocatalyst and process options will be introduced. One consequence is that decisions about the format of the
biocatalyst and reactor type as well as the process flowsheet require more extensive knowledge. In this chapter, some of
the background to these decisions and decision-making tools to help establish effective multienzyme processes in a timely
manner are provided.

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Process characterization of a monoamine oxidase
Redox biocatalysis is currently gaining focus because it offers exquisite selectivity using mild oxidants, such as oxygen
(which is environmentally benign). However, it is often challenging to implement oxidative reactions at scale due to the low
activity and stability of the biocatalyst under industrial conditions. Consequently, it becomes critical to identify the
bottlenecks for specific oxidation reactions as a first step in scale-up. Subsequently, we can identify where research the
effort is required when developing a biocatalytic reaction for implementation in an industrial reaction, i.e., on biocatalyst
development (e.g. improvement of expression levels), process development (e.g. improved oxygen supply, product removal strategies) or biocatalyst stabilization (e.g. through immobilization or directed evolution). This paper presents a systematic method to identify the bottleneck of a potential biocatalytic process using a monoamine oxidase to synthesise an intermediate in the manufacture of a drug for treating Hepatitis C (Telaprevir).

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BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.12 SNIP 1.347 CiteScore 2.98
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Scopus rating (2005): SJR 0.742 SNIP 0.955
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.574 SNIP 0.782
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.585 SNIP 0.856
Scopus rating (2002): SJR 0.599 SNIP 0.788
Scopus rating (2001): SJR 0.562 SNIP 0.821
Selections of minimal conditions for a simple intensification and scale up of w-transaminase reactions

A step wise decision matrix is presented to quickly evaluate w - transaminase for a 'simple scale up' in the synthetic direction. Here a 'simple scale up' is defined as a system without specialized equipment or process development, thus a rapid implementation. The three step method consists of: 1. thermodynamic evaluation, 2. biocatalyst screen and 3. inhibition characterization. Each step of the method has a cut off value for easy implementation. Demonstrated by a case study which eliminated reaction pair candidates based on the cut off criteria. Finally, the most promising candidate was intensified.

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Publication: Research - peer-review › Poster – Annual report year: 2014

Sensor equipment for quantification of spatial heterogeneity in large bioreactor

Suspension cultivation in large stirred tank reactors suffers from imperfect mixing and pressure gradients due to the large size of the liquid column in the bioreactors. This leads to gradients of substrate concentrations and in turn cell population heterogeneity. The processes in large scale cannot be directly compared to laboratory scale experiments due to these reasons, and thus, in order to understand the large scale processes, experimental data has to be collected at large scale. The cost of acquiring data at large scale is high. The bioreactors are usually run with a limited array of sensors and in order to apply more sensor equipment the bioreactor has to be modified which is both costly and results in production downtime. The presence of three phases (gas, liquid, and solid), and the opaque nature of the fermentation broth together with the necessity of heat sterilization further increases the requirements to the sensor equipment. In order to address these issues this study aims to make an investigation into freely floating, battery driven sensor particles that can follow the liquid movement in the reactor and make measurements while being distributed in the whole volume of the bioreactor. The method leaves a minimal footprint and can be applied to running production to gather large scale fermentation data, without the need of dedicated experimental cultivations. Ultimately, data describing the spatial heterogeneity can be used to enhance existing process models and to create better scale - down strategies for lab - scale experiments. Accurate process models and lab - scale experiments could in turn lead to a more scientific approach to scaling of biotechnological processes.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, CAPEC-PROCESS, Novo Nordisk A/S, Novozymes A/S
Authors: Nørregaard, A. (Intern), Formenti, L. R. (Intern), Stocks, S. M. (Ekstern), Madsen, B. (Ekstern), Woodley, J. (Intern), Gernaey, K. (Intern)
Publication date: 2014
Event: Poster session presented at 3rd BioProScale Symposium on Inhomogeneities in large-scale bioprocesses, Berlin, Germany.
Main Research Area: Technical/natural sciences
Electronic versions:
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Source: PublicationPreSubmission
Source-ID: 103604776
Publication: Research - peer-review › Poster – Annual report year: 2014
Shape optimisation of a microreactor for biocatalytic synthesis of optically pure chiral amines

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, CAPEC-PROCESS
Authors: Pereira Rosinha, I. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern), Krühne, U. (Intern)
Publication date: 2014
Main Research Area: Technical/natural sciences
Source: PublicationPreSubmission
Source-ID: 103647566
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2014

Sustainable Process Synthesis-Intensification
Sustainable process design can be achieved by performing process synthesis and process intensification together. This approach first defines a design target through a sustainability analysis and then finds design alternatives that match the target through process intensification. A systematic, multi-stage framework for process synthesis-intensification that identifies more sustainable process designs has been developed. At stages 1-2, the working scale is at the level of unit operations, where a base case design is identified and analyzed with respect to sustainability metrics. At stages 3-4, the working scales are at the levels of unit operations, tasks and phenomena. Here, first intensified flowsheet alternatives are generated through a task-based process synthesis method where tasks performed in unit operations are identified, analyzed and recombined through a means-ends analysis. Next, a phenomena-based process synthesis method is applied, where the phenomena involved in each tasks are identified, manipulated and recombined to generate new and/or existing unit operations configured into flowsheets that are more sustainable from those found in the previous levels. An overview of the key concepts and the framework are presented together with the results from a case study highlighting the application of the framework to the sustainable design of a production process for dimethyl carbonate.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, CAPEC-PROCESS, Technical University of Dortmund
Authors: Babi, D. K. (Intern), Holtbruegge, J. (Ekstern), Lutze, P. (Ekstern), Góra, A. (Ekstern), Woodley, J. (Intern), Gani, R. (Intern)
Pages: 255-260
Publication date: 2014
Main Research Area: Technical/natural sciences

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BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.245 SNIP 0.249 CiteScore 0.39
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.239 SNIP 0.217 CiteScore 0.4
Web of Science (2014): Indexed yes
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Scopus rating (2013): SJR 0.216 SNIP 0.175 CiteScore 0.28
ISI indexed (2013): ISI indexed no
Scopus rating (2012): SJR 0.196 SNIP 0.267 CiteScore 0.33
ISI indexed (2012): ISI indexed no
Scopus rating (2011): SJR 0.194 SNIP 0.199 CiteScore 0.3
ISI indexed (2011): ISI indexed no
Scopus rating (2010): SJR 0.181 SNIP 0.135
Sustainable Process Synthesis-Intensification

The chemical and biochemical industry needs major reductions in energy consumption, waste generation, number of equipment used in the construction of plants and capital/operational cost. These required reductions can be addressed through process intensification that is the efficient use of raw materials (feedstock) and the use of sustainable technologies or processes which directly impacts and improves sustainability/LCA factors. Process intensification is a concept by which processes, whether conceptual or existing, can be designed or redesigned to achieve more efficient and sustainable designs. Therefore sustainable process design can be achieved by performing process synthesis and process intensification together. The main contribution of this work is the development of a systematic computer-aided multi-scale, multi-level framework for performing process synthesis-intensification that aims to make a process more sustainable than a base case design, which represents either a new or existing process. The framework consists of eight steps (step 1 to step 8) that operates at the unit operation scale and task scale, and four integrated task-phenomena-based steps (IT-PBS.1 to IT-PBS.4) that operates at the task scale and phenomena scale. The concept of generating more sustainable designs through the combination of phenomena provides the opportunity to innovate through the generation of novel unit operations and thereby expand the search space of available unit operations. At the unit operations scale a conceptual base case design is synthesized through the sequencing of unit operations. The base case is then designed and analysed for identifying process limitations or bottlenecks (hot-spots) using a comprehensive analysis consisting of economic, life cycle and sustainability analyses that are translated into design targets. These hot-spots are associated with tasks that may be targeted for overall process improvement. Next an integrated task-phenomena-based synthesis method is applied, where the involved phenomena in various tasks are identified, manipulated and recombined using combination rules in order to generate new and/or existing unit operations that are configured into flowsheet alternatives inclusive of hybrid/intensified unit operations. The flowsheet alternatives that satisfy the performance criteria and design targets, give innovative and more sustainable, non-trade off flowsheet designs that otherwise could not be found from the higher scales. The framework is applied to three case studies related to the chemical and bioprocess industry in order to test the applicability of the framework for covering a wide range of applications, showing that process intensification provides major benefits related to the generation of more sustainable process designs.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, CAPEC-PROCESS
Authors: Babi, D. K. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Number of pages: 224
Publication date: 2014

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Publisher: DTU Chemical Engineering
ISBN (Print): 978-87-93054-61-5
Original language: English
Main Research Area: Technical/natural sciences
Electronic versions:
Deenesh_Kavi_Babi_PEC14_41.pdf
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Sustainable Process Synthesis-Intensification

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, CAPEC-PROCESS, Technical University of Dortmund
Authors: Babi, D. K. (Intern), Holtbrügge, J. (Ekstern), Lutze, P. (Ekstern), Görak, A. (Ekstern), Woodley, J. (Intern), Gani, R. (Intern)
Publication date: 2014
Main Research Area: Technical/natural sciences
Electronic versions:
Poster_DKBabi_FOCAPD.pdf
Source: PublicationPreSubmission
Source-ID: 103646040
Publication: Research - peer-review › Poster – Annual report year: 2014

The focus of this work is on process systems engineering (PSE) methods and tools, and especially on how such PSE methods and tools can be used to accelerate and support systematic bioprocess development at a miniature scale. After a short presentation of the PSE methods and the bioprocess development drivers, three case studies are presented. In the first example it is demonstrated how experimental investigations of the bi-enzymatic production of lactobionic acid can be modeled with help of a new mechanistic mathematical model. The reaction was performed at lab scale and the prediction quality analyzed. In the second example a computational fluid dynamic (CFD) model is used to study mass transfer phenomena in a microreactor. In this example the model is not only used to predict the transient dynamics of the reactor system but also to extract material properties like the diffusion velocities of substrate and product, which is otherwise difficult to access. In the last example, a new approach to the design of microbio reactor layouts using topology optimization is presented and discussed. Finally, the PSE methods are carefully discussed with respect to the complexity of the presented approaches, the applicability with respect to practical considerations and the opportunity to analyze experimental results and transfer the knowledge between different scales.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, CAPEC-PROCESS, Center for Process Engineering and Technology
Authors: Krühne, U. (Intern), Larsson, H. (Intern), Heintz, S. (Intern), Ringborg, R. H. (Intern), Pereira Rosinha, I. (Intern), Bodla, V. K. (Intern), Andrade Santacoloma, P. D. G. (Intern), Tufvesson, P. (Intern), Woodley, J. (Intern), Gernaey, K. (Intern)
Pages: 203-214
Publication date: 2014
Main Research Area: Technical/natural sciences
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Journal: Chemical and Biochemical Engineering Quarterly
Volume: 28
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Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.293 SNIP 0.499 CiteScore 0.9
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.287 SNIP 0.457 CiteScore 0.84
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.386 SNIP 0.804 CiteScore 1.18
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.3 SNIP 0.621 CiteScore 0.91
Systematic Process Design and Operation of Intensified Processes

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, CAPEC-PROCESS
Authors: Mansouri, S. S. (Intern), Huusom, J. K. (Intern), Woodley, J. M. (Intern), Gani, R. (Intern)
Number of pages: 1
Publication date: 2014

Test design of particles for immobilization of ω-transaminase in a packed bed microreactor

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, CAPEC-PROCESS
Authors: Pereira Rosinha, I. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern), Krühne, U. (Intern)
Publication date: 2014
Thermodynamic Evaluation of the Production of Chiral Amines from Long-Chain Aliphatic Alcohols

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, CAPEC-PROCESS
Authors: Abu, R. (Intern), Lima Ramos, J. (Intern), Woodley, J. (Intern)
Publication date: 2014
Main Research Area: Technical/natural sciences
Electronic versions:
MECP14_Abu_et_al._2014_.pdf
Source: PublicationPreSubmission
Source-ID: 103263552
Publication: Research - peer-review › Poster – Annual report year: 2014

The Virtual Product-Process Design Laboratory for Structured Chemical Product Design and Analysis

The objective of this paper is to present new methods for design of chemicals based formulated products and their implementation in the software, the Virtual Product-Process Design Laboratory. The new products are tailor-made blended liquid products and emulsion-based products. The new software employs a template approach, where each template follows the same common steps in the workflow for design of formulated products, but has the option to employ different product specific property models, data and calculation routines, when necessary. With the new additions, the software is able to support the design and analysis of a wide range of homogeneous formulated products: tailor-made blends, single phase liquid formulations and emulsion-based products. The decision making process is supported by dedicated property models and structured databases, specifically developed for each design problem scenario. Output from the software is a small set of most promising product candidates and a short list of recommended experiments that can validate and further fine-tune the product composition. The application of the new features is highlighted through two case studies relative to an emulsion-based product and a tailor-made blend.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, CAPEC-PROCESS, Center for Energy Resources Engineering, CERE – Center for Energy Resources Engineering
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Pages: 61-66
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2014

μ-structured devices as tools for screening process intensification in biocatalysis

Biocatalytic processes have been emerging as potential replacements of traditional chemical synthesis in many industrial relevant production processes. However the implementation of new biocatalytic processes can be a very challenging procedure which requires both biocatalyst and process screening and characterization for economic evaluation before scale-up. Microstructured devices have been used as screening tools that allow paradigm changes in process development by shortening process development times through modularity and intensification. Customized reactor designs and process configurations by integrating different modules can be developed at microscale. Such configurations enable effective screening and rapid process development of biocatalytic reactions assuring economic viability and shorter time to market for pharmaceutical products. Thus the work presented in this thesis is based on the application of microstructured devices for screening and characterization of process options in biocatalytic processes. The thesis focuses
on interesting case studies like the asymmetric synthesis of chiral amines using ω-transaminases and synthesis of an industrially relevant imine product using monoamine oxidase. The first part of the thesis is focused on the development of novel reactor configurations for biocatalysis. A combination of micro reactors and computational fluid dynamics (CFD) has been found to contribute significantly towards the understanding of diffusional properties of the substrate and the product. Such knowledge is subsequently applied to design customized reactor configurations. It has been demonstrated that this knowledge can be crucial for the choice and design of reactors. The second part focuses on developing μ-scale modules for rapid screening and integrating process units. The increase in productivity is evaluated through process metrics. A case study demonstrates the applicability of using a micro-scale packed bed column for screening synthetic resins for in-situ product removal. CFD simulations were performed to guide the design of a packed column for efficient operation. Further case studies demonstrate the development of modular set-ups with integrated processes at microscale to address process limitations which were determined by initial experiments at lab scale. The degree of integration of functionalities requires process optimization. Thus optimization studies were also performed by varying operational parameters. From an academic point of view, a general methodology is desired and thus a systematic screening methodology is proposed that relies on microstructured devices during process development. The methodology can be applied to other biocatalytic reactions with some limitations.
Achieving More Sustainable Solutions through Process Intensification

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center, Center for Process Engineering and Technology
Authors: Gani, R. (Intern), Babi, D. K. (Intern), Mansouri, S. S. (Intern), Ismail, M. I. (Ekstern), Huusom, J. K. (Intern), Woodley, J. (Intern)
Number of pages: 1
Publication date: 2013
Event: Abstract from 50th Anniversary Symposium of the Department of Chemical & Biological Engineering, Korea University, Seoul, Korea, Republic of.
Main Research Area: Technical/natural sciences

Advances in the Process Development of Biocatalytic Processes

Biocatalysis is already established in chemical synthesis on an industrial scale, in particular in the pharmaceutical sector. However, the wider implementation of biocatalysis is currently hindered by the extensive effort required to develop a competitive process. In order that resources spent on development are used in the most efficient manner for these challenging systems, a holistic view on process development and a more in-depth understanding of the underlying constraints (process related as well as biocatalyst related) are required. In this concept article a systematic approach to solve this problem is proposed, involving the use of process tools and methods to assist in development.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Tufvesson, P. (Intern), Lima Ramos, J. (Intern), Al-Haque, N. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern)
Pages: 1233-1238
Publication date: 2013
Main Research Area: Technical/natural sciences

Publication information
Journal: Organic Process Research and Development
Volume: 17
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Scopus rating (2016): CiteScore 2.48 SJR 1.062 SNIP 0.859
Web of Science (2016): Indexed yes
A flexible modular process design for enzymatic biodiesel production

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Seita, C. S. (Intern), Nordblad, M. (Intern), Woodley, J. (Intern)
Publication date: 2013
Event: Abstract from 104th AOCS Annual Meeting & Expo, Montreal, Canada.
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013
A Framework for Process Synthesis integrated with Sustainability and Process Intensification

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center, Center for Process Engineering and Technology, Technical University of Dortmund
Authors: Babi, D. K. (Intern), Holtbruegge, J. (Ekstern), Lutze, P. (Ekstern), Woodley, J. (Intern), Górak, A. (Ekstern), Gani, R. (Ekstern)
Number of pages: 2
Publication date: 2013
Main Research Area: Technical/natural sciences

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Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

A future perspective on the role of industrial biotechnology for chemicals production

The development of recombinant DNA technology, the need for renewable raw materials and a green, sustainable profile for future chemical processes have been major drivers in the implementation of industrial biotechnology. The use of industrial biotechnology for the production of chemicals is well established in the pharmaceutical industry but is moving down the value chain toward bulk chemicals. Chemical engineers will have an essential role in the development of new processes where the need is for new design methods for effective implementation, just as much as new technology. Most interesting is that the design of these processes relies on an integrated approach of biocatalyst and process engineering.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Computer Aided Process Engineering Center, BASF, DSM Chemtech Center
Authors: Woodley, J. (Intern), Breuer, M. (Ekstern), Mink, D. (Ekstern), Gani, R. (ed.) (Intern)
Pages: 2029-2036
Publication date: 2013
Main Research Area: Technical/natural sciences

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Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.79 SJR 0.813 SNIP 1.303
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.855 SNIP 1.449 CiteScore 2.7
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.027 SNIP 1.692 CiteScore 2.91
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.957 SNIP 1.668 CiteScore 2.56
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.933 SNIP 1.614 CiteScore 2.31
The potential advantages displayed by biocatalytic processes for organic synthesis (such as exquisite selectivity under mild operating conditions), have prompted the increasing number of processes running on a commercial scale. However, biocatalysis is still a fairly underutilised technology. As a relatively new technology biocatalytic processes often do not immediately fulfil the required process metrics that are key for an economically and/or environmentally competitive process at an industrial scale (high concentration, high reaction yield, high space-time-yield and high biocatalyst yield). These process metrics can often be attained by improvements in the reaction chemistry, the biocatalyst, and/or by process engineering, which often requires a complex process development strategy. Interestingly this complexity, which arises from the need for integration of biological and process technologies, is also the source of the greatest opportunities. Indeed, recombinant DNA technology offers a superb complement to process technologies. Potentially this is one of the biggest advantages of biocatalysis when compared with conventional chemical catalysis, where all the reaction boundaries are fixed by the physical and thermodynamic properties of the reaction compounds. Therefore, the main avenue that still remains to be explored by process engineers is how to promote process development in a systematic way rather than on a case-by-case basis, as is frequently the case today. One of the main challenges in process development is selecting between different process alternatives. The development effort for a novel process is considerable and thus, an increasing number of conceptual process design methods are now applied in chemical industries. Since the natural environment of the biocatalyst is often very different from the operating conditions suitable for a viable process (high substrate and product concentrations, unnatural substrates, presence of organic solvents, etc.), process development strategies are particularly relevant for biocatalytic processes. However, state-of-the-art methodologies for process development applied to biocatalysis often prove to be unsuccessful. At the early development stage the biocatalysts are usually still under development and many of the reactions have not yet achieved their full potential, many of the process technologies are not yet well described and their relationship with the overall process is not clear. The work described in this thesis presents a methodological approach for early stage development of biocatalytic...
processes, understanding and dealing with the reaction, biocatalyst and process constraints. When applied, this methodology has a decisive role in helping to identify many of the process bottlenecks up-front and in a straightforward way, whilst indicating development targets, allowing a better use of resources and shortening development time. The methodology is illustrated through three different case studies: H-caprolactam production by a multi-enzymatic process, chiral amine production using Z-transaminase and finally long-chain chiral aliphatic Abstract ii alcohol production by a bi-enzymatic system. For each case study presented, a different tool is used to guide development and evaluate the process when different levels of underlying process knowledge are available. The first case study presents a rational approach for defining a development strategy for multi-enzymatic processes. The proposed methodology requires a profound and structured knowledge of the multi-enzyme systems, integrating chemistry, biological and process engineering. In order to suggest a reduced number of feasible process design options, cofactor and interaction matrices are used, identifying the challenges and addressing them by selecting appropriate process configurations. Based on this information, feasible flowsheets and mass and energy balances are identified. By applying evaluation tools, the number of options can be much reduced and the current process bottlenecks identified. By applying a priori this methodology, the Laboratory experts are better able to understand the most favourable operating conditions at fullscale and thus be able to collect information at these relevant conditions. In the second case study, windows of operation are used to quantify and visualise process performance and feasibility when interactions between process Technologies and biocatalyst performance (or reaction) are significant. The methodology constitutes a useful tool that provides easy interpretable results to enable rational design choices of different available process technologies. In the particular case of the asymmetric synthesis of chiral amines, the reaction constraints (thermodynamic equilibrium) must be solved prior to implementation and these fix the hard boundaries of the operating space. Improvements in the biocatalyst specific activity are also required for a successful full-scale implementation. In the third case study a methodology for bottleneck analysis is presented, incorporating process modelling and engineering evaluation tools. The benefit of such models, when integrated with evaluation tools, is that they can be used to predict the process performance and identify bottlenecks, without requiring experimental examination thereby reducing the resources and time for process development. The use of this methodology in the context of reaction engineering is to propose new operating conditions at which the process performance is improved, while identifying the remaining bottlenecks and suggesting further research efforts. Although the proposed methodology is still in its infancy when compared with other established operating conditions at fullscale and process. The proposed methodological approach establishes a systematic evaluation of different process options and indicates required fundamental data collection and development efforts for further development stages. This methodology could be greatly enhanced by the implementation and integration of in-silico tools for property and thermodynamic data as well as process mechanistic models to assist in the selection of process technologies.
Applications, benefits and challenges of flow chemistry

Organic synthesis (incorporating both chemo-catalysis and biocatalysis) is essential for the production of a wide range of small-molecule pharmaceuticals. However, traditional production processes are mainly based on batch and semi-batch operating modes, which have disadvantages from an economic, environmental and manufacturing perspective. A potential solution to resolve these issues is to use flow chemistry in such processes, preferably with applications of micro- and mini-sized equipment. In addition, Process Analytical Technology (PAT) may be implemented in a very efficient way in such equipment due to the high degree of automation and process controllability that can be achieved in small scale continuous equipment.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Mitic, A. (Intern), Heintz, S. (Intern), Ringborg, R. H. (Intern), Bodla, V. K. (Intern), Woodley, J. (Intern), Gernaey, K. (Intern)
Pages: 4-8
Publication date: 2013
Main Research Area: Technical/natural sciences

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Journal: Chimica Oggi
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Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.231 SNIP 0.196 CiteScore 0.44
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.242 SNIP 0.229 CiteScore 0.47
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.183 SNIP 0.185 CiteScore 0.35
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.207 SNIP 0.161 CiteScore 0.37
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.241 SNIP 0.179 CiteScore 0.45
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.218 SNIP 0.167 CiteScore 0.33
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.195 SNIP 0.148
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.244 SNIP 0.199
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.241 SNIP 0.182
Scopus rating (2007): SJR 0.251 SNIP 0.167
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.206 SNIP 0.153
A rational approach for ω-transaminase-catalyzed process design: Synthesis of p-Br-1-phenylethylamine

Herein we describe a novel rational approach to the design of a ω-transaminase process such that it will fulfill criteria necessary for industrial use. By first determining the fundamental properties of the reaction system, it is possible to suggest appropriate process strategies that may be used to overcome any unfavorable parameters. The ω-transaminase is used as a model system because it is an important enzyme class and developing a systematic methodology would have significant value.

General information
State: Published
Organisations: Center for Process Engineering and Technology, Department of Chemical and Biochemical Engineering, Dr. Reddy's Chirotech Technology Centre
Authors: T. Gundersen, M. (Intern), Lloyd, R. (Ekstern), Tufvesson, P. (Intern), Woodley, J. (Intern)
Publication date: 2013
Main Research Area: Technical/natural sciences
Electronic versions:
A_rational_approach_for_transaminase_catalyzed_process_design_synthesis_of_p_Br_1_phenylethylamine_Maria_T_Gundersen.pdf
Publication: Research - peer-review › Poster – Annual report year: 2013

Biokatalysatorens vej til industrien

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Krühne, U. (Intern), Heintz, S. (Intern), Pereira Rosinha, I. (Intern), Ringborg, R. H. (Intern), Tufvesson, P. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern)
Pages: 18-22
Publication date: 2013
Main Research Area: Technical/natural sciences
Electronic versions:
Biokatalysatorens vej til industrien Dansk Kemi 2013.pdf
Publication: Research - peer-review › Journal article – Annual report year: 2013
Considerations for a methodology for selection of cascades for co-product removal in ω-transaminase systems

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Janes, K. (Intern), Gernaey, K. (Intern), Tufvesson, P. (Intern), Woodley, J. (Intern)
Publication date: 2013
Event: Abstract from BIOTRANS 2013, Manchester, United Kingdom.
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

Design of sustainable blended products using an integrated methodology

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center, Center for Process Engineering and Technology
Authors: Yunus, N. A. B. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern), Gani, R. (Intern)
Publication date: 2013
Main Research Area: Technical/natural sciences
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Design of Sustainable Blended Products using an Integrated Methodology

This paper presents a systematic methodology for designing blended products consisting of three stages; product design, process identification and experimental verification. The product design stage is considered in this paper. The objective of this stage is to screen and select suitable chemicals to be used as building blocks in the mixture design, and then to propose the blend formulations that fulfill the desired product attributes. The result is a set of blends that match the constraints, the compositions, values of the target properties and information about their miscibility. The methodology has been applied to design several blended products. A case study on design of blended lubricants is highlighted. The objective is to identify blended products that satisfy the product attributes with at least similar or better performance compared to conventional products.
Design of Sustainable Blended Products using an Integrated Methodology

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center, Center for Process Engineering and Technology
Authors: Yunus, N. A. B. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern), Gani, R. (Intern)
Publication date: 2013
Main Research Area: Technical/natural sciences
Product design, Integrated methodology, Lubricant base oil

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Effect of critical process parameters on the synthesis of chiral amines
Developing a biocatalytic transferase process involves many challenges, and choices have to be made regarding several aspects. Primarily, the selection of the biocatalyst itself and which biocatalyst formulation to use, but also the choice of amine donor has a decisive impact not only on reaction equilibrium, the inhibition profiles for substrates and products but also on the possibilities for in-situ product removal (ISPR) and technologies for shifting the equilibrium. In a challenging process such as the synthesis of optically pure chiral amines using ω-transaminase, these decisions will have a major influence on the process. Understanding these parameters and their effect on the process for the different reaction systems is important as it will help engineers make the right choices during process design. In this study we have therefore carried out an in depth characterization of different process parameters involved in the production of two chiral amines (S-methylbenzylamine and 3-amino-1-phenylbutane) (Figure 1) to demonstrate the effects of such decisions.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Technical University of Denmark, C-LEcta Gmbh
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Main Research Area: Technical/natural sciences

Enzymatic process intensification across scales

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Heintz, S. (Intern), Woodley, J. (Intern), Krühne, U. (Intern), Gernaey, K. (Intern)
Publication date: 2013
Event: Abstract from International Conference on Implementation of Microreactor Technology into Biotechnology (IMTB2013), Cavtat, Croatia.
Enzymatic Production of FAME Biodiesel with Soluble Lipases
Biodiesel is a viable alternative to fossil fuels, and biocatalysis is gaining interest as a greener process. We focus on converting oils to Fatty Acid Methyl Ester (FAME) using soluble lipases, which offer an advantage compared to immobilized enzymes by cost efficiency and ease of implementation. Firstly, we defined the range of interest for process parameters of a low catalyst loading system, intended for single use. Furthermore, we systematically studied the effect and interaction between these parameters. Based on experimental data, a model was developed to evaluate the optimal conditions within the defined operating space concerning: temperature, water content, initial methanol concentration and enzyme content. The identified optimum range was experimentally evaluated, and model findings were confirmed. Another barrier in lipase use in biodiesel production is the higher melting point (m.p.) of certain oils, which is not compatible with the temperature range where lipases are most active. To address this, here we explored a novel production strategy that accommodates the enzymatic requirements with the chemical limits of the substrates. The m.p. of the methyl ester product is lower than that of the starting material. Thus, we have incorporated a varying amount of the product to lower the m.p. of the starting material. Our case study is the reaction of Palm Fatty Acid Distillate (PFAD) to FAME. Conversion rates have been measured with varying temperatures, water concentration, and initial methanol content. The results of this investigation will be presented and discussed in this poster.

Framework for assessing stability of biocatalytic oxidations
General information
State: Published
Organisations: Department of Systems Biology, Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Ramesh, H. (Intern), Woodley, J. (Intern)
Publication date: 2013
Event: Abstract from BIOTRANS 2013, Manchester, United Kingdom.
Main Research Area: Technical/natural sciences
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Implementing the next-generation of biocatalytic processes
General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Woodley, J. (Intern)
Publication date: 2013
Event: Abstract from International Workshop: Advances in Industrial Biotechnology, Sao Carlos, Brazil.
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

Kinetic model of biodiesel production using immobilized lipase Candida antarctica lipase B
We have designed a kinetic model of biodiesel production using Novozym 435 (Nz435) with immobilized Candida antarctica lipase B (CALB) as a catalyst. The scheme assumed reversibility of all reaction steps and imitated phase effects by introducing various molecular species of water and methanol. The global model was assembled from separate reaction blocks analyzed independently. Computer simulations helped to explore behavior of the reaction system under different conditions. It was found that methanolysis of refined oil by CALB is slow, because triglycerides (T) are the least reactive substrates. Conversion to 95% requires 1.5–6 days of incubation depending on the temperature, enzyme concentration, glycerol inhibition, etc. Other substrates, free fatty acids (F), diglycerides (D) and monoglycerides (M), are utilized much faster (1–2h). This means that waste oil is a better feedstock for CALB. Residual enzymatic activity in biodiesel of standard quality causes increase of D above its specification level because of the reaction 2M↔D+G. Filtration or alkaline treatment of the product prior to storage resolves this problem. The optimal field of Nz435 application appears to be decrease of F,
M, D in waste oil before the conventional alkaline conversion. Up to 30-fold reduction of F-content can be achieved in 1–2h, and the residual enzyme (if any) does not survive the following alkaline treatment.

**General information**

**State:** Published

**Organisations:** Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Aarhus University, Novozymes A/S

**Authors:** Fedosov, S. (Forskerdatabase), Brask, J. (Ekstern), Pedersen, A. K. (Intern), Nordblad, M. (Intern), Woodley, J. (Intern), Xu, X. (Ekstern)

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- **BFI (2011):** BFI-level 1
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- **ISI indexed (2011):** ISI indexed yes
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- **Scopus rating (2010):** SJR 0.797 SNIP 1.032
- **BFI (2009):** BFI-level 1
- **Scopus rating (2009):** SJR 0.898 SNIP 1.136
- **Web of Science (2009):** Indexed yes
- **BFI (2008):** BFI-level 1
- **Scopus rating (2008):** SJR 0.975 SNIP 1.021
- **Web of Science (2008):** Indexed yes
- **Scopus rating (2007):** SJR 0.835 SNIP 1.007
- **Scopus rating (2006):** SJR 0.723 SNIP 1.069
- **Scopus rating (2005):** SJR 0.742 SNIP 0.955
- **Web of Science (2005):** Indexed yes
- **Scopus rating (2004):** SJR 0.574 SNIP 0.782
- **Web of Science (2004):** Indexed yes
- **Scopus rating (2003):** SJR 0.585 SNIP 0.856
- **Scopus rating (2002):** SJR 0.599 SNIP 0.788
- **Scopus rating (2001):** SJR 0.562 SNIP 0.821
Life cycle assessment in green chemistry: overview of key parameters and methodological concerns

Several articles within the area of green chemistry often promote new techniques or products as ‘green’ or ‘more environmentally benign’ than their conventional counterpart although these articles often do not quantitatively assess the environmental performance. In order to do this, life cycle assessment (LCA) is a valuable methodology. However, on the planning stage, a full-scale LCA is considered to be too time consuming and complicated. Two reasons for this have been recognised, the method is too comprehensive and it is hard to find inventory data. In this review, key parameters are presented with the purpose to reduce the time-consuming steps in LCA. In this review, several LCAs of so-called ‘green chemicals’ are analysed and key parameters and methodological concerns are identified. Further, some conclusions on the environmental performance of chemicals were drawn. For fossil-based platform chemicals several LCAs exists but for chemicals produced with industrial biotechnology or from renewable resources the number of LCAs is limited, with the exception of biofuels, for which a large number of studies are made. In the review, a significant difference in the environmental performance of bulk and fine chemicals was identified. The environmental performance of bulk chemicals are closely connected to the production of the raw material and thereby different land use aspects. Here, a lot can be learnt from biofuel LCAs. In many of the reviewed articles focusing on bulk chemicals a comparison regarding fossil and renewable raw material was done. In most of the comparisons the renewable alternative turned out to be more environmentally preferable, especially for the impact on GWP and energy use. However, some environmental concerns were identified as important to include to assess overall environmental concern, for example eutrophication and the use of land. To assess the environmental performance of green chemicals, quantitative methods are needed. For this purpose, both simple metrics and more comprehensive methods have been developed, one recognised method being LCA. However, this method is often too time consuming to be valuable in the process planning stage. This is partly due to a lack of available inventory data, but also because the method itself is too comprehensive. Here, key parameters for the environmental performance and methodological concerns were described to facilitate a faster and simpler use of LCA of green chemicals in the future.
Lipase-catalysed formation of sugar fatty acid ester surfactants using supercritical carbon dioxide as a reaction medium

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Doherty, C. (Ekstern), Lima Ramos, J. (Intern), Al-Haque, N. (Intern), Turner, N. (Ekstern), Woodley, J. (Intern)
Publication date: 2013
Event: Abstract from BIOTRANS 2013, Manchester, United Kingdom.
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

Microreactors and CFD as Tools for Biocatalysis Reactor Design: A case study
Microreactors have been used for acquiring process data while consuming significantly lower amounts of expensive reagents. In this article, the combination of microreactor technology and computational fluid dynamics (CFD) is shown to
contribute significantly towards understanding the diffusional properties of the substrate and the product of a biocatalytic reaction. Such knowledge is then applied to design reactor configurations. It has been demonstrated that this kind of knowledge is crucial for the choice and design of reactors. In the discussion, it is highlighted how microreactor-based platforms with similar dimensions to the ones tested here can be used as a screening tool for screening biocatalyst and process alternatives.
Optimization of Substrate Feeding for Enzymatic Biodiesel Production

Many traditional bio-processes are operated in semi-batch mode, in which, a feed stream containing substrate and or nutrients is fed into the reactor during the course of the reaction. One key advantage of a semi-batch operation is that regulation of the substrate concentration has been found to be effective in mitigating the effects of substrate inhibition. Using enzymatic biodiesel production as a case study, the volumetric productivity of the reactor is increased while minimizing inactivation of the enzyme due to the alcohol. This is done by using a simple optimization routine where the substrate (both the vegetable oil and alcohol) feed rate/concentration is manipulated simultaneously. The results of the simulation were tested in the laboratory and are sufficiently positive to suggest the implementation of a feeding strategy for large scale enzymatic biodiesel production.
Optimization of Substrate Feeding for Enzymatic Biodiesel Production

Many traditional bio-processes are operated in semi-batch mode, in which, a feed stream containing substrate and or nutrients is fed into the reactor during the course of the reaction. One key advantage of a semi-batch operation is that regulation of the substrate concentration has been found to be effective in mitigating the effects of substrate inhibition. Using enzymatic biodiesel production as a case study, the volumetric productivity of the reactor is increased while minimizing inactivation of the enzyme due to the alcohol. This is done by using a simple optimization routine where the substrate (both the vegetable oil and alcohol) feed rate/concentration is manipulated simultaneously. The results of the simulation were tested in the laboratory and are sufficiently positive to suggest the implementation of a feeding strategy for large scale enzymatic biodiesel production.
phenomena level. The highest impact is expected by looking at processes at the lowest level of aggregation which is the phenomena level. In this paper, a phenomena based synthesis/design methodology incorporating process intensification is presented. Using this methodology, a systematic identification of necessary and desirable (integrated) phenomena as well as generation and screening of phenomena based flowsheet options are presented using a decomposition based solution approach. The developed methodology as well as necessary tools and supporting methods are highlighted through a case study involving the production of isopropyl-acetate.

General information
State: Published
Organisations: Center for Process Engineering and Technology, Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Lutze, P. (Intern), Babi, D. K. (Intern), Woodley, J. (Intern), Gani, R. (Intern)
Pages: 7127-7144
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Web of Science (2016): Indexed yes
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Scopus rating (2015): SJR 0.949 SNIP 1.146 CiteScore 2.87
Web of Science (2015): Indexed yes
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Scopus rating (2014): SJR 1.012 SNIP 1.292 CiteScore 2.85
Web of Science (2014): Indexed yes
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Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.066 SNIP 1.338 CiteScore 2.56
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Web of Science (2012): Indexed yes
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Scopus rating (2011): SJR 1.086 SNIP 1.24 CiteScore 2.58
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Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.047 SNIP 1.165
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.002 SNIP 1.164
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.142 SNIP 1.267
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.105 SNIP 1.239
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.035 SNIP 1.204
Process Considerations for the Asymmetric Synthesis of Chiral Amines using \(\omega\)-Transaminase

The implementation of new biocatalytic processes can be a very challenging procedure, which can require several stages of screening, characterization and evaluation prior to scale-up. Indeed, several process parameters, with different weights on the final process costs, need to be considered side-by-side. Process design and economic evaluation represent a very important part of the early process development stage. However, often the parameters set at these initial stages are based on assumptions. Therefore, a laboratory scale characterization of the biocatalyst and different process options are important in order to eliminate infeasible routes. This work illustrates the Laboratory scale characterization of different process options for the asymmetric synthesis of chiral amines catalysed by \(\omega\)-transaminase (\(\omega\) –TAm). The studied process options include: (i) the immobilization of the biocatalyst to improve its stability and allow recycling and easy separation; (ii) the use of controlled release of substrate (fed-batch) or in situ substrate supply – (ISSS) to decrease substrate inhibition and deal with the substrate low solubility; and (iii) the use of in situ product (ISPR) and co-product removal (IScPR) to respectively alleviate product inhibition and shift the reaction equilibrium. From an academic point of view, more important than the implementation of these technologies to a specific example, is the development of a general methodology that can be later applied in other cases. Hence, this work has also focused on development of comprehensive screening methodologies and guidelines to aid (i) the selection and characterization of suitable biocatalysts for the process; (ii) the selection and characterization of suitable carriers for immobilization of (S)- and (R)-selective \(\omega\)-TAm; and (iii) the selection of suitable polymeric resins for product removal. The work has been performed in collaboration with c-LEcta GmbH (Leipzig, Germany) and DSM Innovative Synthesis (Geleen, The Netherlands) who supplied the enzymes for the case study, making possible the successful demonstration of the screening methodologies developed. Furthermore, the work addresses several practical questions regarding to the implementation of the process strategies mentioned above.

General information

State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Lima Afonso Neto, W. (Intern), Woodley, J. (Intern), Tufvesson, P. (Intern)
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Process intensification for bioprocesses

General information
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Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Woodley, J. (Intern)
Publication date: 2013
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Process strategies for implementing ω-transaminase catalysed reactions

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Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Lima Afonso Neto, W. (Intern), Tufvesson, P. (Intern), Woodley, J. (Intern)
Publication date: 2013
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Process strategies for implementing ω-transaminase catalysed reactions

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Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Lima Afonso Neto, W. (Intern), Schwarze, D. (Ekstern), Vogel, A. (Ekstern), Panella, L. (Ekstern), Schurmann, M. (Ekstern), Tufvesson, P. (Intern), Woodley, J. (Intern)
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Main Research Area: Technical/natural sciences
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Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center, Center for Process Engineering and Technology, Auburn University, Norwegian University of Science and Technology, Aristotle University of Thessaloniki, University of Nottingham, Malaysia Campus, University of Kansas, Purdue University, Universidad Autonoma Metropolitana
Authors: Gani, R. (Intern), Eden, M. R. (Ekstern), Gundersen, T. (Ekstern), Georgiadis, M. C. (Ekstern), Woodley, J. (Intern), Lopez-Arenas, T. (Ekstern), Sales-Cruz, M. (Ekstern), Perez-Cisneros, E. S. (Ekstern), Solvason, C. C. (Ekstern), Chemmangattuvalappillil, N. G. (Ekstern), Eden, M. R. (Ekstern), Lutze, P. (Intern), Roughton, B. C. (Ekstern), Camarda, K. V. (Ekstern), Topp, E. M. (Ekstern)
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Bibliographical note
Process Technology for Immobilized Lipase catalyzed Bioconversion

Biocatalysis has attracted significant attention recently, mainly due to its high selectivity and potential benefits for sustainability. Applications can be found in biorefineries, turning biomass into energy and chemicals, and also for products in the food and pharmaceutical industries. However, most applications remain in the production of high-value fine chemicals, primarily because of the expense of introducing new technology. In particular lipase-catalyzed synthesis has already achieved efficient operations for high-value products and more interesting now is to establish opportunities for low-value products. In order to guide the industrial implementation of immobilized-lipase catalyzed reactions, especially for high-volume low-value products, a methodological framework for dealing with the technical and scientific challenges and establishing an efficient process via targeted scale-down experimental work is described in this thesis. The methodology uses economic targets to test options characterized via a set of tools. In order to validate the methodology, two processes based on immobilized lipase-catalysis have been studied: transesterification and esterification of vegetable oils for the production of biodiesel. The two processes are focused on the conversion of the two main components of vegetable oil materials, glyceride esters and free fatty acids respectively, into fatty acid alkyl esters. Although biodiesel is conventionally prepared via chemical-catalyzed transesterification of vegetable oils with methanol to produce fatty acid methyl esters (FAME), this work has been focused on the production of fatty acid ethyl esters (FAEE) with bioethanol due to the expected improved sustainability of this type of biodiesel. A key reaction characteristic of the immobilized lipase-catalyzed transesterification is that it is multi-phasic system. The by-product glycerol can potentially impose inhibitory effects on immobilized lipases and likewise the un-dissolved ethanol can inhibit the lipase. The options for addressing these issues can be used as the basis for selecting the biocatalyst and the reactor (e.g. a hydrophobic carrier for the immobilized lipase and the capabilities to provide sufficient mixing as well as stepwise/continuous feeding of ethanol to the reactor). An STR is efficient for batch operation while a PBR is efficient for a continuous production. An STR can more easily provide sufficient external mass transfer for a reaction, but will lead to more mechanical damage of the biocatalyst particles, than a PBR. A reactor combination of CSTR with PBR can couple the advantages of both, delivering an efficient continuous process. The second case study (esterification) shares some similar process characteristics to the first case (e.g. the multi-phasic nature). However, instead of glycerol, water shows a great impact on the extent of reaction. The removal of water should therefore be feasible during the operation of the reactor, either intermittently or preferably in situ. Highly anhydrous reaction conditions and the smaller substrates for this reaction place particular requirements on the lipase. In order to validate the established processes at a larger scale, both lipase-catalyzed transesterification and esterification developed in the lab-scale STRs have been carried out in pilot-scale STRs. Results in both scale STRs correlate well with respect to the biocatalyst performance and mechanical stability. Once the technical and scientific challenges of the process have been addressed, it is of course important to evaluate its economic and environmental feasibility. To that end, process evaluation has been performed for six processes composed of transesterification and product purification for making ‘in-spec’ biodiesel and the conventional chemical process is taken as a bench mark for comparison. The optimal process is a process composed of lipase-catalyzed transesterification with ‘in-spec’ biodiesel product as output with less feedstock input and waste production and much saved energy from the absence of product purification.

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Authors: Xu, Y. (Intern), Woodley, J. (Intern), Nordblad, M. (Intern)
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Protein engineering of enzymes for process applications
Scientific progress in the field of enzyme modification today enables the opportunity to tune a given biocatalyst for a specific industrial application. Much work has been focused on extending the substrate repertoire and altering selectivity. Nevertheless, it is clear that many new forthcoming opportunities will be targeted on modification to enable process application. This article discusses the challenges involved in enzyme modification focused on process requirements, such as the need to fulfill reaction thermodynamics, specific activity under the required conditions, kinetics at required concentrations, and stability. Finally, future research directions are discussed, including the integration of biocatalysis with
neighboring chemical steps.

**General information**

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Authors: Woodley, J. M. (Intern)
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- BFI (2015): BFI-level 2
- Scopus rating (2015): SJR 3.495 SNIP 1.732 CiteScore 7.03
- Web of Science (2015): Indexed yes
- BFI (2014): BFI-level 2
- Scopus rating (2014): SJR 3.582 SNIP 1.572 CiteScore 6.41
- BFI (2013): BFI-level 2
- Scopus rating (2013): SJR 4.332 SNIP 2.249 CiteScore 8.91
- ISI indexed (2013): ISI indexed yes
- Web of Science (2013): Indexed yes
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- Scopus rating (2012): SJR 4.535 SNIP 2.397 CiteScore 8.95
- ISI indexed (2012): ISI indexed yes
- BFI (2011): BFI-level 2
- Scopus rating (2011): SJR 4.915 SNIP 2.355 CiteScore 9.24
- ISI indexed (2011): ISI indexed yes
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- Scopus rating (2010): SJR 4.216 SNIP 2.069
- BFI (2009): BFI-level 2
- Scopus rating (2009): SJR 4.638 SNIP 2.18
- BFI (2008): BFI-level 2
- Scopus rating (2008): SJR 3.927 SNIP 1.835
- Scopus rating (2007): SJR 4.268 SNIP 2.054
- Scopus rating (2006): SJR 3.899 SNIP 1.993
- Scopus rating (2005): SJR 4.029 SNIP 2.176
- Scopus rating (2004): SJR 3.836 SNIP 2.17
- Scopus rating (2003): SJR 3.368 SNIP 2.016
- Scopus rating (2002): SJR 3.207 SNIP 1.883
- Scopus rating (2001): SJR 3.293 SNIP 1.895
- Scopus rating (2000): SJR 3.528 SNIP 1.635
- Scopus rating (1999): SJR 2.838 SNIP 1.45
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Source: dtu
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Purification of 5-hydroxymethylfurfural (hmf) by crystallization

This invention relates to an efficient procedure for purifying HMF by crystallization at low temperature from an organic solvent.

General information
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Organisations: Department of Chemistry, Centre for Catalysis and Sustainable Chemistry, Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Riisager, A. (Intern), Jensen, J. S. (Ekstern), Ståhlberg, T. J. B. (Intern), Woodley, J. (Intern)
Publication date: 2013

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IPC: C07D307
Patent number: WO2013024162
Date: 21/02/2013
Original language: English
Electronic versions:
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Bibliographical note
DTU reference number: 92579
Main Research Area: Technical/natural sciences
Publication: Research › Patent – Annual report year: 2013

Reaction Engineering of Biocatalytic Enantioselective Reduction: A Case Study for Aliphatic Ketones

Previously, it could be demonstrated, that the monophasic, enzymatic reduction of aliphatic 2-ketones into the corresponding (R)-2-alcohols is an adequate and viable method as carried out in a cascade of two enzyme–membrane reactors (Leuchs, S.; Na'amnieh, S. N.; Greiner, L. Green Chemistry 2013, 15, 167–176.). In the present work, the process metrics of the ketone reduction were calculated. A cost analysis revealed that the enzyme costs are negligible, but the cost for nicotinamide cofactor NADP+ is dominating the overall cost of the chemical raw material followed by the ionic liquid (TEGO IL K5) used as solubiliser and the buffer. The overall cost of chemicals was €148/kgproduct. To assess the environmental impact of the process, the E-factor (kgwaste/kgproduct) 132 and the process mass intensity 133 (PMI, kgsubstrate/kgproduct) were calculated. A process model based on initial rate experiments was elaborated and used to improve the process under cost and environmental aspects. Applying several measures to enhance the cofactor utilisation, the cost base could be reduced by 65% and the E-factor (PMI) to 17 (18).

General information
State: Published
Organisations: Center for Process Engineering and Technology, Department of Chemical and Biochemical Engineering, DECHHEMA Research Institute, Technical University of Denmark, Mannheim University of Applied Sciences
Authors: Leuchs, S. (Ekstern), Lima-Ramos, J. (Ekstern), Greiner, L. (Ekstern), Al-Haque, N. (Intern), Tufvesson, P. (Intern), Woodley, J. (Intern)
Pages: 1027-1035
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Main Research Area: Technical/natural sciences

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Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.318 SNIP 1.029 CiteScore 2.54
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.027 SNIP 0.99 CiteScore 2.38
Reactor selection for multi-step enzymatic reactions

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Xue, R. (Intern), Woodley, J. (Intern)
Publication date: 2013
Event: Abstract from BIOTRANS 2013, Manchester, United Kingdom.
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

Scale-up and intensification of (S)-1-(2-chlorophenyl)ethanol bioproduction: Economic evaluation of whole cell-catalyzed reduction of o-Chloroacetophenone
Escherichia coli cells co-expressing genes coding for Candida tenuis xylose reductase and Candida boidinii formate dehydrogenase were used for the bioreduction of o-chloroacetophenone with in situ coenzyme recycling. The product, (S)-1-(2-chlorophenyl)ethanol, is a key chiral intermediate in the synthesis of polo-like kinase 1 inhibitors, a new class of chemotherapeutic drugs. Production of the alcohol in multi-gram scale requires intensification and scale-up of the
biocatalyst production, biotransformation, and downstream processing. Cell cultivation in a 6.9-L bioreactor led to a more than tenfold increase in cell concentration compared to shaken flask cultivation. The resultant cells were used in conversions of 300 mM substrate to (S)-1-(2-chlorophenyl)ethanol (e.e. >99.9%) in high yield (96%). Results obtained in a reaction volume of 500 mL were identical to biotransformations carried out in 1 mL (analytical) and 15 mL (preparative) scale. Optimization of product isolation based on hexane extraction yielded 86% isolated product. Biotransformation and extraction were accomplished in a stirred tank reactor equipped with pH and temperature control. The developed process lowered production costs by 80% and enabled (S)-1-(2-chlorophenyl)ethanol production within previously defined economic boundaries. A simple and efficient way to synthesize (S)-1-(2-chlorophenyl)ethanol in an isolated amount of 20 g product per reaction batch was demonstrated. Biotechnol. Bioeng. 2013; 110: 2311–2315. © 2013 Wiley Periodicals, Inc.
Simulation study of microbioreactor configurations for production of optically pure chiral amines

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Pereira Rosinha, I. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern), Krühne, U. (Intern)
Publication date: 2013
Event: Abstract from International Conference on Implementation of Microreactor Technology into Biotechnology (IMTB2013), Cavtat, Croatia.
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

Sustainable Intensified Process Retrofit for the Production of MDI
Process intensification (PI) is a means by which processes can be made more efficient and sustainable at different levels, the unit operations, functional and phenomena levels. Therefore PI can be used for making process improvements at the functional level for the production of an important polyurethane, methylene diphenyldi-isocyanate (MDI).

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center, Center for Process Engineering and Technology, Huntsman Polyurethanes Limited
Authors: Babi, D. K. (Intern), Woodley, J. (Intern), Gani, R. (Intern), Jones, D. (Ekstern), Zeeuw, A. J. (Ekstern)
Number of pages: 1
Publication date: 2013
Main Research Area: Technical/natural sciences
Source: dtu
Source-ID: u::8408
Publication: Research - peer-review › Poster – Annual report year: 2013

Systematic design of tailor-made blended products

General information
Systematic Design of Tailor-Made Blended Products

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center, Center for Process Engineering and Technology
Authors: Yunus, N. A. B. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern), Gani, R. (Intern)
Publication date: 2013
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

Systematic Design of Tailor-Made Blended Products

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center, Center for Process Engineering and Technology
Authors: Yunus, N. A. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern), Gani, R. (Intern)
Number of pages: 1
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Main Research Area: Technical/natural sciences
Product design, Computer-aided approach, Gasoline, Lubricant
Source: dtu
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Systematic Design of Tailor-Made Blended Products

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center, Center for Process Engineering and Technology
Authors: Singh, R. (Intern), Godfrey, A. (Ekstern), Gregertsen, B. (Ekstern), Muller, F. (Ekstern), Gernaey, K. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Pages: 344-368
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Main Research Area: Technical/natural sciences
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Journal: Computers and Chemical Engineering
Towards an integrated µ-factory: Integrated micro membrane packed bed reactor

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Bodla, V. (Ekstern), Woodley, J. (Intern), Krühne, U. (Intern), Gernaey, K. (Intern)
Publication date: 2013
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

Towards an integrated µ-factory: Design and development of a microfluidic system to include fermentation and biocatalysis

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Bodla, V. K. (Intern), Woodley, J. (Intern), Krühne, U. (Intern), Gernaey, K. (Intern)
Publication date: 2013
Event: Abstract from International Conference on Implementation of Microreactor Technology into Biotechnology (IMTB2013), Cavtat, Croatia.
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

Towards an integrated µ-factory: Integrated micro membrane packed bed reactor

General information
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Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Bodla, V. K. (Intern), Woodley, J. (Intern), Krühne, U. (Intern), Gernaey, K. (Intern)
Publication date: 2013
Event: Abstract from BIOTRANS 2013, Manchester, United Kingdom.
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

Towards a standardized way of reporting physicochemical data and process metrics for transaminase reactions

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Tufvesson, P. (Intern), Woodley, J. (Intern)
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Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

Towards effective biocatalytic process development using microreactor technology

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Woodley, J. (Intern), Heintz, S. (Intern), Ringborg, R. H. (Intern), Pereira Rosinha, I. (Intern), Tufvesson, P. (Intern), Krühne, U. (Intern), Gernaey, K. (Intern)
Publication date: 2013
Event: Abstract from International Conference on Implementation of Microreactor Technology into Biotechnology (IMTB2013), Cavtat, Croatia.
Main Research Area: Technical/natural sciences
Towards process development for whole cell P450 hydroxylation identifying the bottlenecks using CYP153 as model system

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Andersson, M. T. (Intern), Woodley, J. (Intern)
Publication date: 2013
Event: Abstract from BIOTRANS 2013, Manchester, United Kingdom.
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

Use of 'windows of operation' to guide process design of ω-transaminase catalysed reactions

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Lima Ramos, J. (Intern), Tufvesson, P. (Intern), Woodley, J. (Intern)
Publication date: 2013
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

Using micro technology in process screening for improved ω-transaminases

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State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Ringborg, R. H. (Intern), Krühne, U. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern)
Publication date: 2013
Event: Abstract from International Conference on Implementation of Microreactor Technology into Biotechnology (IMTB2013), Cavtat, Croatia.
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

A systematic synthesis and design methodology to achieve process intensification in (bio) chemical processes

Process intensification (PI) has the potential to improve existing processes or create new process options, which are needed in order to produce products using more sustainable methods. In principle, an enormous number of process options can be generated but where and how the process should be intensified for the biggest improvement is difficult to identify. In this paper the development of a systematic computer aided model-based synthesis and design methodology incorporating PI is presented. In order to manage the complexities involved, the methodology employs a decomposition-based solution approach. Starting from an analysis of existing processes, the methodology generates a set of process options and reduces their number through several screening steps until from the remaining options, the optimal is found. The application of the methodology is highlighted through a case study involving the chemo-enzymatic synthesis of N-
acetyl-d-neuraminic acid (Neu5Ac).

**General information**

State: Published  
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center  
Authors: Lutze, P. (Intern), Roman Martinez, A. (Intern), Woodley, J. (Intern), Gani, R. (Intern)  
Pages: 189-207  
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Scopus rating (2010): SJR 1.176 SNIP 1.796  
Web of Science (2010): Indexed yes  
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Scopus rating (2009): SJR 1.154 SNIP 2.166  
Web of Science (2009): Indexed yes  
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Scopus rating (2008): SJR 1.293 SNIP 2.127  
Web of Science (2008): Indexed yes  
Scopus rating (2007): SJR 1.625 SNIP 1.959  
Web of Science (2007): Indexed yes  
Scopus rating (2006): SJR 1.304 SNIP 1.936  
Scopus rating (2005): SJR 1.314 SNIP 1.953  
Web of Science (2005): Indexed yes  
Scopus rating (2004): SJR 1.125 SNIP 1.908  
Web of Science (2004): Indexed yes  
Scopus rating (2003): SJR 1.348 SNIP 1.936  
Scopus rating (2002): SJR 1.042 SNIP 0.92
Achieving process intensification form the application of a phenomena based synthesis, Design and intensification methodology

Process intensification/Process Systems Engineering.

Process intensification (PI) is a means by which one can achieve a more efficient and sustainable chemical process. Major success in the area of PI has been achieved by Eastman chemicals [1] which in 1984 intensified the process for the manufacture of methyl acetate by replacing with one single reactive distillation column the multi-step process which consisted of one reactor, extractive distillation, liquid-liquid separation and azeotropic distillation. However, except for reactive distillation and dividing wall columns, the implementation of PI still faces challenges [2] because the identification and design of intensified processes is not simple [3]. Lutze et al [3] has developed a systematic PI synthesis/design method at the unit operations (Unit-Ops) level, where the search space is based on a knowledge-base of existing PI equipment. Siirola [4] has proposed a task-based approach known as the means-ends analysis. A limitation with the means-ends analysis is that it becomes difficult to apply if too many corrective tasks should be identified and replaced and if too many alternatives should be considered. From the above PI methods, the starting point is knowledge of existing Unit-Ops and therefore a limitation arising from their application is that they are able to generate new integrations/combinations of intensified equipment but are unable to generate novel PI solutions employing new Unit-Ops. Therefore, incentives exist for a more systematic, efficient and flexible PI methodology covering a wider range of applications which is able to find truly innovative and predictive solutions, not only using knowledge of the existing methods at the Unit-Ops level but also operating at a lower level of aggregation (that is, the phenomena level). This enables the use of apriori knowledge of the Unit-Ops as well as the possibility to design new Unit-Ops. A first version for a phenomena-based synthesis/design (PhenPI) methodology has been developed [5] in which a process flowsheet is generated through the use of involved phenomena such as mixing, phase transition and phase separation [5]. In principle, generating processes from phenomena leads to a large number of process options and therefore, an efficient solution procedure for the evaluation of these process options is needed. To manage this complexity, the PhenPI methodology uses a decomposition based solution approach which breaks down the complex mathematical synthesis/design problem into manageable sub-problems (6 steps). It allows the generation of PI options and their subsequent stepwise reduction of the search space and identification of the best intensified process option. In step-1, the problem definition of the process to be intensified, the process scenario (batch or continuous) and constraints are defined. In step-2, the process is analysed based on the base case design and the flowsheet is converted into a task and phenomena based flowsheet. In step-3, analysis of the process at the task and phenomena level and the use of different tools such as analysis of pure component and mixture properties are used to identify limitations/bottlenecks of the process. From this data, desirable tasks and suitable phenomena are identified to overcome these limitations/bottlenecks and for the processing of tasks in the most efficient manner. In step-4, the involved phenomena are aggregated and/or connected using a set of connectivity rules based on the operating windows of each phenomenon. Based on this, a large number of flowsheet options are generated which are subsequently screened for feasibility by applying logical and structural constraints. In step-5, the remaining flowsheet options are fast screened by constraints for feasibility and for performance using a set of PI performance metrics. The most promising phenomena-based options are transformed into a unit-operation based flowsheet using a set of rules. In step-6, the most promising unit-operation based options from step-5 are optimized in order to identify the best process option. In this paper the PhenPI methodology is presented in detail and highlighted by its application to the production of methyl acetate in order to identify the best PI option with respect to sustainability and other processes requiring reaction-separation processing tasks. It will be shown that the PhenPI methodology systematically not only generates the reactive distillation option proposed by Siirola but also other alternatives which have not been previously considered.

General information

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Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center, Center for Process Engineering and Technology
Authors: Babi, D. K. (Intern), Lutze, P. (Intern), Woodley, J. (Intern), Gani, R. (Intern)
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Main Research Area: Technical/natural sciences

Bibliographical note
Oral presentation.

References:
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Adaptive Continuous Template-Based Novel Manufacturing Technique for Faster Manufacturing of New APIs for Clinical Trials

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Computer Aided Process Engineering Center
Authors: Singh, R. (Intern), Gernaey, K. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Publication date: 2012
Main Research Area: Technical/natural sciences
Electronic versions:
AIChE_Paper 467e.pdf
Links:
https://aiche.confex.com/aiche/2012/webprogram/Paper275021.html

Bibliographical note
Oral presentation.
Source: dtu
Source-ID: u::5321
Publication: Research › Conference abstract for conference – Annual report year: 2012

A generic process template for continuous pharmaceutical production
In the work reported here, a conceptual generic continuous process template for pharmaceutical production is presented. The template is demonstrated on a nitro reduction case study that should in principle be generic such that it can handle a series of substrates with similar molecular functionality. To assist in adoption of different substrates, a systematic substrate adoption methodology (SAM) has also been developed. The objective of the generic process template together with the SAM is to provide flexibility as well as increased efficiency to continuous processes while reducing inventory for safer operations (from 50 to 100 L in batch or 3 to 5 L in continuous processes). It is shown that the use of the template together with SAM can lead to potential savings in product development times through flexible and efficient production of Kg amounts of product material for clinical trials and other analyses.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Computer Aided Process Engineering Center, AstraZeneca
Authors: Singh, R. (Intern), Rozada-Sanches, R. (Ekstern), Dean, W. (Ekstern), Perkins, J. (Ekstern), Muller, F. (Ekstern), Godfrey, A. (Ekstern), Gernaey, K. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Pages: 715-719
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A generic process template for continuous pharmaceutical production

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State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Computer Aided Process Engineering Center, AstraZeneca
Authors: Singh, R. (Intern), Rozada-Sanches, R. (Ekstern), Dean, W. (Ekstern), Perkins, J. (Ekstern), Muller, F. (Ekstern), Godfrey, A. (Ekstern), Gernaey, K. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Publication date: 2012
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Article in proceedings – Annual report year: 2012

A methodology for cascade selection for co-product removal in the $\omega$-transaminase system

Production of chiral amines using transaminases has indeed been proposed recently as an interesting alternative to conventional methods to help in the synthesis of many new pharmaceuticals. Two reaction strategies have been demonstrated: kinetic resolution and asymmetric synthesis. The latter approach has the advantage that the theoretical yield is 100% compared to 50% for the former [1]. However, a major challenge for asymmetric synthesis is the unfavourable thermodynamic equilibrium for many of the most interesting reactions. Meeting the feasibility criteria that are typical for most pharmaceutical processes can only be achieved by selectively removing the product and/or co-product formed during the reaction (so called in-situ (co)product removal (IS(C)PR)). Several different alternative co-product removal strategies have been suggested, all of which have different impacts on the overall process. Among others, one of the most promising strategies is to use a second enzyme reaction to remove the co-product in an enzymatic cascade [2].

Currently there are no decision tools available to help select appropriate cascade systems for process implementation. In the current work a methodology for choosing a feasible cascade system that will remove co-product to meet process requirements under process relevant conditions will be presented. Decisions are based on thermodynamic constraints, kinetics, selectivity, stability, pH change, cascade enzyme compatibility and downstream processing. The methodology has been applied to an $\omega$-transaminase system which is thermodynamically challenged and enzymatic ISCPR is deployed to shift the equilibrium. The enzymes proposed for co-product removal are dehydrogenases: lactate dehydrogenase (EC 1.1.1.27), alanine dehydrogenase (EC 1.4.1.1), yeast alcohol dehydrogenase (EC 1.1.1.1), pyruvate decarboxylase (EC 4.1.1.1), acetolactate synthase (EC 2.2.1.6) and as co-factor recycling enzymes: glucose dehydrogenase (EC 1.1.1.47), formate dehydrogenase (EC 1.2.1.2) and phosphite dehydrogenase (EC 1.20.1.1). The methodology gives an insight into the constraints of different cascade systems and is the basis for process set-up of selected cascades. Experimental and calculated data will be used to illustrate the methodology.

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State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Janes, K. (Intern), Gernaey, K. (Intern), Tufvesson, P. (Intern), Woodley, J. (Intern)
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References:
A methodology for cascade selection for co-product removal in the ω-transaminase system

Production of chiral amines using transaminases has indeed been proposed recently as an interesting alternative to conventional methods to help in the synthesis of many new pharmaceuticals. Two reaction strategies have been demonstrated: kinetic resolution and asymmetric synthesis. The latter approach has the advantage that the theoretical yield is 100% compared to 50% for the former [1]. However, a major challenge for asymmetric synthesis is the unfavourable thermodynamic equilibrium for many of the most interesting reactions. Meeting the feasibility criteria that are typical for most pharmaceutical processes can only be achieved by selectively removing the product and/or co-product formed during the reaction (so called in-situ (co)product removal (IS(C)PR)). Several different alternative co-product removal strategies have been suggested, all of which have different impacts on the overall process. Among others, one of the most promising strategies is to use a second enzyme reaction to remove the co-product in an enzymatic cascade [2]. Currently there are no decision tools available to help select appropriate cascade systems for process implementation. In the current work a methodology for choosing a feasible cascade system will that will remove co-product to meet process requirements under process relevant conditions will be presented. Decisions are based on thermodynamic constraints, kinetics, selectivity, stability, pH change, cascade enzyme compatibility and downstream processing. The methodology has been applied to an ω-transaminase system which is thermodynamically challenged and enzymatic ISCPR is deployed to shift the equilibrium. The enzymes proposed for co-product removal are dehydrogenases: lactate dehydrogenase (EC 1.1.1.27), alanine dehydrogenase (EC 1.4.1.1), yeast alcohol dehydrogenase (EC 1.1.1.1); pyruvate decarboxylase (EC 1.1.1.27), alanine dehydrogenase (EC 1.4.1.1), yeast alcohol dehydrogenase (EC 1.1.1.1); pyruvate decarboxylase (EC 1.1.1.27), alanine dehydrogenase (EC 1.4.1.1), yeast alcohol dehydrogenase (EC 1.1.1.1); pyruvate decarboxylase (EC 1.1.1.1). The methodology gives an insight into the constraints of different cascade systems and is the basis for process set-up of selected cascades. Experimental and calculated data will be used to illustrate the methodology.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Janes, K. (Intern), Gernaey, K. (Intern), Tufvesson, P. (Intern), Woodley, J. (Intern)
Publication date: 2012
Main Research Area: Technical/natural sciences

Bibliographical note
Acknowledgement:
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References:

Publication: Research - peer-review › Poster – Annual report year: 2012

A methodology for cascade selection for co-product removal in the ω-transaminase system
Production of chiral amines using transaminases has indeed been proposed recently as an interesting alternative to conventional methods to help in the synthesis of many new pharmaceuticals. Two reaction strategies have been demonstrated: kinetic resolution and asymmetric synthesis. The latter approach has the advantage that the theoretical yield is 100% compared to 50% for the former [1]. However, a major challenge for asymmetric synthesis is the unfavourable thermodynamic equilibrium for many of the most interesting reactions. Meeting the feasibility criteria that are typical for most pharmaceutical processes can only be achieved by selectively removing the product and/or co-product formed during the reaction (so called in-situ (co)product removal (IS(C)PR)). Several different alternative co-product removal strategies have been suggested, all of which have different impacts on the overall process. Among others, one of the most promising strategies is to use a second enzyme reaction to remove the co-product in an enzymatic cascade [2]. Currently there are no decision tools available to help select appropriate cascade systems for process implementation. In the current work a methodology for choosing a feasible cascade system will that will remove co-product to meet process requirements under process relevant conditions will be presented. Decisions are based on thermodynamic constraints, kinetics, selectivity, stability, pH change, cascade enzyme compatibility and downstream processing. The methodology has been applied to an ω-transaminase system which is thermodynamically challenged and enzymatic ISCPR is deployed to shift the equilibrium. The enzymes proposed for co-product removal are dehydrogenases: lactate dehydrogenase (EC 1.1.1.27), alanine dehydrogenase (EC 1.4.1.1), yeast alcohol dehydrogenase (EC 1.1.1.1); pyruvate decarboxylase (EC 1.1.1.1). The methodology gives an insight into the constraints of different cascade systems and is the basis for process set-up of selected cascades. Experimental and calculated data will be used to illustrate the methodology.
4.1.1.1), acetolactate synthase (EC 2.2.1.6) and as co-factor recycling enzymes: glucose dehydrogenase (EC 1.1.1.47), formate dehydrogenase (EC 1.2.1.2) and phosphite dehydrogenase (EC 1.20.1.1). The methodology gives an insight into the constraints of different cascade systems and is the basis for process set-up of selected cascades. Experimental and calculated data will be used to illustrate the methodology.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Janes, K. (Intern), Gernaey, K. (Intern), Tufvesson, P. (Intern), Woodley, J. (Intern)
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Main Research Area: Technical/natural sciences

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References:

An Integrated Methodology for Design of Tailor-Made Blended Products
A computer-aided methodology has been developed for the design of blended (mixture) products. Through this methodology, it is possible to identify the most suitable chemicals for blending, and “tailor” the blend according to specified product needs. The methodology has three stages: 1) product design, 2) process identification, and 3) experimental verification. The principle problem, which is the product design stage is divided into four sub-problems and solved with a decomposition-based approach. In stage two, the ability to produce the chemicals used as building blocks in the blends is analyzed. Finally, experimental work (or detailed model-based verification) is conducted in stage three to validate the selected blend candidates. In this study, the product design stage is highlighted through a case study of gasoline blends with bio-based chemicals. The objective of this study is to identify blended gasoline products that match (or improve) the performance of the conventional gasoline.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center, Center for Process Engineering and Technology
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An Integrated Methodology for Design of Tailor-Made Blended Products
An important issue for the production of many chemical-based products is related to the future supply of the essential raw materials. Currently, many of these products are derived from fossil fuel based raw materials and from a sustainability point of view, other renewable alternatives need to be considered. In order to achieve this, new products need to be developed by blending the conventional materials with other chemicals that can be produced from renewable resources,
such as bio-based chemicals. Blending could offer several advantages, such as, reducing the amount of fossil fuel consumption, decreasing the pollution level and increasing the product safety. In addition, potentially the product attributes also can be improved by blending. However, the product performance may decline when other chemicals are added. In order to maintain/improve the blended product performance, it is necessary to identify the best product blend with the most appropriate chemicals. Therefore, an integrated methodology to design mixture/blend products is developed, which is able to find the most suitable chemicals for blending, and produce blended products that satisfy specific product needs. The methodology has three stages: 1) product design, 2) process identification, and 3) experimental verification. At the first stage, a computer-aided methodology is implemented to quickly identify and evaluate the most promising blend candidates. Subsequently, the ability to produce the chemicals used as the components in the mixtures is analyzed. Finally, experimental work (or detailed model-based verification) is conducted to validate the selected blend candidates. In this paper, the product design issues are highlighted considering only chemicals from known bio-based sources. The product design stage has four tasks. First, the design problem is defined where the product needs are identified, translated into target properties and given target values. Secondly, target property models are retrieved from a property model library developed specifically for this methodology. Thirdly, a mixture/blend design algorithm is applied to obtain the mixtures/blends that match the set of constraints (design targets). This algorithm employs a decomposition based solution strategy to solve the mixture/blend problem. The result is a set of blends that match the constraints, the compositions, values of the target properties and information about their miscibility. Finally, the mixture target property values are verified either with experimental data (if available) or by means of rigorous models for the properties and mixtures that require it. The application of this systematic methodology is highlighted through case studies related to the design of blended gasoline, lubricants and refrigerants, where the objective is to identify blended products that satisfy all the product attributes with at least similar or better performance compared to conventional products.
A perspective on PSE in pharmaceutical process development and innovation

The pharmaceutical industry is under growing pressure to increase efficiency, both in production and in process development. This paper discusses the central role of Process Systems Engineering (PSE) methods and tools in pharmaceutical process development and innovation, and searches for answers to questions such as: Which PSE methods can be applied readily? Where is more method development needed? The paper covers key subjects for development of economically and environmentally sustainable pharmaceutical processes, including Process Analytical Technology in its broadest sense, continuous pharmaceutical manufacturing and green processes, and is illustrated with a series of short examples taken from the literature and ongoing research projects.
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Scopus rating (2008): SJR 1.293 SNIP 2.127
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Scopus rating (2007): SJR 1.625 SNIP 1.959
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Scopus rating (2006): SJR 1.304 SNIP 1.936
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Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 1.348 SNIP 1.936
Scopus rating (2002): SJR 1.042 SNIP 0.92
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 0.955 SNIP 0.728
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 1.366 SNIP 1.025
Web of Science (2000): Indexed yes
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A phenomena-based methodology for process synthesis incorporating process intensification

General information
State: Published
Organisations: Center for Process Engineering and Technology, Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Lutze, P. (Intern), Babi, D. K. (Intern), Woodley, J. (Intern)
Publication date: 2012
Main Research Area: Technical/natural sciences

Bibliographical note
Oral presentation.
Publication: Research › Paper – Annual report year: 2012

A robust methodology for kinetic model parameter estimation for biocatalytic reactions

Effective estimation of parameters in biocatalytic reaction kinetic expressions are very important when building process models to enable evaluation of process technology options and alternative biocatalysts. The kinetic models used to describe enzyme-catalyzed reactions generally include several parameters, which are strongly correlated with each other. State-of-the-art methodologies such as nonlinear regression (using progress curves) or graphical analysis (using initial rate data, for example, the Lineweaver-Burke plot, Hanes plot or Dixon plot) often incorporate errors in the estimates and rarely lead to globally optimized parameter values. In this article, a robust methodology to estimate parameters for biocatalytic reaction kinetic expressions is proposed. The methodology determines the parameters in a systematic manner by exploiting the best features of several of the current approaches. The parameter estimation problem is decomposed into five hierarchical steps, where the solution of each of the steps becomes the input for the subsequent step to achieve the final model with the corresponding regressed parameters. The model is further used for validating its performance and determining the correlation of the parameters. The final model with the fitted parameters is able to describe both initial rate and dynamic experiments. Application of the methodology is illustrated with a case study using the x-transaminase catalyzed synthesis of 1-phenylethylamine from acetophenone and 2-propylamine.
A two-stage ethanol-based biodiesel production in a packed bed reactor.

A two-stage enzymatic process for producing fatty acid ethyl ester (FAEE) in a packed bed reactor is reported. The process uses an experimental immobilized lipase (NS 88001) and Novozym 435 to catalyze transesterification (first stage) and esterification (second stage), respectively. Both stages were conducted in a simulated series of reactors by repeatedly passing the reaction mixture through a single reactor, with separation of the by-product glycerol and water between passes in the first and second stages, respectively. The second stage brought the major components of biodiesel to 'in-spec' levels according to the European biodiesel specifications for methanol-based biodiesel. The highest overall productivity achieved in the first stage was 2.52 kg FAEE(kg catalyst)−1 h−1 at a superficial velocity of 7.6 cm min−1, close to the efficiency of a stirred tank reactor under similar conditions. The overall productivity of the proposed two-stage process was 1.56 kg FAEE(kg catalyst)−1 h−1. Based on this process model, the challenges of scale-up have been addressed and potential continuous process options have been proposed.
Catalytic aerobic oxidation of bio-renewable chemicals

This thesis covers the investigation of new catalytic systems for the aerobic oxidation of chemicals derived from bio-renewable sources. The effects of different factors and conditions on the reactions were examined. The employed catalysts were characterized by physisorption measurements, SEM, TEM, EDS, XRF and other methods. Supported gold and ruthenium hydroxide catalyst systems were explored for the aerobic oxidation of 5-hydroxymethylfurfural (HMF) to 2,5-furandicarboxylic acid (FDA), a potential polymer building block for the plastic industry, or its dimethyl ester (FDMC). High product selectivities and yields were obtained under optimized conditions. Heterogeneous catalysts consisting of Au nanoparticles on different supports were shown to efficiently oxidize HMF to FDA or FDMC in water or methanol, respectively. Additionally, the reaction conditions were shown to be adjustable for the exclusive production of intermediate products of the oxidation. Catalysts consisting of Ru(OH)x deposited on metal oxide supports, such as, for instance, CeO2 and MgAl2O4, were employed in the aerobic oxidation of HMF in different “green” reaction media, e.g. water and various ionic liquids, under base-free conditions. Moreover, a detailed study on the performance and stability of the ruthenium hydroxide catalysts on magnesium-containing supports under reaction conditions was conducted.

The aerobic oxidation of HMF to form another value-added chemical, 2,5-diformylfuran (DFF), was also investigated with supported Ru(OH)x catalysts in organic solvents. The examined catalyst systems and reaction conditions were also shown to be applicable for the efficient oxidation of other substituted furans. Furthermore, novel catalytic systems comprising vanadia supported on zeolites were investigated for the aerobic oxidation of HMF to DFF in organic solvents, and a lixiviation study was performed.

The oxidation of aliphatic alcohols over supported Ru(OH)x and RuOx catalysts is also described. The highly selective and efficient oxidation of ethanol to acetic acid was shown with supported Ru(OH)x and highly dispersed RuOx deposited on various metal oxides. Furthermore, this thesis presents the results of the catalytic aerobic oxidative degradation of higher alcohols over supported ruthenium hydroxide catalysts. A very efficient oxidative cleavage of vic-diols to form respective acids was also shown under examined conditions.

Thus, the oxidative transformations of biomass-derived chemicals over different gold and ruthenium-based catalyst systems with oxygen as the abundant oxidant were explored.

General information
State: Published
Organisations: Department of Chemistry, Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Centre for Catalysis and Sustainable Chemistry
Authors: Gorbanev, Y. (Intern), Woodley, J. (Intern), Riisager, A. (Intern)
Number of pages: 300
Publication date: 2012

Catalytic conversion of glycos to 5-hydroxymethylfurfural in ionic liquids: A techno-economic process assessment

General information
State: Published
Organisations: Department of Chemistry, Centre for Catalysis and Sustainable Chemistry, Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Riisager, A. (Intern), Ståhlberg, T. J. B. (Intern), Fu, W. (Intern), Woodley, J. (Intern)
Publication date: 2012
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2013

Computer-aided approach for design of tailor-made blended products

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center, Center for Process Engineering and Technology
Computer-aided approach for design of tailor-made blended products

A computer-aided methodology has been developed for the design of blended (mixture) products. Through this methodology, it is possible to identify the most suitable chemicals for blending, and “tailor” the blend according to specified product needs (usually product attributes, e.g. performance as well as regulatory). The product design methodology has four tasks. First, the design problem is defined: the product needs are identified, translated into target properties and the constraints for each target property are defined. Secondly, target property models are retrieved from a property model library developed specifically for this methodology. Thirdly, a mixture/blend design algorithm is applied to obtain the mixtures/blends (gasoline blend in this case) that match the set of constraints (design targets). The result is a set of blends that match the constraints, the composition of the chemicals present in the blend, values of the target properties and information about their miscibility. Finally, the mixture target property values are verified by means of rigorous models for the properties and mixtures. The application of this systematic methodology is highlighted through case studies related to the design of blended gasoline with different types of blending agents. The objective of this study is to identify blended gasoline products that match the traditional gasoline attributes and identify suitable blending agents for gasoline.

Design of microfluidic reactors for biocatalytic reactions

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Bodla, V. K. (Intern), Bolic, A. (Intern), Krühne, U. (Intern), Woodley, J. (Intern), Gernaey, K. (Intern)
Number of pages: 2
Publication date: 2012
Event: Abstract from 12th International Conference on Microreaction Technology, Lyon, France.
Main Research Area: Technical/natural sciences
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Development of continuous pharmaceutical production processes supported by process systems engineering methods and tools
The pharmaceutical industry is undergoing a radical transition towards continuous production processes. Systematic use of process systems engineering (PSE) methods and tools form the key to achieve this transition in a structured and efficient way.

Enzymatic isomerization of glucose and xylose in ionic liquids
Glucose isomerase has been found for the first time to catalyze the isomerization of glucose to fructose in the ionic liquid N, N-dibutylethanolammonium octanoate (DBAO). Isomerization was achieved at temperatures of 60-80 degrees C although a substantial amount of mannose was formed at elevated temperatures via the Lobry-de Bruyn-van Ekenstein transformation. Complete recovery of the sugars after reaction was achieved by extraction with aqueous HCl, thus making the protocol attractive for continuous operation.
Enzyme stability: Process engineering requirements

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Törnvall, U. (Intern), Nordblad, M. (Intern), Tufvesson, P. (Intern), Woodley, J. (Intern)
Number of pages: 23
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Enzyme stability Process engineering requirements - Ulrika Törnvall.pdf

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Experimental determination of thermodynamic equilibrium in biocatalytic transamination

The equilibrium constant is a critical parameter for making rational design choices in biocatalytic transamination for the synthesis of chiral amines. However, very few reports are available in the scientific literature determining the equilibrium constant (K) for the transamination of ketones. Various methods for determining (or estimating) equilibrium have previously been suggested, both experimental as well as computational (based on group contribution methods). However, none of these were found suitable for determining the equilibrium constant for the transamination of ketones. Therefore, in this communication we suggest a simple experimental methodology which we hope will stimulate more accurate determination of thermodynamic equilibria when reporting the results of transaminase-catalyzed reactions in order to increase understanding of the relationship between substrate and product molecular structure on reaction thermodynamics.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, University of Graz
Authors: Tufvesson, P. (Intern), Jensen, J. S. (Intern), Kroutil, W. (Ekstern), Woodley, J. M. (Intern)
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BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.589 SNIP 1.401 CiteScore 4.16
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.621 SNIP 1.425 CiteScore 4.44
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Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.639 SNIP 1.366 CiteScore 4.04
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.668 SNIP 1.483 CiteScore 4.08
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.538 SNIP 1.357
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
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Identification of bottlenecks for P450 biotransformation processes

Cytochrome P450 monooxygenases (P450 or CYP) is a group of heme-containing enzymes hydroxylating non-activated hydrocarbons in a stereospecific manner, something that is hard to achieve via classical chemistry. The importance of these reactions can be stressed by the hydroxylation of steroids, but hydroxylation of e.g. alkanes, alcohols and fatty acids are also highly interesting in e.g. the polymer industry if the processes can be designed with high yield and productivity. The requirement for cofactors, corresponding electron transporting proteins, limited activity and stability of this group of enzymes makes these reactions suitable for whole cell transformations. With the limitations that follow with these requirements it is however a challenging task to reach industrial relevant process targets, especially when it comes to bulk chemicals but also for fine chemicals. Stoichiometric amounts of oxygen and limited water solubility of substrates and products are issues demanding process engineering solutions and if this can be done in parallel with strain development and enzyme engineering it would be optimal. We will present where the current research stands in perspective to an industrial mature P450 biotransformation process identifying the limiting parameters and defining relevant targets.
Immobilization of Escherichia coli containing ω-transaminase activity in LentiKats®
Whole Escherichia coli cells overexpressing ω-transaminase (ω-TA) and immobilized cells entrapped in LentiKats® were used as biocatalysts in the asymmetric synthesis of the aromatic chiral amines 1-phenylethylamine (PEA) and 3-amino-1-phenylbutane (APB). Whole cells were permeabilized with different concentrations of cetrimonium bromide (CTAB) and ethanol; the best results were obtained with CTAB 0.1% which resulted in an increase in reaction rate by 40% compared to the whole cells. The synthesis of PEA was carried out using isopropyl amine (IPA) and L-alanine (Ala) as amino donors. Using whole cell biocatalysis, the reaction with IPA was one order of magnitude faster than with Ala. No reaction was detected when permeabilized E. coli cells containing ω-TA were employed using Ala as the amino donor. Additionally, the synthesis of APB from 4-phenyl-2-butanone and IPA was studied. Whole and permeabilized cells containing ω-TA and their immobilized LentiKats® counterparts showed similar initial reactions rates and yields in the reaction systems, indicating 100% of immobilization efficiency (observed activity/activity immobilized) and absence of diffusional limitations (due to the immobilization). Immobilization of whole and permeabilized cells containing ω-TA in LentiKats® allowed improved stability as the biocatalyst was shown to be efficiently reused for five reaction cycles, retaining around 80% of original activity. © 2012 American Institute of Chemical Engineers Biotechnol. Prog., 2012

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Scopus rating (2016): CiteScore 2.12 SJR 0.668 SNIP 0.762
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Scopus rating (2015): SJR 0.727 SNIP 0.825 CiteScore 2.07
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.808 SNIP 0.931 CiteScore 2.2
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.764 SNIP 0.847 CiteScore 2.16
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.84 SNIP 0.868 CiteScore 2.35
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.918 SNIP 0.956 CiteScore 2.4
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.988 SNIP 0.947
Web of Science (2010): Indexed yes
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Improving productivity and enzyme stability through process design: Lipase catalyzed synthesis of epoxides and esters.

General information
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Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Lund University, Aalborg University
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Publication date: 2012
Main Research Area: Technical/natural sciences
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Publication: Research › Poster – Annual report year: 2012

Integrating Porous Resins In Enzymatic Processes
Increasing pressure mandated by different government policies, for developing sustainable chemical processes for the synthesis of optically pure compounds, has resulted in increased considerations of biocatalysis as a viable option by many industries. Biocatalysis, with its exquisite selective properties and potential ‘green’ attributes, presents it as a sustainable alternative. Today, the role of biocatalysis is most evident in the pharmaceutical industry and is currently extending towards fine and bulk chemical production as well. The use of hydrolytic enzymes (lipases) is well established in several chemical industries, though certain challenges persist in other types of enzymes (transferases and ketoreductases), thus limiting their implementation in industry. Inhibition by substrate and product as well as low aqueous solubility of substrates has constrained the full potential of these enzymes to be harnessed. Porous resins as opposed to other auxiliary phases, for example organic solvents, are nonbioavailable, biocompatible and offer simpler operational handling (no foaming and emulsification). This strategy has been applied effectively to single substrate – single product systems (oxidation, V microbial degradation and hydrolysis). However, this concept has not been extended to other industrially relevant reactions which are two substrate – two product systems. In this thesis, a methodological framework has been successfully developed to aid in implementing the strategy of integrating porous resins for multi-component systems. In this manner, a generic platform has been established for biocatalytic reactions that require the integration of this strategy. The framework identifies the key information about the reaction and the process using a step-wise protocol with the required tools. It includes the use of kinetic modelling in characterizing the reaction kinetics, a heuristic approach for screening resins and a model based approach for evaluating the process. Greater knowledge about the enzymatic
processes with integrated porous resins can therefore be gained and thus the efficiency of process development with respect to time and resources required (reduced number of experiments) could be increased. Estimating kinetic model parameters for enzymatic reactions is quite complex and frequently leads to identifiability issues. In order to understand the different techniques to estimate the parameters, a number of concepts are discussed in chapter four of this thesis. This knowledge has contributed to the development of a robust methodology for the estimation of kinetic model parameters for biocatalytic reactions, which has also been published in a peer reviewed journal. Screening resins for moderately hydrophobic multi-component systems is challenging. Often it is found that the capacity of the resin is inversely related with product selectivity. Therefore a tradeoff has to be made between these parameters which can be crucial from an economic point of view. A low resin capacity points towards the need for higher resin loading, which in turn determines the equilibrium concentration of the substrate in the reactor and the type of reactor that can be used (stirred tank reactor or packed bed reactor). Similarly low product selectivity would result in higher product concentration in the reactor and thus not aid in alleviating inhibition. Further considerations are discussed in chapter four.

Process modelling is a very effective tool in evaluating a process. Critical information about the process can be gained by means of simulations, which can further be re-used to tune the reaction or process conditions to harness the full potential of the enzyme. State-of-the-art mathematical techniques for model quality evaluation, such as uncertainty and sensitivity analysis, have been included in this analysis in order to identify the key model parameters for better understanding of the process. Three case studies were used to illustrate the applicability of the methodology to fulfill different objective requirements. The case studies were selected for not only being industrially relevant but as well as having certain limitations which contributed in developing the tools and strategies to overcome them. The asymmetric synthesis of 1-phenylethylamine using α-transaminase, the asymmetric synthesis of 1-methyl-3-phenylpropylamine using α-transaminase and enantioselective synthesis of 2-octanol using alcohol dehydrogenase were selected. VI of resin stability and cost also have to be taken into account in the screening procedure. The screening therefore becomes a multi-objective task that has to be solved simultaneously. Such an approach has been applied in the method formulated in this framework.

To overcome these challenges, different process strategies are required to obtain high yields. A number of different challenges and proposed solutions are discussed in chapter one of this thesis and have also been published as a review. In recent years, integrating porous resins as an auxiliary phase in enzymatic processes, to non-selectively bind the substrate and product as a means to alleviate substrate and product inhibition, has gained considerable recognition. The resins act as a reservoir for the inhibitory substrate and a sink for the inhibitory product and simultaneously attain the required high substrate loading to make the process economically feasible. In this way the potential benefit of the enzyme can be exploited.

General information
State: Published
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Ionic liquids in integrated catalytic technologies to produce furanic chemical

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Organisations: Department of Chemistry, Centre for Catalysis and Sustainable Chemistry, Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Organic Chemistry
Authors: Riisager, A. (Intern), Ståhlberg, T. J. B. (Intern), Fu, W. (Intern), Woodley, J. (Intern), Fristrup, P. (Intern)
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Kinetics of acetic acid synthesis from ethanol over a Cu/SiO2 catalyst

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Organisations: Department of Chemical and Biochemical Engineering, CHEC Research Centre, Center for Process Engineering and Technology
Authors: Voss, B. (Intern), Schjødt, N. (Ekstern), Grunwaldt, J. (Intern), Andersen, S. (Ekstern), Woodley, J. (Intern)
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Managing biocatalytic productivity

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Measuring the eco-efficiency of bioprocesses

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Metrics for environmental evaluation of biocatalytic processes

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Authors: Lima Ramos, J. (Intern), Tufvesson, J. (Ekstern), Tufvesson, P. (Intern), Woodley, J. (Intern)
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Multi-enzyme Process Modeling
The subject of this thesis is to develop a methodological framework that can systematically guide mathematical model building for better understanding of multi-enzyme processes. In this way, opportunities for process improvements can be identified by analyzing simulations of either existing or potential process configurations operated under different conditions. In these cases, process engineering, enzyme immobilization and protein engineering are presented as fields that can offer feasible solutions for better process configurations or biocatalyst modification to enhance actual process implementation, especially at an industrial level.
Multi-enzyme processes are characterized by a high degree of complexity due to the mixture of enzymes that catalyze
several reactions. Therefore, it is necessary to understand how enzymes act in a coordinated and interactive way, and also how enzymes are affected (in a positive or negative way) by the presence of the other enzymes and compounds in the media.

In this thesis the concept of multi-enzyme in-pot term is adopted for processes that are carried out by the combination of enzymes in a single reactor and implemented at pilot or industrial scale. In order to understand the difference between multi-enzyme processes, a number of concepts are discussed in the second chapter of this thesis and has also been published as a review. Furthermore, a classification of multi-enzyme processes is suggested to clarify the ambiguous definitions found in the scientific literature.

Reliable mathematical models of such multi-catalytic schemes can exploit the potential benefit of these processes. In this way, the best outcome of the process can be obtained understanding the types of modification that are required for process optimization. An effective evaluation of these processes is achieved by applying a methodological framework which provides a systematic way of modeling, a structure, guidance, documentation and support to the modeler.

The methodological framework developed here brings many benefits to multienzyme process modeling. This framework identifies generic features of the process and provides the information required to structure the process model by using a step-by-step procedure with the required tools and methods. In this way, this framework increases efficiency of the model development process with respect to time and resources needed (fast and effective model development). Furthermore, this methodology incorporates state-of-the-art methods and provides background and insight into their applications for model development purposes.

The methodological framework, which comprises five steps, is the main result of this thesis. The novel feature of this methodology is the emphasis on the multi-enzyme process concepts that is introduced in all steps. In this way, the most relevant and necessary modeling issues can be precisely identified in order to achieve reliable mathematical structures of the processes. In the same way, specific mathematical techniques, for model quality evaluation such as uncertainty and sensitivity analyses, are included in this methodology. Multienzyme process modeling is tremendously benefited with the introduction of these analyses which mark a big difference in the formulation of reliable models for the multi-enzyme processes. In this way the model parameters that drives the main dynamic behavior can be identified and thus a better understanding of this type of processes.

In order to develop, test and verify the methodology, three case studies were selected, specifically the bi-enzyme process for the production of lactobionic acid, the bi-enzyme process for the production of N-acetyl-D-neuraminic acid, and the tri-enzyme process for the production of 1-phenylethylamine. Furthermore, different capabilities of the methodology are developed due to the valuable contributions of each case study. In this way, the methodology was also proven to be useful for a fast model formulation of multi-enzyme processes. Additionally, programming codes were developed using MATLAB (The Mathworks, Natick, MA) which were also used as computational tools to support the implementation, solution and analysis of all the mathematical problems faced in the case studies.

General information
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Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Computer Aided Process Engineering Center
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Operation and Control of Enzymatic Biodiesel Production
This work explores the control of biodiesel production via an enzymatic catalyst. The process involves the transesterification of oils/fats with an alcohol (usually methanol or ethanol), using enzymatic catalysts to generate monoaoyl esters (the basis of biodiesel) and glycerol as by-product. Current literature indicates that enzymatic processing of oils and fats to produce biodiesel is technically feasible and developments in immobilization technology indicate that enzyme catalysts can become cost effective compared to chemical processing. However, with very few exceptions, enzyme technology is not currently used in commercial-scale biodiesel production. This is mainly due to non-optimized process designs, which do not use the full potential of the catalysts in a cost-efficient way. Furthermore it is unclear what process variables need to be monitored and controlled to ensure optimal economics. Critical to the project is to develop a control methodology to optimize the productivity of biodiesel production (e.g. the dosing of alcohol to minimize catalyst deactivation, minimization of waste and delivering consistent product quality meeting specifications). For production of biodiesel (BD) via an enzymatic route, batch operation is a straightforward and efficient means for producing BD with its
main disadvantage being the downtime between batches. For large-scale production of biodiesel, continuous operation is an attractive alternative as it enables efficient use of manpower and capital assets including equipment and raw materials. Currently our group is evaluating various process configurations for continuous BD production in packed bed reactors (PBRs), continuous stirred tank reactors (CSTRs) and a combination of the aforementioned reactors in series. These configurations will be reviewed to identify the process variables that need to be monitored and controlled.

**General information**
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Price, J. A. (Intern), Huusom, J. K. (Intern), Nordblad, M. (Intern), Woodley, J. (Intern)
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**Overcoming kinetic limitations in biocatalysis**

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Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Computer Aided Process Engineering Center
Authors: Al-Haque, N. (Intern), Tufvesson, P. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
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Event: Abstract from biocat 2012, Hamburg, Germany.
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**Overcoming kinetic limitations in biocatalysis**

**General information**
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Computer Aided Process Engineering Center
Authors: Al-Haque, N. (Intern), Tufvesson, P. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
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**Phenomena-based Process Synthesis and Design to achieve Process Intensification**

Process intensification (PI) has the potential to improve existing processes, necessary to achieve a more sustainable production. PI can be achieved at different levels. That is, the unit operations, functional and/or phenomena level. The highest impact is expected by looking at processes at the lowest level of aggregation: phenomena. Therefore, in this paper, a phenomena-based synthesis/design methodology is presented. Using this methodology, a systematic identification of necessary and desirable (integrated) phenomena as well as generation and screening of phenomena-based flowsheet options are made using a decomposition based solution approach. The developed methodology is highlighted through a case study involving the production of isopropyl-acetate.

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State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Computer Aided Process Engineering Center
Process considerations for protein engineering of ω-Transaminase

Over the past decades, the use of biocatalysis in the chemical and pharmaceutical industry has significantly increased. In parallel and contributing to this trend, many enzymes have been discovered and isolated from different biological sources. This has broadened the scope of biocatalysis and nowadays allows the green regio- and enantio-selective synthesis of many compounds, potentially with less time and energy demand and avoiding the use of toxic reagents. The technology therefore has many advantages over classical chemical synthesis to prepare fine chemical and pharmaceutical intermediates.

However, often wild type enzyme does not fit the requirements of the process conditions, where high substrate and product concentrations as well as high productivity demands of the catalyst (g product per g biocatalyst), are key to economic feasibility. The question thus arises whether to fit the process to the catalysat or the other way around. Modern biotechnology has indeed seen a tremendous development in the last decades which in fact makes it possible to improve many of the enzyme properties needed, such as, tolerance to pH and temperature, substrate and product inhibition and finally the enantio specificity (e.e). However, it is critical that this is done in parallel process development to make sure that the properties developed also fit the process requirements.

As an example, ω-transaminases (EC 2.6.1.18) can be used to produce optically pure chiral amines (with 100% theoretical yield) which are important building blocks for the chemical and pharmaceutical industries. On the other hand, there are a number of challenges associated with the use of this enzyme for instance substrate and product inhibition, and a potentially unfavorable equilibrium.

In the present work it was investigated how changes to a wild type transaminase through protein engineering changed the characteristics of the biocatalyst and the implications this would have on a process. A methodology for characterizing the biocatalyst was developed which was subsequently applied to the wild type and 5 mutants selected. It was seen that the mutants had a better tolerance to the substrate and to higher temperature as well as displaying a broader pH tolerance.

Based on the improved properties it could be shown that the feasibility of the process was significantly improved and that these properties opened up the potential for improvements in the process, such as operating at a higher pH for facilitated in-situ product removal.
Process Design and Evaluation for Chemicals Based on Renewable Resources

One of the key steps in process design is choosing between alternative technologies, especially for processes producing bulk and commodity chemicals. Recently, driven by the increasing oil prices and diminishing reserves, the production of bulk and commodity chemicals from renewable feedstocks has gained considerable interest. Renewable feedstocks usually cannot be converted into fuels and chemicals with existing process facilities due to the molecular functionality and variety of the most common renewable feedstock (biomass). Therefore new types of catalytic methods as well as new types of processes for converting renewable feedstocks to bulk and commodity chemicals are required. In the future, it seems increasingly likely that a combination of biocatalysts (in the form of enzymes) as well as chemical catalysts will be needed in the production of bulk chemicals from renewable feedstocks. In addition, another characteristic of chemicals based on renewable feedstocks is that many alternative technologies and possible routes exist, resulting in many possible process flowsheets. The challenge for process engineers is then to choose between possible process routes and alternative technologies as well as to match different catalyst conditions. These kinds of problems are crucial, especially at the early stages of process development, when information is limited. This thesis describes a methodological framework for dealing with the challenges and giving direction to research in the process development of chemicals based on renewable feedstocks. As an example, this thesis especially focuses on applying the methodology in process design and evaluation of the synthesis of 5-hydroxymethylfurfural (HMF) from the renewable feedstock glucose/fructose. The selected example is part of the chemoenzymatic process design of the synthesis 2,5-furandicarboxylic acid (FDA) from glucose.

By using the selected case study, the complexity and challenges for the process engineer to choose between different alternative routes and technologies as well as to combine two different kinds of catalysis (enzymatic catalysis and chemical catalysis) were illustrated. Different process routes for the synthesis of HMF from fructose in the literature have been analyzed and evaluated. Using an aqueous route for HMF production is not economically feasible due to the low reaction yield. Using an anhydrous solvent for HMF synthesis is associated with high energy consumption and difficulties with solvent recycle in a large-scale production. The synthesis of HMF from fructose using a biphasic route is found to be promising, cost effective and give a better chance to be integrated with chemo-enzymatic cascades for producing FDA from glucose. A process flowsheet using chemo-enzymatic cascades for HMF production from glucose has been proposed and evaluated. The process flowsheet is characterized by using glucose isomerase (EC 5.3.1.5) to convert glucose into fructose with a biphasic reaction for dehydration of fructose into HMF with recycle of the aqueous phase back to the enzymatic reaction. Costing analysis indicates the HMF production cost by the designed process is very sensitive to the dehydration reaction yield, the amount of solvent used in the whole process and the glucose price. In addition, increasing scale is also help to decrease the HMF production cost.

Using an ionic liquid (IL) route for HMF production has been evaluated with the dehydration reaction in [BMIm]Cl with different options starting from fructose and glucose with different initial concentrations. The HMF production cost is highly affected by the recycle of IL and catalyst. Processes with a high feed concentration show better economic potential than processes with a low feed concentration. IL processes starting from fructose are more costly than IL processes starting from glucose. A high concentration feed of glucose showed the best economic potential.

To sum up, the dehydration reaction yield is found to be the key important factor to achieve a feasible production cost of HMF. The use of the organic solvent can not be avoided and plays a very important role in determining the process economics. Recycling (unconverted sugar, reaction medium and solvent) become essential issues for HMF processes to reach a feasible production cost. Future directions and suggestions for the synthesis of HMF from sugar in a large-scale have been proposed. The developed methodology is helpful in evaluation and giving research directions. The methodology can be applied to other chemical process design and evaluation problems and in particular those for the next generation of production processes.

General information
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Process engineering for biocatalytic reactions and biotransformations

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Process engineering for transaminase-catalysed reactions

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Process engineering tools to guide implementation and scale-up of transaminase cascades

Biocatalysis is gaining ground in the pharmaceutical and fine chemical industry as a selective and potentially green technology to help synthesize industrially interesting products. In particular in the last decade the application of transaminases (E.C. 2.6.1.X ) has gained particular attention as a means to synthesize optically pure chiral amines from prochiral ketones using an amine donor. Chiral amines can also be synthesized by other routes but the importance of the compounds mean that a variety of routes will be required to cover the synthesis of many different chiral amines of different properties and values.

A major challenge in the transaminase catalysed synthesis of chiral amines is the unfavourable equilibrium position [1]. There are several solutions to such equilibrium problems, including the use of in-situ product removal (ISPR) and cascade reactions to degrade or recycle the co-product formed. Such techniques, especially those using cascades can be a great tool to overcome the thermodynamic hurdle, but also present some new challenges with respect to compatibility of reaction conditions, recycling of co-factors and last but not least, the added cost of the cascade system components [2].

In this lecture we will present several process engineering tools including the use of mathematical modelling, uncertainty and sensitivity analysis [3] as well as economic evaluation and defined experimental protocols to help evaluate the feasibility of new biocatalytic cascades. The concepts will be illustrated with data from transaminase catalysed syntheses we have been modelling and studying experimentally at DTU.

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Product Intensification of the Production of Di-Methyl Carbonate (DMC) Using a New Synthesis and Design Process Intensification Methodology Framework

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Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center, Center for Process Engineering and Technology, Technical University of Dortmund
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Process/Reactor Selection for Multistep Biocatalysis

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Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Center for BioProcess Engineering
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Process Synthesis, Design and Intensification: An Integrated Approach

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center, Center for Process Engineering and Technology, Carnegie Mellon University, Federal University of Uberlândia
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Publication date: 2012
Biocatalysis has attracted significant attention recently, mainly due to its high selectivity and potential benefits for sustainability. Applications can be found in biorefineries, turning biomass into energy and chemicals, and also for products in the food and pharmaceutical industries. However, most applications remain in the production of high-value fine chemicals, primarily because of the expense of introducing new technology. In particular, lipase-catalyzed synthesis has already achieved efficient operations for high-value products and more interesting now is to establish opportunities for low-value products. In order to guide the industrial implementation of immobilized-lipase catalyzed reactions, especially for high-volume low-value products, a methodological framework for dealing with the technical and scientific challenges and establishing an efficient process via targeted scale-down experimental work is described in this thesis. The methodology uses economic targets to test options characterized via a set of tools.

In order to validate the methodology, two processes based on immobilized lipase-catalysis have been studied: transesterification and esterification of vegetable oils for the production of biodiesel. The two processes are focused on the conversion of the two main components of vegetable oil materials, glyceride esters and free fatty acids respectively, into fatty acid alkyl esters. Although biodiesel is conventionally prepared via chemical-catalyzed transesterification of vegetable oils with methanol to produce fatty acid methyl esters (FAME), this work has been focused on the production of fatty acid ethyl esters (FAEE) with bioethanol due to the expected improved sustainability of this type of biodiesel.

A key reaction characteristic of the immobilized lipase-catalyzed transesterification is that it is a multi-phasic system. The by-product glycerol can potentially impose inhibitory effects on immobilized lipases and likewise the un-dissolved ethanol can inhibit the lipase. The options for addressing these issues can be used as the basis for selecting the biocatalyst and the reactor (e.g., a hydrophobic carrier for the immobilized lipase and the capabilities to provide sufficient mixing as well as stepwise/continuous feeding of ethanol to the reactor). An STR is efficient for batch operation while a PBR is efficient for a continuous production. An STR can more easily provide sufficient external mass transfer for a reaction, but will lead to more mechanical damage of the biocatalyst particles, than a PBR. A reactor combination of CSTR with PBR can couple the advantages of both, delivering an efficient continuous
process. The second case study (esterification) shares some similar process characteristics to the first case (e.g. the multi-phasic nature). However, instead of glycerol, water shows a great impact on the extent of reaction. The removal of water should therefore be feasible during the operation of the reactor, either intermittently or preferably in situ. Highly anhydrous reaction conditions and the smaller substrates for this reaction place particular requirements on the lipase.

In order to validate the established processes at a larger scale, both lipase-catalyzed transesterification and esterification developed in the lab-scale STRs have been carried out in pilot-scale STRs. Results in both scale STRs correlate well with respect to the biocatalyst performance and mechanical stability.

Once the technical and scientific challenges of the process have been addressed, it is of course important to evaluate its economic and environmental feasibility. To that end, process evaluation has been performed for six processes composed of transesterification and product purification for making ‘in-spec’ biodiesel and the conventional chemical process is taken as a benchmark for comparison. The optimal process is a process composed of lipase-catalyzed transesterification with ‘in-spec’ biodiesel product as output with less feedstock input and waste production and much saved energy from the absence of product purification.

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Process technology for multi-enzymatic reaction systems
In recent years, biocatalysis has started to provide an important green tool in synthetic organic chemistry. Currently, the idea of using multi-enzymatic systems for industrial production of chemical compounds becomes increasingly attractive. Recent examples demonstrate the potential of enzymatic synthesis and fermentation as an alternative to chemical-catalysis for the production of pharmaceuticals and fine chemicals. In particular, the use of multiple enzymes is of special interest. However, many challenges remain in the scale-up of a multi-enzymatic system. This review summarizes and discusses the technology options and strategies that are available for the development of multi-enzymatic processes. Some engineering tools, including kinetic models and operating windows, for developing and evaluating such processes are also introduced.

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PSE opportunities in biocatalytic process design and development

Biocatalysis (the use of one or more isolated enzymes in soluble or immobilized form, as well as enzymes contained within resting whole-cells) is a rapidly growing area of process technology. The introduction of biocatalysis presents new opportunities to develop 'green' synthetic routes to pharmaceuticals and other chemical products, since enzymes usually work in an aqueous solution and under mild conditions. Nevertheless the implementation of a biocatalytic reaction and the integration of a biocatalytic reaction into an otherwise chemical catalytic sequence is a complex task where PSE tools...
have a particularly important role to play. In this paper we will present a variety of PSE tools including computational fluid
dynamics (CFD), operating windows, kinetic modelling, economic analysis and environmental assessment to support the
development of economically viable biocatalytic processes.

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Tools for characterizing the whole-cell bio-oxidation of alkanes at microscale
This article describes the first reported microwell whole-cell bioconversion using a water immiscible substrate that matches
the specific activity and yield achieved in a 1.2 L stirred tank bioreactor. Maximum yields of 0.6 g/L total 1-dodecanol
achieved in 24 h compare favorably to 0.28 g/L total 1-dodecanol after 48 h obtained in a stirred tank reactor. Using the
microwell platform we present a rapid and systematic approach to identify the key bottlenecks in the bio-oxidation of long-
chain alkanes using Escherichia coli expressing the alkane hydroxylase (alkB) complex. The results indicate that mass
transfer rates limit productivity in the n-dodecane bio-oxidation system, rather than inherent enzyme activity. Furthermore,
substrate solubility, oxygen availability and glucose concentration act cooperatively to affect the amount of by-product,
dodecanoic acid. Optimizing these factors using response surface methodology enabled specific yields of 1-dodecanol to
increase eightfold and overoxidation to dodecanoic acid to be reduced from 95% to 55%. This resulted in specific activities
of 10.4 µmol/min/gdcw on n-dodecane; approximately 50% of the 21 µmol/min/gdcw obtained with n-octane. For the first
time, this in vivo rate difference is within the range reported for the purified enzyme. Finally, the results obtained also
provide strong evidence that the mechanism of E. coli interaction with alkanes is mainly via uptake of alkanes dissolved in
the aqueous phase rather than by direct cell–droplet contact.

General information
Tools to evaluate processes for oxidase-based biocatalysis

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Towards continuous enzyme-catalysed processes for the production of biodiesel
The application of lipases in the production of biodiesel can find several roles: in pretreating high FFA oils via esterification, transesterification for converting oil to biodiesel and polishing via esterification to ensure the product is within specification. In all these cases the potential size of the process plants, suggest that continuous operation would be highly beneficial due to the economies of scale. To investigate this, we have examined both oil pretreatment via esterification and biodiesel production via transesterification in batch stirred tank reactors (BSTRs), continuous stirred tank reactors (CSTRs) and continuous packed bed reactors (CPBRs). In addition comparisons have been made between the use of liquid enzyme (in CSTR and BSTR) and immobilized enzyme (in BSTR, CSTR and CPBR) in transesterification reactions. In this presentation an evaluation will be given of the alternative modes of operation based on experimental and modeled data from laboratory scale studies. Implications for scale-up will be discussed, together with guidelines for the implementation of continuous processes for enzymatic reactions.

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Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
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Towards systematic scale-up and development of biocatalytic processes

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Main Research Area: Technical/natural sciences

Wettability Improvement with Enzymes: Application to Enhanced Oil Recovery under Conditions of the North Sea Reservoirs

Enzymes are well-known biological agents and have been applied previously in petroleum industry. However, only recently they have been introduced into the field of enhanced oil recovery (EOR). Although initially reported results of the application of enzymes for EOR are quite positive and promising (Nasiri et al., 2009), working mechanisms are poorly known and understood. The main goal of the present work is to establish possible mechanisms in which enzymes may enhance oil recovery.

Improvement of the brine wettability of the rock and decrease of oil adhesion to it by addition of an enzyme is one of the possible mechanisms of enzymatic action. This mechanism has been investigated experimentally, by measurements of the contact angles between oil drops and enzyme solutions in brine on the mineral surfaces.

Fifteen enzyme samples belonging to different enzyme classes, such as esterases/lipases, carbohydrases, proteases and oxidoreductases, provided by Novozymes, have been investigated. Two commercial mixtures containing enzymes: Apollo-GreenZyme™ and EOR-ZYMAX™ have also been applied. The North Sea dead oil and the synthetic sea water were used as test fluids. Internal surface of a carbonate rock has been mimicked using calcite crystals.

Overall, the group of esterases/lipases has demonstrated the best performance in terms of wettability alteration. Particularly, a non-specific esterase product has been found to turn the mineral surfaces into non-adhesive state at concentrations of 0.1-0.5% wt. Proteases appear to be relatively ambiguous, while carbohydrases and oxidoreductases have the lowest potential for EOR in the light of the present experiments. Suggested mechanisms for wettability improvement for esterases/lipases are adsorption of enzymes onto the mineral and/or formation of additional interfacially active oil compounds. Application of the commercial product Apollo-GreenZyme™ has also resulted in positive wettability changes, but according to the observations the working mechanisms are different. In an attempt to assess validity of the proposed mechanisms, the reference experiments have been conducted with concentrated enzymes, enzyme product stabilizers, surfactant and protein.

Membrane Assisted Enzyme Fractionation

Purification of proteins is an increasingly important process for the biotechnology industry. Separation of the desired high value protein from other proteins produced by the cell is usually attempted using a combination of different chromatographic techniques. These techniques separate mixtures of proteins on the basis of their charge, degree of hydrophobicity, affinity or size. Adequate purity is often not achieved unless several purification steps are combined thereby increasing cost and reducing product yield. Conventional fractionation of proteins using ultrafiltration membranes is limited to the variation in size of the proteins and a reasonable separation factor can be observed only when the size difference is in the order of 10 or more. This is partly caused by concentration polarization and membrane fouling which hinders an effective separation of the proteins. Application of an electric field across the porous membrane has been demonstrated to be an effective way to reduce concentration polarization and membrane fouling. In addition, this technique can also be used to separate the proteins based on difference in charge, which to some extent overcome the
limitations of size difference. In this thesis, separations using crossflow electro-membrane filtration (EMF) of amino acids, bovine serum albumin (BSA) and industrial enzymes from Novozymes were performed. The main objective of this study was to investigate the technological feasibility of EMF in the application of industrial enzyme fractionation, such as removal of a side activity from the main enzyme activity. As a proof-of-concept, amino acids were used as model solution to test the feasibility of EMF in the application of amphoteric molecule separation. A single amino acid was used to illustrate the effect of an electric field on the transport of a charged amino acid; the mass transport can be enhanced or decreased enormously when an electric field is applied in the same direction with convective transport or opposite to the direction of convective transport. Water splitting caused by limiting current density situation was observed at polarity +UF-(anode at ultrafiltration membrane side) due to the depletion of ions in the permeate compartment. By applying the electric field in UF filtration, it was possible to uncouple the transport between the charged Glutamic acid (Glu) and neutral Leucine (Leu) due to the fact that mass transport of Glu was enormously decreased because of electrophoretic force and that of Leu was not affected. The separation performance can be tuned by choosing different combinations of current density and TMP. The highest selectivity value (Leu separation from Glu) was achieved at nearly 90 in the condition of 60 A/m² current density and TMP 0.3bar. The effect of electric field was also investigated and verified with EMF filtration of BSA solution. EMF filtration of BSA both with ultrafiltration (UF) membrane and more open microfiltration (MF) membrane was studied and compared with normal UF and MF filtration in terms of flux and transmission. It was found that the flux and BSA transmission can be well manipulated and predicted based on the knowledge of solution pH and the polarity of electric field. However, the membrane-protein and protein-protein interactions caused by electrostatic interactions have to be taken into account and should be considered for optimization purpose. Finally the separation experiments with a binary mixture of Lipase (LP) and Phospholipase (PLA) were performed. Results have shown that separation of LP (side activity) from PLA (main activity) which is not possible to achieve with normal MF has been successfully performed with EMF filtration using MF membrane. The highest selectivity value (LP separation from PL A) of around 5 was obtained when operating with EMF. The effects of feed concentration, solution pH, property of porous membrane TMP and electric field strength have been investigated in the EMF experiments. It has been found that the separation performance in terms of selectivity and Lipase purity in permeate was dependent on the feed concentration, solution pH and membrane properties. The effects of increasing electric field strength and TMP on the separation performance were very small in the investigated range. The mass transport of each enzyme can be well explained by the Extended-Nernst-Planck equation. Better separation was observed at lower feed concentration, higher solution pH in the investigated range and with a polysulfone (PS) MF membrane. It can be concluded that EMF has been successfully demonstrated for the separation of enzymes which normal pressure-driven membrane process could not achieve. However, in order to achieve better separation a holistic optimization procedure is needed for future work.

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A model-based framework for design of intensified enzyme-based processes
This thesis presents a generic and systematic model-based framework to design intensified enzyme-based processes. The development of the presented methodology was motivated by the needs of the bio-based industry for a more systematic approach to achieve intensification in its production plants without an excessive investment in experimental resources. Process intensification has recently gained a lot of attention since it is a holistic approach to design safer, cleaner, smaller, cheaper and more efficient processes. This dissertation proposes a methodological approach to achieve intensification in enzyme-based processes which have found significant application in the pharmaceutical, food, and renewable fuels sector. The framework uses model-based strategies for (bio)-chemical process design and optimization, including the use of a superstructure to generate all potential reaction(s)-separation(s) options according to a desired performance criteria and a generic mathematical model represented by the superstructure to derive the specific models corresponding to a specific process option. In principle, three methods of intensification of bioprocess are considered in this thesis: 1. enzymatic one-pot synthesis, where, for example, the combination of two enzymatic reactions in one single reactor is examined; 2. chemo-enzymatic one pot synthesis, where, for example, one enzymatic reaction and one alkaline catalytic reaction occur simultaneously in a single reactor; and 3. in-situ product recovery/removal (ISPR), where, for example, a separation step is integrated with the reaction step. Often, enzyme-based processes have limited productivity and yield, which may be due to the unfavorable reaction equilibrium, product inhibition to the enzyme and/or product...
recommendations are given under the consideration of the initial project objective. The results of the thesis, taking one
conclusions and suggested improvements listed. Eventually, with an outlook on some alternative process possibilities, my
partly oxidative dehydrogenation conditions, allowing for immense process improvements. Finally, the ethanol to acetic
model to the industrial pressure regime indicates a satisfactory activity. The Cu/SiO₂ catalyst is further able to withstand
support the establishment of an improved economic evaluation of the investigated process. Extrapolation of the derived
indicated by the comparison of the activity and XRPD analyses obtained for crushed and whole catalyst pellets. Empirical
angle. Several means of improving its activity are elucidated. For example an activity dependence on the Cu crystal size is
support, shows far higher robustness to process variations, but immediately exhibits a too low activity from an industrial
activation. This theory explains several phenomena observed for this catalyst. The Cu/SiO₂ catalyst, having an inert
compounds covering the catalytic surface, being catalysed by acidic alumina sites present during and after catalyst
through characterisation as well as activity, selectivity and stability studies in appropriately developed experimental set-
understanding of the catalytic behaviour of down-selected catalysts, Cu spinel (CuAl₂O₄) and Cu/SiO₂, is obtained
ethanol reserves in order to reduce the emission of CO₂ to the atmosphere. The replacement or supplementation of oil based
transportation fuels through biomass based conversions has already been implemented. The subject on chemical
production has received less attention. This thesis describes and evaluates the quest for an alternative conversion route, based on a biomass feedstock and employing a heterogeneous catalyst capable of converting the feedstock, to a value-added chemical. The project work to fulfil the above objective has been conducted with a multi-disciplinary approach ranging from fundamental catalyst research, through experiments, characterisation and process evaluation to market analysis. The motivation herein is sought in the assets of sustainable resource utilisation obtained for such a process and the hypothesis that process feasibility in comparison with the conventional synthesis gas based technologies may further be attainable, taking advantage of the conservation of chemical C-C bonds in biomass based feedstocks. With ethanol as one example of a biomass based feedstock, having retained one C-C bond originating from the biomass precursor, the aspects of utilising heterogeneous catalysis for its conversion to value added chemicals is investigated. Through a simple analysis of known, but not industrialised catalytic routes, the direct conversion of ethanol to acetic acid product is identified to show good perspectives. The nesting of a useful catalyst and an effective process is crucial to the potential of the overall process innovation. In a pre-screening study, a group of Cu based catalysts active in the conversion have been identified. Considering the freedom to operate, the prospects of process development are further identified through process calculations based on the experimental evidence attained, theory and the process elements described in literature (primarily patent-related). The protection of the process inventions made in relation to this is sought through the filing of three patent applications. The most important contributions of this thesis are reflected in the eventual conclusion that an ethanol to acetic acid process and a related catalyst, both subject to further development, are identified. The understanding of the catalytic behaviour of down-selected catalysts, Cu spinel (CuAl₂O₄) and Cu/SiO₂, is obtained through characterisation as well as activity, selectivity and stability studies in appropriately developed experimental set-ups. Through numerous characterisation analyses (XAFS, XRPD, SEM, TEM, TPR, carbon analysis etc.) the rapid deactivation of the Cu spinel catalyst may be concluded to be attributed to the formation of high molecular carbonaceous compounds covering the catalytic surface, being catalysed by acidic alumina sites present during and after catalyst activation. This theory explains several phenomena observed for this catalyst. The Cu/SiO₂ catalyst, having an inert support, shows far higher robustness to process variations, but immediately exhibits a too low activity from an industrial angle. Several means of improving its activity are elucidated. For example an activity dependence on the Cu crystal size is indicated by the comparison of the activity and XRPD analyses obtained for crushed and whole catalyst pellets. Empirical kinetic models, in good agreement with the experimental data obtained for the Cu/SiO₂ catalyst, are developed in order to support the establishment of an improved economic evaluation of the investigated process. Extrapolation of the derived model to the industrial pressure regime indicates a satisfactory activity. The Cu/SiO₂ catalyst is further able to withstand partly oxidative dehydrogenation conditions, allowing for immense process improvements. Finally, the ethanol to acetic acid process is put into a broader context, by reviewing the methods used in this work, the market influence on its fate, the conclusions and suggested improvements listed. Eventually, with an outlook on some alternative process possibilities, my recommendations are given under the consideration of the initial project objective. The results of the thesis, taking one
example of biomass conversion, show that the utilisation of biomass in the production of chemicals by heterogeneous catalysis is promising from a technical point of view. But risks of market price excursions dominated by fossil based chemicals further set a criterion of a solid economic margin. Therefore, under market considerations other alternatives are to be investigated. In addition to the technical conclusions it appears that a multi-disciplinary approach to process innovation is advantageous.

**General information**

State: Published
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**Achieving Process Intensification: A Phenomena-Based Synthesis/Design Methodology**

**General information**

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Authors: Lutze, P. (Intern), Babi, D. K. (Intern), Woodley, J. (Intern), Gani, R. (Intern)
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**A method of producing hydroxymethyfurfural**

The present invention relates to a method of producing 5-hydroxymethylfurfural by dehydration of fructose and/or glucose and/or mannose.

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Organisations: Department of Chemistry, Centre for Catalysis and Sustainable Chemistry, Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
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An Innovative Synthesis Methodology for Process Intensification

Process intensification (PI) has the potential to improve existing processes or create new process options, which are needed in order to produce products using more sustainable methods. A variety of intensified equipment has been developed which potentially creates a large number of options to improve a process. However, to date only a limited number have achieved implementation in industry, such as reactive distillation, dividing wall columns and reverse flow reactors. A reason for this is that the identification of the best PI option is neither simple nor systematic. That is to decide where and how the process should be intensified for the biggest improvement. Until now, most PI has been selected based on case-based trial-and-error procedures, not comparing different PI options on a quantitative basis.

Therefore, the objective of this PhD project is to develop a systematic synthesis/design methodology to achieve PI. It allows the quick identification of the best PI option on a quantitative basis and will push the implementation and acceptance of PI in industry. Such a methodology should be able to handle a large number of options. The method of solution should be efficient, robust and reliable using a well-defined screening procedure. It should be able to use already existing PI equipment as well as to generate novel PI equipment.

This PhD-project succeeded in developing such a synthesis/design methodology. In order to manage the complexities involved, the methodology employs a decomposition-based solution approach. Starting from an analysis of existing processes, the methodology generates a set of PI process options. Subsequently, the initial search space is reduced through an ordered sequence of steps. As the search space decreases, more process details are added, increasing the complexity of the mathematical problem but decreasing its size. The best PI options are ordered in terms of a performance index and a related set are verified through detailed process simulation. Two building blocks can be used for the synthesis/design which is PI unit-operations as well as phenomena. The use of PI unit-operations as building block aims to allow a quicker implementation/retrofit of processes while phenomena as building blocks enable the ability to develop novel process solutions beyond those currently in existence. Implementation of this methodology requires the use of a number of methods/algorithms, models, databases, etc., in the different steps which have been developed. PI unit-operations are stored and retrieved from a knowledge-base tool. Phenomena are stored and retrieved from a phenomena library.

The PI synthesis/design methodology has been tested for both building blocks on a number of case studies from different areas such as conventional and bio-based bulk chemicals as well as pharmaceuticals.
A retrofit strategy to achieve "Fast, Flexible, Future (F3)" pharmaceutical production processes

In the work reported here, a substrates adoption methodology for a series of similar substrates has been developed as part of a retrofit strategy. The objective is to achieve "fast, flexible and future" pharmaceutical production processes by adapting a generic modular process-plant template. Application of the methodology is illustrated through a case study from the pharmaceutical industry. Use of computer-aided models, methods and tools as part of the methodology is also highlighted.

General information
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A retrofit strategy to achieve "Fast, Flexible, Future (F3)" pharmaceutical production processes

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A systematic synthesis and design methodology to achieve process intensification in (bio) chemical processes

Process intensification (PI) has the potential to improve existing processes or create new process options which are needed in order to produce products using more sustainable methods. Potentially, PI creates an enormous number of process options. For identification where and how the process should be intensified for biggest improvement, process synthesis and design tools are applied which results in the development of a systematic methodology incorporating PI. In order to manage the complexity of PI process options in which a feasible and optimal process solution may exist, the solution procedure of this methodology is based on the decomposition approach. Starting from an analysis of existing processes, this methodology generates a set of feasible process options and reduces their number through several screening steps until from the remaining feasible options, the optimal is found. In this presentation, the application of the computer-aided systematic synthesis and design methodology is highlighted via a case study which is the chemo-enzymatic synthesis of N-acetyl-D-neuraminic acid (Neu5Ac)).

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Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Lutze, P. (Intern), Woodley, J. (Intern), Gani, R. (Intern)
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Cascade systems in ω-transaminase reactions

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Organisations: Department of Chemical and Biochemical Engineering
Authors: Janes, K. (Intern), Gernaey, K. (Intern), Tufvesson, P. (Intern), Woodley, J. (Intern)
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Chemo-enzymatic epoxidation—process options for improving biocatalytic productivity
The reactor choice is crucial when designing a process where inactivation of the biocatalyst is a problem. The main bottleneck for the chemo-enzymatic epoxidation has been found to be enzyme inactivation by the hydrogen peroxide, H2O2, substrate. In the work reported here, the effect of reaction parameters on the reaction performance have been
investigated and used to establish suitable operating strategies to minimize the inactivation of the enzyme, using rapeseed methyl ester (RME) as a substrate in a solvent-free system. The use of a controlled fed-batch reactor for maintaining H2O2 concentration at 1.5 M resulted in increased productivity, up to 76 grams of product per gram of biocatalyst with higher retention of enzyme activity. Further investigation included a multistage design that separated the enzymatic reaction and the saturation of the RME substrate with H2O2 into different vessels. This setup showed that the reaction rate as well as enzyme inactivation is strongly dependent on the H2O2 concentration. A 20-fold improvement in enzymatic efficiency is required for reaching an economically feasible process. This will require a combination of enzyme modification and careful process design. © 2010 American Institute of Chemical Engineers Biotechnol. Prog., 2011
Design and analysis of membrane based process intensification and hybrid processing options

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Organisations: Computer Aided Process Engineering Center, Department of Chemical and Biochemical Engineering
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Design of an Optimal Biorefinery
In this paper we propose a biorefinery optimization model that can be used to find the optimal processing route for the production of ethanol, butanol, succinic acid and blends of these chemicals with fossil fuel based gasoline. The approach unites transshipment models with a superstructure, resulting in a Mixed Integer Non-Linear Program (MINLP). We consider a specific problem based on a network of 72 processing steps (including different pretreatment steps, hydrolysis, fermentation, different separations and fuel blending steps) that can be used to process two different types of feedstock. Numerical results are presented for four different optimization objectives (maximize yield, minimize costs, minimize waste and minimum fixed cost), while evaluating different cases (single product and multi-product).

General information
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Design of an Optimal Biorefinery

In this paper we propose a biorefinery optimization model that can be used to find the optimal processing route for the production of ethanol, butanol, succinic acid and blends of these chemicals with fossil fuel based gasoline. The approach unites transshipment models with a superstructure, resulting in a Mixed Integer Non-Linear Program (MINLP). We consider a specific problem based on a network of 72 processing steps (including different pretreatment steps, hydrolysis, fermentation, different separations and fuel blending steps) that can be used to process two different types of feedstock. Numerical results are presented for four different optimization objectives (maximize yield, minimize costs, minimize waste and minimum fixed cost), while evaluating different cases (single product and multi-product).

Design of tailor-made chemical blend using a decomposition-based computer-aided approach

Computer aided techniques form an efficient approach to solve chemical product design problems such as the design of blended liquid products (chemical blending). In chemical blending, one tries to find the best candidate, which satisfies the product targets defined in terms of desired product attributes (properties). The systematic computer-aided technique first establishes the search space, and then narrows it down in subsequent steps until a small number of feasible and promising candidates remain. At this point, experimental work may be conducted to verify if any or all the candidates satisfy the desired product attributes. Alternatively, rigorous modeling could also be used in this final step. In other words, the candidates are quickly generated and screened until a small number is left for final selection and evaluation by experiments and/or rigorous modeling. This paper presents a design methodology for blended liquid products that identifies a set of feasible chemical blends. The blend design problem is formulated as a Mixed Integer Nonlinear Programming (MINLP) model where the objective is to find the optimal blended gasoline or diesel product subject to types of chemicals and their compositions and a set of desired target properties of the blended product as design constraints. This blend design problem is solved using a decomposition approach, which eliminates infeasible and/or redundant candidates gradually through a hierarchy of (property) model based constraints. This decomposition method reduces the search space in a systematic manner and the general blend design problem is decomposed into two stages. The first stage investigates the mixture stability where all unstable mixtures are eliminated and the stable blend candidates are retained for further testing (note that all blends must be stable liquid mixture). In the second stage, the blend candidates have to satisfy a set of target properties that are ranked according to a specified priority. Finally, a short list of candidates, ordered in terms of specified performance criteria, is produced for final testing and selection. The application of this systematic and computer-aided approach is illustrated through a case study involving the design of blends of gasoline with oxygenated compounds resulting from degradation and fermentation of biomass for use in internal combustion engines. Emphasis is given here on the concepts used and on the validation of the property models, mainly, the Reid vapor pressure model and the liquid phase stability tests.
Directed evolution of a thermostable l-aminoacylase biocatalyst

Enzymes from extreme environments possess highly desirable traits of activity and stability for application under process conditions. One such example is l-aminoacylase (E.C. 3.5.1.14) from Thermococcus litoralis (TliACY), which catalyzes the enantioselective amide hydrolysis of N-protected l-amino acids, useful for resolving racemic mixtures in the preparation of chiral intermediates. Variants of this enzyme with improved activity and altered substrate preference are highly desirable. We have created a structural homology model of the enzyme and applied various two different directed evolution strategies to identify improved variants. Mutants P237S and F251Y were 2.4-fold more active towards N-benzoyl valine relative to the wild type at 65°C. F251 mutations to basic residues resulted in 4.5–11-fold shifts in the substrate preference towards N-benzoyl phenylalanine relative to N-benzoyl valine. The substrate preference of wild type decreases with increasingly branched and sterically hindered substrates. However, the mutant S100T/M106K disrupted this simple trend by selectively improving the substrate preference for N-benzoyl valine, with a >30-fold shift in the ratio of kcat values for N-benzoyl valine and N-benzoyl phenylalanine. Mutations that favoured N-benzoyl-phenylalanine appeared at the active site entrance, whereas those improving activity towards N-benzoyl-valine occurred in the hinge region loops linking the dimerization and zinc-binding domains in each monomer. These observations support a previously proposed substrate induced conformational transition between open and closed forms of aminoacylases.
Electro-membrane filtration: An Alternative Way to Fractionate Industrial Enzymes

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Guidelines and cost analysis for catalyst production in biocatalytic processes
Biocatalysis is an emerging area of technology, and to date few reports have documented the economics of such processes. As it is a relatively new technology, many processes do not immediately fulfill the economic requirements for commercial operation. Hence, early-stage economic assessment could be a powerful tool to guide research and development activities in order to achieve commercial potential. This study discusses the cost contribution of the biocatalyst in processes that use isolated enzymes, immobilized enzymes, or whole cells to catalyze reactions leading to the production of chemicals. A methodology for rapidly estimating the production cost of the biocatalyst is presented, and examples of how the cost of the biocatalyst is affected by different parameters are given. In particular, it is seen that the fermentation yield in terms of final achievable cell concentration and expression level as well as the production scale are crucial for decreasing the total cost contribution of the biocatalyst. Moreover, it is clear that, based on initial process performance, the potential to reduce production costs by several orders of magnitude is possible. Guideline minimum productivities for a feasible process are suggested for different types of processes and products, based on typical values of biocatalyst and product costs. Such guidelines are dependent on the format of the biocatalyst (whole-cell, soluble enzyme, immobilized enzyme), as well as product market size and value. For example commodity chemicals require productivities in the range 2000–10000 kg product/kg immobilized enzyme, while pharmaceutical products only require productivities around 50–100 kg product/kg immobilized enzyme.

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In situ visualization and effect of glycerol in lipase-catalyzed ethanolation of rapeseed oil

Immobilized lipases can be used in biodiesel production to overcome many disadvantages of the conventional base-catalyzed process. However, the glycerol by-product poses a potential problem for the biocatalytic process as it is known to inhibit immobilized lipases, most likely by clogging of the catalyst particles. In this paper, this negative effect was further investigated and confirmed in ethanolation of rapeseed oil. A dyeing method was developed for in situ visualization of glycerol in order to study its partitioning and accumulation during the ethanolation reaction. The method was used to illustrate the interaction of glycerol with immobilized lipases and thus provided an aid for screening supports for lipase immobilization according to their interaction with glycerol. Glycerol was found to have great affinity for silica, less for polystyrene and no affinity for supports made from polymethylmethacrylate and polypropylene. It was also found that the immobilization of enzyme on the support influenced the adsorption of glycerol to the surface of the enzyme carrier.
Ionic liquid Catalysis for Upgrading Biomass to Value-added Chemicals

General information
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Organisations: Department of Chemistry, Centre for Catalysis and Sustainable Chemistry, Organic Chemistry, Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Riisager, A. (Intern), Ståhlberg, T. J. B. (Intern), Shunmugavel, S. (Intern), Fristrup, P. (Intern), Fu, W. (Intern), Woodley, J. (Intern)
Publication date: 2011
Main Research Area: Technical/natural sciences
Publication: Journal article – Annual report year: 2011

Kinetics of acetic acid synthesis from ethanol over a Cu/SiO2 catalyst
The dehydrogenation of ethanol via acetaldehyde for the synthesis of acetic acid over a Cu based catalyst in a new process is reported. Specifically, we have studied a Cu on SiO2 catalyst which has shown very high selectivity to acetic acid via acetaldehyde compared to competing condensation routes. The dehydrogenation experiments were carried out in a flow through lab scale tubular reactor. Based on 71 data sets a power law kinetic expression has been derived for the description of the dehydrogenation of acetaldehyde to acetic acid. The apparent reaction order was 0.89 with respect to water and 0.45 with respect to acetaldehyde, and the apparent activation energy was 33.8kJ/mol. The proposed oxidation of acetaldehyde with hydroxyl in the elementary rate determining step is consistent with these both. Density Functional Theory (DFT) calculations show the preference of water cleavage at the Cu step sites. In light of this, an observed intrinsic activity difference between whole catalyst pellets and crushed pellets may be explained by the Cu crystal size and growth.
rate being functions of the catalyst particle size and time.

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Organisations: Department of Chemical and Biochemical Engineering, Haldor Topsoe AS, Karlsruhe Institute of Technology KIT
Authors: Voss, B. (Ekstern), Schjødt, N. C. (Ekstern), Grunwaldt, J. (Ekstern), Andersen, S. I. (Ekstern), Woodley, J. (Intern)
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Methodological Approach for Modeling of Multienzyme in-pot Processes

This paper presents a methodological approach for modeling multi-enzyme in-pot processes. The methodology is exemplified stepwise through the bi-enzymatic production of N-acetyl-D-neuraminic acid (Neu5Ac) from N-acetyl-D-glucosamine (GlcNAc). In this case study, sensitivity analysis is also used to evaluate the reliability of all parameters of the model suggested in literature [5]. Results, from the sensitivity analysis, are used as criteria for a systematic simplification of the model structure. Consequently, model complexity was reduced without compromising the general predictive performance. A deviation of less than 5% from the original model was found.

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Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Andrade Santacoloma, P. D. G. (Intern), Roman Martinez, A. (Intern), Sin, G. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern)
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Methodological Approach for Modeling of Multienzyme in-pot Processes

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Microfluidic enzymatic reactors using ω-transaminases

General information
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Organisations: Department of Chemical and Biochemical Engineering
Authors: Bodla, V. K. (Intern), Krühne, U. (Intern), Woodley, J. (Intern), Gernaey, K. (Intern)
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Event: Abstract from Biotrans 2011, Giardini Naxos, Italy.
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Modeling framework for multi-enzyme in-pot processes applied in amine production

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Authors: Andrade Santacoloma, P. D. G. (Intern), Sin, G. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern)
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Multi-enzyme catalyzed processes: Next generation biocatalysis
Biocatalysis has been attracting increasing interest in recent years. Nevertheless, most studies concerning biocatalysis have been carried out using single enzymes (soluble or immobilized). Currently, multiple enzyme mixtures are attractive for the production of many compounds at an industrial level. In this review, a classification of multienzyme-catalyzed processes is proposed. Special emphasis is placed on the description of multienzyme ex-vivo systems where several reactions are carried out by a combination of enzymes acting outside the cell. Furthermore, reaction and process considerations for mathematical modeling are discussed for the specific case where the synthetic reactions are carried out in a single reactor, the so-called multienzyme ‘in-pot’ process. In addition, options for multienzyme ‘in-pot’ process improvements via process engineering and enzyme immobilization technology are described. Finally, enzyme modification via protein engineering is also discussed, such that a better compatibility of the enzymes in the reactor is achieved as a means of assisting the implementation of multienzyme ‘in-pot’ processes.

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Authors: Andrade Santacoloma, P. D. G. (Intern), Sin, G. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern)
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Operating windows for transaminase processes using thermodynamic and biocatalyst constraints

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering
Authors: Tufvesson, P. (Intern), Lima Ramos, J. (Intern), Jensen, J. S. (Intern), Woodley, J. (Intern)
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Optimal design of a multi-product biorefinery system

In this paper we propose a biorefinery optimization model that can be used to find the optimal processing route for the production of ethanol, butanol, succinic acid and blends of these chemicals with fossil fuel based gasoline. The approach unites transshipment models with a superstructure, resulting in a Mixed Integer Non-Linear Program (MINLP). We consider a specific problem based on a network of 72 processing steps (including different pretreatment steps, hydrolysis, fermentation, different separations and fuel blending steps) that can be used to process two different types of feedstock. Numerical results are presented for four different optimization objectives (maximize yield, minimize costs, minimize waste and minimum fixed cost), while evaluating different cases (single product and multi-product).
In order to improve processes incorporating process intensification and to allow them to go beyond pre-defined unit operations, the process has to be viewed at a lower level of aggregation, namely the phenomena scale. In this contribution, an approach for aggregating processes through phenomena building blocks in a systematic methodology is presented. First, all potential phenomena are identified, and then synthesized to phenomena-based flowsheets which are then screened against pre-defined constraints before the most promising options are identified, optimized and verified at the unit operation level. This phenomena-based synthesis/design methodology is tested through a case study.
Phenomena-Based Process Synthesis and Design to Achieve Process Intensification

In recent years, Process Intensification (PI) has attracted considerable interest as a potential means of process improvements and to meet the increasing demands for sustainable production. PI aims to improve processes by increasing efficiency, reducing energy consumption, operational costs, volume, and waste as well as simplifying the flowsheet. A variety of intensified operations and equipment has been developed. Potentially, this creates a large number of options for possible process improvement, however, to date only a limited number of intensified technologies have achieved implementation, such as reactive distillation, dividing wall columns and reverse flow reactors [1]. One major reason for this is that the identification of the best PI option is neither simple nor systematic. In previous work [2] we reported the development of a general computer-aided systematic synthesis and design methodology in which redundant intensified options are systematically removed by checking against predefined constraints through a decomposition approach of a superstructure optimization problem. In this approach lower level steps employ simple and easy calculations, while the higher level steps employ more rigorous and detailed calculations. However, up to now, this methodology is limited to already reported PI unit operations which can be retrieved, together with all information necessary for synthesis and design of each of them, from a knowledge base tool. In order to invent new unit operations going beyond those currently in existence, process synthesis and design incorporating PI needs to be investigated at the phenomenological level [3, 4] which will be presented in this contribution. The basis of the phenomena-based process synthesis is transfer units consisting of mass, component, energy and momentum balances as well as phenomena building blocks and model equations describing them. Following the same rationale as the general methodology described previously, the problem is first defined, given a set of product quality and quantity as well as additional process constraints in addition to the potential need for the improvement. Next, the given information is analyzed to identify all potential phenomena building blocks. In the next step, the phenomena building blocks are joined together according to combination rules to match process intensification targets defined through a superstructure of flowsheet options. Based on these, the generated options are screened through performance specifications before unit operations are identified. For example, a counter-current sequence of similar simultaneous mixing and vapour-liquid phenomena with the final steps at both ends being simultaneous heat transfer, mixing and vapour-liquid phase change phenomena can be identified as a distillation column. In the penultimate step, the remaining options are optimized with respect to a defined objective function. The results are verified through rigorous model simulations in the final step. The advantage of the phenomena-based process synthesis and design is that it generates potentially novel process options because the initial search space is wider than the search space of existing units (truly predictive models lead to reliable predictive solutions) as well as the simultaneous development of the necessary process models. In this contribution the application of a phenomena-based process synthesis combined with a systematic methodology through a computer-aided framework will be described and highlighted with selected examples in the area of distillation systems, together with a focus on some of the suitable methods and tools.
Process considerations and economic evaluation of biocatalytic production of chiral amines using transaminases

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State: Published
Organisations: Department of Chemical and Biochemical Engineering
Authors: Lima Ramos, J. (Intern), Tufvesson, P. (Intern), Woodley, J. (Intern)
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Event: Poster session presented at 8th European Congress of Chemical Engineering, Berlin, Germany.
Main Research Area: Technical/natural sciences

Economic evaluations are crucial for ensuring the cost-effectiveness of any production process, and biocatalytic transamination is being established as a key tool for the production of chiral amine pharmaceuticals and precursors due to its excellent enantioselectivity as well as green credentials. Recent examples demonstrate the potential for developing economically competitive processes using a combination of modern biotechnological tools for improving the biocatalyst alongside using process engineering and integrated separation techniques for improving productivities. However, many challenges remain in order for the technology to be more widely applicable, such as technologies for obtaining high yields and productivities when the equilibrium of the desired reaction is unfavorable. This review summarizes both the process challenges and the strategies used to overcome them, and endeavors to describe these and explain their applicability based on physicochemical principles. This article also points to the interaction between the solutions and the need for a process development strategy based on fundamental principles.

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Scopus rating (2013): SJR 1.621 SNIP 1.425 CiteScore 4.44
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Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.639 SNIP 1.366 CiteScore 4.04
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Recent advances in biocatalysis have seen increased interest in the use of D-amino acid oxidase to synthesize optically pure amino acids. However, the creation of a genuine oxidase based platform technology will require suitable process technology as well as an understanding of the challenges and opportunities of a wider portfolio of synthetic targets. In this article we address some of the recent progress in process technology to enable the future development of a generic platform technology.
PSE in pharmaceutical process development

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering
Authors: Gernaey, K. (Intern), Cervera Padrell, A. E. (Intern), Woodley, J. (Intern)
Publication date: 2011
PSE in Pharmaceutical Process Development
The pharmaceutical industry is under growing pressure to increase efficiency, both in production and in process development. This paper will discuss the use of Process Systems Engineering (PSE) methods in pharmaceutical process development, and searches for answers to questions such as: Which PSE methods can be applied readily? Where is more method development needed? The paper is illustrated with a series of short examples taken from the literature and ongoing research projects.

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Reactor selection for multi-enzymatic processes

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Organisations: Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering
Authors: Xue, R. (Intern), Mikkelsen, J. D. (Intern), Meyer, A. S. (Intern), Woodley, J. (Intern)
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Substrate Inhibition in ω-transaminase Catalyzed Reaction

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Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Computer Aided Process Engineering Center
Authors: Al-Haque, N. (Intern), Tufvesson, P. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Publication date: 2011
Event: Abstract from Biotrans 2011, Giardini Naxos, Italy.
**Substrates adoption methodology (SAM) to achieve "Fast, Flexible, Future (F3)" pharmaceutical production processes**

There is a significant cost associated with process development of a portfolio of pharmaceutical products, few of which will reach the market. Continuous processing will increase the "chemical space" which can increase development efficiency. For example one, particularly attractive option is to develop manufacturing processes based on modular continuous systems; a flexible generic continuous modular plant which can be adapted for different substrates. In the work reported here, a substrates adoption methodology (SAM) has been developed. The proposed SAM identifies the necessary changes to a template recipe & flowsheet in order to adapt it for a given substrate. The changes can be related to reagents (e.g. reducing agent, solvent, catalyst), process conditions (e.g. operating temperature, flow rates), as well as in the physical arrangement (configuration) of the modular process equipment within the template. In this way the substrates adoption methodology helps to achieve "fast, flexible, future (F3)" pharmaceutical production processes by adapting a recently designed generic modular process-plant. The supporting tools for the substrate adoption are: (1) an ontological knowledge-base consisting of the properties of substances, reaction characteristics and characteristics of unit operations; and (2) a model library consisting of the mathematical models. The objective of this presentation is two-fold: First to highlight the substrates adoption framework and the associated models, methods and tools, and second to demonstrate its applications using a pharmaceutical manufacturing case study involving the nitro reduction of 2-Nitro-4'-chlorodiphenylamine.

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Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center, AstraZeneca
Authors: Singh, R. (Intern), Rozada-Sanchez, R. (Ekstern), Wrate, T. (Ekstern), Muller, F. (Ekstern), Gernaey, K. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
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**Synthesis of 5-(hydroxymethyl)furfural in Ionic Liquids - Paving the Way to Renewable Chemicals**

The synthesis of 5-(hydroxymethyl)furfural (HMF) in ionic liquids is a field that has grown rapidly in recent years. Unique dissolving properties for crude biomass in combination with a high selectivity for HMF formation from hexose sugars make ionic liquids attractive reaction media for the production of chemicals from renewable resources. A wide range of new catalytic systems that are unique for the transformation of glucose and fructose to HMF in ionic liquids has been found. However, literature examples of scale-up and process development are still scarce, and future research needs to complement the new chemistry with studies on larger scales in order to find economically and environmentally feasible processes for HMF production in ionic liquids. This Minireview surveys important progress made in catalyst development for the synthesis of HMF in ionic liquids, and proposes future research directions in process technology.

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Organisations: Department of Chemistry, Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Centre for Catalysis and Sustainable Chemistry
Authors: Ståhlberg, T. (Intern), Fu, W. (Intern), Woodley, J. (Intern), Riisager, A. (Intern)
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Tailor-made Design of Chemical Blends using Decomposition-based Computer-aided Approach

Computer aided technique is an efficient approach to solve chemical product design problems such as design of blended liquid products (chemical blending). In chemical blending, one tries to find the best candidate, which satisfies the product targets defined in terms of desired product attributes (properties). In this way, first the systematic computer-aided technique establishes the search space, and then narrows it down in subsequent steps until a small number of feasible and promising candidates remain and then experimental work may be conducted to verify if any or all the candidates satisfy the desired product attributes. Alternatively, rigorous modelling could also be used in this final step. In other words, the candidates are quickly generated and screened until a small number is left for final selection and evaluation by experiment and/or rigorous modelling. This paper presents a design methodology for blended liquid products that identifies a set of feasible chemical blends. The blend design problem is formulated as a nonlinear programming (NLP) model where the objective is to find the optimal blended gasoline or diesel product subject to blend chemicals and their compositions, a set of desired properties of the product as design constraints. The blend design problem is solved using a decomposition approach, which eliminates infeasible and/or redundant candidates gradually. The decomposition method
reduces the search space in a systematic way. This general blend design problem is decomposed into two stages. The first stage investigates the mixture stability where all unstable mixtures are eliminated and the stable blend candidates are retained for further testing. In the second stage, the blend candidates have to satisfy a set of target properties that are ranked according to a specified priority. Finally, a short list of candidates, ordered in terms of specified performance criteria, is produced for final testing and selection. This systematic and computer-aided approach is illustrated through a case study involving the design of blends of gasoline with oxygenates from biomass for use in internal combustion engines. The blend design formulation is able to find the optimal blend candidate.

Whole-cell bio-oxidation of n-dodecane using the alkane hydroxylase system of P. putida GPo1 expressed in E. coli
The alkane-1-monoxygenase (alkB) complex of Pseudomonas putida GPo1 has been extensively studied in the past and shown to be capable of oxidising aliphatic C5–C12 alkanes to primary alcohols both in the wild-type organism by growth on C5–C12 alkanes as sole carbon source and in vitro. Despite this, successful n-dodecane oxidation for the production of 1-dodecanol or dodecanolic acid has proven elusive in the past when using alkB-expressing recombinants. This article demonstrates, for the first time in vivo, by using the Escherichia coli GEC137 pGEc47ΔJ strain, that n-dodecane oxidation using this enzyme for the production of primary alcohols and carboxylic acids is feasible and in fact potentially more promising than n-octane oxidation due to lower product and substrate toxicity. Yields are reported of 1-dodecanol of up to 2g/Lorganic and dodecanoic acid up to 19.7g/Lorganic in a 2L stirred tank reactor with 1L aqueous phase and 200mL of n-dodecane as a second phase. The maximum volumetric rate of combined alcohol and acid production achieved was 1.9g/Lorganic/h (0.35g/Ltotal/h). The maximum specific activity of combined alcohol and acid production was 7-fold lower on n-dodecane (3.5μmol/min/gdcw) than on n-octane (21μmol/min/gdcw); similar to the 5-fold difference observed between wild-type growth rates using the two respective alkanes as sole carbon source. Despite this, both total volumetric rate and final yield exceeded n-octane oxidation by 3.5-fold under the same conditions, due to the lower toxicity of n-dodecane and its oxidation products to E. coli compared to the 8-carbon equivalents. Substrate access limitations and the overoxidation of 1-dodecanol to dodecanolic acid were identified as the most important limitations to be addressed.
A Model-Based Methodology for Simultaneous Design and Control of a Bioethanol Production Process

In this work, a framework for the simultaneous solution of design and control problems is presented. Within this framework, two methodologies are presented, the integrated process design and controller design (IPDC) methodology and the process-group contribution (PGC) methodology. The concepts of attainable region (AR), driving force (DF), process-group (PG) and reverse simulation are used within these methodologies. The IPDC methodology is used to find the optimal design-control strategy of a process by locating the maximum point in the AR and DF diagrams for reactor and separator, respectively. The PGC methodology is used to generate more efficient separation designs in terms of energy consumption by targeting the separation task at the largest DF. Both methodologies are highlighted through the application of two case studies, a bioethanol production process and a succinic acid production process. In the final discussion, the results are put in context.
A Multidisciplinary Approach Toward the Rapid and Preparative-Scale Biocatalytic Synthesis of Chiral Amino Alcohols: A Concise Transketolase-/ω-Transaminase-Mediated Synthesis of (2S,3S)-2-Aminopentane-1,3-diol

Chiral amino alcohols represent an important class of value-added biochemicals and pharmaceutical intermediates. Chemical routes to such compounds are generally step intensive, requiring environmentally unfriendly catalysts and solvents. This work describes a multidisciplinary approach to the rapid establishment of biocatalytic routes to chiral aminodiolis taking the original synthesis of (2S,3S)-2-aminopentane-1,3-diol as a specific example. An engineered variant of Escherichia coli transketolase (D469T) was used for the initial asymmetric synthesis of (3S)-1,3-dihydroxypentan-2-one from the achiral substrates propanal and hydroxypyruvate. A bioinformatics led strategy was then used to identify and clone an ω-transaminase from Chromobacterium violaceum (DSM30191) capable of converting the product of the transketolase-catalysed step to the required (2S,3S)-2-aminopentane-1,3-diol using isopropylamine as an inexpensive amine donor. Experiments to characterize, optimize and model the kinetics of each reaction step were performed at the 1 mL scale using previously established automated microwell processing techniques. The microwell results provided excellent predictions of the reaction kinetics when the bioconversions were subsequently scaled up to preparative scales in batch stirred-tank reactors. The microwell methods thus provide process chemists and engineers with a valuable tool for the rapid and early evaluation of potential synthetic strategies. Overall, this work describes a concise and efficient biocatalytic route to chiral amino alcohols and illustrates an integrated multidisciplinary approach to bioconversion process design and scale-up.

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Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Smith, M. (Ekstern), Chen, B. (Ekstern), Hibbert, E. (Ekstern), Kaulmann, U. (Ekstern), Smithies, K. (Ekstern), Galman, J. (Ekstern), Baganz, F. (Ekstern), Dalby, P. (Ekstern), Hailes, H. (Ekstern), Lye, G. (Ekstern), Ward, J. (Ekstern), Woodley, J. (Intern), Micheletti, M. (Ekstern)
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Main Research Area: Technical/natural sciences

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Scopus rating (2015): SJR 1.318 SNIP 1.029 CiteScore 2.54
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.027 SNIP 0.99 CiteScore 2.38
Web of Science (2014): Indexed yes
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An Ontological Knowledge-Based System for Identification of Efficient Chemical Production Routes

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Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Singh, R. (Intern), Gernaey, K. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
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Application of a Synthesis and Design Methodology Incorporating Process Intensification

State: Published
Application of bipolar electrodialysis to E. coli fermentation for simultaneous acetate removal and pH control

The application of bipolar electrodialysis (BPED) for the simultaneous removal of inhibitory acetate and pH control during E. coli fermentation was investigated. A two cell pair electrodialysis module, consisting of cation exchange, anion exchange and bipolar membranes with working area of 100 cm² each, was integrated with a standard 7 l stirred tank bioreactor. Results showed that BPED was beneficial in terms of in situ removal of inhibitory acetate and a reduction in the amount NH₄OH used for pH control. In batch and fed-batch BPED fermentations, base additions were decreased by up to 50% in both cases compared to electrodialysis (ED) fermentations with pH controlled at 6.7 ± 0.1. Consequently, the final biomass (34.2 g DCW l⁻¹) and recombinant protein (5.5 g l⁻¹) concentrations obtained were increased by up to 37 and 20%, respectively.

General information

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Organisations: Department of Chemical and Biochemical Engineering
Authors: Wong, M. (Ekstern), Woodley, J. (Intern), Lye, G. (Ekstern)
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Application of mechanistic models to fermentation and biocatalysis for next-generation processes

Mechanistic models are based on deterministic principles, and recently, interest in them has grown substantially. Herein we present an overview of mechanistic models and their applications in biotechnology, including future perspectives. Model utility is highlighted with respect to selection of variables required for measurement, control and process design. In the near future, mechanistic models with a higher degree of detail will play key roles in the development of efficient next-generation fermentation and biocatalytic processes. Moreover, mechanistic models will be used increasingly in the frame of multi-objective decision-making under uncertainty and to promote increased selectivity of products.

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Organisations: Department of Chemical and Biochemical Engineering, Center for Microbial Biotechnology, Department of Systems Biology, Computer Aided Process Engineering Center
Authors: Gernaey, K. (Intern), Eliasson Lantz, A. (Intern), Tufvesson, P. (Intern), Woodley, J. (Intern), Sin, G. (Intern)
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Main Research Area: Technical/natural sciences

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BFI (2015): BFI-level 2
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Application of Solid Resins for Controlled Substrate supply to biocatalytic reactions

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Al-Haque, N. (Intern), Tufvesson, P. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Publication date: 2010
Event: Poster session presented at BEST 2010, Bologna, Italy.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 265047
Publication: Research - peer-review › Journal article – Annual report year: 2010
Asymmetric Baeyer-Villiger Reactions using Whole-cell Biocatalysts

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Sigma-Aldrich Chemie GmbH
Authors: Wohlgemuth, R. (Ekstern), Woodley, J. (Intern)
Pages: 231-248
Publication date: 2010

Host publication information
Title of host publication: Asymmetric Catalysis on Industrial Scale: Challenges, Approaches and Solutions, Second Edition
Publisher: John Wiley & Sons Ltd
Editors: Blaser, H., Federsel, H.
Edition: 2nd Edition
ISBN (Print): 9783527324897
Main Research Area: Technical/natural sciences
enzyme catalysis, oxidation, whole-cell biocatalysts, asymmetric Baeyer–Villiger reactions

Bibliographical note
DOI: 10.1002/9783527630639.ch14
Source: orbit
Source-ID: 268570
Publication: Research - peer-review › Book chapter – Annual report year: 2010

A systematic methodology to synthesize/design processes, incorporating process intensification

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Lutze, P. (Intern), Jensen, J. S. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 267045
Publication: Research › Sound/Visual production (digital) – Annual report year: 2010

A systematic synthesis and design methodology to achieve process intensification for multi-phase reactions

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Lutze, P. (Intern), Jensen, J. S. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Publication date: 2010
Event: Poster session presented at 19th International Congress of Chemical and Process Engineering and 7th European Congress of Chemical Engineering, Prague, Czech Republic.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 267048
Publication: Research - peer-review › Poster – Annual report year: 2010

A systematic synthesis and design methodology to achieve process intensification in (bio) chemical processes

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Lutze, P. (Intern), Román-Martínez, A. (Intern), Woodley, J. (Intern), Gani, R. (Intern)
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
A systematic synthesis and design methodology to achieve process intensification in (bio)chemical processes

Process intensification (PI) has the potential to improve existing processes or create new process options which are needed in order to produce products using more sustainable methods. PI creates an enormous number of process options. In order to manage the complexity of options in which a feasible and optimal process solution may exist, the application of process synthesis tools results in the development of a systematic methodology to implement PI. Starting from an analysis of existing processes, this methodology generates a set of feasible process options and reduces their number through a number of screening steps until from the remaining feasible options, the optimal is found. The application of this systematic methodology through a computer-aided framework is presented through a case study, the chemo-enzymatic synthesis of N-acetyl-D-neuraminic acid (Neu5Ac).

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Lutze, P. (Intern), Román-Martínez, A. (Intern), Woodley, J. (Intern), Gani, R. (Intern)
Pages: 241-246
Publication date: 2010

Host publication information
Title of host publication: Proceedings of the 20th European Symposium on Computer Aided Process Engineering
Publisher: Elsevier Science
Series: Computer - Aided Chemical Engineering
Volume: 28
ISSN: 1570-7946
Main Research Area: Technical/natural sciences
Conference: 20th European Symposium on Computer Aided Process Engineering, Ischia, Italy, 06/06/2010 - 06/06/2010
Methodology, Process synthesis, Process intensification, Biocatalysis, N-acetylneuraminic acid (Neu5Ac)
DOIs: 10.1016/S1570-7946(10)28041-0
Source: orbit
Source-ID: 255431
Publication: Research - peer-review › Article in proceedings – Annual report year: 2010

Biocatalytic process technology

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering
Authors: Woodley, J. (Intern), Gernaey, K. (Intern), Tufvesson, P. (Intern)
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 268572
Publication: Research › Sound/Visual production (digital) – Annual report year: 2010

Biokatalytisk procesteknologi i produktionen af lægemidler

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Tufvesson, P. (Intern), Christiansen, L. (Ekstern), Jensen, J. S. (Intern), Woodley, J. (Intern)
Pages: 21-22
Publication date: 2010
Main Research Area: Technical/natural sciences
Bioprocesses: Modelling needs for process evaluation and sustainability assessment

The next generation of process engineers will face a new set of challenges, with the need to devise new bioprocesses, with high selectivity for pharmaceutical manufacture, and for lower value chemicals manufacture based on renewable feedstocks. In this paper the current and predicted future roles of process system engineering and life cycle inventory and assessment in the design, development and improvement of sustainable bioprocesses are explored. The existing process systems engineering software tools will prove essential to assist this work. However, the existing tools will also require further development such that they can also be used to evaluate processes against sustainability metrics, as well as economics as an integral part of assessments. Finally, property models will also be required based on compounds not currently present in existing databases. It is clear that many new opportunities for process systems engineering will be forthcoming in the area of integrated bioprocesses.
Chemicals from Biomass: Sustainability and Feasibility of a Cu-based Catalyst

General information
State: Published
Organisations: CHEC Research Centre, Department of Chemical and Biochemical Engineering
Authors: Voss, B. (Intern), Grunwaldt, J. (Intern), Woodley, J. (Intern), Andersen, S. I. (Intern)
Pages: 112-113
Publication date: 2010

Host publication information
Title of host publication: Proceedings of Dansk Kemiengiørkonference 2010
Main Research Area: Technical/natural sciences
Conference: 3. Dansk KemiengiørKonference, Kgs. Lyngby, Denmark, 16/06/2010 - 16/06/2010
Source: orbit
Source-ID: 266258
Publication: Research › Article in proceedings – Annual report year: 2010

Chemicals from Biomass: Sustainability and Feasibility of a Cu-based Catalyst
Chemoenzymatic combination of glucose oxidase with titanium silicalite-1

Zeozymes: A proof-of-concept is presented for the chemoenzymatic combination of titanium silicalite-1 zeolite with glucose oxidase. In this combination, glucose is oxidized to gluconic acid and the H2O2 byproduct formed in situ is used for the simultaneous oxidation of chemical substrates. Both a soluble glucose oxidase and a truly integrated heterogeneous combination whereby the oxidase enzyme is anchored onto the zeolite surface are reported.
Combining enzymes with heterogeneous chemical catalysts

General information
State: Published
Organisations: Department of Chemistry, Administration, Department of Chemical and Biochemical Engineering, CHEC Research Centre
Authors: Vennestrøm, P. N. R. (Ekstern), Pedersen, S. (Intern), Christensen, C. H. (Intern), Grunwaldt, J. (Intern), Woodley, J. (Intern)
Publication date: 2010
Event: Poster session presented at 14th Nordic Symposium on Catalysis, Helsingør, Denmark.
Main Research Area: Technical/natural sciences
Source: orbit
Publication: Research - peer-review › Journal article – Annual report year: 2010

Combining enzymes with heterogeneous chemical catalysts: chemoenzymatic combination of oxidase enzymes with titanium silicalite-1

General information
State: Published
Organisations: Department of Chemistry, Department of Chemical and Biochemical Engineering, CHEC Research Centre
Authors: Vennestrøm, P. N. R. (Ekstern), Pedersen, S. (Intern), Christensen, C. H. (Intern), Grunwaldt, J. (Intern), Woodley, J. (Intern)
Pages: 184-185
Publication date: 2010
Host publication information
Title of host publication: Proceedings of Dansk Kemiingeniørkonference 2010
Main Research Area: Technical/natural sciences
Conference: 3. Dansk KemiingeniørKonference, Kgs. Lyngby, Denmark, 16/06/2010 - 16/06/2010
Source: orbit
Publication: Research › Article in proceedings – Annual report year: 2010

Combining enzymes with heterogeneous chemical catalysts: chemoenzymatic combination of oxidase enzymes with titanium silicalite-1

General information
State: Published
Organisations: Department of Chemistry, Department of Chemical and Biochemical Engineering, CHEC Research Centre
Authors: Vennestrøm, P. N. R. (Ekstern), Pedersen, S. (Intern), Christensen, C. H. (Intern), Grunwaldt, J. (Intern), Woodley, J. (Intern)
Publication date: 2010
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 266277
Publication: Research › Poster – Annual report year: 2010

Concepts in multi-step biocatalysis

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Woodley, J. (Intern), Andrade Santacoloma, P. D. G. (Intern), Vennestrøm, P. N. R. (Ekstern), Sin, G. (Intern), Gernaey, K. (Intern)
Publication date: 2010

Publication information
Development of a Systematic Synthesis/Design Methodology incorporating Process Intensification

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Lutze, P. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Pages: 186-187
Publication date: 2010

Host publication information
Title of host publication: Proceedings of Dansk Kemiingeniørkonference 2010
Main Research Area: Technical/natural sciences
Conference: 3. Dansk KemiingeniørKonference, Kgs. Lyngby, Denmark, 16/06/2010 - 16/06/2010
Source: orbit
Source-ID: 266243
Publication: Research › Article in proceedings – Annual report year: 2010

Development of a Systematic Synthesis/Design Methodology incorporating Process Intensification

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Lutze, P. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Publication date: 2010
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 266270
Publication: Research › Poster – Annual report year: 2010

Development of reactor technology for improved catalytic productivity in enzymatic FAEE-biodiesel production

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering
Authors: Xu, Y. (Intern), Nordblad, M. (Intern), Woodley, J. (Intern)
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 268744
Publication: Research › Sound/Visual production (digital) – Annual report year: 2010

Electro-membrane filtration for amino acid separation

General information
State: Published
Organisations: Membrane Technology group, Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Yuan, L. (Intern), Jonsson, G. E. (Intern), Woodley, J. (Intern), Korsholm, L. (Ekstern)
Number of pages: 162
Publication date: 2010

Host publication information
Title of host publication: Proceedings of Dansk Kemiingeniørkonference 2010
Electro-membrane filtration for amino acid separation

General information
State: Published
Organisations: Membrane Technology group, Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Yuan, L. (Intern), Jonsson, G. E. (Intern), Woodley, J. (Intern), Korsholm, L. (Ekstern)
Publication date: 2010
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 266279
Publication: Research › Poster – Annual report year: 2010

Electro-membrane filtration for amino acid separation

General information
State: Published
Organisations: Membrane Technology group, Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Yuan, L. (Intern), Korsholm, L. (Ekstern), Jakobsen, S. (Ekstern), Woodley, J. (Intern), Jonsson, G. E. (Intern)
Publication date: 2010
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 268574
Publication: Research - peer-review › Poster – Annual report year: 2010

Enzymatic Bioprocess Considerations when Changing Substrate

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering
Authors: Tindal, S. (Intern), Xue, R. (Ekstern), Archer, I. (Ekstern), Carr, R. (Ekstern), Farid, S. (Ekstern), Hailes, H. (Ekstern), Woodley, J. (Intern)
Number of pages: 201
Publication date: 2010

Host publication information
Title of host publication: Proceedings of Dansk Kemiingeniørkonference 2010
Main Research Area: Technical/natural sciences
Conference: 3. Dansk KemiingeniørKonference, Kgs. Lyngby, Denmark, 16/06/2010 - 16/06/2010
Source: orbit
Source-ID: 266251
Publication: Research › Article in proceedings – Annual report year: 2010

Enzymatic Bioprocess Considerations when Changing Substrate

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering
Authors: Tindal, S. (Intern), Xue, R. (Ekstern), Archer, I. (Ekstern), Carr, R. (Ekstern), Farid, S. (Ekstern), Hailes, H. (Ekstern), Woodley, J. (Intern)
Publication date: 2010
Main Research Area: Technical/natural sciences
Source: orbit
Evaluation of reaction engineering parameters in enzyme based FAEE-biodiesel processes

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering
Authors: Nordblad, M. (Intern), Xu, Y. (Intern), Woodley, J. (Intern)
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 268743
Publication: Research › Sound/Visual production (digital) – Annual report year: 2010

F3 process design for fine chemical and Pharmaceutical transformations

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Muller, F. (Ekstern), Sanchez, R. R. (Ekstern), Wrate, T. (Ekstern), Davison, S. (Ekstern), Manipura, A. (Ekstern)
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 267042
Publication: Research › Sound/Visual production (digital) – Annual report year: 2010

Heterogeneous Catalytic Distillation - A Patent Review

General information
State: E-pub ahead of print
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Lutze, P. (Intern), Dada, E. (Ekstern), Gani, R. (Intern), Woodley, J. (Intern)
Publication date: 2010
Main Research Area: Technical/natural sciences

Publication information
Journal: Recent Patents on Chemical Engineering
Volume: 3
Original language: English
Source: orbit
Source-ID: 265036
Publication: Research - peer-review › Journal article – Annual report year: 2010

Impact of reaction engineering parameters on process design for enzyme-based FAEE-biodiesel production

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering
Authors: Nordblad, M. (Intern), Xu, Y. (Intern), Pedersen, L. S. (Intern), Woodley, J. (Intern)
Number of pages: 173
Publication date: 2010

Host publication information
Title of host publication: Proceedings of Dansk Kemifingeniørkonference 2010
Impact of reaction engineering parameters on process design for enzyme-based FAEE-biodiesel production

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Department of Chemistry
Authors: Nordblad, M. (Intern), Xu, Y. (Intern), Saaby Pedersen, L. (Intern), Woodley, J. (Intern)
Publication date: 2010
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 266273
Publication: Research › Poster – Annual report year: 2010


General information
State: Published
Organisations: Computer Aided Process Engineering Center, Department of Chemical and Biochemical Engineering
Authors: Roman Martinez, A. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 268877
Publication: Research › Sound/Visual production (digital) – Annual report year: 2010

Integrating chemical engineering fundamentals in the capstone process design project

All B.Eng. courses offered at the Technical University of Denmark (DTU) must now follow CDIO standards. The final “capstone” course in the B.Eng. education is Process Design, which for many years has been typical of chemical engineering curricula worldwide. The course at DTU typically has about 30 students. The B.Eng. education lasts for 3½ years (seven semesters), of which the 5th semester consists of practical training with a company and the final (7th) semester consists of a research project. The design course falls in the 6th semester, and is thus the last formal instruction that the students receive. The education is designed to provide students with the necessary tools to become productive in a company in a short time – so there is a strong industrial focus. Some students choose to continue with their studies and can then complete an M.Sc. after a further two years of study. The demands of the CDIO standards – especially standard 3 – Integrated Curriculum - means that the course projects must draw on competences provided in other subjects which the students are taking in parallel with Process Design – specifically Process Control and Reaction Engineering. In each semester of the B.Eng. education, one course is designated the “project” course, which should draw on material learned in parallel courses. In the 6th semester, Process Design is the project course. Process Control and Reaction Engineering are then incorporated into the final plant design project. Specifically, almost all chemical plants will incorporate one or more chemical reactors. In the initial stages of a process design, it is sufficient to express simply the reactor inputs and outputs. However in later stages, details about the reactor need to be specified. This is only possible using tools learned in the course Reaction Engineering. In order to incorporate reactor design into process design in a meaningful way, the teachers of the respective courses need to collaborate (Standard 9 – Enhancement of Faculty CDIO skills). The students also see that different components of the chemical engineering curriculum relate to each other. Similarly, in process design, steady state is always assumed for processes (i.e. production of a given chemical occurs at a constant rate, temperature, pressure and composition; feeds enter the plant at constant rates, etc.). However, in practice, chemical plants need to be carefully controlled to operate at a specified set of steady-state conditions. This is the science of Process Control and the students are asked to apply what they have learned here in order to show how to control the operation of the plant they have designed. The key difference from typical (earlier) process design courses is that the interaction between the courses is formalized, requiring (amongst other things) increased, broader teacher competence and communication between teachers across different disciplines, thereby also tying in with Standard 9 – Enhancement of Faculty CDIO skills. From a CDIO perspective, Process Design provides an opportunity for a comprehensive implementation of CDIO principles in a single course. Already the traditional chemical engineering “capstone” design course has for decades embodied many of the essential features of CDIO (for example the focus on group work, development of interpersonal skills, the open-ended nature of design problems, etc.).
Mechanistic modeling for systematic design and analysis of PAT systems (Invited Lecture)

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Singh, R. (Intern), Abdul Samad, N. A. F. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern), Gani, R. (Intern)
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 265115
Publication: Research › Sound/Visual production (digital) – Annual report year: 2010

Model-based design and analysis of integrated biocatalytic processes

General information
State: Published
Organisations: Computer Aided Process Engineering Center, Department of Chemical and Biochemical Engineering
Authors: Roman Martinez, A. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Number of pages: 135
Publication date: 2010

Host publication information
Title of host publication: Proceedings of Dansk Kemiingeniørkonference 2010
Main Research Area: Technical/natural sciences
Conference: 3. Dansk KemiingeniørKonference, Kgs. Lyngby, Denmark, 16/06/2010 - 16/06/2010
Source: orbit
Source-ID: 266247
Publication: Research › Article in proceedings – Annual report year: 2010

Model-based design and analysis of integrated biocatalytic processes

General information
State: Published
Organisations: Computer Aided Process Engineering Center, Department of Chemical and Biochemical Engineering
Authors: Roman Martinez, A. ( Intern), Gani, R. (Intern), Woodley, J. (Intern)
Publication date: 2010
Main Research Area: Technical/natural sciences
Next-Generation Catalysis for Renewables: Combining Enzymatic with Inorganic Heterogeneous Catalysis for Bulk Chemical Production

Nowadays, production of bulk and commodity chemicals from renewable feedstocks is widely debated and investigated as an alternative to the fossil platform. The conversion of biomass necessitates the development of a new generation of catalysts that enable new kinds of reactions from a different chemical platform under different conditions than those conventionally employed. Indeed, new process and catalyst concepts need to be established. Both enzymatic catalysis (biocatalysis) and heterogeneous inorganic catalysis are likely to play a major role and, potentially, be combined. One type of combination involves one-pot cascade catalysis with active sites from bio- and inorganic catalysts. In this article the emphasis is placed specifically on oxidase systems involving the coproduction of hydrogen peroxide, which can be used to create new in situ collaborative oxidation reactions for bulk chemical production.

General information
State: Published
Organisations: CHEC Research Centre, Department of Chemical and Biochemical Engineering, Technical University of Denmark, Haldor Topsoe AS, Novozymes A/S
Authors: Vennestrøm, P. N. R. (Ekstern), Christensen, C. (Ekstern), Pedersen, S. (Ekstern), Grunwaldt, J. (Intern), Woodley, J. (Intern)
Pages: 249-258
Publication date: 2010
Main Research Area: Technical/natural sciences

Publication information
Journal: CHEMCATCHEM
Volume: 2
Issue number: 3
ISSN (Print): 1867-3880
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 4.33 SJR 1.636 SNIP 0.932
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.751 SNIP 1 CiteScore 4.57
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.88 SNIP 1.102 CiteScore 4.52
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 2.167 SNIP 1.06 CiteScore 4.82
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
Scopus rating (2012): SJR 2.375 SNIP 1.142 CiteScore 4.58
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
Scopus rating (2011): SJR 2.238 SNIP 1.056 CiteScore 4.3
ISI indexed (2011): ISI indexed no
Scopus rating (2010): SJR 1.664 SNIP 0.926
Web of Science (2010): Indexed yes
Original language: English
enzyme catalysis, heterogeneous catalysis, cascade reactions, industrial chemistry, renewable resources
DOIs:
10.1002/ccct.200900248
Source: orbit
Source-ID: 263154
Publication: Research › Journal article – Annual report year: 2010
Process considerations for the catalytic dehydration of sugars to 5-hydroxymethylfurfural

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering
Authors: Jensen, J. S. (Intern), Fu, W. (Intern), Christensen, T. (Ekstern), Woodley, J. (Intern)
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 268751
Publication: Research › Sound/Visual production (digital) – Annual report year: 2010

Process considerations for the scale-up and implementation of biocatalysis
With increasing emphasis on renewable feed-stocks and green chemistry, biocatalytic processes will have an important role in the next generation of industrial processes for chemical production. However, in comparison with conventional industrial chemistry, the use of bioprocesses in general and biocatalysis in particular is a rather young technology. Although significant progress has been made in the implementation of new processes (especially in the pharmaceutical industry) no fixed methods for process design have been established to date. In this paper we present some of the considerations required to scale-up a biocatalytic process and some of the recently developed engineering tools available to assist in this procedure. The tools will have a decisive role in helping to identify bottlenecks in the biocatalytic development process and to justify where to put effort and resources.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering
Authors: Tufvesson, P. (Intern), Fu, W. (Intern), Jensen, J. S. (Intern), Woodley, J. (Intern)
Pages: 3-11
Publication date: 2010
Main Research Area: Technical/natural sciences

Publication information
Journal: Food and Bioproducts Processing
Volume: 88
Issue number: C1
ISSN (Print): 0960-3085
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.881 SNIP 1.178 CiteScore 2.59
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.182 SNIP 1.87 CiteScore 3.44
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.236 SNIP 2.098 CiteScore 3.24
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.932 SNIP 1.951 CiteScore 2.92
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.787 SNIP 1.703 CiteScore 2.36
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.643 SNIP 1.054 CiteScore 2.07
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.548 SNIP 0.745
Process Design for Chemo-enzymatic Synthesis of 2,5-Furandicarboxylic Acid

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Department of Chemistry, Centre for Catalysis and Sustainable Chemistry, Computer Aided Process Engineering Center
Authors: Fu, W. (Intern), Jensen, J. S. (Intern), Boisen, A. (Intern), Pedersen, S. (Ekstern), Riisager, A. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Publication date: 2010


Process Design for Chemo-enzymatic Synthesis of 2,5-Furandicarboxylic Acid (Best Poster Award)

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Department of Chemistry, Centre for Catalysis and Sustainable Chemistry, Computer Aided Process Engineering Center
Authors: Fu, W. (Intern), Jensen, J. S. (Intern), Boisen, A. (Ekstern), Pedersen, S. (Ekstern), Riisager, A. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Publication date: 2010

Process design for chemo-enzymatic synthesis of 5-hydroxymethylfurfural

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Department of Chemistry, Centre for Catalysis and Sustainable Chemistry, Computer Aided Process Engineering Center
Authors: Fu, W. (Intern), Jensen, J. S. (Intern), Riisager, A. (Intern), Pedersen, S. (Ekstern), Gani, R. (Intern), Woodley, J. (Intern)
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 267265
Publication: Research › Sound/Visual production (digital) – Annual report year: 2010

Process Design for Chemo-enzymatic Synthesis of 5-Hydroxymethylfurfural

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Sustainable and Green Chemistry, Department of Chemistry, Computer Aided Process Engineering Center, Centre for Catalysis and Sustainable Chemistry
Number of pages: 205
Publication date: 2010

Host publication information
Title of host publication: Proceedings of Dansk Kemiingeniørkonference 2010
Main Research Area: Technical/natural sciences
Conference: 3. Dansk KemiingeniørKonference, Kgs. Lyngby, Denmark, 16/06/2010 - 16/06/2010
Source: orbit
Source-ID: 266239
Publication: Research › Article in proceedings – Annual report year: 2010

Process Design for Chemo-enzymatic Synthesis of 5-Hydroxymethylfurfural

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Sustainable and Green Chemistry, Department of Chemistry, Computer Aided Process Engineering Center, Centre for Catalysis and Sustainable Chemistry
Publication date: 2010
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 266266
Publication: Research › Poster – Annual report year: 2010

Process Development and Design for Greener Pharmaceutical Processes

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering
Authors: Gernaey, K. (Intern), Tufvesson, P. (Intern), Woodley, J. (Intern)
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
**Process Intensification: A Perspective on Process Synthesis**

In recent years, process intensification (PI) has attracted considerable academic interest as a potential means for process improvement, to meet the increasing demands for sustainable production. A variety of intensified operations developed in academia and industry creates a large number of options to potentially improve the process but to identify the set of feasible solutions for PI in which the optimal can be found takes considerable resources. Hence, a process synthesis tool to achieve PI would potentially assist in the generation and evaluation of PI options. Currently, several process design tools with a clear focus on specific PI tasks exist. Therefore, in this paper, the concept of a general systematic framework for synthesis and design of PI options in hierarchical steps through analyzing an existing process, generating PI options in a superstructure and evaluating intensified process options is presented. For each step, different tools and methods will be needed. In this paper, a knowledge base tool storing and retrieving necessary information/data about intensified processes/equipments has been highlighted including metrics for performance evaluation. The application of the main concepts is illustrated through an example involving the operation of a membrane reactor.

**General information**

State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Lutze, P. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Pages: 547-558
Publication date: 2010
Main Research Area: Technical/natural sciences

**Publication information**

Journal: Chemical Engineering and Processing
Volume: 49
Issue number: 6
ISSN (Print): 0255-2701
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.766 SNIP 1.205 CiteScore 2.57
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.837 SNIP 1.389 CiteScore 2.63
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.87 SNIP 1.427 CiteScore 2.41
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.972 SNIP 1.391 CiteScore 2.5
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.017 SNIP 1.604 CiteScore 2.38
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.979 SNIP 1.518 CiteScore 2.26
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.957 SNIP 1.47
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.873 SNIP 1.457
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.765 SNIP 1.387
Process Technology for the Application of D-Amino Acid Oxidases in Pharmaceutical Intermediate Manufacturing

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering
Authors: Tindal, S. (Intern), Farid, S. (Ekstern), Hailes, H. (Ekstern), Carr, R. (Ekstern), Archer, I. (Ekstern), Woodley, J. (Intern)
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 265033
Publication: Research - peer-review › Journal article – Annual report year: 2010

Recent Advances in Reactive Distillation

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Lutze, P. (Intern), Gani, R. (Intern), Woodley, J. (Intern), Dada, E. A. (Ekstern)
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 268889
Publication: Research › Sound/Visual production (digital) – Annual report year: 2010

Recent Advances in Reactive Distillation

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Lutze, P. (Intern), Gani, R. (Intern), Woodley, J. (Intern), Dada, E. A. (Ekstern)
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Recent Advances in Reactive Distillation

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Lutze, P. (Intern), Gani, R. (Intern), Woodley, J. (Intern), Dada, E. A. (Ekstern)
Publication date: 2010

Renewable building block for plastic industry: Gold-catalyzed oxidation of HMF to FDA in water

General information
State: Published
Organisations: Department of Chemistry, Sustainable and Green Chemistry, Centre for Catalysis and Sustainable Chemistry, Department of Chemical and Biochemical Engineering, Administration
Authors: Gorbanev, Y. (Intern), Kegnæs, S. (Intern), Woodley, J. (Intern), Christensen, C. H. (Intern), Riisager, A. (Intern)
Publication date: 2010
Event: Poster session presented at 14th Nordic Symposium on Catalysis, Helsingør, Denmark.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 268754
Publication: Research - peer-review › Poster – Annual report year: 2010

Renewable building block for plastic industry: Gold-catalyzed oxidation of HMF to FDA in water

General information
State: Published
Organisations: Department of Chemistry, Centre for Catalysis and Sustainable Chemistry, Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Gorbanev, Y. (Intern), Kegnæs, S. (Intern), Woodley, J. (Intern), Christensen, C. H. (Intern), Riisager, A. (Intern)
Publication date: 2010
Event: Abstract from 14th Nordic Symposium on Catalysis, Helsingør, Denmark.
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2010

Scale-down and design of experiments in improving bio-oxidation of long-chain alkanes

General information
State: Published
Organisations: Department of Environmental Science and Engineering, Department of Chemical and Biochemical Engineering
Authors: Grant, C. (Ekstern), Pinto, A. P. T. (Intern), Yan, W. (Intern), Woodley, J. (Intern), Baganz, F. (Ekstern)
Publication date: 2010
Event: Poster session presented at Zing Biocatalysis conference, Puerto Morelos, Mexico.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 272707
Publication: Research - peer-review › Poster – Annual report year: 2010

Scale down and design of experiments toward improving bio-oxidation of alkanes

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering
Authors: Grant, C. (Ekstern), Woodley, J. (Intern), Baganz, F. (Ekstern)
Publication date: 2010

**Publication information**
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 268756
Publication: Research › Sound/Visual production (digital) – Annual report year: 2010

**Sensitivity Analysis of a Kinetic Model Describing the Bi-enzymatic Synthesis of Lactobionic Acid**

**General information**
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Andrade Santacoloma, P. D. G. (Intern), Sin, G. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern)
Pages: 1491-1496
Publication date: 2010

**Host publication information**
Title of host publication: Computer-Aided Chemical Engineering Series
Volume: 28
Publisher: Elsevier Science
Main Research Area: Technical/natural sciences
Conference: 20th European Symposium on Computer Aided Process Engineering, Ischia, Italy, 06/06/2010 - 06/06/2010
Source: orbit
Source-ID: 264996
Publication: Research - peer-review › Article in proceedings – Annual report year: 2010

**Sensitivity Analysis of a Kinetic Model Describing the Bi-enzymatic Synthesis of Lactobionic Acid**

**General information**
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Andrade Santacoloma, P. D. G. (Intern), Sin, G. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern)
Publication date: 2010

**Publication information**
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 265227
Publication: Research › Sound/Visual production (digital) – Annual report year: 2010

**Separation of amino acids by electro-membrane filtration**

**General information**
State: Published
Organisations: Membrane Technology group, Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Yuan, L. (Intern), Korsholm, L. (Ekstern), Jakobsen, S. (Ekstern), Woodley, J. (Intern), Jonsson, G. E. (Intern)
Publication date: 2010

**Publication information**
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 272701
Publication: Research › Sound/Visual production (digital) – Annual report year: 2010

**Synthesis, Design and Analysis of Downstream Separation in Bio-refinery Processes through a Group-Contribution Approach**
Synthesis, Design and Analysis of Downstream Separation in Bio-refinery Processes through a Group-Contribution Approach

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Alvarado-Morales, M. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern), Gani, R. (Intern)
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 265222
Publication: Research - Sound/Visual production (digital) – Annual report year: 2010

Systematic Framework for Design and Adaption of Fast, Flexible, Continuous Modular Plants

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Singh, R. (Intern), Gernaey, K. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Publication date: 2010

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 268884
Publication: Research - Sound/Visual production (digital) – Annual report year: 2010

Transketolases
The enzyme transketolase is a potentially useful catalyst for asymmetric carbon–carbon bond formation. Given the importance of this reaction in organic synthesis, it is not surprising that in recent years there has been particular interest in transketolase. In this review, we describe the background to the reaction, mechanistic and structural information, application in synthesis, and the requirements for larger scale application and implementation.

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering, Sigma-Aldrich Chemie GmbH, University College London
Authors: Wohlgemuth, R. (Ekstern), Smith, M. E. (Ekstern), Dalby, P. A. (Ekstern), Woodley, J. (Intern)
Pages: 4746-4752
Publication date: 2010

Host publication information
Whole cell reduction as a key step in the production of chiral drugs: a comprehensive engineering approach and evaluation methodology

A computer aided model framework for process design of chemo-enzymatic synthetic cascades

A Model-Based Methodology for Simultaneous Design and Control of a Bioethanol Production Process

A Model-Based Methodology for Simultaneous Design and Control of a Bioethanol Production Process
An efficient approach to bioconversion kinetic model generation based on automated microscale experimentation integrated with model driven experimental design

Reliable models of enzyme kinetics are required for the effective design of bioconversion processes. Kinetic expressions of the enzyme-catalysed reaction rate however, are frequently complex and establishing accurate values of kinetic parameters normally requires a large number of experiments. These can be both time consuming and expensive when working with the types of non-natural chiral intermediates important in pharmaceutical syntheses. This paper presents an automated microscale approach to the rapid and cost effective generation of reliable kinetic models useful for bioconversion process design. It incorporates a model driven approach to the experimental design that minimises the number of experiments to be performed, while still generating accurate values of kinetic parameters. The approach has been illustrated with the transketolase mediated asymmetric synthesis of L-erythrulose. Experiments were performed using automated microwell studies at the 150 or 800 μL scale. The derived kinetic parameters were then verified in a second round of experiments where model predictions showed excellent agreement with experimental data obtained under conditions not included in the original experimental design. In comparison with conventional methodology, the modelling approach enabled a nearly 4-fold decrease in the number of experiments while the microwell experimentation enabled a 45-fold decrease in material requirements and a significant increase in experimental throughput. The approach is generic and could be applied to a wide range of enzyme catalysed bioconversions.

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Chen, B. H. (Ekstern), Micheletti, M. (Ekstern), Baganz, F. (Ekstern), Woodley, J. (Intern), Lye, G. (Ekstern)
Pages: 403-409
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Chemical Engineering Science
Volume: 64
Issue number: 2
ISSN (Print): 0009-2509
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.05 SJR 1.037 SNIP 1.442
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.038 SNIP 1.606 CiteScore 2.96
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.115 SNIP 1.642 CiteScore 2.81
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.157 SNIP 1.866 CiteScore 2.95
ISI indexed (2013): ISI indexed yes
Application of modeling and simulation tools for the evaluation of biocatalytic processes: a future perspective

General information
State: Published
Organisations: Computer Aided Process Engineering Center, Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering
Authors: Sin, G. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern)
Pages: 1529-1538
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Biotechnology Progress
Volume: 25
Biocatalysis using transketolase mutants and an ω-transaminase: synthesis of aromatic aminodiols

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Galman, J. (Ekstern), Cazares-Robles, A. (Ekstern), Coward, L. (Ekstern), Smith, M. (Ekstern), Hibbert, E. (Ekstern), Smithies, K. (Ekstern), Kaulmann, U. (Ekstern), Dalby, P. (Ekstern), Lye, G. (Ekstern), Ward, J. (Ekstern), Woodley, J. (Intern), Hailes, H. (Ekstern)
Publication date: 2009

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 255658
Publication: Research › Sound/Visual production (digital) – Annual report year: 2009

Biocatalysts for selective introduction of oxygen
Three types of oxygenase biocatalysts are treated in detail in this review: the non-haem iron alkene mono-oxygenases, the haem and vanadium haloperoxidases, and flavin-based Baeyer-Villiger mono-oxygenases. Other oxygenases are briefly included for comparison. Characteristics of the biocatalysts are presented, and the scope and limitations concerning their applicability for the selective introduction of oxygen are discussed. Key issues include catalytic activity, productivity, cloning and expression, as well as process engineering aspects. Various bottlenecks are identified for the different biocatalysts and measures to increase the number of oxygenase reactions in practical use are discussed.

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Leak, D. J. (Ekstern), Sheldon, R. A. (Ekstern), Woodley, J. (Intern), Adlercreutz, P. (Ekstern)
Pages: 1-26
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Biocatalysis and Biotransformation
Volume: 27
Issue number: 1
ISSN (Print): 1024-2422
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.274 SNIP 0.366 CiteScore 0.76
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.293 SNIP 0.376 CiteScore 0.89
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.311 SNIP 0.492 CiteScore 0.8
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.369 SNIP 0.531 CiteScore 1.08
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.358 SNIP 0.586 CiteScore 0.94
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.406 SNIP 0.547 CiteScore 1.07
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.415 SNIP 0.515
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.455 SNIP 0.583
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.519 SNIP 0.438
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.491 SNIP 0.687
Scopus rating (2006): SJR 0.527 SNIP 0.78
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.496 SNIP 0.509
Scopus rating (2004): SJR 0.422 SNIP 0.465
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.34 SNIP 0.533
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.408 SNIP 0.457
Scopus rating (2001): SJR 0.434 SNIP 0.788
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 0.459 SNIP 0.657
Scopus rating (1999): SJR 0.565 SNIP 0.653
Original language: English
chloroperoxidase, oxygenation, Mono-oxygenase, peroxidase
DOI:
10.1080/10242420802393519
Source: orbit
Source-ID: 243225
Publication: Research - peer-review › Journal article – Annual report year: 2009

Biocatalytic process technology for chiral APIs

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Tufvesson, P. (Intern), Woodley, J. (Intern)
Pages: 26-29
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: SP2
Original language: English
Source: orbit
Source-ID: 255705
Publication: Communication › Journal article – Annual report year: 2009

Biorefining: Computer aided tools for sustainable design and analysis of bioethanol production

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering, Computer Aided Process Engineering Center
Authors: Alvarado-Morales, M. (Intern), Terra, J. (Ekstern), Gernaey, K. (Intern), Woodley, J. (Intern), Gani, R. (Intern)
Pages: 1171-1183
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Chemical Engineering Research & Design
Catalytic conversion of biomass – A new chemical infrastructure

General information
State: Published
Organisations: Department of Chemistry, Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, Centre for Catalysis and Sustainable Chemistry
Authors: Hansen, T. S. (Intern), Woodley, J. (Intern), Riisager, A. (Intern)
Publication date: 2009
Event: Abstract from 9th European Congress on Catalysis, Salamanca, Spain.
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2009

Catalytic conversion of biomass - a new infrastructure

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering, Sustainable and Green Chemistry, Department of Chemistry
Authors: Hansen, T. (Ekstern), Woodley, J. (Intern), Riisager, A. (Intern)
Publication date: 2009
Event: Poster session presented at 9th European Congress on Catalysis, Salamanca, Spain.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 255671
Publication: Research - peer-review › Poster – Annual report year: 2009

Computer aided Process Design of Chemo-enzymatic Synthetic Cascades

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering
Authors: Fu, W. (Intern), Woodley, J. (Intern)
Publication date: 2009
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 265108
Publication: Research - peer-review › Poster – Annual report year: 2009

Conversion of biomass resources into chemicals with integrated catalytic technologies

General information
State: Published
Organisations: Sustainable and Green Chemistry, Department of Chemistry, Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering, BioChemical Engineering
Authors: Riisager, A. (Intern), Søndergaard Hansen, T. (Intern), Ståhlberg, T. (Intern), Kegnæs, S. (Intern), Jensen, J. S. (Intern), Woodley, J. (Intern), Boisen, A. (Intern), Pedersen, S. (Intern)
Publication date: 2009
Event: Abstract from Annual Green Chemistry and Engineering Conference, College Park, MD, USA, .
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 257494
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2009

Conversion of Biomass Resources Into Chemicals with Integrated Catalytic Technologies

General information
State: Published
Organisations: Department of Chemistry, Centre for Catalysis and Sustainable Chemistry, Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Riisager, A. (Intern), Hansen, T. (Ekstern), Ståhlberg, T. (Ekstern), Kiltgaard, S. (Ekstern), Jensen, J. (Ekstern), Woodley, J. (Intern), Boisen, A. (Ekstern), Pedersen, S. (Ekstern)
Design methodology for intensified bioprocesses

General information
State: Published
Organisations: Computer Aided Process Engineering Center, Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering
Authors: Román-Martínez, A. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Number of pages: 285
Publication date: 2009

Host publication information
Title of host publication: Proceedings of AMIDIQ XXX (Academia Mexicana de Investigación y Docencia en Ingeniería Química 2009)
Main Research Area: Technical/natural sciences
Conference: Academia Mexicana de Investigación y Docencia en Ingeniería Química, Mazatlán, Mexico, 19/05/2009 - 19/05/2009
Source: orbit
Source-ID: 248232
Publication: Research › Article in proceedings – Annual report year: 2009

Design Strategies for Neuraminic Acid Synthesis: Comparative Study of Chemical and Biochemical Routes and Integration of Purification Steps

General information
State: Published
Organisations: Computer Aided Process Engineering Center, Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering
Authors: Román-Martínez, A. (Intern), Gani, R. (Intern), Woodley, J. (Intern)
Publication date: 2009
Event: Poster session presented at Biotrans 09, Bern, Switzerland.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 248268
Publication: Research - peer-review › Poster – Annual report year: 2009

Dyeing Method for Determination of Glycerol Partitioning in Biodiesel Production

General information
Efficient microwave-assisted synthesis of 5-hydroxymethylfurfural from concentrated aqueous fructose

Studies on the HCl-catalysed microwave-assisted dehydration of highly concentrated aqueous fructose (27 wt %) to 5-hydroxymethylfurfural (HMF) revealed a significant increase in the fructose conversion rate over the conventional heated systems. Water, being the most benign solvent and therefore ideal for green and sustainable chemistry, normally is a poor solvent for the dehydration process resulting in low HMF selectivities and yields. However, reaction at 200 °C with microwave irradiation with a short reaction time of only 1 s resulted in good HMF selectivity of 63% and fructose conversion of 52%, while prolonged irradiation for 60 s (or more) resulted in nearly full fructose conversion (95%) but lower HMF yield (53%). Decreasing the fructose concentration significantly improved the HMF selectivity, but possibly made the production route less attractive from an industrial point of view due to the resultant low throughput.

General information

Efficient microwave-assisted synthesis of 5-hydroxymethylfurfural from concentrated aqueous fructose

Efficient microwave-assisted synthesis of 5-hydroxymethylfurfural from concentrated aqueous fructose

Studies on the HCl-catalysed microwave-assisted dehydration of highly concentrated aqueous fructose (27 wt %) to 5-hydroxymethylfurfural (HMF) revealed a significant increase in the fructose conversion rate over the conventional heated systems. Water, being the most benign solvent and therefore ideal for green and sustainable chemistry, normally is a poor solvent for the dehydration process resulting in low HMF selectivities and yields. However, reaction at 200 °C with microwave irradiation with a short reaction time of only 1 s resulted in good HMF selectivity of 63% and fructose conversion of 52%, while prolonged irradiation for 60 s (or more) resulted in nearly full fructose conversion (95%) but lower HMF yield (53%). Decreasing the fructose concentration significantly improved the HMF selectivity, but possibly made the production route less attractive from an industrial point of view due to the resultant low throughput.
Enhanced recombinant protein synthesis in batch and fed-batch Escherichia coli fermentation based on removal of inhibitory acetate by electrodialysis

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Wong, M. (Ekstern), Wright, M. (Ekstern), Woodley, J. (Intern), Lye, G. (Ekstern)
Pages: 1284-1291
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Chemical Technology and Biotechnology
Volume: 84
Issue number: 9
ISSN (Print): 0268-2575
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.843 SNIP 1.111 CiteScore 2.94
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.8 SNIP 0.967 CiteScore 2.55
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.942 SNIP 1.03 CiteScore 2.49
BFI (2013): BFI-level 1
Evaluating the impact of substrate and product concentration on a whole-cell biocatalyst during a Baeyer-Villiger reaction

The presence of high concentrations of substrate or product may impede the optimal functioning of a biocatalyst, more so in the case of whole cell biocatalysts where the metabolic status of the cells may be compromised. In this article we investigate these effects using as an example the Baeyer-Villiger oxidation of racemic bicyclo[3.2.0]hept-2-en-6-one to yield \((-\)-1(S),5(R)-2-oxabicyclo[3.3.0]oct-6-en-3-one and \((-\)-1(R),5(S)-3-oxabicyclo[3.3.0]oct-6-en-2-one by CHMO expressed in Escherichia coli TOP10. Multi parameter flow cytometry was used to illustrate that substrate (racemic bicyclo[3.2.0]hept-2-en-6-one) associated cell damage was concentration dependent. One of the two regio-isomeric products \([-\)-1(S),5(R)-2-oxabicyclo[3.3.0]oct-6-en-3-one] was also used to identify that product associated cell damage was time dependent. In addition, both substrate and product concentrations affected the observed reaction rate.
Evaluation methodology and multi-level engineering approach to improve whole cell ketone reduction

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Kratzer, R. (Intern), Pival, S. (Ekstern), Woodley, J. (Intern), Nidetzky, B. (Ekstern)
Publication date: 2009

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 257426
Publication: Research › Sound/Visual production (digital) – Annual report year: 2009

Gold-Catalyzed Aerobic Oxidation of 5-Hydroxymethylfurfural in Water at Ambient Temperature
The aerobic oxidation of 5-hydroxymethylfurfural, a versatile biomass-derived chemical, is examined in water with a titania-supported gold-nanoparticle catalyst at ambient temperature (30 degrees C). The selectivity of the reaction towards 2,5-furandicarboxylic acid and the intermediate oxidation product 5-hydroxymethyl-2-furancarboxylic acid is found to depend on the amount of added base and the oxygen pressure, suggesting that the reaction proceeds via initial oxidation of the aldehyde moiety followed by oxidation of the hydroxymethyl group of 5-hydroxymethylfurfural. Under optimized reaction conditions, a 71% yield of 2,5-furandicarboxylic acid is obtained at full 5-hydroxymethylfurfural conversion in the presence of excess base.

General information
State: Published
Organisations: Sustainable and Green Chemistry, Department of Chemistry, Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Gorbanev, Y. (Intern), Kegnæs, S. (Intern), Woodley, J. (Intern), Christensen, C. H. (Ekstern), Riisager, A. (Intern)
Pages: 672-675
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: ChemSusChem (Print)
Volume: 2
Issue number: 7
ISSN (Print): 1864-5631
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 6.7 SJR 2.385 SNIP 1.276
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 2.494 SNIP 1.411 CiteScore 7.33
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 2.863 SNIP 1.663 CiteScore 7.97
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 2.548 SNIP 1.452 CiteScore 6.79
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
Scopus rating (2012): SJR 3.046 SNIP 1.563 CiteScore 6.72
ISI indexed (2012): ISI indexed yes
Scopus rating (2011): SJR 2.767 SNIP 1.504 CiteScore 5.53
ISI indexed (2011): ISI indexed no
Web of Science (2011): Indexed yes
Hybrid technologies: In-situ product removal from enzyme-catalysed reactions

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering, Centre for Catalysis and Sustainable Chemistry
Authors: Christensen, T. (Ekstern), Fu, W. (Ekstern), Jensen, J. (Ekstern), Jurgensen, V. (Ekstern), Boisen, A. (Ekstern), Pedersen, S. (Ekstern), Woodley, J. (Intern)
Publication date: 2009

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 255567
Publication: Research › Sound/Visual production (digital) – Annual report year: 2009

Induction studies with Escherichia coli expressing recombinant interleukin-13 using multi-parameter flow cytometry

The expression of interleukin-13 (IL13) following induction with IPTG in Escherichia coli results in metabolic changes as indicated by multi-parameter flow cytometry and traditional methods of fermentation profiling (O2 uptake rate, CO2 evolution rate and optical density measurements). Induction early in the rapid growth phase was optimal although this led to lower overall biomass concentrations and lower maximum specific growth rates. In contrast, induction in the mid-rapid growth phase was the most detrimental to cell quality as measured by cytoplasmic membrane depolarisation.

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Shitu, J. O. (Ekstern), Woodley, J. (Intern), Wnek, R. (Ekstern), Chartrain, M. (Ekstern), Hewitt, C. J. (Ekstern)
Pages: 577-584
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Biotechnology Letters
Volume: 31
Issue number: 4
ISSN (Print): 0141-5492
Ratings:
Introducing mechanistic models in Process Analytical Technology education

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Gernaey, K. (Intern), Woodley, J. (Intern), Sin, G. (Intern)
Pages: 593-598
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Biotechnology Journal
Volume: 4
Issue number: 5
ISSN (Print): 1860-6768
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 3.2 SJR 1.29 SNIP 0.969
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.172 SNIP 0.874 CiteScore 2.91
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.189 SNIP 1.062 CiteScore 2.98
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.136 SNIP 1.093 CiteScore 3.01
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.944 SNIP 0.957 CiteScore 2.4
ISI indexed (2012): ISI indexed no
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.785 SNIP 0.726 CiteScore 1.94
ISI indexed (2011): ISI indexed no
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.787 SNIP 0.798
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.695 SNIP 0.749
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.581 SNIP 0.806
Scopus rating (2007): SJR 0.568 SNIP 0.709
Web of Science (2007): Indexed yes
Original language: English
Source: orbit
Source-ID: 248060
Publication: Research - peer-review › Journal article – Annual report year: 2009

Kemikalier fra biomasse - når plast gror på træerne

General information
State: Published
Organisations: Sustainable and Green Chemistry, Department of Chemistry, Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Mechanistic models and advanced model analysis within a PAT framework

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering, Center for Microbial Biotechnology, Department of Systems Biology, Computer Aided Process Engineering Center
Authors: Gernaey, K. (Intern), Woodley, J. (Intern), Eliasson Lantz, A. (Intern), Sin, G. (Intern)
Publication date: 2009
Event: Poster session presented at 14th European Congress on Biotechnology, Barcelona, Spain.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 255677
Publication: Research - peer-review › Poster – Annual report year: 2009

Modelling and simulation of a transketolase mediated reaction: Sensitivity analysis of kinetic parameters

In this paper we have used a proposed mathematical model, describing the carbon-carbon bond format ion reaction between beta-hydroxypropyruvate and glycolaldehyde to synthesise L-erythulose, catalysed by the enzyme transketolase, for the analysis of the sensitivity of the process to its kinetic parameters. The model was validated with experimental data. As a conclusion, kinetic parameters with a possible positive impact on reaction performance were identified and assessed in relation to operating conditions. This resulted in the identification of suitable catalyst and process development targets.

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General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Sayar, N. (Ekstern), Chen, B. (Ekstern), Lye, G. (Ekstern), Woodley, J. (Intern)
Pages: 1-9
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Biochemical Engineering Journal
Volume: 47
Issue number: 1-3
ISSN (Print): 1369-703X
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 3.16
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 2.75
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 2.72
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 3.03
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 3.15
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
New opportunities for Process Systems Engineering in Industrial Biotechnology

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Woodley, J. (Intern)
Pages: 157-162
Publication date: 2009

Host publication information
Volume: 27A
Editors: Alves, R. M. D. B., Oller do Nascimento, C. A., Chalbaud Biscia Jr., E.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 255528
Publication: Research - peer-review › Article in proceedings – Annual report year: 2009

New opportunities for PSE in industrial biotechnology

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Woodley, J. (Intern)
Publication date: 2009

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 255668
Publication: Research › Sound/Visual production (digital) – Annual report year: 2009

Optimization of long-term planning, supply chain and processing routes for tailor-made bio-chemicals

General information
State: Published
Organisations: Computer Aided Process Engineering Center, Department of Chemical and Biochemical Engineering, Operations Management, Department of Management Engineering, CHEC Research Centre
Optimization of tailor-made chemicals from renewable and non-renewable sources

General information
State: Published
Organisations: Computer Aided Process Engineering Center, Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering, CHEC Research Centre
Authors: Swangkotchakorn, C. (Intern), Gani, R. (Intern), Woodley, J. (Intern), Grunwaldt, J. (Intern)
Publication date: 2009

Process design and development issues for pharmaceutical processes

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Gernaey, K. (Intern), Woodley, J. (Intern)
Publication date: 2009

Process design and production of chemicals. Food ingredients, fuels and pharmaceuticals

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Meyer, A. S. (Intern), Woodley, J. (Intern), Gani, R. (Intern)
Pages: 170-179
Publication date: 2009

Host publication information
Title of host publication: Engineering challenges: energy, climate change and health
Place of publication: Kgs.Lyngby
Publisher: Technical University of Denmark (DTU)
Editor: Hansen, C. B.
ISBN (Print): 978-87-985544-4-8

Series: DTU research series
Main Research Area: Technical/natural sciences
Electronic versions:
Engineering_challenges_2009.pdf
Source: orbit
Process design of chemo-enzymatic synthesis cascades

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Fu, W. (Ekstern), Jensen, J. (Ekstern), Christensen, T. (Ekstern), Boisen, A. (Ekstern), Pedersen, S. (Ekstern), Riisager, A. (Ekstern), Woodley, J. (Intern)
Publication date: 2009

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 255574
Publication: Research › Sound/Visual production (digital) – Annual report year: 2009

Process design of chemo-enzymatic synthetic cascades

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Fu, W. (Ekstern), Jensen, J. (Ekstern), Boisen, A. (Ekstern), Pedersen, S. (Ekstern), Riisager, A. (Ekstern), Woodley, J. (Intern)
Publication date: 2009

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 255682
Publication: Research › Sound/Visual production (digital) – Annual report year: 2009

Process engineering tools to guide biocatalyst modification

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Tufvesson, P. (Intern), Schurmann, M. (Ekstern), Vogel, A. (Ekstern), Woodley, J. (Intern)
Publication date: 2009
Event: Poster session presented at Biotrans 09, Bern, Switzerland.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 255660
Publication: Research - peer-review › Poster – Annual report year: 2009

Process integration for the conversion of glucose to 2,5-furandicarboxylic acid

The development of biorefineries means that a key feedstock for many new processes will be sugars in various forms, such as glucose or fructose. From these feedstocks a range of chemicals can be synthesized using heterogeneous catalysis, immobilized enzymes, homogeneous catalysts, soluble enzymes, fermentations or combinations thereof. This presents a particularly interesting process integration challenge since the optimal conditions for each conversion step will be considerably different from each other. Furthermore, compared to oil-based refineries the feedstock represents a relatively high proportion of the final product value and therefore yield and selectivity in these steps are of crucial importance. In this paper using the conversion of glucose to 2,5-furandicarboxylic acid and associated products as an example, alternative routes will be compared with respect to achievable selectivity, and achievable yield.

General information
State: Published
Organisations: Sustainable and Green Chemistry, Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering, Novozymes A/S
Process modelling and simulation of a transketolase mediated reaction; analysis of alternative modes of operation

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Sayar, N. (Ekstern), Chen, B. (Ekstern), Lye, G. (Ekstern), Woodley, J. (Intern)
Pages: 10-18
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Biochemical Engineering Journal
Volume: 47
Issue number: 1-3
ISSN (Print): 1369-703X
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 3.16
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 2.75
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 2.72
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 3.03
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 3.15
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 2.95
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Web of Science (2008): Indexed yes
Web of Science (2007): Indexed yes
Web of Science (2005): Indexed yes
Web of Science (2003): Indexed yes
Web of Science (2001): Indexed yes
Production of HMF from aqueous fructose – a microwave study

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering, Department of Chemistry, Centre for Catalysis and Sustainable Chemistry
Authors: Hansen, T. (Ekstern), Boisen, A. (Ekstern), Woodley, J. (Intern), Pedersen, S. (Ekstern), Riisager, A. (Intern)
Publication date: 2009

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Publication: Research › Journal article – Annual report year: 2009

Product limitations in a whole-cell two-liquid phase bio-oxidation

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Grant, C. (Ekstern), Baganz, F. (Ekstern), Woodley, J. (Intern)
Publication date: 2009
Event: Poster session presented at Biotrans 09, Bern, Switzerland.
Main Research Area: Technical/natural sciences
Source: orbit
Publication: Research › Sound/Visual production (digital) – Annual report year: 2009

Reactor design and selection for improved stability of immobilized amino-acid oxidase from Trigonopsis variabilis

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering
Authors: Tindal, S. (Intern), Archer, I. (Ekstern), Carr, R. (Ekstern), Farid, S. (Ekstern), Hailes, H. (Ekstern), Woodley, J. (Intern)
Publication date: 2009
Event: Poster session presented at ProStab 2009, Graz, Austria, 14-17 April, .
Main Research Area: Technical/natural sciences
Source: orbit
Publication: Research - peer-review › Poster – Annual report year: 2009

Scale-up of biocatalytic processes

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Woodley, J. (Intern)
Publication date: 2009

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 255561
Sensitivity Analysis of a Two-Enzyme One-Pot System for Production of Lactobionic Acid

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Andrade Santacoloma, P. D. G. (Intern), Sin, G. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern)
Publication date: 2009
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 252828
Publication: Research - peer-review › Poster – Annual report year: 2009

Study of Electro-membrane Filtration in Enzyme Fractionation using Amino Acid

General information
State: Published
Organisations: Membrane Technology group, Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering, Computer Aided Process Engineering Center
Authors: Yuan, L. (Intern), Korsholm, L. (Ekstern), Jakobsen, S. (Intern), Woodley, J. (Intern), Jonsson, G. E. (Intern)
Publication date: 2009
Event: Poster session presented at Membrane Science and Technology Conference of Visegrad Countries, Prague, Czech Republic.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 248172
Publication: Research - peer-review › Poster – Annual report year: 2009

Sustainable Bioprocess Synthesis Routes for Tailor-Made Chemicals

General information
State: Published
Organisations: Computer Aided Process Engineering Center, Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering, CHEC Research Centre
Authors: Swangkotchakorn, C. (Intern), Gani, R. (Intern), Woodley, J. (Intern), Grunwaldt, J. (Intern)
Publication date: 2009

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 252817
Publication: Research › Sound/Visual production (digital) – Annual report year: 2009

Sustainable Design of Chemical and Biochemical Processes: The Role of Models and Modeling

General information
State: Published
Organisations: Computer Aided Process Engineering Center, Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering
Authors: Gani, R. (Intern), Woodley, J. (Intern)
Publication date: 2009

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 248271
Publication: Research › Sound/Visual production (digital) – Annual report year: 2009
Synthesis, Design and Analysis of Downstream Separation in Chemical and Bio-Processes

General information
State: Published
Organisations: Department of Environmental Engineering, Residual Resource Engineering, Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Alvarado-Morales, M. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern), Gani, R. (Intern)
Publication date: 2009

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 252814
Publication: Research › Sound/Visual production (digital) – Annual report year: 2009

Systematic framework for modeling multi-enzymatic synthetic processes

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Authors: Andrade Santacoloma, P. D. G. (Intern), Sin, G. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern)
Publication date: 2009
Event: Poster session presented at Biotrans 09, Bern, Switzerland.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 255602
Publication: Research - peer-review › Poster – Annual report year: 2009

The influence of reaction conditions on the humin formation in microwave assisted dehydration of fructose to 5-hydroxymethylfurfural

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Jensen, J. (Ekstern), Hansen, T. (Ekstern), Riisager, A. (Ekstern), Woodley, J. (Intern)
Publication date: 2009

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 255663
Publication: Research › Sound/Visual production (digital) – Annual report year: 2009

The influence of reaction conditions on the humin formation in microwave assisted dehydration of fructose to 5-hydroxymethylfurfural

General information
State: Published
Organisations: Department of Chemistry, Centre for Catalysis and Sustainable Chemistry, Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology
Authors: Jensen, J. S. (Ekstern), Hansen, T. S. (Intern), Riisager, A. (Intern), Woodley, J. (Intern)
Publication date: 2009
Event: Abstract from 2009 World Congress on Industrial Biotechnology and Bioprocessing, Montreal, Canada.
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 2009

Tools for Biocatalytic Process Design
Using HPLC to monitor enzymatic biodiesel production

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering
Authors: Christiansen, L. (Ekstern), Vargas, C. (Ekstern), Xu, Y. (Intern), Nordblad, M. (Intern), Woodley, J. (Intern)
Publication date: 2009
Event: Poster session presented at 2nd International Congress on Biodiesel, Munich, Germany.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 255694
Publication: Research - peer-review › Poster – Annual report year: 2009

Whole-cell two-liquid phase bio-oxidation: Characterisation and evaluation of a product plateau

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Grant, C. (Ekstern), Baganz, F. (Ekstern), Woodley, J. (Intern)
Publication date: 2009
Event: Poster session presented at Young Researchers BESG Meeting, Sheffield, UK, 13 January, .
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 255558
Publication: Research - peer-review › Poster – Annual report year: 2009

A new approach to bioconversion reaction kinetic parameter identification

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering, University College London
Authors: Chen, B. H. (Ekstern), Hibbert, E. G. (Ekstern), Dalby, P. A. (Ekstern), Woodley, J. (Intern)
Pages: 2155-2163
Publication date: 2008
Main Research Area: Technical/natural sciences

Publication information
Journal: AIChE Journal
Volume: 54
Issue number: 8
ISSN (Print): 0001-1541
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.11 SJR 1.034 SNIP 1.268
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Application of mechanistic models within a PAT framework

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering, Computer Aided Process Engineering Center
Bioprocess Synthesis, Design and Analysis through a Group-Contribution Approach

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering, Computer Aided Process Engineering Center
Authors: Alvarado-Morales, M. (Intern), Terra, J. (Ekstern), Gernaey, K. (Intern), Woodley, J. (Intern), Gani, R. (Intern)
Pages: 997-1002
Publication date: 2008

CAFE methods and tools for systematic analysis of new chemical product design and development

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering, Computer Aided Process Engineering Center
Authors: Alvarado-Morales, M. (Intern), Al-Haque, N. (Intern), Gernaey, K. (Intern), Woodley, J. (Intern), Gani, R. (Intern)
Pages: 761-767
Publication date: 2008

Characterization of enzymatic D-xylulose 5-phosphate synthesis

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering, University College London, Sigma-Aldrich Co. Ltd., Sigma-Aldrich Chemie GmbH
Authors: Shaeri, J. (Ekstern), Wright, I. (Ekstern), Rathbone, E. B. (Ekstern), Wohlgemuth, R. (Ekstern), Woodley, J. (Intern)
Pages: 761-767
Publication date: 2008
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 4.14 SJR 1.411 SNIP 1.163
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.613 SNIP 1.37 CiteScore 4.44
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.589 SNIP 1.401 CiteScore 4.16
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.621 SNIP 1.425 CiteScore 4.44
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.639 SNIP 1.366 CiteScore 4.04
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.668 SNIP 1.483 CiteScore 4.08
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.538 SNIP 1.357
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.491 SNIP 1.356
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.238 SNIP 1.288
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.368 SNIP 1.362
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.458 SNIP 1.43
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.123 SNIP 1.239
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 1.094 SNIP 1.249
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 1.041 SNIP 1.228
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 1.197 SNIP 1.278
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 1.07 SNIP 1.177
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 1.102 SNIP 1.541
Web of Science (2000): Indexed yes
Scopus rating (1999): SJR 1.511 SNIP 1.567

Original language: English

DOIs:
10.1002/bit.21949
Design tools to evaluate the implementation of biocatalysis in pharmaceutical processes

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Woodley, J. (Intern)
Publication date: 2008

Development of sustainable chemical processes

General information
State: Published
Organisations: Computer Aided Process Engineering Center, Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering
Authors: Gani, R. (Intern), Woodley, J. (Intern)
Publication date: 2008

EHS & LCA assessment for 7-ACA synthesis: A case study for comparing biocatalytic & chemical synthesis

A Green Technology Comparison framework incorporating a life cycle approach and sustainability metrics has been used to compare the performance, and the environment, health, safety, and life cycle impacts of two synthetic methods used to produce 7-aminocephalosporic acid (7-ACA). The routes under study were a chemical synthetic process and a two-enzyme catalyzed process, both starting from the potassium salt of cephalosporin C. Cradle-to-gate life cycle impact estimations were performed using the Fast Life Cycle Assessment of Synthetic Chemistry (FLASC™) tool and following modular gate-to-gate methodology. The results compare the synthetic efficiency, environment, health, safety, and life cycle metrics for a mature chemical process and a more recent but less developed enzymatic process for making 7-ACA. The chemical process has a higher yield, but a significantly lower reaction mass efficiency and half the mass productivity of the enzymatic process. The chemical process uses more hazardous materials and solvents and requires about 25% more process energy than the enzymatic process. When accounting for the cradle-to-gate environmental life cycle, the chemical process has a larger overall environmental impact, mainly derived from the production of raw materials. In comparison to the enzyme-catalyzed process, the chemical process uses approximately 60% more energy, about 16% more mass (excluding water), has double the greenhouse gas (GHG) impact, and about 30% higher photochemical ozone creation potential (POCP) and acidification impact.

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Pages: 180-192
Publication date: 2008
Main Research Area: Technical/natural sciences
Future directions for in-situ product removal (ISPR)

This paper summarizes the main findings of a round-table discussion held to examine the key bottlenecks in the further application and industrial implementation of in-situ product removal (ISPR) techniques. It is well established that ISPR can yield great benefits for processes limited by inhibitory or toxic products, as well as unstable products or reactions that are thermodynamically unfavorable. However, several issues for industrial implementation were revealed in the discussion. Most notably implementation will be dependent on (1) research into the appropriate process structure, (2) methods to achieve process robustness, (3) systematic selection methods for separation operations and (4) the nature of the product market. Here, these four issues will be discussed as a basis for future work in this area.

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering, Xendo Manufacturing BV, Delft University of Technology
Authors: Woodley, J. (Intern), Bisschops, M. (Ekstern), Straathof, A. J. J. (Ekstern), Ottens, M. (Ekstern)
Pages: 121-123
Publication date: 2008
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Chemical Technology and Biotechnology
Volume: 83
Issue number: 2
ISSN (Print): 0268-2575
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Grøn kemi via hvid bioteknologi

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Woodley, J. (Intern)
Pages: 12-14
Publication date: 2008
Main Research Area: Technical/natural sciences

downstream processing, in-situ product removal, process integration

DOIs:
10.1002/jctb.1790
Source: orbit
Source-ID: 221521
Publication: Research - peer-review › Journal article – Annual report year: 2008
Industrial biocatalysis - a new era

Mechanistic models for evaluation of alternative fermentation control strategies within a PAT framework

Model visualization for evaluation of biocatalytic processes
New opportunities for biocatalysis: making pharmaceutical processes greener

The pharmaceutical industry requires synthetic routes to be environmentally compatible as well as to fulfill the demands of process economics and product specification and to continually reduce development times. Biocatalysis has the potential to deliver ‘greener’ chemical syntheses, and in this review some of these opportunities are outlined and outstanding challenges presented. Future development will require research targeted towards increased commercial availability of key enzymes, as well as the improvement of enzyme stability and substrate repertoire, to fully realize the potential of biocatalysis for making pharmaceutical processes greener.

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Woodley, J. (Intern)
Pages: 321-327
Publication date: 2008
Main Research Area: Technical/natural sciences

Publication information
Journal: Trends in Biotechnology
Volume: 26
Issue number: 6
ISSN (Print): 0167-7799
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 9.97 SJR 4.037 SNIP 3.143
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 4.091 SNIP 3.391 CiteScore 9.72
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 4.344 SNIP 3.35 CiteScore 10.31
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 3.763 SNIP 3.151 CiteScore 10.5
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 3.353 SNIP 3.083 CiteScore 9.77
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 3.321 SNIP 3.05 CiteScore 9.82
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 3.062 SNIP 2.734
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 2.751 SNIP 2.682
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 2.509 SNIP 2.185
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 2.361 SNIP 2.393
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 2.149 SNIP 2.196
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.911 SNIP 2.109
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 1.797 SNIP 1.762
Quantification of kinetics for enzyme-catalysed reactions: implications for diffusional limitations at the 10 ml scale

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Matosevic, S. (Ekstern), Micheletti, M. (Ekstern), Woodley, J. (Intern), Lye, G. J. (Ekstern), Baganz, F. (Ekstern)
Pages: 995-1000
Publication date: 2008
Main Research Area: Technical/natural sciences

Publication information
Journal: Biotechnology Letters
Volume: 30
Issue number: 6
ISSN (Print): 0141-5492
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.61 SNIP 0.721 CiteScore 1.89
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.591 SNIP 0.673 CiteScore 1.66
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.627 SNIP 0.809 CiteScore 1.75
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.713 SNIP 0.941 CiteScore 2.03
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.758 SNIP 0.949 CiteScore 2.03
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.722 SNIP 0.912 CiteScore 1.97
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.698 SNIP 0.894
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.707 SNIP 0.816
Web of Science (2009): Indexed yes
Scale-up issues for chemo-enzymatic processes

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Woodley, J. (Intern)
Publication date: 2008

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 211071
Publication: Research - peer-review › Journal article – Annual report year: 2008

Scale-up of biocatalytic processes

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Woodley, J. (Intern), Gernaey, K. (Intern)
Publication date: 2008

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 231442
Publication: Research › Sound/Visual production (digital) – Annual report year: 2008

Stability of immobilised amino acid oxidase from Trigonopsis variabilis

General information
State: Published
The First 200-L Scale Asymmetric Baeyer–Villiger Oxidation Using a Whole-Cell Biocatalyst

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering, University College London, Sigma-Aldrich Chemie GmbH
Authors: Baldwin, C. (Ekstern), Wohlgemuth, R. (Ekstern), Woodley, J. (Intern)
Pages: 660-665
Publication date: 2008
Main Research Area: Technical/natural sciences

Publication information
Journal: Organic Process Research and Development
Volume: 12
Issue number: 4
ISSN (Print): 1083-6160
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.48 SJR 1.062 SNIP 0.859
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.318 SNIP 1.029 CiteScore 2.54
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.027 SNIP 0.99 CiteScore 2.38
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.13 SNIP 0.977 CiteScore 2.44
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.185 SNIP 1.12 CiteScore 2.32
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.212 SNIP 0.914 CiteScore 2.22
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.114 SNIP 0.97
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.046 SNIP 0.922
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.943 SNIP 0.901
Web of Science (2008): Indexed yes
Tools for implementing biocatalytic processes

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Woodley, J. (Intern)
Publication date: 2008

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 231443
Publication: Research › Poster – Annual report year: 2007

Accelerating biocatalytic process design: Integrating new tools from biology, chemistry and engineering

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Baganz, F. (Ekstern), Chen, B. (Ekstern), Dalby, P. (Ekstern), Hailes, H. (Ekstern), Hibbert, E. (Ekstern), Kaulmann, U. (Ekstern), Lye, G. (Ekstern), Micheletti, M. (Ekstern), Smith, M. (Ekstern), Smithies, K. (Ekstern), Ward, J. (Ekstern), Woodley, J. (Intern)
Publication date: 2007
Event: Poster session presented at Biochemical Engineering XV, Quebec City, Canada,
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202612
Publication: Research › Poster – Annual report year: 2007
Biocatalysis

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Woodley, J. (Intern)
Pages: 1053-1054
Publication date: 2007
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Chemical Technology and Biotechnology
Volume: 82
Issue number: 12
ISSN (Print): 0268-2575
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.843 SNIP 1.111 CiteScore 2.94
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.8 SNIP 0.967 CiteScore 2.55
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.942 SNIP 1.03 CiteScore 2.49
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.027 SNIP 1.196 CiteScore 2.82
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.136 SNIP 1.146 CiteScore 2.58
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.981 SNIP 0.963 CiteScore 2.28
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.887 SNIP 0.896
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.843 SNIP 0.941
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.805 SNIP 1.019
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.625 SNIP 0.856
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.676 SNIP 0.915
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.595 SNIP 0.921
Biocatalysis for Chemical Synthesis: Green and Clean Catalysis

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Woodley, J. (Intern)
Pages: 42-43
Publication date: 2007
Main Research Area: Technical/natural sciences

Publication information
Journal: G.I.T. Laboratory Journal
Volume: 11
Issue number: 9-10
Original language: English
Source: orbit
Source-ID: 203103
Publication: Communication › Journal article – Annual report year: 2007

Biocatalysis for pharmaceutical intermediates: the future is now
Biocatalysis is continuing to gain momentum and is now becoming a key component in the toolbox of the process chemist, with a place alongside chemocatalysis and chromatographic separations. The pharmaceutical industry demands a speed of development that must be on a parallel with conventional chemistry and high optical purity for complex compounds with multiple chiral centres. This review describes how these demands are being addressed to make biocatalysis successful, particularly by the use of micro-scale technology for high-speed catalyst screening and process development alongside discipline integration of biology and engineering with chemistry. Developments in recombinant technology will further expand the repertoire of biocatalysis in the coming years to new chemistries and enable catalyst design to fit the process. Further development of biocatalysis for green chemistry and high productivity processes can also be expected.

General information
State: Published
Organisations: University College London
Authors: Pollard, D. (Ekstern), Woodley, J. (Intern)
Pages: 66-73
Publication date: 2007
Main Research Area: Technical/natural sciences

Publication information
Journal: Trends in Biotechnology
Volume: 25
Issue number: 2
ISSN (Print): 0167-7799
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 9.97 SJR 4.037 SNIP 3.143
Biocatalytic synthesis of a biodegradable chelant (S,S-EDDS)

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Law, H. (Ekstern), Woodley, J. (Intern)
Publication date: 2007

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Chemoenzymatic synthesis of structurally diverse compounds

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Coward, L. (Ekstern), Smith, M. (Ekstern), Hibbert, E. (Ekstern), Woodley, J. (Intern), Hailes, H. (Ekstern), Dalby, P. (Ekstern)
Publication date: 2007
Event: Poster session presented at 8th International Symposium on Biocatalysis and Biotransformations, Oviedo, Spain.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202611
Publication: Research › Poster – Annual report year: 2007

EHS and LCA comparison of biocatalytic and chemical processes for the production of 7-ACA

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Publication date: 2007
Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202613
Publication: Research › Sound/Visual production (digital) – Annual report year: 2007

High throughput screening for novel substrate specificity of an L-aminoacylase

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Parker, B. (Ekstern), R., L. (Ekstern), IN, T. (Ekstern), Woodley, J. (Intern)
Publication date: 2007
Event: Poster session presented at 8th International Symposium on Biocatalysis and Biotransformations, Oviedo, Spain.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202610
Publication: Research › Poster – Annual report year: 2007

Integration of biocatalytic conversions into chemical synthesis

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering, University College London
Authors: Hailes, H. C. (Ekstern), Dalby, P. A. (Ekstern), Woodley, J. (Intern)
Pages: 1063-1066
Publication date: 2007
Main Research Area: Technical/natural sciences
Publication information
Journal: Journal of Chemical Technology and Biotechnology
Volume: 82
Issue number: 12
ISSN (Print): 0268-2575
Modelling and optimisation of a transketolase mediated carbon-carbon bond formation reaction

In this paper, we have integrated process characterisation and reaction kinetic data for a transketolase catalysed carbon-carbon bond formation to build a comprehensive reaction model. Based on the synthesis of erythulose from beta-hydroxypyruvate and glycolaldehyde, the model includes component degradation as a function of time and concentration as well as glycolaldehyde toxicity towards the enzyme. Using the ratio of initial substrate concentration as a process variable, simulations and analysis based on this model allowed process options to be evaluated. The model links
bioconversion to upstream fermentation for enzyme production and downstream product purification and this could provide guidelines for process development. (c) 2007 Elsevier Ltd. All rights reserved.
Using biocatalysis for some chemical synthesis steps has unique advantages such as achieving higher product selectivity under ambient process conditions. However, a common limitation with such systems is the inhibition or toxicity posed by the starting substrate as well as limited aqueous solubility in many cases. In this review, we discuss the supply of substrate to bioconversions. The delivery of substrate via an auxiliary, which may be water-miscible, or a second phase such as a water-immiscible organic solvent, adsorbing resin, or a gas, is examined through recent examples in the field. Finally, guidelines for experimental planning and process considerations are suggested to facilitate the choice of substrate delivery method and accelerate process development.
Systematic evaluation of alternative biocatalyst forms for asymmetric carbon-carbon bond formation

General information
State: Published
Organisations: Center for BioProcess Engineering, Department of Chemical and Biochemical Engineering
Authors: Chen, B. (Ekstern), Matosevic, S. (Ekstern), Micheletti, M. (Ekstern), Woodley, J. (Intern), Baganz, F. (Ekstern), Lye, G. (Ekstern)
Publication date: 2007
Systematic evaluation of alternative biocatalytic synthetic routes to D-xylulose-5-phosphate

A dual resin concept for overcoming substrate / product inhibition during biocatalytic processes

A hybrid approach to bioreaction kinetic parameter estimation

Biocatalysis – at the interface of engineering, molecular biology and chemistry
Biocatalytic and organocatalytic approaches to ketodiols and aminodiols

General information
Organisations: University College London
Authors: Smith, M. (Ekstern), Smithies, K. (Ekstern), Hibbert, E. (Ekstern), Kaulmann, U. (Ekstern), Senussi, T. (Ekstern), Costelloe, S. (Ekstern), Hailes, H. (Ekstern), Dalby, P. (Ekstern), Ward, J. (Ekstern), Woodley, J. (Intern)
Publication date: 2006
Event: Poster session presented at IUPAC International Conference of Biodiversity and Natural Products, Kyoto, Japan.
Main Research Area: Technical/natural sciences
Source-ID: 202757
Publication: Research › Sound/Visual production (digital) – Annual report year: 2006

Biocatalytic process evaluation using microscale processing techniques and process modelling

General information
Organisations: University College London
Authors: Chen, B. (Ekstern), Micheletti, M. (Ekstern), Sayar, A. (Ekstern), Dalby, P. (Ekstern), Baganz, F. (Ekstern), Lye, G. (Ekstern), Woodley, J. (Intern)
Publication date: 2006
Event: Poster session presented at 6th European Symposium on Biochemical Engineering Science, Salzburg, Austria.
Main Research Area: Technical/natural sciences
Source-ID: 202749
Publication: Research › Poster – Annual report year: 2006

Biocatalytic reaction development for synthetic chemistry

General information
Organisations: University College London
Authors: Hailes, H. (Ekstern), Woodley, J. (Intern)
Pages: 3-4
Publication date: 2006
Main Research Area: Technical/natural sciences
Publication information
Journal: Chemistry Today
Volume: 24
Original language: English
Source-ID: 202748
Publication: Research › Poster – Annual report year: 2006

Choice of biocatalyst form for scalable processes

The design of biocatalytic processes for industrial synthetic chemistry is determined in large part by the choice of isolated enzyme of whole-cell catalyst form. In the present paper, the considerations for choice are identified and some important classes of bioconversion are discussed in relation to the choice to be made. Recent developments in cell and protein engineering as well as reactor and process engineering are discussed in addition.

General information
Organisations: University College London
Authors: Woodley, J. (Intern)
Pages: 301-303
Publication date: 2006
Conference: Biochemical Society Focused Meetings, 01/01/2006
Main Research Area: Technical/natural sciences
Combining organocatalysis and enzyme catalysis: Carbon-carbon bond formation followed by amination

General information
State: Published
Organisations: University College London
Authors: Smithies, K. (Ekstern), Kaulmann, U. (Ekstern), Smith, M. (Ekstern), Ward, J. (Ekstern), Woodley, J. (Intern), Hailes, H. (Ekstern)
Publication date: 2006
Main Research Area: Technical/natural sciences
Source: orbit
Fluid mixing in shaken bioreactors: Implications for scale-up predictions from microlitre scale microbial and mammalian cell cultures

General information
State: Published
Organisations: Unknown
Authors: Micheletti, M. (Ekstern), Barrett, T. (Ekstern), Doig, S. (Ekstern), Baganz, F. (Ekstern), Levy, M. (Ekstern), Woodley, J. (Intern), Lye, G. (Ekstern)
Publication date: 2006

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202756
Publication: Research › Sound/Visual production (digital) – Annual report year: 2006

Fluid mixing in shaken bioreactors: Implications for scale-up predictions from microlitre scale microbial and mammalian cell cultures

Pressures on pharmaceutical companies to speed bioprocess development have led to significant interest in small scale, parallel experimentation. A particular focus is cell cultivation and the optimisation of protein synthesis because of the number of biological and engineering variables involved. In this work, we briefly review the current understanding of mixing and mass transfer phenomena in shaken bioreactors with a view to defining criteria for the scale-up of results obtained in shaken microwell systems to conventional laboratory scale. Scale-tip approaches are illustrated for two different cell cultures. The first involves an automated microscale process (1000 µL) for the aerobic fermentation of E. coli JM107-pQR706 overexpressing transketolase (TK) which is subsequently used for asymmetric carbon-carbon bond formation. The kinetics of both the fermentation and bioconversion stages are first quantified as a function of fermentation medium composition (LB or LB-glycerol) and shaking frequency with oxygen transfer rates being identified as rate limiting in certain cases. Successful scale-up of the microwell process (in terms of maximum cell growth rate, biomass yield and specific TK activity) to a 1.41 scale mechanically stirred bioreactor is then demonstrated based on experiments performed at constant k(L)a values. The second process investigated involved antibody production in suspension cultures of VPM8 hybridoma cells. Initial results suggest that experiments performed at constant mean energy dissipation rates provide a satisfactory basis for scale translation from shaken microwells (800 µL) to conical flasks (100 ml) and are indicative of results obtained in a mechanically stirred bioreactor (3.51). Overall this work provides an initial insight into the engineering characterisation of shaken bioreactors and how key parameters may be used to define suitable scale-up criteria for different cell cultures. (c) 2005 Elsevier Ltd. All rights reserved.

General information
State: Published
Organisations: University College London
Authors: Micheletti, M. (Ekstern), Barrett, T. (Ekstern), Doig, S. (Ekstern), Baganz, F. (Ekstern), Levy, M. (Ekstern), Woodley, J. (Intern), Lye, G. (Ekstern)
Pages: 2939-2949
Publication date: 2006
Main Research Area: Technical/natural sciences

Publication information
Journal: Chemical Engineering Science
Volume: 61
Issue number: 9
ISSN (Print): 0009-2509
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.05 SJR 1.037 SNIP 1.442
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.038 SNIP 1.606 CiteScore 2.96
Web of Science (2015): Indexed yes
Ketodiol and amoniodiol synthesis

General information
State: Published
Organisations: University College London
Authors: Hailes, H. (Ekstern), Smith, M. (Ekstern), Smithies, K. (Ekstern), Hibbert, E. (Ekstern), Kaulmann, U. (Ekstern), Senussi, T. (Ekstern), Costelloe, S. (Ekstern), Dalby, P. (Ekstern), Ward, J. (Ekstern), Woodley, J. (Intern)
Publication date: 2006
Microbial biocatalytic processes and their development

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern)
Pages: 1-15
Publication date: 2006
Main Research Area: Technical/natural sciences

Publication information
Journal: Advances in Applied Microbiology
Volume: 60
Ratings:
- BFI (2017): BFI-level 1
- BFI (2016): BFI-level 1
- BFI (2015): BFI-level 1
- BFI (2014): BFI-level 1
- BFI (2013): BFI-level 1
- ISI indexed (2013): ISI indexed yes
- BFI (2012): BFI-level 1
- ISI indexed (2012): ISI indexed yes
- BFI (2011): BFI-level 1
- ISI indexed (2011): ISI indexed yes
- BFI (2010): BFI-level 1
- ISI indexed (2010): ISI indexed yes
- BFI (2009): BFI-level 1
- Scopus rating (2009): SJR 0.79 SNIP 0.581
- Scopus rating (2008): SJR 0.795 SNIP 0.642
- Scopus rating (2007): SJR 0.996 SNIP 1.04
- Scopus rating (2006): SJR 0.845 SNIP 0.66
- Scopus rating (2005): SJR 0.7 SNIP 0.633
- Web of Science (2005): Indexed yes
- Scopus rating (2004): SJR 0.676 SNIP 0.71
- Scopus rating (2003): SJR 0.869 SNIP 0.895
- Scopus rating (2002): SJR 0.763 SNIP 0.433
- Scopus rating (2001): SJR 0.41 SNIP 1.046
- Scopus rating (2000): SJR 0.948
- Scopus rating (1999): SJR 0.891 SNIP 1.908
Original language: English
Source: orbit
Source-ID: 202630
Publication: Research - peer-review › Journal article – Annual report year: 2006
On oxygen limitation in a whole-cell biocatalytic Baeyer-Villiger oxidation process

In this article, a recombinant cyclohexanone monooxygenase (CHMO), overexpressed in Escherichia coli has been used to study the oxidation of bicyclo[3.2.0]-hept-2-ene-6-one to its two corresponding lactones at very high enantiomeric excess. The reaction is a useful model for the study of biocatalytic oxidations to create optically pure molecules. The major limitations to a highly productive biocatalytic oxidation in this case are oxygen supply, product inhibition, and biocatalyst stability. In this article, we investigate the effects of whole cell biocatalyst concentration on the rate of reaction at a range of scales from shake flasks to 75 L bioreactors. At low cell concentrations (< 2 g(dcw)/L) the maximum specific rate (0.65 g/(dcw)(.h)) is observed. However, at higher cell concentrations (> 2 gdcw/L), the reaction becomes oxygen limited and both the specific rate and absolute rate decrease with further increases in cell concentration. The role of oxygen limitation in reducing the rate of reaction with scale was investigated by increasing the maximum oxygen transfer rate in the reactor at a high cell concentration and observing the increase in product formation rate. We propose a qualitative model demonstrating the relationship between oxygen limitation, biocatalyst concentration, and the rate of reaction. This conceptual model will be a useful guide in the industrial scale-up of whole cell mediated Baeyer-Villiger biocatalysis.

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General information
State: Published
Organisations: University College London
Authors: Baldwin, C. V. (Ekstern), Woodley, J. (Intern)
Pages: 362-369
Publication date: 2006
Main Research Area: Technical/natural sciences

Publication information
Journal: Biotechnology and Bioengineering
Volume: 95
Issue number: 3
ISSN (Print): 0006-3592
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 4.14 SJR 1.411 SNIP 1.163
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.613 SNIP 1.37 CiteScore 4.44
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.589 SNIP 1.401 CiteScore 4.16
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.621 SNIP 1.425 CiteScore 4.44
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.639 SNIP 1.366 CiteScore 4.04
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.668 SNIP 1.483 CiteScore 4.08
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.538 SNIP 1.357
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.491 SNIP 1.356
On the influence of oxygen and cell concentration in an SFPR whole-cell biocatalytic Baeyer-Villiger oxidation process

Efficient whole cell biotransformations, in particular microbial whole cell Baeyer-Villiger oxidation with molecular oxygen, demand comprehension and optimization of the process details involved. Optimal provision of oxygen and control of bioprocess parameters are pivotal for their success. The interrelation of cell density and oxygen supply in an in situ substrate feeding and product removal (SFPR) whole cell Baeyer-Villiger oxidation process was investigated in detail. Both parameters were optimized with respect to practical considerations. The outcome of this study supports a schematic process model, allows estimation of optimum process conditions and exploration of its limits. (c) 2006 Wiley Periodicals, Inc.
Process limitations in a whole-cell catalysed oxidation: sensitivity analysis

Biocatalytic oxidation processes have to date presented major problems for scale-up, in part due to the complexity of the number of process variables. In this paper we have analysed the key limitations in such processes using the Baeyer-Villiger monooxygenase catalysed synthesis of optically pure lactones as an illustrative example. Limitations in product concentration, catalyst longevity and reaction rate were quantified and their effect on previously defined process metrics identified. Of particular interest is the way these metrics change with catalyst concentration. Using this assessment, the
sensitivity of the metrics to potential changes to process and catalyst were analysed. We believe such an analysis is of general use to guide development efforts for a given biocatalytic reaction. (c) 2006 Elsevier Ltd. All rights reserved.
Reaction modelling and simulation to assess the integrated use of transketolase and ω-transaminase for the synthesis of an aminotriol

The most attractive, as well as challenging, multistep organic syntheses would preferably be carried out in a single reactor, as a one-pot synthesis. For biocatalytic syntheses, multistep reactions in one-pot mode bring a number of advantages, while at the same time raising unique challenges such as the compatibility of different biocatalysts. In this paper, we have developed a transketolase-transaminase (TK-TAm) two-step one-pot aminotriol synthesis reaction model, which integrates reaction kinetic models with process characterization (consisting of component degradation as a function of pH and concentration, aldehyde toxicity towards the enzyme, and ketol donor and acceptor side-reactions with TAm). Based on the analysis of the effect of the TAm/TK activity ratio on product yield, simulations provided guidance for further process and biocatalyst development.

General information
State: Published
Organisations: University College London
Authors: Chen, B. (Ekstern), Sayar, A. (Ekstern), Kaulmann, U. (Ekstern), Dalby, P. (Ekstern), Ward, J. (Ekstern), Woodley, J. (Intern)
Pages: 449-457
Publication date: 2006
Main Research Area: Technical/natural sciences

Publication information
Journal: Biocatalysis and Biotransformation
Volume: 24
Issue number: 6
ISSN (Print): 1024-2422
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.274 SNIP 0.366 CiteScore 0.76
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.293 SNIP 0.376 CiteScore 0.89
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.311 SNIP 0.492 CiteScore 0.8
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.369 SNIP 0.531 CiteScore 1.08
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.358 SNIP 0.586 CiteScore 0.94
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
Reactor modelling and simulation to assess operation using transketolase and ω-transaminase for the synthesis of aminodiols

General information
State: Published
Organisations: University College London
Authors: Chen, B. (Ekstern), Kaulmann, U. (Ekstern), Dalby, P. (Ekstern), Ward, J. (Ekstern), Woodley, J. (Intern)
Publication date: 2006

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202755
Publication: Research › Sound/Visual production (digital) – Annual report year: 2006

Scale-up issues for whole-cell biocatalytic oxidation

General information
State: Published
Organisations: Unknown
Authors: Woodley, J. (Intern)
Publication date: 2006

Publication information
Original language: English
Semi-quantitative process screening for the biocatalytic synthesis of D-xylulose 5-phosphate

General information
State: Published
Organisations: Sigma-Aldrich Chemie GmbH, University College London
Authors: Shaeri, J. (Ekstern), Wohlgemuth, R. (Ekstern), Woodley, J. (Intern)
Pages: 605-610
Publication date: 2006
Main Research Area: Technical/natural sciences

Publication information
Journal: Organic Process Research And Development
Volume: 10
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.48 SJR 1.062 SNIP 0.859
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.318 SNIP 1.029 CiteScore 2.54
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.027 SNIP 0.99 CiteScore 2.38
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.13 SNIP 0.977 CiteScore 2.44
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.185 SNIP 1.12 CiteScore 2.32
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.212 SNIP 0.914 CiteScore 2.22
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.114 SNIP 0.97
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.046 SNIP 0.922
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.943 SNIP 0.901
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.012 SNIP 0.875
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.083 SNIP 0.882
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.847 SNIP 0.821
Scopus rating (2004): SJR 0.701 SNIP 0.787
Tools for rapid biocatalytic process development

General information
State: Published
Organisations: Unknown
Authors: Woodley, J. (Intern)
Publication date: 2006

Towards a two-step enzymatic system for chiral aminodiol formation

General information
State: Published
Organisations: Unknown
Authors: Kaulmann, U. (Ekstern), Smithies, K. (Ekstern), Smith, M. (Ekstern), Woodley, J. (Intern), Ward, J. (Ekstern)
Publication date: 2006

Transketolase mediated carbon-carbon bond synthesis

General information
State: Published
Organisations: Unknown
Authors: Chen, B. (Ekstern), Sayar, A. (Ekstern), Micheletti, M. (Ekstern), Lye, G. (Ekstern), Woodley, J. (Intern)
Publication date: 2006

Automated microscale process evaluation of recombinant biocatalyst libraries

General information
State: Published
Organisations: Technical University of Denmark
Authors: Micheletti, M. (Ekstern), Hibbert, E. (Ekstern), Kaulmann, U. (Ekstern), Dalby, P. (Ekstern), Ward, J. (Ekstern), Lye, G. (Ekstern), Woodley, J. (Intern)
Biocatalytic and organocatalytic approaches to ketodiol synthesis

General information
State: Published
Organisations: University College London
Authors: Smith, M. (Ekstern), Smithies, K. (Ekstern), Senussi, T. (Ekstern), Hibbert, E. (Ekstern), Hailes, H. (Ekstern), Dalby, P. (Ekstern), Woodley, J. (Intern)
Publication date: 2005
Event: Poster session presented at 7th International Symposium on Biocatalysis and Biotransformations, Delft, Netherlands.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202807
Publication: Research › Poster – Annual report year: 2005

Catalyst choice: intact cell or isolated enzyme

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern)
Publication date: 2005
Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202761
Publication: Research › Sound/Visual production (digital) – Annual report year: 2005

Chemoenzymatic approaches to aminodiols

General information
State: Published
Organisations: University College London
Authors: Smithies, K. (Ekstern), Smith, M. (Ekstern), Senussi, T. (Ekstern), Hailes, H. (Ekstern), Dalby, P. (Ekstern), Woodley, J. (Intern)
Publication date: 2005
Event: Poster session presented at Frontiers in Chemical Biology, Exeter, UK.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202759
Publication: Research › Poster – Annual report year: 2005

Chemoenzymatic synthesis of aminodiols: Engineering and directed evolution of biocatalytic pathways

General information
State: Published
Organisations: University College London
Authors: Hailes, H. (Ekstern), Smith, M. (Ekstern), Smithies, K. (Ekstern), Dalby, P. (Ekstern), Ward, J. (Ekstern), Woodley, J. (Intern)
Publication date: 2005
Publication information
Original language: English
Main Research Area: Technical/natural sciences
Comparison of cyclohexanone monooxygenase as an isolated enzyme and whole cell biocatalyst for the enantioselective oxidation of 1,3-dithiane

General information
State: Published
Organisations: Consiglio Nazionale delle Ricerche, Università degli Studi di Milano, University College London
Authors: Zambianchi, F. (Ekstern), Raimondi, S. (Ekstern), Pasta, P. (Ekstern), Carrea, G. (Ekstern), Gaggero, N. (Ekstern), Woodley, J. (Intern)
Pages: 165-171
Publication date: 2005
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Molecular Catalysis B: Enzymatic
Volume: 31
Original language: English
Source: orbit
Source-ID: 202639
Publication: Research - peer-review › Journal article – Annual report year: 2005

Directed evolution of biocatalytic processes

General information
State: Published
Organisations: University College London
Authors: Hibbert, E. G. (Ekstern), Baganz, F. (Ekstern), Hailes, H. C. (Ekstern), Ward, J. M. (Ekstern), Lye, G. J. (Ekstern), Woodley, J. (Intern), Dalby, P. A. (Ekstern)
Pages: 11-19
Publication date: 2005
Main Research Area: Technical/natural sciences

Publication information
Journal: Biomolecular Engineering
Volume: 22
ISSN (Print): 1389-0344
Ratings:
BFI (2017): BFI-level 1
BFI (2016): BFI-level 1
BFI (2015): BFI-level 1
BFI (2014): BFI-level 1
BFI (2013): BFI-level 1
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
BFI (2009): BFI-level 1
BFI (2008): BFI-level 1
Web of Science (2005): Indexed yes
Scopus rating (2002): SNIP 1.328
Scopus rating (2001): SNIP 1.183
Scopus rating (2000): SNIP 0.907
Scopus rating (1999): SNIP 0.487
Original language: English
Source: orbit
Engineering and directed evolution of multi0step biocatalytic pathways in bacteria

General information
State: Published
Organisations: University College London
Authors: Smith, M. (Ekstern), Ingam, C. (Ekstern), Faulkner, S. (Ekstern), Hibbert, E. (Ekstern), Micheletti, M. (Ekstern), Kaulmann, U. (Ekstern), Hailes, H. (Ekstern), Lye, G. (Ekstern), Dalby, P. (Ekstern), Ward, J. (Ekstern), Woodley, J. (Intern), Baganz, F. (Ekstern)
Publication date: 2005
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202810
Publication: Research › Poster – Annual report year: 2005

Engineering specificity-enhanced proteases by directed evolution of bovine trypsin

General information
State: Published
Organisations: University College London
Authors: Paramesvaran, J. (Ekstern), Woodley, J. (Intern), Russel, A. (Ekstern), Dalby, P. (Ekstern)
Publication date: 2005
Event: Poster session presented at Biochemical Engineering, Harrison Hot Spring, Canada, .
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202806
Publication: Research › Poster – Annual report year: 2005

Faster development and evaluation of biocatalytic processes

General information
State: Published
Organisations: University College London
Authors: Micheletti, M. (Ekstern), Gill, N. (Ekstern), Chen, B. (Ekstern), Dalby, P. (Ekstern), Baganz, F. (Ekstern), Hailes, H. (Ekstern), Ward, J. (Ekstern), Lye, G. (Ekstern), Woodley, J. (Intern)
Publication date: 2005

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202760
Publication: Research › Sound/Visual production (digital) – Annual report year: 2005

Faster process development for integrating biocatalysis using scale-down and modelling

General information
State: Published
Organisations: University College London
Authors: Lye, G. (Ekstern), Woodley, J. (Intern)
Publication date: 2005

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202813
Publication: Research › Sound/Visual production (digital) – Annual report year: 2005
High throughput identification of novel biocatalysts using LC/MS

General information
State: Published
Organisations: University College London
Authors: Smithies, K. (Ekstern), Smith, M. (Ekstern), Senussi, T. (Ekstern), Hailes, H. (Ekstern), Dalby, P. (Ekstern), Woodley, J. (Intern)
Publication date: 2005
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202762
Publication: Research › Poster – Annual report year: 2005

In-situ product removal (ISPR): Principles and Perspectives

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern)
Publication date: 2005

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 205677
Publication: Research › Sound/Visual production (digital) – Annual report year: 2005

One-pot synthesis and the integration of chemical and biocatalytic conversions

General information
State: Published
Organisations: University College London
Authors: Dalby, P. (Ekstern), Lye, G. (Ekstern), Woodley, J. (Intern)
Pages: 419-428
Publication date: 2005

Host publication information
Title of host publication: Handbook of Chiral Chemicals
Place of publication: Boca Raton
Publisher: CRC Press
Edition: 2
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202623
Publication: Research - peer-review › Book chapter – Annual report year: 2005

Tools for the evaluation of biocatalytic processes

General information
State: Published
Organisations: Unknown
Authors: Woodley, J. (Intern)
Publication date: 2005

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202809
Publication: Research › Sound/Visual production (digital) – Annual report year: 2005
Towards a scaleable CHMO catalysed method for the synthesis of optically pure lactones

General information
State: Published
Organisations: Unknown
Authors: Woodley, J. (Intern)
Publication date: 2005

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202805
Publication: Research › Sound/Visual production (digital) – Annual report year: 2005

An alternative bioreactor concept for application of an isolated oxidoreductase for asymmetric ketone reduction
In this paper an isolated NADH dependent ketone reductase has been used to synthesise (S)-6-bromo-beta-tetralol from 6-bromo-beta-tetralone, together with commercially available formate dehydrogenase (FDH) as a recycle enzyme to produce preparative quantities of the product. Furthermore, initial experiments indicate potential for an alternative bioreactor concept via the use of a resin (XAD L-323) to bind the product (and residual substrate) of the conversion rather than the cofactors or enzymes, thus allowing a new method of recycle, potentially overcoming existing problems. (C) 2003 Published by Elsevier Ltd.

General information
State: Published
Organisations: University College London, Merck Research Laboratories
Authors: Shorrock, V. (Ekstern), Chartrain, M. (Ekstern), Woodley, J. (Intern)
Pages: 781-788
Publication date: 2004
Main Research Area: Technical/natural sciences

Publication information
Journal: Tetrahedron
Volume: 60
Issue number: 3
ISSN (Print): 0040-4020
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.907 SNIP 0.742 CiteScore 2.54
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.954 SNIP 0.84 CiteScore 2.72
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.971 SNIP 0.905 CiteScore 2.79
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.101 SNIP 0.92 CiteScore 2.85
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.32 SNIP 0.999 CiteScore 2.89
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.476 SNIP 1.094 CiteScore 3.22
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.508 SNIP 1.065
Baeyer-Villiger monooxygenase biocatalysis: Comparison of whole cell and isolated enzyme based processes

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern)
Publication date: 2004

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202862
Publication: Research › Sound/Visual production (digital) – Annual report year: 2004

Characterisation of a Reaction to Produce a Biodegradable Chelant by a Carbon-Nitrogen Lyase

General information
State: Published
Organisations: University College London
Authors: Law, H. (Ekstern), Lewis, D. (Ekstern), Woodley, J. (Intern)
Publication date: 2004
Event: Poster session presented at 5th European Symposium on Biochemical Engineering Science, Stuttgart, Germany.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202849
Publication: Research › Poster – Annual report year: 2004

Controlled-release biocatalysis for the synthesis of D-Phenylglycine

An isolated and immobilised aminotransferase cloned from Pseudomonas stutzeri ST-201 into Escherichia coli was used to synthesise D-phenylglycine. The reaction was characterised by an unfavourable equilibrium constant and substrate inhibition. The use of a controlled-release system via the use of Amberlite (IRA 400)-adsorbed benzoylformate proved a useful technique to circumvent these issues. This resulted in a four-fold improvement in product concentration achievable to yield a final Dphenylglycine concentration of 10.25 mg/ml.
Engineering and directed evolution of multi0step biocatalytic pathways in bacteria

General information
State: Published
Organisations: Unknown
Authors: Smith, M. (Ekstern), Ingam, C. (Ekstern), Faulkner, S. (Ekstern), Hibbert, E. (Ekstern), Micheletti, M. (Ekstern), Kaulmann, U. (Ekstern), Hailes, H. (Ekstern), Lye, G. (Ekstern), Dalby, P. (Ekstern), Ward, J. (Ekstern), Woodley, J. (Intern), Baganz, F. (Ekstern)
Publication date: 2004
Event: Poster session presented at Taylor Conference: catalysis at the Interface: Challenges and Opportunities, Belfast, UK.
Main Research Area: Technical/natural sciences
Source-ID: 202860
Publication: Research - peer-review › Journal article – Annual report year: 2004

Flow Cytometric Analysis of Escherichia coli TOP10 pQR239 during a Baeyer-Villiger Monooxygenase Oxidation

General information
State: Published
Organisations: University College London
Authors: Shitu, J. (Ekstern), Chartrain, M. (Ekstern), Woodley, J. (Intern)
Publication date: 2004
Event: Poster session presented at 5th European Symposium on Biochemical Engineering Science, Stuttgart, Germany.
Main Research Area: Technical/natural sciences
Source-ID: 202851
Publication: Research › Poster – Annual report year: 2004

Investigation of the effect of Water Immiscible Liquids and Solid Particles on Oxygen Transfer Rate in Stirred Tank Bioreactors

General information
State: Published
Organisations: University College London
Authors: Fish, S. (Ekstern), Lye, G. (Ekstern), Woodley, J. (Intern)
Publication date: 2004
Event: Poster session presented at 5th European Symposium on Biochemical Engineering Science, Stuttgart, Germany.
Main Research Area: Technical/natural sciences
Source-ID: 202852
Publication: Research › Poster – Annual report year: 2004

Microscale Bioprocessing for the High Throughput Evaluation of Biocatalyst and Process Options

General information
State: Published
Organisations: University College London
Publication date: 2004
Event: Poster session presented at 5th European Symposium on Biochemical Engineering Science, Stuttgart, Germany.
Main Research Area: Technical/natural sciences
Source-ID: 202853
Publication: Research › Poster – Annual report year: 2004
On the stability of a Biocatalytic process: A case study on Enzyme-catalysed Baeyer-Villiger Reaction

General information
State: Published
Organisations: University College London
Authors: Uzir, M. (Ekstern), Bishop, S. (Ekstern), Woodley, J. (Intern)
Publication date: 2004
Main Research Area: Technical/natural sciences
Source: orbit
Publication: Research › Poster – Annual report year: 2004

Process issues for the scale-up of Baeyer-Villiger biocatalysis

General information
State: Published
Organisations: Unknown
Authors: Woodley, J. (Intern)
Publication date: 2004

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202848
Publication: Research › Sound/Visual production (digital) – Annual report year: 2004

Scale-up and process bottlenecks in the implementation of biocatalytic processes

General information
State: Published
Organisations: Unknown
Authors: Law, H. (Ekstern), Woodley, J. (Intern)
Publication date: 2004

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202847
Publication: Research › Sound/Visual production (digital) – Annual report year: 2004

Accelerated design of bioconversion processes using automated microscale processing techniques
Microscale processing techniques are rapidly emerging as a means to increase the speed of bioprocess design and reduce material requirements. Automation of these techniques can reduce labour intensity and enable a wider range of process variables to be examined. This article examines recent research on various individual microscale unit operations including microbial fermentation, bioconversion and product recovery techniques. It also explores the potential of automated whole process sequences operated in microwell formats. The power of the whole process approach is illustrated by reference to a particular bioconversion, namely the Baeyer-Villiger oxidation of bicyclo[3.2.0]hept-2-en-6-one for the production of optically pure lactones.

General information
State: Published
Organisations: University College London
Authors: Lye, G. (Ekstern), Ayazi-Shamlou, P. (Ekstern), Baganz, F. (Ekstern), Dalby, P. (Ekstern), Woodley, J. (Intern)
Pages: 29-37
Publication date: Jan 2003
Main Research Area: Technical/natural sciences
Application of a Baeyer-Villiger monooxygenase from Cunninghamamella echinulata NRRL 3655

General information
State: Published
Organisations: University College London
Authors: Whitcher, C. (Ekstern), Littlechild, J. (Ekstern), Wohlgemuth, R. (Ekstern), Woodley, J. (Intern)
Publication date: 2003

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202870
Publication: Research > Sound/Visual production (digital) – Annual report year: 2003

Characterization of a recombinant Escherichia coli TOP 10 [pQR239] whole-cell biocatalyst for stereoselective Baeyer-Villiger oxidations

General information
State: Published
Organisations: University College London
Authors: Doig, S. D. (Ekstern), Simpson, H. (Ekstern), Alphand, V. (Ekstern), Furstoss, R. (Ekstern), Woodley, J. (Intern)
Pages: 347-355
Publication date: 2003
Main Research Area: Technical/natural sciences

Publication information
Journal: Enzyme and Microbial Technology
Volume: 32
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.83 SJR 0.759 SNIP 1.025
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.85 SNIP 0.969 CiteScore 2.63
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.061 SNIP 1.214 CiteScore 3.12
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.165 SNIP 1.376 CiteScore 3.2
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.204 SNIP 1.281 CiteScore 2.78
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.062 SNIP 1.27 CiteScore 2.74
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.201 SNIP 1.565
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Kinetic studies and parameter estimation of a modelled enzyme-catalysed Baeyer-Villiger reaction

Measurement of strain-dependent toxicity in the indene bioconversion using multi-parameter flow cytometry

The bioconversion of indene to cis-(1S,2R)-indandiol, a potential key intermediate in the synthesis of Merck's HIV protease inhibitor, CRIXIVAN(TM), can be achieved using Rhodococcus, Pseudomonas putida, and Escherichia coli strains. This study reports on the application of multiparameter flow cytometry for the measurement of cytoplasmic membrane integrity and membrane depolarization as indicators of toxic effects of the substrate, product, and by-products using each of these strains. Measurements of oxygen uptake rate (OUR) and optical density (OD) as indicators of metabolic activity and biomass growth, respectively, were also made. Measurements of the cytoplasmic membrane potential, cell viability, and respiratory activity provided a sensitive set of parameters to assess toxicity in the indene bioconversion and provided the basis for process improvements and strain selection. The toxic concentrations of the substrate, product, and by-products for each strain have been determined. The results show that it is possible to accumulate cis-(1S,2R)-indandiol and cis-1-amino-2-indanol up to 20 g/L without significant negative effects on cell physiology using any of the strains tested. The Gram-negative P. putida (421-5 and GM 730) and E. coli strains were more resistant to indene and the isolated chemicals of the biotransformation than the Gram-positive Rhodococcus 124 strain, possibly due to the presence of the outer membrane and efflux pump mechanisms. P. putida GM 730 and the E. coli TDO 123 strains responded similarly to toxic effects, and the E. coli TDO 123 strain was more resistant than the P. putida 421-5 strain. In addition to the recommendations for strain selection, the identified targets for bioprocess improvement include a combination of genetic as well as process engineering approaches. (C) 2003 Wiley Periodicals, Inc.
Multi-enzymatic synthesis of xylulose 5-phosphate

General information
State: Published
Organisations: University College London
Authors: Shaeri, J. (Ekstern), Rathbone, E. (Ekstern), Wright, I. (Ekstern), Wohlgemuth, R. (Ekstern), Woodley, J. (Intern)
Publication date: 2003

Publication Information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202645
Publication: Research - peer-review › Journal article – Annual report year: 2003

Oxygen limitations in the biocatalytic BVMO catalysed synthesis of lactones

General information
State: Published
Organisations: University College London
Authors: Baldwin, C. (Ekstern), Woodley, J. (Intern)
Publication date: 2003

Publication Information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202867
Publication: Research › Sound/Visual production (digital) – Annual report year: 2003

Regiospecific naphthalene monohydroxylation by a recombinant yeast producing a P4501A1-yeast reductase fused enzyme

General information
State: Published
Organisations: University College London
Authors: Shimizu, M. (Ekstern), Lilly, M. D. (Ekstern), Woodley, J. (Intern)
Pages: 606-611
Publication date: 2003
Main Research Area: Technical/natural sciences

Publication information
Journal: Enzyme and Microbial Technology
Volume: 33
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
The ideal biocatalyst: The new approach and its application in biocatalysis process development

General information
State: Published
The role of oxygen limitation in the scale-up of biocatalytic BVMO catalysed synthesis of lactones

General information
State: Published
Organisations: Unknown
Authors: Baldwin, C. (Ekstern), Woodley, J. (Intern)
Publication date: 2003
Event: Poster session presented at 11th European Congress on Biotechnology, Basel, Switzerland.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202865
Publication: Research › Poster – Annual report year: 2003

Tools for biocatalytic process development

General information
State: Published
Organisations: Unknown
Authors: Woodley, J. (Intern)
Publication date: 2003

Tools for the rapid evaluation of process limitations using microscale experimentation

General information
State: Published
Organisations: Unknown
Authors: Ahmed, F. (Ekstern), Lye, G. (Ekstern), Woodley, J. (Intern)
Publication date: 2003
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202868
Publication: Research › Poster – Annual report year: 2003

Towards large-scale synthetic applications of Baeyer-Villiger monooxygenases

Biocatalysis is coming of age, with an increasing number of reactions being scaled-up and developed. The diversity of reactions is also increasing and oxidation reactions have recently been considered for scale-up to commercial processes. One important chemical conversion, which is difficult to achieve enantio- or enantiotopo-selectively, is the Baeyer-Villiger (BV) oxidation of ketones. Using cyclohexanone monooxygenase to catalyse the reaction produces optically pure esters and lactones with exquisite enantiomeric excess values. Recently, these enzymes and their many applications in synthetic chemistry have been explored. The scale-up of these conversions has been examined with the idea of implementing the first commercial Baeyer-Villiger monooxygenase-based process. Here, we review the state-of-the-art situation for the scale-up and exploitation of these enzymes.

General information
State: Published
Whole cell biocatalytic processes for selective oxidations by Baeyer-Villiger monoxygenases

General information
State: Published
Organisations: Unknown
Authors: Baldwin, C. (Ekstern), Woodley, J. (Intern)
Publication date: 2003

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202643
Publication: Research - peer-review › Journal article – Annual report year: 2003

A novel bioreactor concept for an isolated oxidoreductase and a poorly soluble ketone

General information
State: Published
Organisations: University College London
Authors: Shorrock, V. (Ekstern), Chartrain, M. (Ekstern), Woodley, J. (Intern)
Publication date: 2002

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202863
Publication: Research › Sound/Visual production (digital) – Annual report year: 2003

Application of multi-parameter flow cytometry using fluorescent probes to study substrate toxicity in the indene bioconversion

The bioconversion of indene to cis-(1S,2R) indandiol, a potential key intermediate in the synthesis of Merck’s HIV protease inhibitor, CRIXIVAN(TM), can be achieved using a Rhodococcus strain. This study using Rhodococcus 124 reports on the application of multiparameter flow cytometry for the measurement of cell physiological properties based on cytoplasmic membrane (CM) integrity and membrane depolarization as indicators of toxic effects of the substrate, indene.

Quantification of intact polarized CM, intact depolarized CM and permeabilized CM of a large population of bacterial cells has been conducted using specific intracellular and membrane-binding fluorescent stains. Measurements of oxygen uptake rate (OUR) and optical density (OD) as indicators of metabolic activity and biomass growth, respectively, were also made. Indene concentrations of up to 0.25 g/L (0.037 g indene/g dry cell weight) did not significantly (<5% compared to control) affect cell light-scattering properties, intact CM, membrane polarization, respiratory activity, or biomass growth. Between this value and 1.5 g/L (0.221 g indene/g dry cell weight), the changes in intact CM, respiratory activity and biomass growth were relatively insignificant (<5% compared to control), although dissipation of the membrane potential of a significant proportion of the cell population occurred at 0.50 g/L (0.074 g indene/g dry cell weight). At 2.5 g/L (0.368 g indene/g dry cell weight) there was a significant increase in the dead cell population, accompanied by changes in the extracellular cationic concentrations and substantial decrease in respiratory activity. The primary effect of indene toxicity was the disruption of the proton motive force across the cytoplasmic membrane which drives the formation of ATP. The disruption of the proton motive force may have been due to the measured changes in proton permeability across the membrane. In addition, indene may have directly inhibited the membrane-bound enzymes related to respiratory activity. The overall consequence of this was reduced respiratory activity and biomass growth. The cell physiological properties measured via flow cytometry are important for understanding the effects of toxicity at the cellular level which neither measurements of biomass growth or indandiol formation rates can provide since both are cell averaged measurements.

The technique described here can also be used as a generic tool for measuring cell membrane properties in response to toxicity of other indene-resistant strains that may be possible to use as recombinant hosts to perform the biotransformation of indene. This study has demonstrated that flow cytometry is a powerful tool for the measurement of cell physiological properties to assess solvent toxicity on whole cell biocatalysts. (C) 2002 Wiley Periodicals, Inc.
Biocatalytic process modelling to speed development

**General information**

State: Published
Organisations: University College London
Authors: Woodley, J. (Intern)
Publication date: 2002

**Publication information**

Original language: English
Main Research Area: Technical/natural sciences
**Enhanced catalytic dealkylation with whole-cell cytochrome P450**

**General information**
State: Published
Organisations: University College London
Authors: Ahmed, F. (Ekstern), Woodley, J. (Intern)
Publication date: 2002
Event: Poster session presented at International Congress on Biocatalysis, Hamburg, Germany.
Main Research Area: Technical/natural sciences

**Fed-batch bioconversion of indene to cis-indandiol**

**General information**
State: Published
Organisations: University of Birmingham, Merck & Co., Inc., University College London
Authors: Amanullah, A. (Ekstern), Hewitt, C. J. (Ekstern), Nienow, A. W. (Ekstern), Lee, C. (Ekstern), Chartrain, M. (Ekstern), Buckland, B. C. (Ekstern), Drew, S. W. (Ekstern), Woodley, J. (Intern)
Pages: 954-967
Publication date: 2002
Main Research Area: Technical/natural sciences

**Publication information**
Journal: Enzyme and Microbial Technology
Volume: 31
Ratings:
- BFI (2017): BFI-level 1
- Web of Science (2017): Indexed yes
- BFI (2016): BFI-level 1
- Scopus rating (2016): CiteScore 2.83 SJR 0.759 SNIP 1.025
- Web of Science (2016): Indexed yes
- BFI (2015): BFI-level 1
- Scopus rating (2015): SJR 0.85 SNIP 0.969 CiteScore 2.63
- Web of Science (2015): Indexed yes
- BFI (2014): BFI-level 1
- Scopus rating (2014): SJR 1.061 SNIP 1.214 CiteScore 3.12
- Web of Science (2014): Indexed yes
- BFI (2013): BFI-level 2
- Scopus rating (2013): SJR 1.165 SNIP 1.376 CiteScore 3.2
- ISI indexed (2013): ISI indexed yes
- Web of Science (2013): Indexed yes
- BFI (2012): BFI-level 2
- Scopus rating (2012): SJR 1.204 SNIP 1.281 CiteScore 2.78
- ISI indexed (2012): ISI indexed yes
- Web of Science (2012): Indexed yes
- BFI (2011): BFI-level 2
- Scopus rating (2011): SJR 1.062 SNIP 1.27 CiteScore 2.74
- ISI indexed (2011): ISI indexed yes
- Web of Science (2011): Indexed yes
- BFI (2010): BFI-level 2
- Scopus rating (2010): SJR 1.201 SNIP 1.565
- Web of Science (2010): Indexed yes
Modelling biotransformation processes to identify bottlenecks

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern)
Publication date: 2002
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202872
Publication: Research › Poster – Annual report year: 2002

Modelling of the Baeyer-Villiger monooxygenase catalysed synthesis of optically pure lactones

General information
State: Published
Organisations: University College London
Authors: Chen, B. (Ekstern), Doig, S. (Ekstern), Lye, G. (Ekstern), Woodley, J. (Intern)
Pages: 51-55
Publication date: 2002
Main Research Area: Technical/natural sciences

Publication information
Journal: Trans. IChemE. (C)
Volume: 80
Original language: English
Source: orbit
Source-ID: 202665
Publication: Research - peer-review › Journal article – Annual report year: 2002
Near-IR spectroscopic monitoring of analytes during microbially catalysed Baeyer-Villiger bioconversions

Sensitive and robust monitoring of product and reactants in a complex bioconversion stream is essential for the development of effective process-control strategies. In this contribution we report the use of near-infrared spectroscopy (at-line and on-line) to monitor a microbially catalysed Baeyer-Villiger bioconversion of a cyclic ketone to an optically pure lactone. The cyclohexanone monoxygenase-catalysed reaction is characterised by substrate (ketone) and product (lactone) inhibition of enzyme activity at relatively low concentrations. Quantitative multivariate calibration of a near-IR spectrophotometer for ketone and lactone resulted in a standard error of prediction at-line of 0.088 and 0.110 g/L and on-line of 0.130 and 0.180 g/L, respectively. The concentrations of substrate and product could be simultaneously monitored by near-IR, which had a response time of 5.0 and 0.75 min at-line and on-line, respectively. This work has indicated that near-IR spectroscopy has the potential to permit the realisation of an improved control strategy for this conversion based on these response times.
Reaction engineering of oxidative biotransformations

General information
State: Published
Organisations: Unknown
Authors: Woodley, J. (Intern)
Publication date: 2002

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Reactor operation and scale-up of whole cell Baeyer-Villiger catalysed lactone synthesis

The recombinant whole cell biocatalyst Escherichia coli TOP10 [pQR239], expressing cyclohexanone monoxygenase from Acinetobacter calcoaceticus NCIMB 9871, was used in 1.5- and 55-L fed-batch processes to oxidize bicyclo[3.2.0]hept-2-en-6-one to its corresponding regioisomeric lactones, (+)-(1S,5R)-2-oxabicyclo[3.3.0]oct-6-en-3-one and (-)-(1R,5S)-3-oxabicyclo[3.3.0]oct-6-en-2-one. By employing a bicyclo[3.2.0]hept-2-en-6-one feed rate below that of the theoretical volumetric biocatalyst activity (275μmol(·min⁻¹)·L⁻¹), the reactant concentration in the bioreactor was successfully maintained below the inhibitory concentration of 0.2-0.4 g(·L⁻¹). In this way approximately 3.5 g(·L⁻¹) of the combined regioisomeric lactones was produced with a yield of product on reactant of 85-90%. The key limitation to the process was shown to be product inhibition. This process was scaled up to 55 L, producing over 200 g of combined lactone product. Using a simple downstream process (centrifugation, adsorption to-activated charcoal, 5-fold concentration with ethyl acetate elution, and silica gel chromatography), we have shown that the two regioisomeric lactone products could be isolated and purified at this scale.
The search for the ideal biocatalyst

While the use of enzymes as biocatalysts to assist in the industrial manufacture of fine chemicals and pharmaceuticals has enormous potential, application is frequently limited by evolution-led catalyst traits. The advent of designer biocatalysts, produced by informed selection and mutation through recombinant DNA technology, enables production of process-compatible enzymes. However, to fully realize the potential of designer enzymes in industrial applications, it will be necessary to tailor catalyst properties so that they are optimal not only for a given reaction but also in the context of the industrial process in which the enzyme is applied.

General information
State: Published
Organisations: University College London
Authors: Burton, S. (Ekstern), Cowan, D. (Ekstern), Woodley, J. (Intern)
Pages: 37-45
Publication date: 2002
Main Research Area: Technical/natural sciences

Publication information
Journal: Nature Biotechnology
Volume: 20
Issue number: 1
ISSN (Print): 1087-0156
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 13.16 SJR 20.253 SNIP 6.303
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 17.892 SNIP 5.505 CiteScore 11.88
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 16.443 SNIP 5.433 CiteScore 11.4
The use of microscale processing technologies for quantification of biocatalytic Baeyer-Villiger oxidation kinetics

Microscale processing techniques would be a useful tool for the rapid and efficient collection of biotransformation kinetic data as a basis for bioprocess design. Automated liquid handling systems can reduce labor intensity while the small scale reduces the demand for scarce materials such as substrate, product, and biocatalyst. Here we illustrate this concept by establishing the use of several microwell formats (96-round, 96-deep square and 24-round well microtiter plates) for quantification of the kinetics of the E. coli TOP10 [pQR239] resting cell catalyzed Baeyer-Villiger oxidation of bicyclo[3.2.0]hept-2-en-6-one using glycerol as a source of reducing power. By increasing the biocatalyst concentration until the biotransformation rate was oxygen mass-transfer limited we can ensure that kinetic data collected are in the region away from oxygen limitation. Using a 96-round well plate the effect of substrate (bicyclo[3.2.0]hept-2-en-6-one) concentration on the volumetric CHMO activity was examined and compared to data collected from 1.5-L stirred-tank experiments. The phenomenon and magnitude of substrate inhibition, observed at the larger scale, was accurately reproduced in the microwell format. We have used this as an illustrative example to demonstrate that under adequately defined conditions, automated microscale processing technologies can be used for the collection of quantitative kinetic data. Additionally, by using the experimentally determined stoichiometry for product formation and glycerol oxidation, we have estimated the maximum oxygen transfer rates as a function of well geometry and agitation rate. Oxygen-transfer rates with an upper limit of between 33 mmol.L(-1).h(-1) (based solely on product formation) and 390 mmol.L(-1).h(-1) (based on product formation and glycerol oxidation) were achieved using a 96-square well format plate shaken at 1300
rpm operated with a static surface area to volume ratio of 320 m(2).m(-3). (C) 2002 Wiley Periodicals, Inc.
Toward efficient whole-cell catalysis containing Cytochrome P-450 for hydroxylation

Use of isolated cyclohexanone monooxygenase from recombinant Escherichia coli as a biocatalyst for Baeyer-Villiger and sulfide oxidations

The performance, in Baeyer-Villiger and heteroatom oxidations, of a partially purified preparation of cyclohexanone monooxygenase obtained from an Escherichia coli strain in which the gene of the enzyme was cloned and overexpressed was investigated. As model reactions, the oxidations of racemic bicyclo[3.2.0]hept-2-en-6-one into two regioisomeric lactones and of methyl phenyl sulphide into the corresponding (R)-sulphoxide were used. Enzyme stability and reuse, substrate and product inhibition, product removal, and cofactor recycling were evaluated. Of the various NADPH regeneration systems tested, 2-propanol/alcohol dehydrogenase from Thermoanerobium brockii appeared the most suitable because of the low cost of the second substrate and the high regeneration rate. Concerning enzyme stability, kosmotropic salts were the only additives able to improve it (e.g., half-life from 1 day in diluted buffer to 1 week in 1 M sodium sulphate) but only under storage conditions. Instead, significant stabilization under working conditions was obtained by immobilization on Eupergit C (half-life approximately 2.5 days), a procedure that made it possible to reuse the catalyst up to 16 times with complete substrate (5 g . L(-1)) conversion at each cycle. Reuse of free enzyme was also achieved in a membrane reactor but with lower efficiency. Water-organic solvent biphasic systems, which would overcome substrate inhibition and remove from the aqueous phase, where reaction takes place, the formed product, were unsuccessful because of their destabilizing effect on cyclohexanone monooxygenase. More satisfactory was continuous substrate feeding, which shortened reaction times and, very importantly, yielded in the case of bicyclo[3.2.0]hept-2-eno-6-one (10 g . L(-1)) both lactone products with high optical purity (enantiomeric excess greater than or equal to 96%), which was not the case when all of the substrate was added in a single batch. (C) 2002 Wiley Periodicals, Inc.
Use of isolated monooxygenase from recombinant E.coli as biocatalyst for Baeyer-Villiger and sulfide oxidations

General information
State: Published
Organisations: Consiglio Nazionale delle Ricerche, University College London
Authors: Zambianchi, F. (Ekstern), Pasta, P. (Ekstern), Carrea, G. (Ekstern), Collona, S. (Ekstern), Gaggero, N. (Ekstern), Woodley, J. (Intern)
Publication date: 2002
Event: Poster session presented at Applied Biocatalysis 2002, Como, Italy.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202883
Publication: Research › Poster – Annual report year: 2002

Wavelet shrinkage data processing for neural networks in bioprocess modeling

The modeling of biological systems has now become an essential prerequisite for effective bioprocess design, optimization and analysis. The difficulties present in using conventional techniques to model such a complex system make the application of artificial neural networks (ANNs) to these problems particularly attractive because of their capability for nonlinear mapping and lack of necessity for detailed mechanistic knowledge. However, building a reliable ANN model requires sufficient training data, which may be difficult when data are collected from litre-scale experiments. In this work, a bioconversion (with only limited experimental data) was firstly modeled by a radial basis function (RBF) neural network. Although the model provided a very low variance between experiment and simulation, it tended to result in oscillatory behaviour, which clearly does not reflect the accurate profile of the reaction. In order to overcome this drawback, wavelet shrinkage with biorthogonal filters was used to generate a reconstructed function using the RBF model as a base. The synthesis of N-acetyl-D-neuraminic acid by the enzymatic condensation of pyruvate with N-acetyl-D-mannosamine was used as a case study to show the effectiveness of the approach. The effects of alternative filters and border distortion are also discussed. (C) 2002 Elsevier Science Ltd. All rights reserved.

General information
State: Published
Organisations: University College London
Authors: Chen, B. (Ekstern), Woodley, J. (Intern)
Pages: 1611-1620
Publication date: 2002
Main Research Area: Technical/natural sciences

Publication information
Journal: Computers & Chemical Engineering
Volume: 26
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ISSN (Print): 0098-1354
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.39 SJR 1.008 SNIP 1.607
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.122 SNIP 1.724 CiteScore 3.04
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.184 SNIP 1.738 CiteScore 3.22
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.223 SNIP 1.776 CiteScore 3.06
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
Baeyer-Villiger monooxygenase-based biocatalytic process technology for optically pure lactone synthesis

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern)
Publication date: 2001

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202659
Publication: Research - peer-review › Journal article – Annual report year: 2002

Flow-cytometry: A valuable tool to enable process improvements in whole-cell biotransformations

General information

Large scale production of cyclohexanone monoxygenase from Escherichia coli TOP10 pQR239

General information
State: Published
Organisations: University College London
Authors: O'Sullivan, L. M. (Ekstern), Patel, S. (Ekstern), Doig, S. D. (Ekstern), Ward, J. M. (Ekstern), Woodley, J. (Intern)
Pages: 265-274
Publication date: 2001
Main Research Area: Technical/natural sciences

Publication information
Journal: Enzyme and Microbial Technology
Volume: 28
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.83 SJR 0.759 SNIP 1.025
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.85 SNIP 0.969 CiteScore 2.63
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.061 SNIP 1.214 CiteScore 3.12
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.165 SNIP 1.376 CiteScore 3.2
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.204 SNIP 1.281 CiteScore 2.78
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.062 SNIP 1.27 CiteScore 2.74
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.201 SNIP 1.565
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.305 SNIP 1.504
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.208 SNIP 1.34
Near IR monitoring of whole cell biocatalytic processes

General information
State: Published
Organisations: University College London
Authors: Bird, P. (Ekstern), Sharp, D. (Ekstern), Woodley, J. (Intern)
Publication date: 2001

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202904
Publication: Research › Sound/Visual production (digital) – Annual report year: 2001

Packed bed adsorption for the recovery of lactones from Baeyer-Villiger monooxygenase bioconversions

General information
State: Published
Organisations: University College London
Authors: Avenell, P. (Ekstern), Lye, G. (Ekstern), Woodley, J. (Intern)
Publication date: 2001
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202902
Publication: Research › Poster – Annual report year: 2001

Process evaluation and scale-up of whole-cell Baeyer-Villiger catalysts

General information
State: Published
Organisations: Unknown
Authors: Woodley, J. (Intern)
Publication date: 2001

Publication information
Original language: English
Process selection and characterisation for the biocatalytic hydration of poorly water soluble aromatic dinitriles

The biotransformation of poorly water soluble aromatic dinitriles is of industrial and scientific interest. Although processes do exist for the transformation of water soluble nitriles, such as acrylonitrile, no description of a process suitable for the large scale bio trans formation of poorly water soluble nitriles appears in the literature. In this work we illustrate a systematic design procedure for optimising the production of 3-cyanobenzamide from 1,3-dicyanobenzene (1,3-DCB). The regio-selective nitrile hydratase (NHase) of the well characterised Rhodococcus R312 strain was initially selected as catalyst. Isolation of the NHase at process scale however was not feasible due to the rigid cell wall of the bacteria and the poor stability of the isolated enzyme. The whole cell form of the biocatalyst was thus used even though the activity of the associated amidase could overmetabolise the amide product into the corresponding acid. To overcome productivity limitations imposed by the characteristically low aqueous solubility of this class of substrate (similar to 0.34 g l(-1)) in the case of 1,3-DCB) the use of an aqueous-organic two-phase bioreactor was investigated. After screening a wide range of solvents to act as a substrate reservoir toluene was selected as the organic phase due to the most favourable combination of Log P value (2.9) and 1,3-DCB saturation concentration (similar to 30 g l(-1)). The effects of phase volume ratio (0.05-0.3), wet weight biomass concentration (1.25-200 g(ww) l(-1)) and substrate concentration in the organic phase (5-25 g l(-1)) were then combined in a process map to define a suitable operating window where the maximum space-time yield of amide formation could be obtained. Compared to a sin.-le-phase transformation, the two-phase process yielded 12 times as much of the amide product of which less than 8% w/w was lost due to over-metabolism.

General information

State: Published
Organisations: University College London
Authors: Cull, S. G. (Ekstern), Woodley, J. (Intern), Lye, G. J. (Ekstern)
Pages: 131-154
Publication date: 2001
Main Research Area: Technical/natural sciences

Publication information

Journal: Biocatalysis and Biotransformation
Volume: 19
Issue number: 2
ISSN (Print): 1024-2422
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.274 SNIP 0.366 CiteScore 0.76
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.293 SNIP 0.376 CiteScore 0.89
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.311 SNIP 0.492 CiteScore 0.8
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.369 SNIP 0.531 CiteScore 1.08
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.358 SNIP 0.586 CiteScore 0.94
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.406 SNIP 0.547 CiteScore 1.07
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.415 SNIP 0.515
Web of Science (2010): Indexed yes
Production of cyclohexanone monooxygenase from Acinetobacter calcoaceticus for large scale Baeyer-Villiger monooxygenase reactions

Cyclohexanone monooxygenase was produced from Acinetobacter calcoaceticus grown on a medium containing both glutamate (30 g l(-1)) and cyclohexanol (1 g l(-1)). Productivity was increased to 650 U l(-1), an order of magnitude greater than previous production methods, thereby enhancing the potential commercial utility of this enzyme.

General information
State: Published
Organisations: Pfizer Ltd., University College London
Authors: Barclay, S. S. (Ekstern), Woodley, J. (Intern), Lilly, M. D. (Ekstern), Spargo, P. L. (Ekstern), Pettman, A. J. (Ekstern)
Pages: 385-388
Publication date: 2001
Main Research Area: Technical/natural sciences

Publication information
Journal: Biotechnology Letters
Volume: 23
Issue number: 5
ISSN (Print): 0141-5492
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.61 SNIP 0.721 CiteScore 1.89
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.591 SNIP 0.673 CiteScore 1.66
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.627 SNIP 0.809 CiteScore 1.75
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
The use of oxygen uptake rate measurements to control the supply of toxic substrate: toluene hydroxylation by Pseudomonas putida UV4

General information
State: Published
Organisations: University of Ulster, University College London
Authors: Carragher, J. M. (Ekstern), McClean, W. S. (Ekstern), Woodley, J. (Intern), Hack, C. J. (Ekstern)
Pages: 183-188
Publication date: 2001
Main Research Area: Technical/natural sciences

Publication information
Journal: Enzyme and Microbial Technology
Volume: 28
Ratings:
BFI (2017): BFI-level 1
Use of isolated cyclohexanone monooxygenase from recombinant E.coli as biocatalyst for Baeyer Villiger and sulfide oxidations
Advances in enzyme technology – UK contributions

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern)
Pages: 93-108
Publication date: 2000

Host publication information
Title of host publication: History of Modern Biotechnology II
Place of publication: Berlin
Publisher: Springer
Editors: Schepers, T., Fiecher, A.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202621
Publication: Research - peer-review › Book chapter – Annual report year: 2000

Advances in the selection and design of two-liquid phase biocatalytic reactors

General information
State: Published
Organisations: University College London
Authors: Lye, G. (Ekstern), Woodley, J. (Intern)
Pages: 115-134
Publication date: 2000

Host publication information
Title of host publication: Multiphase Bioreactor Design
Place of publication: London
Publisher: Taylor and Francis
Editors: Cabral, J., Mota, M., Tramper, J.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202622
Publication: Research - peer-review › Book chapter – Annual report year: 2001

Application of multi-parameter flow cytometry using fluorescent probes to study substrate and product toxicity in the indene bioconversion

General information
State: Published
Organisations: University College London
Authors: Amanullah, A. (Ekstern), Hewitt, C. (Ekstern), Nienow, A. (Ekstern), Lee, C. (Ekstern), Chartrain, M. (Ekstern), Buckland, B. (Ekstern), Drew, S. (Ekstern), Woodley, J. (Intern)
Publication date: 2000

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Baeyer-Villiger monooxygenase-based processes for lactone synthesis

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern), Doig, S. (Ekstern)
Publication date: 2000

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202917
Publication: Research › Sound/Visual production (digital) – Annual report year: 2000

Biocatalytic Process Selection and Design

General information
State: Published
Organisations: Unknown
Authors: Woodley, J. (Intern)
Publication date: 2000

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202919
Publication: Research › Sound/Visual production (digital) – Annual report year: 2000

Candida cloacae oxidation of long chain fatty acids to dioic acids

General information
State: Published
Organisations: University College London
Authors: Green, K. D. (Ekstern), Turner, M. K. (Ekstern), Woodley, J. (Intern)
Pages: 205-211
Publication date: 2000
Main Research Area: Technical/natural sciences

Publication information
Journal: Enzyme and Microbial Technology
Volume: 27
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.83 SJR 0.759 SNIP 1.025
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.85 SNIP 0.969 CiteScore 2.63
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.061 SNIP 1.214 CiteScore 3.12
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.165 SNIP 1.376 CiteScore 3.2
Design of a control system for biotransformation of toxic substrates: toluene hydroxylation by Pseudomonas putida UV4

**General information**

State: Published
Organisations: Astra Zeneca, University College London
Authors: Hack, C. J. (Ekstern), Woodley, J. (Intern), Lilly, M. D. (Ekstern), Liddell, J. M. (Ekstern)
Pages: 530-536
Publication date: 2000
Main Research Area: Technical/natural sciences

**Publication information**

Journal: Enzyme and Microbial Technology
Volume: 26
Ratings:

BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
Enzyme immobilisation on Eupergit C for Redox Biocatalysis

General information
Modelling of two enzyme reactions in a linked cofactor recycle system for chiral lactone synthesis

A model has been developed to describe the interaction between two enzymes in a stirred vessel. Using the model, cofactor (NADPH) recycle has been investigated by simultaneous solution of the rate equations, solved with the aid of a numerical solution. The overall general aim of this work is to increase the information available to the designer on similar biocatalytic processes so that comparisons between process options can be quantified. This model allows the optimisation of the proportion of two enzymes and total cofactor concentration needed for a satisfactory reaction rate to be achieved. A secondary use of these data is in the prediction of cofactor stability which is a strong function of pH. The model also
indicates the potential cofactor turnover number achievable, an important economic consideration. The accuracy of the model has been assessed and is in good agreement with experimental data. (C) 2000 Elsevier Science Ltd. All rights reserved.
Process options for biocatalytic Baeyer-Villiger oxidations

General information
State: Published
Organisations: Unknown
Authors: Doig, S. (Ekstern), Woodley, J. (Intern)
Publication date: 2000

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202921
Publication: Research › Sound/Visual production (digital) – Annual report year: 2000

Process technology options for biocatalytic Baeyer Villiger oxidations

General information
State: Published
Organisations: Unknown
Authors: Doig, S. (Ekstern), Woodley, J. (Intern)
Publication date: 2000

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202923
Publication: Research › Sound/Visual production (digital) – Annual report year: 2000

Reducing the environmental impact of biocatalytic processes: Case study on the use of ionic liquids with two-phase aromatic nitrile hydration

General information
State: Published
Organisations: Unknown
Authors: Cull, S. (Ekstern), Woodley, J. (Intern), Lye, G. (Ekstern), Angeli, P. (Ekstern)
Publication date: 2000
Event: Poster session presented at Biotechnology 2000, Berlin, Germany.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202916
Publication: Research › Poster – Annual report year: 2000
Alkaline biocatalysis for the direct synthesis of N-acetyl-D-neuraminic acid (Neu5Ac) from N-acetyl-D-glucosamine (GlcNAc)

Integration between the alkaline epimerization of N-acetyl-D-glucosamine (GlcNAc) to N-Acetyl-D-mannosamine (ManNAc) and the N-acetyl-D-neuraminic acid (Neu5Ac) aldolase-catalyzed biotransformation has been assessed experimentally. GlcNAc epimerization took place above pH 9.0, and the initial rate of ManNAc formation increased exponentially to 10.37 mmol/L per hour at pH 12. However, above this pH, severe degradation of pyruvate occurred. A value of 31.3% molar conversion on Pyr was achieved in an integrated biotransformation. The "pseudo"-steady state at the end of the reaction was comparable to the equilibrium achieved with a combination of an epimerase and aldolase enzymes. The integrated reaction proved feasible, but at the expense of pyruvate and Neu5Ac aldolase degradation. (C) 1999 John Wiley & Sons, Inc.
Application of flow cytometry to study substrate and product toxicity in the indene bioconversion

General information
State: Published
Organisations: University College London
Authors: Amanullah, A. (Ekstern), Hewott, C. (Ekstern), Nienow, A. (Ekstern), Chartrain, M. (Ekstern), Buckland, B. (Ekstern), Drew, S. (Ekstern), Woodley, J. (Intern)
Publication date: 1999
Event: Poster session presented at Biochemical Engineering 11, Salt Lake City, USA, .
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202691
Publication: Research - peer-review › Journal article – Annual report year: 1999

Application of in situ product-removal techniques to biocatalytic processes
Biocatalytic processes for the manufacture of small, highly functionalized molecules frequently have limited productivity. A common reason for this is the presence of the reaction products that can cause inhibitory or toxic effects (making poor use of the enzyme) or promote unfavourable equilibria (giving low conversions). In each case, the product needs to be removed as soon as it is formed in order to overcome these constraints and hence increase the productivity of the biocatalytic process. Here, we review the need for in situ product removal and the process research required for its implementation.
Biotransformations using Baeyer-Villiger Monooxygenases

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern), Furstoss, R. (Ekstern), Jensen, D. (Ekstern), Littlechild, J. (Ekstern), Carrea, G. (Ekstern), Wubbolts, M. (Ekstern), Wohlgemuth, R. (Ekstern)
Publication date: 1999

Immobilised transketolase for carbon-carbon bond synthesis: biocatalyst stability

General information
State: Published
Organisations: University College London
Authors: Brocklebank, S. (Ekstern), Woodley, J. (Intern), Lilly, M. (Ekstern)
Pages: 223-231
Publication date: 1999
Main Research Area: Technical/natural sciences

Process design implications of aldehyde properties on transketolase-catalysed condensations

Recently we have devised a systematic approach to selection and operation of biotransformation reactions. Such an approach is based on reaction characterisation leading to the identification of constraints and subsequent process synthesis. In this paper we illustrate how this approach can be applied to a model system (condensation of glycolaldehyde with beta-hydroxypyruvate by transketolase to synthesise L-erythrulose) as the basis for rapidly evaluating a second system with different aldehyde properties (condensation of racemic 3-oxy-benzylglyceraldehyde with beta-hydroxypyruvate to synthesise (3S,4R)-5-oxy-benzyl-D-xylulose). Some general conclusions are drawn.

General information
State: Published
Organisations: University College London
Authors: Mitra, R. K. (Ekstern), Woodley, J. (Intern), Lilly, M. D. (Ekstern)
Pages: 21-36
Publication date: 1999
Main Research Area: Technical/natural sciences
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.274 SNIP 0.366 CiteScore 0.76
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.293 SNIP 0.376 CiteScore 0.89
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.311 SNIP 0.492 CiteScore 0.8
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.369 SNIP 0.531 CiteScore 1.08
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.358 SNIP 0.586 CiteScore 0.94
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.406 SNIP 0.547 CiteScore 1.07
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.415 SNIP 0.515
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.455 SNIP 0.583
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.519 SNIP 0.438
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.491 SNIP 0.687
Scopus rating (2006): SJR 0.527 SNIP 0.78
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.496 SNIP 0.509
Scopus rating (2004): SJR 0.422 SNIP 0.465
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.34 SNIP 0.533
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.408 SNIP 0.457
Scopus rating (2001): SJR 0.434 SNIP 0.788
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 0.459 SNIP 0.657
Scopus rating (1999): SJR 0.565 SNIP 0.653
Original language: English
DOIs:
10.3109/10242429909003204
Source: orbit
Source-ID: 202694
Publication: Research - peer-review › Journal article – Annual report year: 1999

Process effects of by-product carbon dioxide production from transketolase-catalysed condensations
The production of carbon dioxide from transketolase-catalysed condensations has been studied. The effects of carbamate formation, carbon dioxide dissociation and gas/liquid interfacial area were evaluated as potential causes of activity loss on account of by-product carbon dioxide production. At low pH values physical effects (gas/liquid interfacial area) were dominant, while at higher pH values carbamate effects dominated. However, neither of these effects were found to lead to a significant additional activity loss under the conditions chosen. Residual activity loss was evaluated at intermediate pH
values and attributable to non-specific protein oxidation, indicating the need to operate the process under reducing conditions.
Process options for N-acetyl-D-neuraminic acid production using the aldolase enzyme

General information
State: Published
Organisations: Unknown
Authors: Dawson, M. (Ekstern), Mahmoudian, M. (Ekstern), Blayer, S. (Ekstern), Woodley, J. (Intern)
Publication date: 1999

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202967
Publication: Research › Sound/Visual production (digital) – Annual report year: 1999

Process selection for the aldolase-catalysed synthesis of N-acetyl-D-neuraminic acid

General information
State: Published
Organisations: Unknown
Authors: Woodley, J. (Intern), Dawson, M. (Ekstern)
Publication date: 1999

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202963
Publication: Research › Sound/Visual production (digital) – Annual report year: 1999

Rapid, rational selection of cofactor recycling options

General information
State: Published
Organisations: Unknown
Authors: Thomas, K. (Ekstern), Chartrain, M. (Ekstern), Woodley, J. (Intern)
Publication date: 1999
Event: Poster session presented at Enzyme Engineering 15, Kona, HI, United States.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202965
Publication: Research › Poster – Annual report year: 1999

Use of recombinant whole cells as biocatalysts in organic syntheses for stereo specific Baeyer Villiger oxidation of cyclic ketones

General information
State: Published
Organisations: Unknown
Authors: Doig, S. (Ekstern), Woodley, J. (Intern)
Publication date: 1999
Event: Poster session presented at Enzyme Engineering 15, Kona, HI, United States.
Main Research Area: Technical/natural sciences
Source: orbit
Biocatalytic Baeyer-Villiger characterisation leading to reactor design

General information
State: Published
Organisations: University College London
Authors: Hogan, M. (Ekstern), Woodley, J. (Intern), Lilly, M. (Ekstern)
Pages: 466-514
Publication date: 1998

Host publication information
Title of host publication: IChem E Research Event 1998
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 205666
Publication: Research - peer-review › Article in proceedings – Annual report year: 1998

Bioprocess applications of molecularly imprinted polymers

General information
State: Published
Organisations: University College London
Authors: Stein, A. (Ekstern), Woodley, J. (Intern), Lye, G. (Ekstern)
Publication date: 1998
Event: Poster session presented at 2nd European Symposium on Biochemical Engineering Science, Porto, Portugal.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202969
Publication: Research › Poster – Annual report year: 1998

Choice of linked NADPH regeneration enzyme for cyclohexanone monooxygenase catalysed lactone synthesis

General information
State: Published
Organisations: University College London
Authors: Hogan, M. (Ekstern), Woodley, J. (Intern)
Publication date: 1998
Event: Poster session presented at 2nd European Symposium on Biochemical Engineering Science, Porto, Portugal.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202970
Publication: Research › Poster – Annual report year: 1998

Design of feed-back control system

General information
State: Published
Organisations: University College London
Authors: Hack, C. (Ekstern), Woodley, J. (Intern)
Publication date: 1998

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202968
Publication: Research › Sound/Visual production (digital) – Annual report year: 1998
Escherichia coli transketolase-catalysed carbon-carbon bond formation: biotransformation characterization for reactor evaluation and selection

General information
State: Published
Organisations: University College London
Authors: Mitra, R. K. (Ekstern), Woodley, J. (Intern), Lilly, M. D. (Ekstern)
Pages: 64-70
Publication date: 1998
Main Research Area: Technical/natural sciences

Publication information
Journal: Enzyme and Microbial Technology
Volume: 22
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.83 SJR 0.759 SNIP 1.025
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.85 SNIP 0.969 CiteScore 2.63
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.061 SNIP 1.214 CiteScore 3.12
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.165 SNIP 1.376 CiteScore 3.2
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.204 SNIP 1.281 CiteScore 2.78
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.062 SNIP 1.27 CiteScore 2.74
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.201 SNIP 1.565
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.305 SNIP 1.504
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.208 SNIP 1.34
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.976 SNIP 1.257
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.907 SNIP 1.433
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.915 SNIP 1.429
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.847 SNIP 1.263
Scopus rating (2003): SJR 0.798 SNIP 1.218
Web of Science (2003): Indexed yes
Application of FSQ spectrophotometric multicomponent analysis to bioconversion monitoring

Spectrophotometric multicomponent analysis using the novel FSQ algorithm (Full Spectrum Quantitation) allows the rapid and accurate quantitation of complex mixtures of organic compounds. This work investigated the applicability of the FSQ method to the monitoring of substrate and product concentrations during a bioconversion. The hydroxylation of toluene to toluene-cis-glycol (TCG) by Pseudomonas putida (UV4) served as a model system for this study. The reaction is representative of the increasingly important group of biocatalyses of a toxic, poorly water-soluble substrate. Previous work has shown that it is crucial to be able to control the toluene concentration to avoid irreversible damage to the biocatalyst. After establishing a suitable analytical wavelength range (215-340 nm) and determining the linear range for absorbance, FSQ calibration was carried out with standard mixtures of the compounds. Three different systems were tested: toluene/TCG as a two-component system and toluene/TCG/bovine serum albumin and toluene/TCG/cell lysate as three-component systems. The latter accounted for UV-absorbing compounds released into the bioconversion medium due to any lysis of the biocatalyst. It was found that accurate quantitation of toluene and TCG could be achieved, even in the presence of contaminating protein or cell lysate. When monitoring biocatalyses, TCG could be accurately determined up to 18 g/L. The operability range for toluene quantitation was very narrow due to the low levels of toluene in the reactor and requirements for sample dilution (at high TCG concentrations). Additionally FSQ measurements were able to provide important information about the state of lysis of the biocatalyst. In conclusion, it should be underlined that the FSQ method provides a valuable new analytical tool and its applicability for the case studied is only limited by the nature of the biocatalysis itself. Finally its applicability to other types of biocatalysis is discussed.

General information
State: Published
Organisations: University College London

Boron based separations for in situ recovery of L-erythrulose from transketolase-catalyzed condensation

In this article we report on the application of in situ product removal (ISPR) (the concurrent recovery of a product during the product formation process) as a means of improving the productivity of bioconversions. The Escherichia coli transketolase-catalyzed condensation of glycolaldehyde with beta-hydroxypyruvate to yield L-erythrulose (and carbon dioxide) was chosen as a model system. Those ISPR methods based on phenylboronate-diol interactions showed greatest potential for use as a selective means of removing L-erythrulose from the reaction medium. Soluble, insoluble, and immobilized boronates were investigated. Concentrations of free phenylboric acid of 100 mM and above were toxic to transketolase, thus rendering the use of these methods unsuitable for ISPR. However, one of the immobilized phenylboronate resins (Affi-Gel 601(R)) was not toxic to the enzyme, although significant levels of nonspecific binding of both substrates were observed. When ISPR was performed on the model reaction using this resin with substrate feeding, it proceeded to completion. (C) 1997 John Wiley & Sons, Inc.
Increasing the productivity of bioconversion processes

General information
State: Published
Organisations: University College London
Authors: Chauhan, R. (Ekstern), Woodley, J. (Intern)
Pages: 26-30
Publication date: 1997
Main Research Area: Technical/natural sciences

Publication information
Journal: ChemTech
Volume: 27
Issue number: 6
Original language: English
Source: orbit
Source-ID: 202702
Publication: Research - peer-review › Journal article – Annual report year: 1997

Membrane separation for downstream processing of aqueous-organic bioconversions
The use of membranes to separate liquid/liquid mixtures downstream of multiphasic biocatalytic reactor has been examined. Hydrophilic and hydrophobic membranes were used to separate multiphasic organic solvent/water mixtures. It was found that one phase could be separated from the mixture as long as the breakthrough pressure, derived from the Laplace law, was not exceeded. The breakthrough pressure was found to be a function of the pore diameter and the interfacial tension. The flux through the membranes was found to be function of the volume fraction of water. Between a water volume fraction of 0.4 and 0.8, both hydrophilic and hydrophobic membranes were found to give high fluxes in the absence of surface active material. Yeast and Pseudomonas putida were used as examples of microbial material present
in liquid/liquid mixtures downstream of a multiphasic biocatalytic reactor. The fluxes of both membranes decreased upon addition of the cells to the mixture. While the hydrophilic membranes were reversibly fouled and retained acceptable fluxes, in contrast, the hydrophobic membranes were fouled irreversibly. Subsequently, the hydrophobic membranes were modified and the flux through the hydrophobic modified membrane remained high and was a function of the viscosity and solvent volume fraction. Both hydrophilic and hydrophobic membranes could also be used at high pressure when both liquids permeated the membrane. In this case, the membranes acted as coalescence filters although at a considerably reduced flux compared to low-pressure applications.
Process design for the oxidation of fluorobenzene to fluorocatechol by Pseudomonas putida

**General information**
State: Published
Organisations: University College London
Authors: Lynch, R. M. (Ekstern), Woodley, J. (Intern), Lilly, M. D. (Ekstern)
Pages: 167-175
Publication date: 1997
Main Research Area: Technical/natural sciences

**Publication information**
Journal: Journal of Biotechnology
Volume: 58
ISSN (Print): 0168-1656
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.88 SJR 0.978 SNIP 0.937
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.068 SNIP 0.987 CiteScore 2.87
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.113 SNIP 1.144 CiteScore 2.95
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.173 SNIP 1.188 CiteScore 3.22
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.255 SNIP 1.312 CiteScore 3.4
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.157 SNIP 1.064 CiteScore 2.87
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
Production of Baeyer-Villiger monooxygenase for synthetic biotransformation

General information
State: Published
Organisations: Unknown
Authors: Barclay, S. (Ekstern), Spargo, P. (Ekstern), Pettman, A. (Ekstern), Woodley, J. (Intern), Lilly, M. (Ekstern)
Pages: 981-984
Publication date: 1997

Host publication information
Title: IChemE Research Event 1997
Main Research Area: Technical/natural sciences
Conference: IChemE Research Event 1997, Rugby, Great Britain, 01/01/1997
Source: orbit
Source-ID: 205665
Publication: Research - peer-review › Article in proceedings – Annual report year: 1997

A structured approach to design and operation of biotransformation processes

General information
State: Published
Organisations: University College London
Authors: Lilly, M. (Ekstern), Woodley, J. (Intern)
Pages: 24-29
Publication date: 1996
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Industrial Microbiology
A structured approach to transketolase mediated biocatalysis

General information
State: Published
Organisations: University College London
Authors: Mitra, R. (Ekstern), Woodley, J. (Intern), Lilly, M. (Ekstern)
Publication date: 1996
Event: Poster session presented at Gordon Research Conference on Biocatalysis, Meridian, USA.
Main Research Area: Technical/natural sciences

A useful assay for transketolase in asymmetric syntheses

General information
State: Published
Organisations: University College London
Authors: Mitra, R. (Ekstern), Woodley, J. (Intern)
Pages: 167-172
Publication date: 1996
Main Research Area: Technical/natural sciences

Publication information
Journal: Biotechnology Techniques
Volume: 10
Ratings:
BFI (2008): BFI-level 1
Scopus rating (2002): SJR 0.255 SNIP 0.657
Scopus rating (2001): SJR 0.317 SNIP 0.788
Scopus rating (2000): SJR 0.273 SNIP 0.771
Scopus rating (1999): SJR 0.385 SNIP 0.611
Original language: English
Source: orbit
Source-ID: 202714
Publication: Research - peer-review › Journal article – Annual report year: 1996

Biotransformation process selection and design

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern)
Publication date: 1996

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202977
Publication: Research › Sound/Visual production (digital) – Annual report year: 1996

Carbon-carbon bond synthesis: reactor design and operation for transketolase catalyzed biotransformations

General information
State: Published
Carbon-carbon bond synthesis: preparation and use of immobilised transketolase
Carbon-carbon bond synthesis: the impact of rDNA technology on the production and use of E.coli transketolase
The characterization of the chemoenzymatic synthesis of N-acetyl-D-neuraminic acid using a base-catalyzed epimerization and Neu5Ac aldolase-catalyzed condensation is presented. The characterization has been used to exemplify a structured approach to biotransformation process design. In addition, the option of integration of the epimerization with the biotransformation (at alkaline pH) was considered. Process operating windows have been generated as a result of this approach, defining possible operating regions for subsequent scale-up.
Choice of microbial host for the naphthalene dioxygenase bioconversion

General information
State: Published
Organisations: University College London
Authors: Wilkinson, D. (Ekstern), Ward, J. (Ekstern), Woodley, J. (Intern)
Pages: 274-279
Publication date: 1996
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Industrial Microbiology
Volume: 16
Original language: English
Source: orbit
Source-ID: 202711
Publication: Research - peer-review › Journal article – Annual report year: 1996

Design of a fed-batch control system for microbial hydroxylation of toxic substrates

General information
State: Published
Organisations: University College London
Authors: Hack, C. (Ekstern), Woodley, J. (Intern), Lilly, M. (Ekstern)
Publication date: 1996
Event: Poster session presented at Biochemical Engineering Science, Dublin, Ireland.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202973
Publication: Research › Poster – Annual report year: 1996

Development of in-situ recovery techniques for product removal from transketolase catalysed reactions

General information
State: Published
Organisations: University College London
Authors: Chauhan, R. (Ekstern), Woodley, J. (Intern), Powell, L. (Ekstern)
Publication date: 1996

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202976
Enzyme-catalysed carbon-carbon bond formation: large-scale production of Escherichia coli transketolase

General information
State: Published
Organisations: University College London
Authors: Hobbs, G. (Ekstern), Mitra, R. (Ekstern), Chauhan, R. (Ekstern), Woodley, J. (Intern), Lilly, M. (Ekstern)
Pages: 173-179
Publication date: 1996
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Biotechnology
Volume: 45
ISSN (Print): 0168-1656
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.88 SJR 0.978 SNIP 0.937
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.068 SNIP 0.987 CiteScore 2.87
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.113 SNIP 1.144 CiteScore 2.95
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.173 SNIP 1.188 CiteScore 3.22
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.255 SNIP 1.312 CiteScore 3.4
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.157 SNIP 1.064 CiteScore 2.87
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.126 SNIP 1.18
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.216 SNIP 1.235
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.136 SNIP 1.265
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.132 SNIP 1.273
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.091 SNIP 1.383
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.162 SNIP 1.369
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 1.009 SNIP 1.43
In Situ Product Removal from E. coli Transketolase-catalyzed Biotransformations

General information
State: Published
Organisations: University College London, SmithKline Beecham Pharmaceuticals
Authors: Chauhan, R. P. (Ekstern), Woodley, J. (Intern), Powell, L. W. (Ekstern)
Pages: 545-554
Publication date: 1996
Main Research Area: Technical/natural sciences

Publication information
Volume: 799
ISSN (Print): 0077-8923
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 2.183 SNIP 1.393 CiteScore 4.42
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 2.38 SNIP 1.388 CiteScore 4.42
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 2.281 SNIP 1.446 CiteScore 4.37
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 2.137 SNIP 1.477 CiteScore 4.56
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.636 SNIP 1.198 CiteScore 3.61
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.533 SNIP 1.097 CiteScore 3.41
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.321 SNIP 0.905
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.17 SNIP 0.847
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.957 SNIP 0.758
Scopus rating (2007): SJR 0.879 SNIP 0.67
Scopus rating (2006): SJR 0.923 SNIP 0.696
Operating windows for scale-up of biotransformations: chemoenzymatic synthesis of N-acetyl-D-neuraminic acid

General information
State: Published
Organisations: University College London
Authors: Blayer, S. (Ekstern), Woodley, J. (Intern), Dawson, M. (Ekstern), Lilly, M. (Ekstern)
Publication date: 1996
Event: Poster session presented at 10th International Biotechnology Symposium, Sydney, Australia, .
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202773
Publication: Research › Poster – Annual report year: 1996

Select and design

General information
State: Published
Organisations: University College London, Unknown
Authors: Woodley, J. (Intern), Lilly, M. (Ekstern)
Pages: 28-30
Publication date: 1996
Main Research Area: Technical/natural sciences

Publication information
Journal: The Chemical Engineer
Volume: 611
Original language: English
Source: orbit
Source-ID: 202712
Publication: Research - peer-review › Journal article – Annual report year: 1996

The use of windows of operation as a bioprocess design tool
Bioprocess design problems are frequently multivariate and complex. However, they may be visualised by a graphical representation of the design constraints and correlations governing both the process and system under consideration, namely windows of operation. Windows of operation exist at all stages of process design and find use both in the identification of key constraints from limited information, and also, with more detailed knowledge, the sensitivity of a process to design or operating changes. In this way windows of operation may be used to help understand and optimise a bioprocess design. In this paper the formulation, development and application of windows of operation is discussed for a range of biological processes including fermentation, protein recovery and biotransformation.

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern), Titchener-Hooker, N. (Ekstern)
Pages: 263-268
Publication date: 1996
Main Research Area: Technical/natural sciences
Transketolase from Escherichia coli: a practical procedure for using the biocatalyst for asymmetric carbon-carbon bond synthesis

General information
State: Published
Organizations: University of Edinburgh, University College London
Authors: Morris, K. (Ekstern), Smith, M. (Ekstern), Turner, N. (Ekstern), Lilly, M. (Ekstern), Mitra, R. (Ekstern), Woodley, J. (Intern)
Pages: 2185-2188
Publication date: 1996
Main Research Area: Technical/natural sciences

Publication information
Journal: Bioprocess engineering (Berlin. Print)
Volume: 14
Issue number: 5
ISSN (Print): 0178-515X
Ratings:
BFI (2008): BFI-level 1
Original language: English
DOI:
10.1007/BF00369924
Source: orbit
Source-ID: 202713
Publication: Research - peer-review › Journal article – Annual report year: 1996

Publication information
Journal: Tetrahedron-Asymmetry
Volume: 7
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.751 SNIP 0.663 CiteScore 2.05
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.777 SNIP 0.713 CiteScore 2.04
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.75 SNIP 0.723 CiteScore 2.12
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.965 SNIP 0.725 CiteScore 2.24
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.037 SNIP 0.748 CiteScore 2.15
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.288 SNIP 0.839 CiteScore 2.69
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.292 SNIP 0.904
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.275 SNIP 0.84
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.481 SNIP 0.853
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.534 SNIP 0.868
Web of Science (2007): Indexed yes
Determination of reactor operation for the microbial hydroxylation of toluene in a two-liquid phase process
Application of biotransformations to the synthesis of industrial chemicals is in part limited by a number of process challenges. We discuss the conversion of toxic, poorly water-soluble organic substrates by whole cells, using as an illustrative example the specific hydroxylation of toluene to toluene cis-glycol by Pseudomonas putida UV4. Toxic effects may be eliminated through the introduction of tetradecane, to partition toluene away from the biocatalyst, to give product concentrations of 30-60 g L(-1), in a two-liquid-phase reactor. The operational limits of this system have been experimentally determined and are presented in the form of windows of operation.

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for Process Engineering and Technology, University College London
Authors: Collins, A. (Ekstern), Woodley, J. (Intern), Liddell, J. (Ekstern)
Pages: 382-388
Publication date: May 1995
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Industrial Microbiology and Biotechnology
Volume: 14
Issue number: 5
ISSN (Print): 0169-4146
Original language: English
DOIs: 10.1007/BF01569955
Source: orbit
Source-ID: 202710
Publication: Research - peer-review › Journal article – Annual report year: 1996

Application of in-situ product removal techniques to biotransformation

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern)
Publication date: 1995

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202980
Publication: Research › Sound/Visual production (digital) – Annual report year: 1995

Biotransformation process design for aromatic monohydroxylation reactions by genetically engineered yeast
Process synthesis for multi-step microbial conversions

Developments in recombinant DNA technology are now allowing the controlled use of metabolic pathways to carry out a series of sequential organic chemical reactions using a single microbial catalyst. Biological processes of this type have significant industrial potential but in many cases still require the necessary biochemical engineering to translate them into a scalable process. Process synthesis is the systematic application of heuristics to the design of processes. Its application has enabled many chemical processes to be developed rapidly and feasibility assessed at an early stage in development. Here we apply such techniques to the area of multi-step microbial conversions (the use of metabolic pathway engineering to produce industrially useful chemicals). Biological and process engineering issues which require more research are identified. The use of the aromatic oxidation pathway serves as an illustrative example.

General information
State: Published
Organisations: University College London
Authors: Marshall, C. T. (Ekstern), Woodley, J. (Intern)
Pages: 1072-1078
Publication date: 1995
Main Research Area: Technical/natural sciences
Publication information
Journal: BIO-TECHNOLOGY
Volume: 13
Issue number: 10
Some examples of a structured approach to design and operation of biotransformation processes

General information
State: Published
Organisations: Unknown
Authors: Lilly, M. (Ekstern), Woodley, J. (Intern)
Publication date: 1995

Tools for biotransformation process design

General information
State: Published
Organisations: Unknown
Authors: Woodley, J. (Intern)
Publication date: 1995
Event: Poster session presented at Seventh European Congress Biotechnology, Nice, France, .
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202982
Publication: Research › Poster – Annual report year: 1995

Use of membranes to separate emulsions for product recovery from two liquid phase biotransformations

General information
State: Published
Organisations: Unknown
Authors: Woodley, J. (Intern), Laurence, M. (Ekstern), Lilly, M. (Ekstern)
Publication date: 1995

Biotransformation reactor selection and operation

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern), Lilly, M. (Ekstern)
Pages: 371-393
Publication date: 1994

Host publication information
Title of host publication: Applied Biocatalysis
Place of publication: Chur
Determination of reactor operation for the microbial hydroxylation of toluene in a two-liquid phase process

General information
State: Published
Organisations: University College London
Authors: Collins, A. (Ekstern), Woodley, J. (Intern)
Publication date: 1994

Development of a process for transketolase catalysed carbon-carbon bond formation

General information
State: Published
Organisations: University College London
Pages: 247-249
Publication date: 1994

Host publication information
Title of host publication: IChemE Research Event 1994
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 205659
Publication: Research - peer-review › Article in proceedings – Annual report year: 1994

Development of transketolase as a catalyst for carbon-carbon bond formation

General information
State: Published
Organisations: University College London, University College London
Authors: Hobbs, G. (Ekstern), Lilly, M. (Ekstern), Turner, N. (Ekstern), Ward, J. (Ekstern), Woodley, J. (Intern)
Pages: 463-466
Publication date: 1994
Main Research Area: Technical/natural sciences

Publication information
Journal: Progress in Biotechnology
Volume: 9
ISSN (Print): 0921-0423
Ratings:
Scopus rating (2005): SJR 0.139 SNIP 0.177
Scopus rating (2004): SJR 0.167 SNIP 0.318
Scopus rating (2003): SJR 0.115 SNIP 0.112
Scopus rating (2002): SJR 0.109 SNIP 0.111
Scopus rating (2001): SJR 0.119 SNIP 0.09
Scopus rating (2000): SJR 0.115 SNIP 0.115
Scopus rating (1999): SJR 0.139 SNIP 0.136
Enzymic dehalogenation of haloalkanes and haloalcohols

*General information*

State: Published
Organisations: University College London
Authors: Rosen, N. (Ekstern), Woodley, J. (Intern), Lilly, M. (Ekstern), Bull, A. (Ekstern)
Pages: 91-93
Publication date: 1994

*Host publication information*

Title of host publication: IChemE Research Event 1994
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 205657
Publication: Research - peer-review › Article in proceedings – Annual report year: 1994

Kinetic characterisation of aqueous-organic biphasic enzymatic catalysis for the design of multiphasic bioreactors

*General information*

State: Published
Organisations: University College London, University College London
Authors: Cunnah, P. (Ekstern), Woodley, J. (Intern)
Pages: 957-960
Publication date: 1994
Main Research Area: Technical/natural sciences

*Publication information*

Journal: Progress in Biotechnology
Volume: 9
ISSN (Print): 0921-0423
Ratings:
Scopus rating (2005): SJR 0.139 SNIP 0.177
Scopus rating (2004): SJR 0.167 SNIP 0.318
Scopus rating (2003): SJR 0.115 SNIP 0.112
Scopus rating (2002): SJR 0.109 SNIP 0.111
Scopus rating (2001): SJR 0.119 SNIP 0.09
Scopus rating (2000): SJR 0.115 SNIP 0.115
Scopus rating (1999): SJR 0.139 SNIP 0.136
Original language: English
Source: orbit
Source-ID: 202720
Publication: Research - peer-review › Journal article – Annual report year: 1994

Polyphenylenes from biosynthetic cis-dihydroxycyclohexadiene

*General information*

State: Published
Organisations: Unknown
Authors: Ballard, D. (Ekstern), Blacker, A. (Ekstern), Woodley, J. (Intern), Taylor, S. (Ekstern)
Pages: 139-168
Publication date: 1994

*Host publication information*

Title of host publication: Plastics from Microbes
Place of publication: New York
Publisher: Carl Hanser Verlag GmbH
Process implications of solvent interaction with microbial catalysts

General information
State: Published
Organisations: Unknown
Authors: Wilkinson, D. (Ekstern), Woodley, J. (Intern), Ward, J. (Ekstern)
Pages: 162-164
Publication date: 1994

Host publication information
Title of host publication: IChemE Research Event 1994
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 205660
Publication: Research - peer-review › Article in proceedings – Annual report year: 1994

The production of Pseudomonas putida for the hydroxylation of toluene to its cis-glycol
A constitutive blocked mutant (UV4) of Pseudomonas putida was grown in a 2.5-1 fermenter on a mineral salts medium. Glucose was fed normally over an 18-h period. Gluconate reached about 5 g(-1) in the medium and then fell to zero as it was utilised. The maximum toluene dioxygenase specific activity (2 g(g(-1) h(-1))) was obtained over the last 6 h of the fermentation when the pH was fully controlled. In fermentations done at low dissolved O-2 tension (DOT) values there was an overall reduction in the cellular enzyme level. When stored at 4 degrees C in phosphate buffer, pH 7.0, harvested bacteria lost half their activity in about 90 h.

General information
State: Published
Organisations: University College London, Zeneca Bio Products
Authors: Hack, C. (Ekstern), Woodley, J. (Intern), Lilly, M. (Ekstern), Lidell, J. M. (Ekstern)
Pages: 495-499
Publication date: 1994
Main Research Area: Technical/natural sciences

Publication information
Journal: Applied Microbiology and Biotechnology
Volume: 41
Issue number: 5
ISSN (Print): 0175-7598
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 3.57 SJR 1.177 SNIP 1.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.254 SNIP 1.217 CiteScore 3.43
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.327 SNIP 1.458 CiteScore 3.71
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.533 SNIP 1.432 CiteScore 4.3
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Transketolase production for use as a catalyst for carbon-carbon bond formation

General information
State: Published
Organisations: Unknown
Authors: Hobbs, G. (Ekstern), Lilly, M. (Ekstern), Turner, N. (Ekstern), Ward, J. (Ekstern), Woodley, J. (Intern)
Pages: 289-291
Publication date: 1994

Host publication information
Title of host publication: IChemE Research Event 1994
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 205658
Publication: Research - peer-review › Article in proceedings – Annual report year: 1994
A comparison of stirred tank and membrane bioreactors for aqueous-organic biphasic enzymatic reactions

General information
State: Published
Organisations: University College London
Authors: Cunnah, P. (Ekstern), Woodley, J. (Intern)
Pages: 81-92
Publication date: 1993

Host publication information
Title of host publication: Effective Membrane Processes - New Perspectives
Editor: Patterson, R.
Main Research Area: Technical/natural sciences
Conference: 3rd International Conference on Effective Membrane Processes--New Perspectives, London, UK, 01/01/1993
Source: orbit
Source-ID: 202770
Publication: Research - peer-review › Article in proceedings – Annual report year: 1993

Enzyme catalysed carbon-carbon bond formation: use of transketolase from Escherichia coli

General information
State: Published
Organisations: University College London, University of Exeter
Authors: Hobbs, G. R. (Ekstern), Lilly, M. D. (Ekstern), Turner, N. J. (Ekstern), Ward, J. M. (Ekstern), Willets, A. J. (Ekstern), Woodley, J. (Intern)
Pages: 165-166
Publication date: 1993
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Chemical Society ,Perkin Transactions
Volume: 1
Issue number: 2
Original language: English
Source: orbit
Source-ID: 202723
Publication: Research - peer-review › Journal article – Annual report year: 1993

In situ product removal as a tool for bioprocessing
In situ product removal (ISPR) is the fast removal of product from a producing cell thereby preventing its subsequent interference with cellular or medium components. Over the past 10 years ISPR techniques have developed substantially and its feasibility (with improvements in yield or productivity) for several processes demonstrated. Assessment of progress, however, compared to the potential benefits inherent in the ISPR approach to bioprocessing reveals that these are far from being exploited fully. Here we indicate future directions including application of the ISPR approach to a wider range of product groups and the development of novel, more specific ISPR methodologies, applicable under sterile conditions in the immediate vicinity of the producing cells. General guidelines for adaptation of an appropriate ISPR approach for a given product are also provided.

General information
State: Published
Organisations: University College London, Tel Aviv University
Authors: Freeman, A. (Ekstern), Woodley, J. (Intern), Lilly, M. D. (Ekstern)
Pages: 1007-1012
Publication date: 1993
Main Research Area: Technical/natural sciences

Publication information
Journal: BIO-TECHNOLOGY
Volume: 11
Issue number: 9
ISSN (Print): 0733-222X
Original language: English
DOIs:
10.1038/nbt0993-1007
The characterisation of fluorobenzene oxidation to fluorocatechol by Pseudomonas putida leading to bioreactor design

General information
State: Published
Organisations: Unknown
Authors: Lynch, R. (Ekstern), Woodley, J. (Intern), Lilly, M. (Ekstern)
Publication date: 1993

Host publication information
Title of host publication: IChemE Research Event 1993
Main Research Area: Technical/natural sciences
Conference: IChemE Research Event 1993, Birmingham, United Kingdom, 06/01/1993 - 06/01/1993
Source: orbit
Source-ID: 205655
Publication: Research - peer-review › Article in proceedings – Annual report year: 1993

The scale-up of two-liquid phase microbially catalysed aromatic oxidations

General information
State: Published
Organisations: Unknown
Authors: Collins, A. (Ekstern), Woodley, J. (Intern)
Pages: 179-181
Publication date: 1993

Host publication information
Title of host publication: IChemE Research Event 1993
Main Research Area: Technical/natural sciences
Conference: IChemE Research Event 1993, Birmingham, United Kingdom, 06/01/1993 - 06/01/1993
Source: orbit
Source-ID: 205654
Publication: Research - peer-review › Article in proceedings – Annual report year: 1993

Immobilised biocatalysts

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern)
Pages: 254-271
Publication date: 1992

Host publication information
Title of host publication: Solid Supports and Catalysts in Organic Synthesis
Place of publication: Chichester
Publisher: Ellis Horwood
Editor: Smith, K.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202618
Publication: Research - peer-review › Book chapter – Annual report year: 1992

Process aspects for the operation of two-liquid phase biotransformations: a comparison of a stirred tank reactor with a membrane bioreactor

General information
State: Published
Organisations: Unknown
Authors: Cunnah, P. (Ekstern), Woodley, J. (Intern)
Process engineering of two-liquid phase biocatalysis

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern), Lilly, M. (Ekstern)
Pages: 147-154
Publication date: 1992
Main Research Area: Technical/natural sciences

Publication information
Journal: Progress in Biotechnology
Volume: 8
ISSN (Print): 0921-0423
Ratings:
Scopus rating (2005): SJR 0.139 SNIP 0.177
Scopus rating (2004): SJR 0.167 SNIP 0.318
Scopus rating (2003): SJR 0.115 SNIP 0.112
Scopus rating (2002): SJR 0.109 SNIP 0.111
Scopus rating (2001): SJR 0.119 SNIP 0.09
Scopus rating (2000): SJR 0.115 SNIP 0.115
Scopus rating (1999): SJR 0.139 SNIP 0.136
Original language: English
Source: orbit
Source-ID: 202724
Publication: Research - peer-review › Journal article – Annual report year: 1992

Production of naphthalene-cis-glycol by Pseudomonas putida in the presence of organic solvents

General information
State: Published
Organisations: University College London
Authors: Harrop, A. (Ekstern), Woodley, J. (Intern), Lilly, M. (Ekstern)
Pages: 725-730
Publication date: 1992
Main Research Area: Technical/natural sciences

Publication information
Journal: Enzyme and Microbial Technology
Volume: 14
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.83 SJR 0.759 SNIP 1.025
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.85 SNIP 0.969 CiteScore 2.63
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Reactor engineering for multiphasic biotransformations

General information
State: Published
Organisations: Unknown
Authors: Woodley, J. (Intern)
Pages: 146-149
Publication date: 1992

Host publication information
Title of host publication: Harnessing Biotechnology for the 21st Century
Publisher: American Chemical Society
Evaluation of process options for the biotransformation of toluene to toluene cis-glycol by Pseudomonas putida

General information
State: Published
Organisations: University College London
Authors: Hack, C. (Ekstern), Woodley, J. (Intern), Lilly, M. (Ekstern)
Publication date: 1991

Lewis cell studies to determine reactor design data for two-liquid phase bacterial and enzymatic reactions
Substrate transfer rates from organic to aqueous phases were measured in the presence and absence of biocatalyst in the reaction medium, using modified Lewis cells. These measurements, in combination with intrinsic aqueous phase biocatalytic reaction kinetics, were used to confirm that benzyl acetate hydrolysis by pig liver esterase and toluene oxidation by a strain of Pseudomonas putida occur uniformly throughout the bulk of the aqueous phase. Such data may be used to provide a basis for two-liquid-phase biocatalytic reactor design.
Stirred tank two-liquid phase biocatalytic reactor studies: kinetics, evaluation and modelling of substrate mass transfer

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern), Cunnah, P. (Ekstern), Lilly, M. (Ekstern)
Pages: 1-12
Publication date: 1991
Main Research Area: Technical/natural sciences

Publication information
Journal: Biocatalysis
Volume: 5
Original language: English
Source: orbit
Source-ID: 202726
Publication: Research - peer-review › Journal article – Annual report year: 1991
The impact of biocatalyst selection on the design of aqueous-organic biphasic biocatalytic processes

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern), Harrop, A. (Ekstern), Lilly, M. (Ekstern)
Pages: 191-200
Publication date: 1991
Conference: Enzyme Engineering, 01/01/1991
Main Research Area: Technical/natural sciences

Publication information
Volume: 613
ISSN (Print): 0077-8923
Ratings:

BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 2.183 SNIP 1.393 CiteScore 4.42
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 2.38 SNIP 1.388 CiteScore 4.42
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 2.281 SNIP 1.446 CiteScore 4.37
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 2.137 SNIP 1.477 CiteScore 4.56
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.636 SNIP 1.198 CiteScore 3.61
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.533 SNIP 1.097 CiteScore 3.41
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.321 SNIP 0.905
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.17 SNIP 0.847
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.957 SNIP 0.758
Scopus rating (2007): SJR 0.879 SNIP 0.67
Scopus rating (2006): SJR 0.923 SNIP 0.696
Scopus rating (2005): SJR 0.953 SNIP 0.665
Scopus rating (2004): SJR 0.864 SNIP 0.653
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.823 SNIP 0.686
Scopus rating (2002): SJR 0.816 SNIP 0.587
Scopus rating (2001): SJR 0.712 SNIP 0.512
Scopus rating (2000): SJR 0.6 SNIP 0.441
Scopus rating (1999): SJR 0.477 SNIP 0.348

Original language: English
DOIs:
Source: orbit
Source-ID: 202768
Publication: Research - peer-review › Conference article – Annual report year: 1991
A comparison of pig liver esterase and Bacillus subtilis as catalysts for the hydrolysis of menthyl acetate in stirred two-liquid phase reactors

General information
State: Published
Organisations: University College London
Authors: Williams, A. (Ekstern), Woodley, J. (Intern), Ellis, P. (Ekstern), Narendranathan, T. (Ekstern), Lilly, M. (Ekstern)
Pages: 260-265
Publication date: 1990
Main Research Area: Technical/natural sciences

Publication information
Journal: Enzyme and Microbial Technology
Volume: 12
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.83 SJR 0.759 SNIP 1.025
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.85 SNIP 0.969 CiteScore 2.63
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.061 SNIP 1.214 CiteScore 3.12
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.165 SNIP 1.376 CiteScore 3.2
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.204 SNIP 1.281 CiteScore 2.78
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.062 SNIP 1.27 CiteScore 2.74
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.201 SNIP 1.565
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.305 SNIP 1.504
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.208 SNIP 1.34
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.976 SNIP 1.257
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.907 SNIP 1.433
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.915 SNIP 1.429
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.847 SNIP 1.263
Extractive biocatalysis: the use of two-liquid phase biocatalytic reactors to assist product recovery

General information
State: Published
Organisations: University College London
Authors: Woodley, J. (Intern), Lilly, M. (Extern)
Pages: 2391-2396
Publication date: 1990
Main Research Area: Technical/natural sciences

Publication information
Journal: Chemical Engineering Science
Volume: 45
Issue number: 8
ISSN (Print): 0009-2509
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.05 SJR 1.037 SNIP 1.442
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.038 SNIP 1.606 CiteScore 2.96
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.115 SNIP 1.642 CiteScore 2.81
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.157 SNIP 1.866 CiteScore 2.95
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.189 SNIP 1.847 CiteScore 2.77
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.205 SNIP 1.685 CiteScore 2.8
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.319 SNIP 1.708
Stirred tank power input data for the scale-up of two-liquid phase biotransformations

General information
State: Published
Organisations: Unknown
Authors: Woodley, J. (Intern)
Pages: 63-66
Publication date: 1990

Host publication information
Title of host publication: Opportunities in Biotranformations
Place of publication: London
Publisher: Elsevier
Editors: Chopping, L., Martin, R., Pickett, J., Bucke, C., Bunch, A.
Main Research Area: Technical/natural sciences
Conference: Opportunities in Biotranformations, Cambridge, UK, 01/01/1990
Source: orbit
Source-ID: 202767
Publication: Research - peer-review › Article in proceedings – Annual report year: 1990

Two-liquid phase biocatalysis: choice of phase ratio

General information
State: Published
Organisations: University College London
Authors: Lilly, M. (Ekstern), Dervakos, G. (Ekstern), Woodley, J. (Intern)
Pages: 5-16
Publication date: 1990
Two-liquid phase biocatalysis: reactor design

General information
State: Published
Organisations: University College London
Authors: Lilly, M. (Ekstern), Dervakos, G. (Ekstern), Woodley, J. (Intern)
Pages: 337-355
Publication date: 1990

Host publication information
Title of host publication: Biocatalysis
Place of publication: New York
Publisher: Van Nostrand Reinhold
Editor: Abramowicz, D.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202617
Publication: Research - peer-review › Book chapter – Annual report year: 1990

Development of a KBS for biotransformation process design

General information
State: Published
Organisations: University College London
Authors: Dervakos, G. (Ekstern), Woodley, J. (Intern), Keravnou, E. (Ekstern), Washbrook, J. (Ekstern), Lilly, M. (Ekstern)
Publication date: 1989

Host publication information
Title of host publication: Computer Integrated Process Engineering
Volume: 114
Main Research Area: Technical/natural sciences
Conference: Computer Integrated Process Engineering, 01/01/1989
Source: orbit
Source-ID: 205652
Publication: Research - peer-review › Article in proceedings – Annual report year: 1989

Biological conversions involving water-insoluble organic compounds

General information
State: Published
Organisations: University College London
Authors: Lilly, M. (Ekstern), Brazier, A. (Ekstern), Hocknull, M. (Ekstern), Williams, A. (Ekstern), Woodley, J. (Intern)
Pages: 3-17
Publication date: 1987

Host publication information
Title of host publication: Biocatalysis in Organic Media
Volume: 29
Publisher: Elsevier
Editors: Laane, C., Tramper, J., Lilly, M.
Main Research Area: Technical/natural sciences
Denaturation and inhibition studies in a two-liquid phase biocatalytic reaction: the hydrolysis of menthyl acetate by pig liver esterase

General information
State: Published
Organisations: University College London, University College London
Authors: Williams, A. (Ekstern), Woodley, J. (Intern), Ellis, P. (Ekstern), Lilly, M. (Ekstern)
Pages: 399-404
Publication date: 1987

Host publication information
Title of host publication: Biocatalysis in Organic Media
Volume: 29
Publisher: Elsevier
Editors: Williams, A., Tramper, J., Lilly, M.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202765
Publication: Research - peer-review › Article in proceedings – Annual report year: 1985

Biocatalytic reactions involving water-insoluble organic compounds

General information
State: Published
Organisations: University College London
Authors: Lilly, M. (Ekstern), Woodley, J. (Intern)
Pages: 179-192
Publication date: 1985

Host publication information
Title of host publication: Biocatalysts in Organic Syntheses
Publisher: Elsevier
Editors: van der Plas, H., Linko, P.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 202763
Publication: Research - peer-review › Article in proceedings – Annual report year: 1985

Projects:

Continuous Biocatalytic Alkene Hydrogenation
Department of Chemical and Biochemical Engineering
Period: 01/11/2017 → 31/10/2020
Number of participants: 4
Phd Student: Lindeque, Rowan Malan (Intern)
Supervisor: Dam-Johansen, Kim (Intern)
Krühne, Ulrich (Intern)
Main Supervisor: Woodley, John (Intern)

Financing sources
Source: Internal funding (public)
Membrane-based in-situ product removal

Department of Chemical and Biochemical Engineering
Period: 01/09/2017 → 31/08/2020
Number of participants: 4
Phd Student:
Jaksland, Anders (Intern)
Supervisor:
Pinelo, Manuel (Intern)
Wan, Yinhua (Ekstern)
Main Supervisor:
Woodley, John (Intern)

Financing sources
Source: Internal funding (public)

Chemical & Biochemical Sustainable Process Synthesis - Intensification

Department of Chemical and Biochemical Engineering
Period: 15/10/2016 → 14/10/2019
Number of participants: 4
Phd Student:
Garg, Nipun (Intern)
Supervisor:
Gani, Rafiqul (Intern)
Kontogeorgis, Georgios (Intern)
Main Supervisor:
Woodley, John (Intern)

Financing sources
Source: Internal funding (public)

Systematic computer aided methods and tools for lipids process technology

Department of Chemical and Biochemical Engineering
Period: 15/09/2015 → 14/09/2018
Number of participants: 5
Phd Student:
Ana Perederic, Olivia (Intern)
Supervisor:
Gani, Rafiqul (Intern)
Kontogeorgis, Georgios (Intern)
Sarup, Bent (Ekstern)
Main Supervisor:
Woodley, John (Intern)

Financing sources
Source: Internal funding (public)

Development of Large-Scale Processes Using Alcohol Oxidases

Department of Chemical and Biochemical Engineering
Period: 01/09/2015 → 31/08/2018
Number of participants: 3
Phd Student:
Dias Gomes, Mafalda (Intern)
Supervisor:
Nordblad, Mathias (Intern)
Main Supervisor:
Woodley, John (Intern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Anden EU-finansiering
Project: PhD

Development of large-scale processes for baeyer-Villger Biocatalysis

Department of Chemical and Biochemical Engineering
Period: 15/07/2015 → 14/07/2018
Number of participants: 3
Phd Student:
Meissner, Murray Peter (Intern)
Supervisor:
Nordblad, Mathias (Intern)
Main Supervisor:
Woodley, John (Intern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Anden EU-finansiering
Project: PhD

Sustainable process design with process intensification

Department of Chemical and Biochemical Engineering
Period: 01/10/2014 → 14/12/2017
Number of participants: 6
Phd Student:
Frauzem, Rebecca (Intern)
Supervisor:
Woodley, John (Intern)
Main Supervisor:
Gani, Rafiqul (Intern)
Examiner:
Kontogeorgis, Georgios (Intern)
Bode, Andreas (Ekstern)
Zondervan, Edwin (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

Computer-aided Mixture and Blend Design

Department of Chemical and Biochemical Engineering
Period: 15/09/2014 → 13/10/2017
Number of participants: 7
Phd Student:
Cignitti, Stefano (Intern)
Supervisor:
Abildskov, Jens (Intern)
Gernaey, Krist V. (Intern)
Main Supervisor:
Woodley, John (Intern)
Examiner:
Kontogeorgis, Georgios (Intern)
Camarda, Kyle V. (Ekstern)
Kate, Antoon J. B. ten (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

Modelling, Synthesis and Analysis of Biorefinery Networks
Department of Chemical and Biochemical Engineering
Period: 01/09/2014 → 30/11/2017
Number of participants: 4
Phd Student:
Bertran, Maria-Ona (Intern)
Supervisor:
Jensen, Anker Degn (Intern)
Woodley, John (Intern)
Main Supervisor:
Gani, Rafiqul (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD

Modification of polymer surfaces to enhance enzyme activity and stability
Department of Chemical and Biochemical Engineering
Period: 01/08/2014 → 31/07/2017
Number of participants: 7
Phd Student:
Hoffmann, Christian (Intern)
Supervisor:
Pinelo, Manuel (Intern)
Woodley, John (Intern)
Main Supervisor:
Daugaard, Anders Egede (Intern)
Examiner:
Szabo, Peter (Intern)
Gardossi, Lucia (Ekstern)
Malkoch, Michael (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

Biooxidation reactor and process design
Department of Chemical and Biochemical Engineering
Period: 01/04/2014 → 12/07/2017
Number of participants: 6
Phd Student:
Pedersen, Asbjørn Toftgaard (Intern)
enzyme-enhanced CO2 Absorption - rate-based modeling and pilot-scale validation

Department of Chemical and Biochemical Engineering
Period: 01/03/2014 → 25/08/2017
Number of participants: 7
Phd Student:
Gladis, Arne Berthold (Intern)
Supervisor:
Fosbøl, Philip Loldrup (Intern)
Woodley, John (Intern)
Main Supervisor:
von Solms, Nicolas (Intern)
Examiner:
Skiadas, Ioannis V (Intern)
Eimer, Dag (Ekstern)
Gabrielsen, Jostein (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

Improved LCA Methodology and software tool for biorenewable products and processes

Department of Chemical and Biochemical Engineering
Period: 15/12/2013 → 25/01/2017
Number of participants: 6
Phd Student:
Kumar Tula, Anjan (Intern)
Supervisor:
Huusom, Jakob Kjøbsted (Intern)
Main Supervisor:
Gani, Rafiqul (Intern)
Examiner:
Woodley, John (Intern)
Harper, Peter Mathias (Intern)
Manenti, Flavio (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Marie Curie (EU-stipendium)

Relations
Environmental and economical evaluation tools for novel bioprocesses

Department of Chemical and Biochemical Engineering
Period: 01/12/2013 → 26/04/2017
Number of participants: 6
Phd Student: Sanches Seita, Catarina (Intern)
Supervisor: Nordblad, Mathias (Intern)
Main Supervisor: Woodley, John (Intern)
Examiner: Eliasson Lantz, Anna (Intern)
Adlercreutz, Patrick (Ekstern)
Meurer, Guido (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Anden EU-finansiering

Relations
Publications:
Benchmarking of Processes for the Biosynthesis of Natural Products
Project: PhD

Experimental Implementation and model-based optimization for multi-enzyme processes

Department of Chemical and Biochemical Engineering
Period: 01/10/2013 → 15/03/2017
Number of participants: 6
Phd Student: Abu, Rohana (Intern)
Supervisor: Gernaey, Krist V. (Intern)
Main Supervisor: Woodley, John (Intern)
Examiner: Nordblad, Mathias (Intern)
Blazevic, Zvjezdana Findrak (Ekstern)
Riva, Sergio (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Stipendie fra udlandet

Relations
Publications:
Process Evaluation Tools for Enzymatic Cascades Welcome Message
Project: PhD

Modeling and Synthesis of Pharmaceutical processes: Moving from Batch to Continuous Manufacturing

Department of Chemical and Biochemical Engineering
Period: 01/10/2013 → 16/11/2016
Number of participants: 7
Phd Student: Papadakis, Emmanouil (Intern)
Modelling and synthesis of pharmaceutical processes: moving from batch to continuous

Experimental evaluation of carbonic anhydrase as a biocatalyst for implementation in CO2 removal from flue gas

Design, control and analysis of intensified biochemical processes
 Relations
Publications:
Integrated Process Design, Control and Analysis of Intensified Chemical Processes
Project: PhD

Generic model-based tailor-made design and analysis of biphasic reacting systems
Department of Chemical and Biochemical Engineering
Period: 01/08/2013 → 24/10/2016
Number of participants: 6
Phd Student:
Anantpinjwatna, Amata (Intern)
Supervisor:
Woodley, John (Intern)
Main Supervisor:
Gani, Rafiqul (Intern)
Examiner:
Huusom, Jakob Kjøbsted (Intern)
Grosjean, Christophe (Ekstern)
Manenti, Flavio (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Stipendie fra udlandet

Relations
Publications:
Property Model-based Tailor-made Design of Chemical-based Products
Project: PhD

Property Modelling and Process Design involving complex chemical systems
Department of Chemical and Biochemical Engineering
Period: 01/06/2013 → 18/08/2016
Number of participants: 7
Phd Student:
Kalakul, Sawitree (Intern)
Supervisor:
Kontogeorgis, Georgios (Intern)
Sarup, Bent (Ekstern)
Main Supervisor:
Gani, Rafiqul (Intern)
Examiner:
Woodley, John (Intern)
Achenie, Luke E. K. (Ekstern)
Jiménez-González, Concepción (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 FUU, 1/3 inst 1/3 Andet

Relations
Publications:
Property Model-based Tailor-made Design of Chemical-based Products
Project: PhD

Mixing and oxygen transfer processes in bioreactors
Department of Chemical and Biochemical Engineering
Period: 15/01/2013 → 30/06/2016
Number of participants: 6
PhD Student:
Nørregaard, Anders (Intern)
Supervisor:
vanden Berg, Frans M. J. (Intern)
Madsen, Brian (Ekstern)
Stocks, Stuart M. (Ekstern)
Woodley, John (Intern)
Main Supervisor:
Gernaey, Krist V. (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Topology optimisztion in biocatalytic reactions using miniaturized reactors
Department of Chemical and Biochemical Engineering
Period: 01/11/2012 → 20/04/2016
Number of participants: 7
PhD Student:
Pereira Rosinha Grundtvig, Ines (Intern)
Supervisor:
Gernaey, Krist V. (Intern)
Woodley, John (Intern)
Main Supervisor:
Krühne, Ulrich (Intern)
Examiner:
Abildskov, Jens (Intern)
Maier, Petra (Ekstern)
Perozziello, Gerardo (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 FUU, 1/3 inst 1/3 Andet
Project: PhD

Mastering bioprocess Integration and Intensification across scales
Department of Chemical and Biochemical Engineering
Period: 01/10/2012 → 02/12/2015
Number of participants: 7
PhD Student:
Ringborg, Rolf Hoffmeyer (Intern)
Supervisor:
Gernaey, Krist V. (Intern)
Krühne, Ulrich (Intern)
Main Supervisor:
Woodley, John (Intern)
Examiner:
Nordblad, Mathias (Intern)
Hessel, Volker (Ekstern)
Jensen, Klavs F. (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 FUU, 1/3 inst 1/3 Andet
Project: PhD
Process intensification in biocatalytic reactions
Department of Chemical and Biochemical Engineering
Period: 01/09/2012 → 22/02/2016
Number of participants: 7
Phd Student:
Heintz, Søren (Intern)
Supervisor:
Krühne, Ulrich (Intern)
Woodley, John (Intern)
Main Supervisor:
Gernaey, Krist V. (Intern)
Examiner:
Abildskov, Jens (Intern)
Straathof, Adrie J.J. (Ekstern)
Wohlgemuth, Roland (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 FUU, 1/3 inst 1/3 Andet
Project: PhD

Bioprocess engineering for the application of P450s
Department of Chemical and Biochemical Engineering
Period: 01/02/2012 → 02/12/2015
Number of participants: 6
Phd Student:
Lundemo, Marie Therese (Intern)
Supervisor:
Krühne, Ulrich (Intern)
Main Supervisor:
Woodley, John (Intern)
Examiner:
Eliasson Lantz, Anna (Intern)
Hayes, Martin (Ekstern)
Schmid, Andreas (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Marie Curie (EU-stipendium)
Project: PhD

Enhanced Oil Recovery with Application of Enzymes
Department of Chemical and Biochemical Engineering
Period: 01/12/2011 → 26/05/2016
Number of participants: 6
Phd Student:
Khusainova, Alsu (Intern)
Supervisor:
Woodley, John (Intern)
Main Supervisor:
Shapiro, Alexander (Intern)
Examiner:
Yan, Wei (Intern)
Andersen, Simon Ivar (Intern)
Skaug, Arne (Ekstern)

Financing sources
Source: Internal funding (public)
Microalgae withincreased synthesis or diminshed breakdown of triacylglycerol for efficient biodiesel production

Department of Chemical and Biochemical Engineering
Period: 01/12/2011 → 30/11/2013
Number of participants: 5
Phd Student:
Favrholdt, Camilla Emilie (Intern)
Supervisor:
Gernaey, Krist V. (Intern)
Gjermansen, Claes (Intern)
Woodley, John (Intern)
Main Supervisor:
Brandt, Anders Bøving (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut, samfinansiering
Project: PhD

Process Technology for Oxidase-based Biocatalysis

Department of Chemical and Biochemical Engineering
Period: 01/10/2011 → 26/11/2014
Number of participants: 6
Phd Student:
Ramesh, Hemalata (Intern)
Supervisor:
Krühne, Ulrich (Intern)
Main Supervisor:
Woodley, John (Intern)
Examiner:
Huusom, Jakob Kjøbsted (Intern)
Archer, Ian (Ekstern)
Micheletti, Martina (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 FUU, 1/3 inst 1/3 Andet
Project: PhD

Control of Enzymatic Biodiesel Production

Department of Chemical and Biochemical Engineering
Period: 01/09/2011 → 26/11/2014
Number of participants: 7
Phd Student:
Price, Jason Anthony (Intern)
Supervisor:
Huusom, Jakob Kjøbsted (Intern)
Nordblad, Mathias (Intern)
Main Supervisor:
Woodley, John (Intern)
Examiner:
Gernaey, Krist V. (Intern)
Phenomena based process intensification

Department of Chemical and Biochemical Engineering
Period: 01/09/2011 → 04/02/2015
Number of participants: 6
Phd Student:
Babi, Deenesh Kavi (Intern)
Supervisor:
Woodley, John (Intern)
Main Supervisor:
Gani, Rafiqul (Intern)
Examiner:
Huusom, Jakob Kjøbsted (Intern)
Sundmacher, Kai (Ekstern)
Van Gerven, Tom (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 DTU-stip, 2/3 FUR/andet
Project: PhD

Inhibition of gas hydrate formation by ice-structuring proteins

Department of Chemical and Biochemical Engineering
Period: 01/08/2011 → 10/11/2015
Number of participants: 6
Phd Student:
Perfeldt, Christine Malmos (Intern)
Supervisor:
Woodley, John (Intern)
Main Supervisor:
von Solms, Nicolas (Intern)
Examiner:
Thomsen, Kaj (Intern)
Li, Xiaoyun (Ekstern)
Svartås, Thor Martin (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Integrated microfactories for enzyme production

Department of Chemical and Biochemical Engineering
Period: 01/03/2011 → 11/03/2015
Number of participants: 7
Phd Student:
Bodla, Vijaya Krishna (Intern)
Supervisor:
Krühne, Ulrich (Intern)
Woodley, John (Intern)
Main Supervisor:
Gernaey, Krist V. (Intern)
Examiner:
Nordblad, Mathias (Intern)
Baganz, Frank (Ekstern)
Bouwes, Dominique (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

Reactor and Process Design for Multi-enzymatic Synthesis
Department of Chemical and Biochemical Engineering
Period: 01/12/2010 → 01/11/2016
Number of participants: 4
Phd Student:
Xue, Rui (Intern)
Supervisor:
Meyer, Anne S. (Intern)
mikkelsen, Jørn Dalgaard (Intern)
Main Supervisor:
Woodley, John (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Scale-up of biocatalytic cascade reactions for the synthesis of chiral amines
Department of Chemical and Biochemical Engineering
Period: 01/12/2010 → 24/09/2014
Number of participants: 7
Phd Student:
Janes, Kresimir (Intern)
Supervisor:
Tufvesson, Pär (Intern)
Woodley, John (Intern)
Main Supervisor:
Gernaey, Krist V. (Intern)
Examiner:
Krühne, Ulrich (Intern)
Pedersen, Lars Hastrup (Ekstern)
Vasic-Racki, Durda (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Tailor-made design of chemical products: Bio-fuels and other blended products
Department of Chemical and Biochemical Engineering
Period: 15/07/2010 → 07/05/2014
Number of participants: 7
Phd Student:
Yunus, Nor Alafiza Binti (Intern)
Supervisor:
Gernaey, Krist V. (Intern)
Process Considerations for Asymmetric Synthesis of Chiral Amines using Omega-Transaminase

Department of Chemical and Biochemical Engineering
Period: 01/06/2010 → 11/12/2013
Number of participants: 6
PhD Student:
Lima Afonso Neto, Watson (Intern)
Supervisor:
Woodley, John (Intern)
Examiner:
Krühne, Ulrich (Intern)
Adlercreutz, Patrick (Ekstern)
Howard, Roger M. (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Stipendie fra udlandet
Project: PhD

Guiding biocatalytic process improvements using engineering evaluation tools

Department of Chemical and Biochemical Engineering
Period: 01/03/2010 → 24/06/2013
Number of participants: 6
PhD Student:
Lima Ramos, Joana (Intern)
Supervisor:
Woodley, John (Intern)
Examiner:
Gernaey, Krist V. (Intern)
Jiménez-González, Concepción (Ekstern)
Straathof, Adrie J.J. (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Marie Curie (EU-stipendium)
Project: PhD

Modelling controlled release of substrate and removal of products in biocatalysis

Department of Chemical and Biochemical Engineering
Period: 01/11/2009 → 21/05/2013
Number of participants: 7
PhD Student:
Population balance models and computational fluid dynamics: a model framework to describe heterogeneity in fermentors

Department of Chemical and Biochemical Engineering
Period: 01/11/2009 → 19/03/2013
Number of participants: 7
PhD Student:
Lencastre Fernandes, Rita (Intern)
Supervisor:
Jensen, Anker Degn (Intern)
Nopens, Ingmar (Ekstern)
Main Supervisor:
Gernaey, Krist V. (Intern)
Examiner:
Woodley, John (Intern)
Hansen, Ernst (Intern)
Kremling, Andreas (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 FUU, 1/3 inst 1/3 Andet
Project: PhD

Evaluation of new process technology for lipase-catalyzed biodiesel production

Department of Chemical and Biochemical Engineering
Period: 01/03/2009 → 27/06/2012
Number of participants: 6
PhD Student:
Xu, Yuan (Intern)
Supervisor:
Nordblad, Mathias (Intern)
Main Supervisor:
Woodley, John (Intern)
Examiner:
Hobley, Timothy John (Intern)
Basheer, Sobhi (Ekstern)
Hua, Ling (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Offentlig finansiering
Project: PhD
Green Chemistry based innovative process-operation synthesis and design

Department of Chemical and Biochemical Engineering
Period: 01/12/2008 → 18/04/2012
Number of participants: 6
Phd Student:
Lutze, Philip (Intern)
Supervisor:
Gani, Rafiqul (Intern)
Main Supervisor:
Woodley, John (Intern)
Examiner:
Gernaey, Krist V. (Intern)
Berg, Henk van den (Ekstern)
Freund, Hannsjörg (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Multi-enzyme process modelling

Department of Chemical and Biochemical Engineering
Period: 01/11/2008 → 27/06/2012
Number of participants: 7
Phd Student:
Andrade Santacoloma, Paloma de Gracia (Intern)
Supervisor:
Gernaey, Krist V. (Intern)
Sin, Gürkan (Intern)
Main Supervisor:
Woodley, John (Intern)
Examiner:
Jørgensen, Sten Bay (Intern)
Pedersen, Sven (Ekstern)
Vasic-Racki, Durda (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Optimization of Tailor-made Chemicals from Renewable and non-renewable sources

Department of Chemical and Biochemical Engineering
Period: 01/09/2008 → 01/02/2010
Number of participants: 4
Phd Student:
Swangkotchakorn, Chutima (Intern)
Supervisor:
Grunwaldt, Jan-Dierk (Intern)
Woodley, John (Intern)
Main Supervisor:
Gani, Rafiqul (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD
Systematic Modelling, Simulation and Design of Intensified Bio-Chemical Processes
Department of Chemical and Biochemical Engineering
Period: 01/08/2008 → 29/11/2011
Number of participants: 6
Phd Student:
Roman Martinez, Alicia (Intern)
Supervisor:
Woodley, John (Intern)
Main Supervisor:
Gani, Rafiqul (Intern)
Examiner:
Gernaey, Krist V. (Intern)
Sales Cruz, Alfonso Mauricio (Intern)
Wiebe, Lars (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Stipendie fra udlandet
Project: PhD

Catalytic Routes to Renewable Polymer Building Blocks
Department of Chemistry
Period: 01/06/2008 → 14/12/2011
Number of participants: 6
Phd Student:
Hansen, Thomas Søndergaard (Intern)
Supervisor:
Woodley, John (Intern)
Main Supervisor:
Riisager, Anders (Intern)
Examiner:
Clausen, Mads Hartvig (Intern)
Bols, Mikael (Ekstern)
Leitner, Walter (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU-lønnet stipendie
Project: PhD

Valu- added Chemicals from Biomass by Heterogeneous Catalysis
Department of Chemical and Biochemical Engineering
Period: 01/05/2008 → 21/09/2011
Number of participants: 7
Phd Student:
Voss, Bodil (Intern)
Supervisor:
Grunwaldt, Jan-Dierk (Intern)
Schjedt, Niels Christian (Ekstern)
Main Supervisor:
Woodley, John (Intern)
Examiner:
Jensen, Anker Degn (Intern)
Jakobsson, Niklas (Ekstern)
Patience, Gregory S. (Ekstern)
**Bio-Petrochemicals**

Department of Chemistry  
Period: 01/04/2008 → 08/02/2012  
Number of participants: 6  
Phd Student:  
Gorbanev, Yury (Intern)  
Supervisor:  
Woodley, John (Intern)  
Main Supervisor:  
Riisager, Anders (Intern)  
Examiner:  
Fristrup, Peter (Intern)  
Grunwaldt, Jan-Dierk (Intern)  
Herbst, Konrad (Ekstern)

**Financing sources**  
Source: Internal funding (public)  
Name of research programme: ErhvervPhD-ordningen VTU  
Project: PhD

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**Membrane Assisted Enzyme Fractionation**

Department of Chemical and Biochemical Engineering  
Period: 15/03/2008 → 08/02/2012  
Number of participants: 8  
Phd Student:  
Yuan, Linfeng (Intern)  
Supervisor:  
Jakobsen, Sune (Intern)  
Korsholm, Lars (Ekstern)  
Woodley, John (Intern)  
Main Supervisor:  
Jonsson, Gunnar Eigil (Intern)  
Examiner:  
Gernaey, Krist V. (Intern)  
Kristensen, Steen (Ekstern)  
Thom, Volkmar (Intern)

**Financing sources**  
Source: Internal funding (public)  
Name of research programme: Offentlig finansiering  
Project: PhD

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**reactor and process design for chem.-enzymatic synthesis of FDA**

Department of Chemical and Biochemical Engineering  
Period: 01/03/2008 → 18/04/2012  
Number of participants: 6  
Phd Student:  
Fu, Wenjing (Intern)  
Supervisor:  
Riisager, Anders (Intern)  
Main Supervisor:  
Woodley, John (Intern)
Examiner:
Gernaey, Krist V. (Intern)
Lye, Gary J. (Ekstern)
Wiebe, Lars (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU-lønnet stipendie
Project: PhD

Process-Product Synthesis, Design and Analysis through the Group- Contribution Approach
Department of Chemical and Biochemical Engineering
Period: 01/04/2007 → 01/09/2010
Number of participants: 7
Phd Student:
Alvarado-Morales, Merlin (Intern)
Supervisor:
Gernaey, Krist V. (Intern)
Woodley, John (Intern)
Main Supervisor:
Gani, Rafiqul (Intern)
Examiner:
Kontogeorgis, Georgios (Intern)
Camarda, Kyle V. (Ekstern)
Zondervan, Edwin (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU-lønnet stipendie
Project: PhD

Enzymatic Opening of Diferulate Cross-Links in Plant Cell Walls
Department of Chemical and Biochemical Engineering
Period: 15/03/2007 → 15/06/2011
Number of participants: 6
Phd Student:
Wittrup Agger, Jane (Intern)
Supervisor:
Johansen, Katja Salomon (Ekstern)
Main Supervisor:
Meyer, Anne S. (Intern)
Examiner:
Woodley, John (Intern)
Biely, Peter (Ekstern)
Thomsen, Anne Belinda (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 DTU-stip, 2/3 FUR/andet
Project: PhD

Mechanisms of Enzymatic Inactivation in the Animal Feed Pelleting Process
Department of Chemical and Biochemical Engineering
Period: 01/01/2007 → 17/06/2010
Number of participants: 7
Phd Student:
Puder, Katja (Intern)
Model-Based Computer Aided Framework for Design of Process Monitoring and Analysis Systems

Department of Chemical and Biochemical Engineering
Number of participants: 6
PhD Student:
Singh, Ravendra (Intern)
Supervisor:
Gernaey, Krist V. (Intern)
Main Supervisor:
Gani, Rafiqul (Intern)
Examiner:
Woodley, John (Intern)
Venkatasubramanian, Venkat (Ekstern)
Wiebe, Lars (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU, Samfinansiering
Project: PhD

Continuous Culture Microbioreactors

Department of Chemical and Biochemical Engineering
Period: 01/05/2006 → 29/09/2010
Number of participants: 7
PhD Student:
Schäpper, Daniel (Intern)
Supervisor:
Eliasson Lantz, Anna (Intern)
Stocks, Stuart M. (Ekstern)
Main Supervisor:
Gernaey, Krist V. (Intern)
Examiner:
Woodley, John (Intern)
Duetz, Wouter A. (Ekstern)
Franco-Lara, Ezequiel (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU-lønnet stipendie
Project: PhD

Micro-sensor based on Click Chemistry
Department of Chemical and Biochemical Engineering
Period: 01/03/2006 → 27/05/2009
Number of participants: 5
Phd Student:
Daugaard, Anders Egede (Intern)
Main Supervisor:
Hvilsted, Søren (Intern)
Examiner:
Woodley, John (Intern)
Binder, Wolfgang H. (Ekstern)
Hult, Anders (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU, Samfinansiering
Project: PhD

Controlled Release of Environmentally Friendly Antifouling Agents from Marine Coatings

Department of Chemical and Biochemical Engineering
Period: 01/11/2005 → 01/04/2009
Number of participants: 7
Phd Student:
Olsen, Stefan Møller (Intern)
Supervisor:
Dam-Johansen, Kim (Intern)
Pedersen, Lars Thorslund (Intern)
Main Supervisor:
Kill, Søren (Intern)
Examiner:
Woodley, John (Intern)
Swain, Geoffrey W. (Ekstern)
Erik Weinell, Claus (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: ErhvervsPhD-ordningen VTU
Project: PhD

Module Design and Performance in Microfiltration, Ultrafiltration and Membrane Contactors

Department of Chemical and Biochemical Engineering
Period: 01/09/2005 → 19/12/2008
Number of participants: 5
Phd Student:
Beier, Søren (Intern)
Main Supervisor:
Jonsson, Gunnar Eigil (Intern)
Examiner:
Woodley, John (Intern)
Aimar, Pierre (Ekstern)
Kristensen, Steen (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU-lønnet stipendie
Project: PhD

Scaleable Assembly of Protein Machines using Magnetic Adsorbents
Department of Systems Biology  
Number of participants: 5  
Phd Student:  
Ottow, Kim Ekelund (Intern)  
Main Supervisor:  
Hobley, Timothy John (Intern)  
Examiner:  
Woodley, John (Intern)  
Regenberg, Birgitte (Intern)  
Thomas, Owen R. T. (Intern)  

Financing sources  
Source: Internal funding (public)  
Name of research programme: Anden EU-finansiering  
Project: PhD

Influence of Formulation in Formation of Enzyme Granules by Sparay Drying  
Department of Chemical and Biochemical Engineering  
Period: 01/09/2004 → 28/01/2007  
Number of participants: 7  
Phd Student:  
Sloth, Jakob (Intern)  
Supervisor:  
Bach, Poul (Ekstern)  
Jensen, Anker Degn (Intern)  
Main Supervisor:  
Kil, Søren (Intern)  
Examiner:  
Woodley, John (Intern)  
Hansen, Tomas T. (Ekstern)  
Seville, Jonathan P. K. (Ekstern)  

Financing sources  
Source: Internal funding (public)  
Name of research programme: DTU, Samfinansiering  
Project: PhD