Evaluation of the efficiency of alternative enzyme production technologies

Enzymes are used in an increasing number of industries. The application of enzymes is extending into the production of lignocellulosic ethanol in processes that economically can compete with fossil fuels. Since lignocellulosic ethanol is based on renewable resources it will have a positive impact on for example the emission of greenhouse gases. Cellulases and hemi-cellulases are used for enzymatic hydrolysis of pretreated lignocellulosic biomass, and fermentable sugars are released upon the enzymatic process. Even though many years of research has decreased the amount of enzyme needed in the process, the cost of enzymes is still considered a bottleneck in the economic feasibility of lignocellulose utilization. The purpose of this project was to investigate and compare different technologies for production of these enzymes. The filamentous fungus Trichoderma reesei is currently used for industrial production of cellulases and hemi-cellulases. The aim of the thesis was to use modeling tools to identify alternative technologies that have higher energy or raw material efficiency than the current technology.

The enzyme production by T. reesei was conducted as an aerobic fed-batch fermentation. The process was carried out in pilot scale stirred tank reactors and based on a range of different process conditions, a process model was constructed which satisfactorily described the course of fermentation. The process was governed by the rate limiting mass transfer of oxygen from the gas to the liquid phase. During fermentation, filamentous growth of the fungus lead to increased viscosity which hindered mass transfer. These mechanisms were described by a viscosity model: A correlation containing the superficial gas velocity and the apparent viscosity of the fermentation broth was shown to describe the experimental data well. The mass transfer rate was approximately 20% lower than the literature data for airlift reactors. Mixing in the pilot scale airlift reactor was also studied. As the mixing time was of the same order of magnitude as the characteristic time for oxygen transfer, mixing could also be limiting the process at that scale. The process model for the airlift reactor was also shown to describe the experimental data well for a range of process conditions.

A cost function for oxygen transfer including the equipment cost and running cost for nutrients and electricity was developed for both the stirred tank reactor and the airlift reactor. The cost function was used to identify an optimum range of reactor configuration and process conditions for industrial scale enzyme production fermentors. It was shown that compared to the stirred tank reactor 22% of the electricity cost might be reduced for the airlift reactor, and the capital cost might also be somewhat lower. However, since the electricity cost is a relatively minor part of the total cost, there might currently not be an obvious fiscal motive to change technology. The cost of nutrients is considerably larger than the electricity cost and was shown to be independent of the technology and process conditions. If the cost structure changes in the future and the airlift reactor is chosen as the alternative production technology, suggestions on the practical scale-up procedure are given. These include the use of Computational Fluid Dynamics (CFD) and scale-down models of the production environment.