Synthesis and characterization of iron-cobalt (FeCo) alloy nanoparticles supported on carbon

Iron-cobalt nanocrystalline bimetallic alloys supported on carbon microparticles were synthesized and characterized. The preparation methods involved the use of iron and cobalt chloride or acetate precursor salts in water and direct co-precipitation or wet impregnation techniques. The size of the alloy nanoparticles differed depending on the preparation method. When the wet impregnation technique of acetate precursor salts of Fe and Co were used for the synthesis, the size of FeCo alloy nanoparticles was approximately 13 nm. FeCo alloy nanoparticles were characterized by crystallography (XRD), thermogravimetric analysis (TGA), electron microscopy, energy dispersive X-ray spectroscopy analysis (EDX), and atomic force microscopy (AFM). In all cases, we observed well-dispersed nanometer size alloy particles on the surface of carbon microparticles. FeCo supported on such carbon microparticles are chemically and mechanically stable for prolonged periods of time. AFM analysis showed that the FeCo nanoparticles were formed on the surface of the carrier. The results of this study suggest that using these easy and inexpensive synthetic methods iron-cobalt nanoparticles can be formed on carbon microparticles support materials with applications in catalysis, microelectronics, and biomedicine.

General information
Publication status: Published
Organisations: Department of Chemistry, Centre for Catalysis and Sustainable Chemistry, Organic Chemistry, Technical University of Denmark
Contributors: Koutsopoulos, S., Barfod, R., Eriksen, K. M., Fehrmann, R.
Pages: 1210-1216
Publication date: 2017
Peer-reviewed: Yes

Publication information
Journal: Journal of Alloys and Compounds
Volume: 725
ISSN (Print): 0925-8388
Ratings: BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 3.66 SJR 1.02 SNIP 1.403
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Web of Science (2017): Indexed yes
Original language: English
Keywords: FeCo bimetallic alloy, Nanoparticles, Catalysis, Ammonia synthesis, Magnetization, Carbon nanotubes
DOIs: 10.1016/j.jallcom.2017.07.105
Research output: Contribution to journal › Journal article – Annual report year: 2017 › Research › peer-review

Structure of caesium disulfate at 120 and 273 K

The crystal structures of Cs2S2O7 at 120 and 273 K have been determined from X-ray single-crystal data. Caesium disulfate represents a new structure type with a uniquely high number of independent formula units at 120 K: In one part caesium ions form a tube surrounding the disulfate ions, [Cs8(S2O7)6+]n; in the other part a disulfate double-sheet sandwiches a zigzagging caesium ion chain, [Cs2(S2O7)6−]n. Caesium disulfate shows an isostructural order–disorder transition between 230 and 250 K, where two disulfate groups become partially disordered above 250 K. The Cs+ ion arrangement shows a remarkable similarity to the high-pressure RbIIV metal structure.

General information
Publication status: Published
Organisations: X-ray Crystallography, Department of Chemistry, Energy and Materials, Sustainable and Green Chemistry
Contributors: Ståhl, K., Berg, R. W., Eriksen, K. M., Fehrmann, R.
Pages: 551-557
Publication date: 2009
Peer-reviewed: Yes

Publication information
Journal: Acta Crystallographica. Section B: Structural Science
Volume: 65
Issue number: 5
ISSN (Print): 0108-7681
Ratings: BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.45 SNIP 1.046
Alternative flue gas cleaning by catalysis, electrocatalysis and selective gas absorption

General information
Publication status: Published
Organisations: Department of Chemistry, Sustainable and Green Chemistry, Centre for Catalysis and Sustainable Chemistry, Department of Chemistry
Publication date: 2007
Peer-reviewed: No

Caesium disulfate at 120 and 273 K.

General information
Publication status: Published
Organisations: Department of Chemistry
Contributors: Ståhl, K., Berg, R. W., Eriksen, K. M., Fehrmann, R.
Publication date: 2007
Peer-reviewed: Yes
Event: Abstract from 24th European Crystallographic Meeting, Marrakech, Morocco.

Caesium disulfate at 120 and 273 K. A novel structure type.

General information
Publication status: Published
Organisations: X-ray Crystallography, Department of Chemistry, Energy and Materials, Department of Chemistry, Centre for Catalysis and Sustainable Chemistry
Contributors: Ståhl, K., Berg, R. W., Eriksen, K. M., Fehrmann, R.
Publication date: 2007
Peer-reviewed: No
Event: Abstract from 36th Danish Crystallographer Meeting, Odense, Denmark.

Conductivity, calorimetry and phase diagram of the NaHSO₄–KHSO₄ system
Physico-chemical properties of the binary system NaHSO₄–KHSO₄ were studied by calorimetry and conductivity. The enthalpy of mixing has been measured at 505 K in the full composition range and the phase diagram calculated. The phase diagram has also been constructed from phase transition temperatures obtained by conductivity for 10 different compositions and by differential thermal analysis. The phase diagram is of the simple eutectic type, where the eutectic is found to have the composition X(KHSO₄)=0.44 (melting point ≈ 406 K). The conductivities in the liquid region have been fitted to polynomials of the form κ(X)=A(X)+B(X)(T-Tₘ)+C(X)(T-Tₘ)², where Tₘ is the intermediate temperature of the measured temperature range and X the mole fraction of KHSO₄. The possible role of this binary system as a catalyst solvent is also discussed. (C) 2005 Elsevier B.V. All rights reserved.

General information
Synthesis and characterization of supported Pt and Pt alloys nanoparticles used for the catalytic oxidation of sulfur dioxide.

Controlled pore glass silica (CPG) was used as support to prepare platinum-based catalysts using the wet impregnation method and DMSO or CHCl3 as solvent. In all cases, the catalyst loading with the active phase was 2 wt%. The catalysts were tested for the SO2 oxidation reaction at atmospheric pressure in the temperature range of 250–700 °C. The effect of doping the active metal with rhodium and palladium was also studied. The catalytic activities of the supported catalysts were found to follow the order Pt–Pd/CPG > Pt–Rh/CPG > Pt/CPG. A significant synergistic effect of the Pt–Pd alloy was observed compared with the SO2 conversion efficiency of the individual metals supported on CPG. The effect of the solvent used in the impregnation step is also discussed with regard to the properties of the final product and to catalytic activity.

General information
Publication status: Published
Organisations: Department of Chemistry, Technical University of Denmark
Contributors: Koutsopoulos, S., Eriksen, K. M., Fehrmann, R.
Pages: 270-276
Publication date: 2006
Peer-reviewed: Yes

Publication information
Journal: Journal of Catalysis
Volume: 238
Issue number: 2
ISSN (Print): 0021-9517
Ratings:
Scopus rating (2006): SJR 3.137 SNIP 2.043
Web of Science (2006): Indexed yes
Original language: English
Keywords: Controlled pore silica; Platinum; Palladium; Rhodium; Catalyst; Sulphur dioxide oxidation
DOIs:
10.1016/j.jcat.2005.12.009
Source: orbit
Source-ID: 194422

Research output: Contribution to journal > Journal article – Annual report year: 2006 > Research > peer-review
pH of the impregnation solution and of the reduction temperature of the precursor salts resulted in a very active catalyst with average particle size of 1.7 nm. (c) 2006 Elsevier B.V. All rights reserved.

**General information**
Publication status: Published
Organisations: Department of Chemistry, Centre for Catalysis and Sustainable Chemistry
Contributors: Koutsopoulos, S., Rasmussen, S. B., Eriksen, K. M., Fehrmann, R.
Pages: 142-148
Publication date: 2006
Peer-reviewed: Yes

**Publication information**
Journal: Applied Catalysis A - General
Volume: 306
ISSN (Print): 0926-860X
Ratings:
Scopus rating (2006): SJR 1.679 SNIP 1.528
Web of Science (2006): Indexed yes
Original language: English
Keywords: Silica, Titania, Platinum, Palladium, Rhodium, Catalyst, Sulphur dioxide oxidation
DOIs:
10.1016/j.apcata.2006.03.041
Source: orbit
Source-ID: 194501
Research output: Contribution to journal › Journal article – Annual report year: 2006 › Research › peer-review

**Titania Supported Pt and Pt/Pd Nano-particle Catalysts for the Oxidation of Sulfur Dioxide.**
Several types of titania (anatase) were used as supports for pure platinum and Pt–Pd bimetallic alloy catalysts. The preparation methods, normal wet impregnation technique and flame aerosol synthesis, obtained metal loadings of 2% by weight. The prepared catalysts were tested for SO2 oxidation activity at atmospheric pressure in the temperature range 250–600 °C. The SO2 to SO3 conversion efficiency of the Pt–Pd alloy was significantly higher than that of the individual metals. The effects of the preparation method and the titania type used on the properties and activity of the resulting catalyst are discussed.

**General information**
Publication status: Published
Organisations: Department of Chemical and Biochemical Engineering, Department of Chemistry, Technical University of Denmark
Contributors: Koutsopoulos, S., Johannessen, T., Eriksen, K. M., Fehrmann, R.
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Peer-reviewed: Yes

**Publication information**
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Ratings:
Scopus rating (2006): SJR 3.137 SNIP 2.043
Web of Science (2006): Indexed yes
Original language: English
Keywords: Pallinum; Titania; Catalyst; Nanoparticle synthesis; Sulfur dioxide oxidation
DOIs:
Source: orbit
Source-ID: 194415
Research output: Contribution to journal › Journal article – Annual report year: 2006 › Research › peer-review

**Vanadium-Sulfate-Pyrosulfate Electrolytes for Electrochemical Removal of**

**General information**
Publication status: Published
Organisations: Department of Chemistry, Department of Chemistry
Supported Liquid Phase Catalysis: An old success with molten salts - a new era with ionic liquids?

The crystal structure determination and refinements of K2S2O7, KNaS2O7 and Na2S2O7 from X-ray powder and single crystal diffraction data

Crystal Structure and Spectroscopic Properties of CsVO2SO4
**Physico-chemical Properties and Transition Metal Complex formation in Alkali Pyrosulphate and Hydrogen Sulphate Melts.**

**General information**
Publication status: Published
Organisations: Department of Chemistry, Faculté des Sciences St Jérôme, Institut Universitaire des Systèmes Thermiques Industriels
Contributors: Rasmussen, S. B., Hamma, H., Eriksen, K. M., Hatem, G., Gaune-Escard, M., Fehrmann, R.
Pages: 189-196
Publication date: 2004

**Host publication information**
Title of host publication: Proc. 7th International Conference on Molten Slags, Fluxes and Salts.
Source: orbit
Source-ID: 178200
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2004

**Vanadia-silica and vanadia-cesium-silica catalysts for oxidation of SO2**
Mesoporous vanadia-silica catalysts have been prepared by three different sol-gel procedures using tetraethylorthosilicate (TEOS), vanadyl acetylacetonate (VAA), or VOCI3 and in some cases quaternary ammonium salts ((CH3)(3)C14H29N+Br- or (C10H21)(4)N+Br-) as surfactants. According to procedure A, TEOS and VAA were concomitantly hydrolyzed, in procedure B TEOS was prehydrolyzed and vanadium precursor was added to the silica sol, and in procedure C both TEOS and vanadium precursors were separately prehydrolyzed. The sol-gel procedures were controlled by checking the effect of the hydrolysis pH, refluxing time, surfactant, and conditions of gellifications (slow evaporation at room temperature or autoclavization). The samples were dried under vacuum, first at room temperature, then at 373 K, and finally calcined at 773 K. ICP-AES analysis indicated for all samples a vanadium content of around 6.5 wt%. The samples were impregnated with Cs2SO4 resulting in a Cs:V ratio of 3:1 and then dried and calcined under the same conditions. The catalysts were characterized using several methods: sorption isotherms of N2 at 77 K, XRD, and XPS. The results of the characterization indicated that during calcination of the V/Cs catalysts vanadia is dissolved in a sulfate containing molten salt. The activity of these catalysts for the oxidation of SO2 was tested in a gas containing 2% SO2, 19% O2, and 79% N2 in the temperature range 523-823 K. Similar experiments with gases containing 10% H2O in the feed or with wet catalysts were also performed. The activation of the catalysts and the catalytic behavior were monitored by in situ Raman and EPR spectroscopy. These characterization techniques indicated that the active molten phase contains vanadium oxosulfato complexes similar to the V2O5-M2S2O7 (M = alkali metal)-based industrial catalyst, where kieselghur is used as carrier material. The high dispersion of vanadium in the studied catalysts results in an increased catalytic activity for the oxidation of SO2 contained in feed gases with low SO2 content.

**General information**
Publication status: Published
Organisations: Department of Chemistry, University of Bucharest, Institute of Chemical Engineering and High Temperature Chemical Processes
Contributors: Pârvulescu, V. I., Paun, C., Pârvulescu, V., Alifanti, M., Giakoumelou, I., Boghosian, S., Rasmussen, S. B., Eriksen, K. M., Fehrmann, R.
Pages: 24-36
Publication date: 2004
Peer-reviewed: Yes

**Journal: Journal of Catalysis**
Volume: 225
Issue number: 1
ISSN (Print): 0021-9517
Ratings:
Catalytic and Chemical Properties of Boiler Deposits from Orimulsion Fuel

General information
Publication status: Published
Organisations: Department of Chemistry, Department of Physics, Energi E2 A/S
Pages: 360-369
Publication date: 2003
Peer-reviewed: Yes

Publication information
Journal: PowerPlant Chemistry
Volume: 5
Issue number: 6
ISSN (Print): 1438-5325
Original language: English
Source: orbit
Source-ID: 39012
Research output: Contribution to journal › Journal article – Annual report year: 2003 › Research › peer-review

High Temperature NMR Studies of Ionic-Liquid Catalysts

General information
Publication status: Published
Organisations: Department of Chemistry, Boreskov Institute of Catalysis SB RAS
Contributors: Lapina, O., Terskikh, V., Bal’zhinimaev, B., Eriksen, K. M., Fehrmann, R.
Pages: 85-104
Publication date: 2003

Host publication information
Title of host publication: Green Industrial Applications of Ionic Liquids : II. Mathematics, Physics and Chemistry
Volume: 92
Place of publication: Dordrecht, The Netherlands
Publisher: Kluwer Academic Publishers
ISBN (Print): 1-4020-1137-7
Source: orbit
Source-ID: 39044
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2003 › Research › peer-review

Ionic Liquids as Catalysts for Sulfuric acid Production and Cleaning of Flue Gases

General information
Publication status: Published
Organisations: Department of Chemistry, Georgia Institute of Technology
Contributors: Fehrmann, R., Eriksen, K. M., Rasmussen, S. B., Winnick, J.
Pages: 253-262
Publication date: 2003

Host publication information
Title of host publication: Green Industrial Applications of Ionic Liquids : II. Mathematics, Physics and Chemistry
Volume: 92
Place of publication: Dordrecht, The Netherlands
Publisher: Kluwer Academic Publishers
ISBN (Print): 1-4020-1137-7
Source: orbit
Propene and 1-octene hydroformylation with silica-supported, ionic liquid-phase (SILP) Rh-phosphine catalysts in continuous fixed-bed mode

General information
Publication status: Published
Organisations: Department of Chemistry
Contributors: Riisager, A., Eriksen, K. M., Wasserscheid, P., Fehrmann, R.
Pages: 149-153
Publication date: 2003
Peer-reviewed: Yes

Publication information
Journal: Catalysis Letters
Volume: 90
ISSN (Print): 1011-372X
Ratings:
Scopus rating (2003): SJR 1.339 SNIP 1.041
Web of Science (2003): Indexed yes
Original language: English
Source: orbit
Source-ID: 210450

Propene and 1-octene hydroformylation with silica-supported, ionic liquid-phase (SILP) Rh-phosphine catalysts in continuous fixed-bed mode

Supported ionic liquid-phase (SILP) catalysts were made by immobilizing Rh-monophosphine complexes of bis(m-phenylguanidinium) phenylphosphine 1 and NORBOS 2 ligands in 1-n-butyl-3-methylimidazolium hexafluorophosphate, [BMIM][PF6], on a silica support. The catalysts were active in continuous gas- and liquid-phase hydroformylation of propene and 1-octene, exhibiting TOFs up to 88 h(-1) for SILP Rh-2 catalysts, while only low selectivities up to 74% n-aldehyde (n/iso ratio of 2.8) were obtained. This is the first example of continuous fixed-bed liquid-phase hydroformylation using SILP catalysts.

General information
Publication status: Published
Organisations: Department of Chemistry, Rheinisch-Westfälische Technische Hochschule Aachen
Contributors: Riisager, A., Eriksen, K. M., Wasserscheid, P., Fehrmann, R.
Pages: 149-152
Publication date: 2003
Peer-reviewed: Yes

Publication information
Journal: CATALYSIS LETTERS
Volume: 90
Issue number: 3-4
ISSN (Print): 1011-372X
Ratings:
Scopus rating (2003): SJR 1.339 SNIP 1.041
Web of Science (2003): Indexed yes
Original language: English
Source: orbit
Source-ID: 39003

Propene Hydroformylation by Supported Aqueous-phase Rh-NORBOS Catalysts

The gas-phase hydroformylation reaction of propene using supported aqueous-phase (SAP) Rh-NORBOS modified catalysts in a continuous flow reactor has been examined. SAP catalysts supported on six different support materials were made by wet impregnation using solutions of the precursor complex Rh(acac)(CO)(2) and NORBOS ligand. Catalytic performance of silica gel-based catalysts was examined by altering catalyst composition and reaction conditions. Results were compared to analogous TPPTS catalysts and to catalysts supported on alternative support materials, e.g. silica glass, alumina and carbon. Based on these results the aqueous and the homogeneous nature of the SAP catalysts are
Thermal, conductivity, NMR, and Raman spectroscopic measurements and phase diagram of the Cs2S2O7-CsHSO4 system

The conductivity of the binary system Cs2S2O7-CsHSO4 has been measured at 20 different molten compositions in the full composition range and in the temperature range 430-750 K. From the obtained liquidus-solidus phase transition temperatures, the phase diagram has been constructed. It is of the simple eutectic type with the composition X(CsHSO4) = 0.86 and temperature of fusion of 470 K for the eutectic. The previously unpublished temperature of fusion of CsHSO4 was found to be 491.7 K. The experimental phase diagram is in good accordance with a calculated diagram based on measured thermodynamic properties of the pure compounds and the heat of liquid-liquid mixing measured for X(CsHSO4) = 0.5 and 1.0. Cs-113 and O-17 NMR spectra and Raman spectra of the liquid Cs2S2O7-CsHSO4 system indicate the presence of a temperature sensitive equilibrium 2HSO(4) reversible arrow S2O72- + H2O Where the water molecules are strongly associated in the melt. Fast exchange reactions take place between the species present, leading to the observed O-17 NMR single line with an averaged chemical shift. Super-ionic and thermodynamic stable phases and the temperatures of phase transitions have been identified from the NMR measurements on CsHSO4, Cs2S2O7, and Cs2S2O7-CsHSO4 mixtures. For 11 selected compositions covering the entire composition range of the Cs2S2O7-CsHSO4 binary system, the conductivity of the molten state has been expressed by equations of the form k(X) = A(X) + B(X)(T - T-m) + C(X)(T - T-m)(2) where T-m is the intermediate temperature of the measured temperature range and X is the initial mol fraction of CsHSO4.

General information
Publication status: Published
Organisations: Department of Chemistry, Faculté des Sciences St Jérôme, Boreskov Institute of Catalysis SB RAS
Contributors: Rasmussen, S. B., Hama, H., Lapina, O., Khabibulin, D. F., Eriksen, K. M., Berg, R. W., Hatem, G., Fehrmann, R.
Pages: 13823-13830
Publication date: 2003
Peer-reviewed: Yes

Publication information
Journal: Journal of physical chemistry b
Volume: 107
Issue number: 50
ISSN (Print): 1520-6106
Ratings:
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Web of Science (2003): Indexed yes
Original language: English
Source: orbit
Source-ID: 39005
Research output: Contribution to journal › Journal article – Annual report year: 2003 › Research › peer-review
Catalytic and electrocatalytic cleaning of alkali containing flue gases

General information
Publication status: Published
Organisations: Department of Chemistry, Georgia Institute of Technology
Contributors: Rasmussen, S. B., Eriksen, K. M., Winnick, J., Rasmussen, R. C., Fehrmann, R.
Publication date: 2002
Peer-reviewed: No
Event: Abstract from 223rd ACS Meeting, Orlando, USA, 7th-11th April.
Source-ID: 42863
Research output: Contribution to conference > Conference abstract for conference – Annual report year: 2002 > Research

Crystal structure and spectroscopic properties of Na2K6(VO)(2)(SO4)(7)

Red-brown crystals of a new mixed alkali oxo sulfato vanadium(V) compound Na2K6(VO)(2)(SO4)(7), suitable for X-ray determination, have been obtained from the catalytically important binary molten salt system M2S2O7-V2O5 (M = 80% K and 20% Na). By slow cooling of a mixture with the mole fraction X-V2O5 = 0.24 from 325 degreesC, i.e., just below the liquidus temperature, to the solidus temperature of around 300 degreesC, a dark reddish amorphous phase was obtained containing crystals of the earlier described V(V)-V(IV) mixed valence compound K-6(VO)(4)(SO4)(8) and Na2K6-(VO)(2)(SO4)(7) described here. This compound crystallizes in the tetragonal space group P4(3)2(1)2 (No. 96) with a = 9.540(3) Angstrom, c = 29.551(5) Angstrom at 20 degreesC and Z = 4. It contains a distorted VO6 octahedron with a short V-O bond of 1.552(6) Angstrom, a long one of 2.276(5) Angstrom trans to this, and four equatorial V-O bonds in the range 1.881(6)-1.960(6) A. The deformation of the VO6 octahedron is less pronounced compared to that of the known oxo sulfato V(IV) compounds. Each VO3+ group is coordinated to five sulfate groups of which two are unidentately coordinated and three are bidentate bridging to neighboring VO3+ groups. The length of the S-O bonds in the S-O-V bridges of the two unidentately coordinated sulfato groups are 1.551(6) Angstrom and 1.568(6) Angstrom, respectively, which are unusually long compared to our earlier measurements of sulfate groups in other V(111), V(IV), and V(V) compounds.

General information
Publication status: Published
Organisations: Department of Chemistry, University of Patras, Foundation for Research and Technology-Hellas
Contributors: Karydis, D., Boghosian, S., Nielsen, K., Eriksen, K. M., Fehrmann, R.
Pages: 2417-2421
Publication date: 2002
Peer-reviewed: Yes

Publication information
Journal: Inorganic Chemistry
Volume: 41
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ISSN (Print): 0020-1669
Ratings:
Scopus rating (2002): SJR 1.635 SNIP 1.354
Web of Science (2002): Indexed yes
Original language: English
Source-ID: 42874
Research output: Contribution to journal > Journal article – Annual report year: 2002 > Research > peer-review

EPR and UV/VIS spectroscopic investigations of VO2+ complexes and compounds formed in alkali pyrosulfates

The catalytically important molten salt-gas system M2S2O7-M2SO4-V2O5/SO2(g) (M = Na, K, Rb, Cs) has been investigated by X- and Q-band EPR spectroscopy. In order to obtain information about the V(IV) complex formation in the melts, samples rather dilute in V2O5 were quenched from the molten state at 450-460 degreesC to 0 degreesC. EPR spectra of the quenched samples were recorded on samples with alkali to vanadium (M/V) ratios 40, 80 and 160. The spectra show that two V(IV) complexes dominate in the melt regardless of the type of alkali metal ion. In systems with low activity of sulfate a paramagnetic V(IV) complex with g(parallel to) = 1.915, g(perpendicular to) = 1.978 and line widths 5-15 Gauss is observed. In systems saturated with M2SO4 the obtained EPR spectra show a paramagnetic complex with the g-tensors g(parallel to) = 1.930, g(perpendicular to) = 1.980 and line widths 20-60 Gauss. These results fit very well with the assumption that the species VO(SO4)(2)(2-) and SO42- are in equilibrium with VO(SO4)(3)(4-). It has also been shown for the system M2S2O7-M2SO4(sat)-V2O5/SO42-(g) that the line widths in the system increase with higher cation radius, and depend linearly on the volume fraction of the sample occupied by the cation. This indicates that spin-spin relaxation effects are the major contribution to line broadening. Combining information from UV/VIS and EPR spectra shows that the VO2+ unit in the molten salt solvent exhibits electronic properties close to aqueous solutions of V(IV).
Etude thermodynamique des systèmes binaires MHSO₄-NHSO₄ (M,N=Na,K,Rb),

Molten Salt Electrocatalytic Membrane Cells for Flue Gas Cleaning.

Molten V₂O₅/Ce₀.9K₀.9Na₀.2S₂O₇ and V₂O₅/K₂S₂O₇ catalysts as electrolytes in an electrocatalytic membrane separation device for SO₂ removal

Bench scale fuel cell tests have been carried out on the SO₂ oxidation catalyst systems V₂O₅/M₂S₂O₇ (M = alkali) used as electrolytes in a standard molten carbonate fuel cell (MCFC) fuel cell setup for removal of SO₂ from power plant flue gases. Porous LiₓNi(1-ₓ)O electrodes were used both as anode and cathode. The cleaning cell removes SO₂ when a potential is applied across the membrane, potentially providing cheap and ecological viable means for regeneration of SO₂ from off-gases into high quality H₂SO₄. Results show that successful removal of up to 80% SO₂ at 450 degreesC can be achieved at approximately 5 mA cm⁻². However, the data obtained during the experiments explain the current limitations of the process, especially in terms of electrolyte wetting capability and acid/base chemistry of the electrolyte.
SO2 oxidation catalyst model systems characterized by thermal methods

The molten salts M2S2O7 and MHSO4, the binary molten salt Systems M2S2O7-MHSO4 and the molten salt-gas systems M2S2O7 V2O5 and M2S2O7-M2SO4 V2O5 (M = Na, K, Rb, Cs) in O2, SO2 and At atmospheres have been investigated by thermal methods like calorimetry, Differential Enthalpic Analysis (DEA) and Differential Scanning Calorimetry (DSC). Fundamental thermodynamic data like temperatures and molar heats of solid-solid transition and fusion, phase diagrams, heat capacities of solids and liquids, heat of mixing and heats of complex formation have been obtained and the results are discussed in relation to the mechanism Of SO2 oxidation by V2O5 based industrial catalysts.

Thermodynamic study of the molten salt binary system KHSO4-NaHSO4

The partial molar enthalpies of mixing of NaHSO4 and KHSO4 have been measured at 528 K by dropping samples of pure compounds into molten mixtures of NaHSO4 and KHSO4 in Calvet calorimeter. From these values the molar enthalpy of mixing has been deducted. The same method has been used for the determination of the heat capacity of the two pure compounds in the solid and liquid states. The phase diagram of this system has been confirmed by conductometric and thermal analysis methods. By an optimization method the excess entropy of the liquid mixtures was also calculated.
An ESR Investigation of VO2+ Complexes in Alkali Pyrosulfate

Calorimetric and spectroscopic measurements on the SO2 oxidation catalyst model system M2S2O7-M2SO4-V2O5/Ar(g) or SO2(g) (M = K or Cs) at 430-470 degrees C

Conductivity, thermal measurements, X-ray investigations, and phase diagram of the Na2S2O7-K2S2O7 system
Røggasrensning-katalysatorer og processer under udvikling.

General information
Publication status: Published
Organisations: Department of Chemistry
Contributors: Rasmussen, R. C., Rasmussen, S. B., Eriksen, K. M., Fehrmann, R.
Pages: 4
Publication date: 2001
Peer-reviewed: Unknown

Publication Information
Journal: Dansk Kemi
Volume: 82
Issue number: 11
ISSN (Print): 0011-6335
Original language: English
Source: orbit
Source-ID: 42923
Research output: Contribution to journal › Journal article – Annual report year: 2001 › Communication

SCR by NH3 Over Impregnated Fiber-Glass Catalysts

General information
Publication status: Published
Organisations: Department of Chemistry
Contributors: Suchnev, A. P., Masters, S. G., Goncharou, V. B., Bal'zhinimaev, B. S., Eriksen, K. M., Fehrmann, R.,
 TOKtarev, A. V., Simonova, L. G., Bareiko, V. V.
Publication date: 2001
Peer-reviewed: No
Event: Poster session presented at 17 th North American Catalysis Society Meeting, Toronto, Canada,.
Source: orbit
Source-ID: 50560
Research output: Contribution to conference › Poster – Annual report year: 2001 › Research

Selective catalytic reduction of NO by NH3 over high surface area vanadia-silica catalysts

General information
Publication status: Published
Organisations: Department of Chemistry, University of Bucharest, Technical University of Denmark
Contributors: Caraba, R., Masters, S., Eriksen, K. M., Parvulescu, V., Fehrmann, R.
Pages: 191-200
Publication date: 2001
Peer-reviewed: Yes

Publication information
Journal: APPLIED CATALYSIS B-ENVIRONMENTAL
Volume: 34
Issue number: 3
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Web of Science (2001): Indexed yes
Original language: English
Source: orbit
Source-ID: 42881
Structure and Reactivity of Rh/NORBOS Hydroformylation Catalysts

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Organisations: Department of Chemistry
Contributors: Riisager, A., Eriksen, K. M., Fehrmann, R.
Publication date: 2001
Peer-reviewed: No
Event: Poster session presented at 5th European Congress on Catalysis, Limerick, Ireland.
Source: orbit
Source-ID: 50563
Research output: Contribution to conference > Poster – Annual report year: 2001 > Research

Sulfate Solubility and Sulfato Complex Formation of V(V) and V(IV) in Pyrosulfate Melts

General information
Publication status: Published
Organisations: Department of Chemistry, Department of Chemistry
Contributors: Rasmussen, S. B., Eriksen, K. M., Fehrmann, R.
Pages: 161-174
Publication date: 2001

Host publication information
Title of host publication: Proceedings of the International Jondal 2000 Symposium
Source: orbit
Source-ID: 276671
Research output: Chapter in Book/Report/Conference proceeding > Article in proceedings – Annual report year: 2001 > Research > peer-review

Thermodynamic study of the molten salt binary system KHSO4-NaHSO4

General information
Publication status: Published
Organisations: Department of Chemistry
Contributors: Eriksen, K. M., Fehrmann, R., Hatem, G.
Publication date: 2001
Peer-reviewed: Yes
Event: Poster session presented at Journées de Calorimétrie et d'Analyse Thermique, Hammamet, Tunisia, .
Source: orbit
Source-ID: 50558
Research output: Contribution to conference > Poster – Annual report year: 2001 > Research > peer-review

Diagramme de Phases du Systeme Binaire CsHSO4-Cs2S2O7

General information
Publication status: Published
Organisations: Department of Chemistry
Contributors: Rasmussen, S. B., Eriksen, K. M., Fehrmann, R., Hatem, G.
Pages: 42-45
Publication date: 2000

Host publication information
Title of host publication: Proc. XXVI Journees d'Etude des Equilibres entre Phases, eds. C. Bergman and G. Hatem
Place of publication: Marseille, France
Publisher: Comptes Rendus CNRS Université de Provence
Source: orbit
Source-ID: 176728
Research output: Chapter in Book/Report/Conference proceeding > Article in proceedings – Annual report year: 2000 > Research > peer-review
Electrochemical Flue Gas Cleaning Using Molten Pyrosulfate-Based Membranes

General information
Publication status: Published
Organisations: Department of Chemistry
Contributors: Rasmussen, S. B., Eriksen, K. M., Fehrmann, R., Winnick, J.
Pages: 694-697
Publication date: 2000

Host publication information
Title of host publication: Twelfth International Symposium on Molten Salts, ed. P. Trulove et al.
Place of publication: Pennington, N.J., USA
Publisher: The Electrochemical Society
Source: orbit
Source-ID: 176727

Environmental Catalysis - Pillared Clay DeNOX Catalysts and Electrocatalytical DeSOX Process

General information
Publication status: Published
Organisations: Department of Chemistry
Contributors: Mattsson, R., Rasmussen, S. B., Eriksen, K. M., Winnick, J., Fehrmann, R.
Pages: 341
Publication date: 2000
Peer-reviewed: Yes

Publication information
Volume: 1
Original language: English
Source: orbit
Source-ID: 176729

On the solid phases in the Na2S2O7 - K2S2O7 phase diagram

General information
Publication status: Published
Organisations: Department of Chemistry, Université de Provence
Contributors: Ståhl, K., Hatem, G., Eriksen, K. M., Fehrmann, R.
Pages: P5
Publication date: 2000
Peer-reviewed: No

Publication information
Journal: Unknown title
Original language: English
Source: orbit
Source-ID: 176026
Research output: Contribution to journal – Journal article – Annual report year: 2000 – Research

Electrochemical Flue Gas Cleaning using Molten Pyrosulfate-Based Membranes

General information
Publication status: Published
Organisations: Department of Chemistry, Georgia Institute of Technology
Contributors: Rasmussen, S. B., Eriksen, K. M., Fehrmann, R., Winnick, J.
Pages: 2326
Publication date: 1999
Peer-reviewed: No

Publication information
EPR Spectroscopic Characterization of DeNox and SO2 Oxidation Catalysts and Model-Systems

**General information**
Publication status: Published
Organisations: Department of Chemistry, Hempel A/S, B.P. Chemicals Ltd., Boreskov Institute of Catalysis SB RAS
Contributors: Eriksen, K. M., Jensen, C., Rasmussen, S. B., Oehlers, C., Bal'zhinimaev, B., Fehrmann, R.
Pages: 465
Publication date: 1999
Peer-reviewed: Yes

**Publication information**
Journal: Catal. Today
Volume: 54
Ratings:
Scopus rating (1999): SJR 1.373 SNIP 1.437
Original language: English
Source: orbit
Source-ID: 174120
Research output: Contribution to journal - Journal article - Annual report year: 1999 - Research - peer-review

Equilibres entre Phases dans les Melanges Rb2S2O7-V2O5

**General information**
Publication status: Published
Organisations: Department of Chemistry, Université de Provence
Contributors: Hatem, G., Gaune-Escard, M., Eriksen, K. M., Fehrmann, R.
Pages: 122-125
Publication date: 1999

**Host publication information**
Title of host publication: Equilibres entre Phases dans les Melanges Rb2S2O7-V2O5
Place of publication: Annecy, France
Publisher: J.L. Jorda, M. Lomello- Tafin and C. Opagiste, Comtes Rendus, LAIMAN and ESIA
Source: orbit
Source-ID: 174123
Research output: Chapter in Book/Report/Conference proceeding - Article in proceedings - Annual report year: 1999 - Research

High-Temperature Multinuclear NMR Studies of Vanadia Catalysts for SO2 Oxidation

**General information**
Publication status: Published
Organisations: Department of Chemistry, Boreskov Institute of Catalysis SB RAS
Contributors: Lapina, O. B., Terskikh, V. V., Shubin, A. A., Eriksen, K. M., Fehrmann, R.
Pages: 255
Publication date: 1999
Peer-reviewed: Yes

**Publication information**
Journal: Colloids and Surfaces A: Physicochemical and Engineering Aspects
ISSN (Print): 0927-7757
Ratings:
Scopus rating (1999): SJR 0.602 SNIP 0.818
Original language: English
Source: orbit
Source-ID: 174113
Research output: Contribution to journal - Journal article - Annual report year: 1999 - Research - peer-review
Progress on the mechanistic understanding of SO2 oxidation catalysts

For almost a century vanadium oxide based catalysts have been the dominant materials in industrial processes for sulfuric acid production. A vast body of information leading to fundamental knowledge on the catalytic process was obtained by Academician [G.K. Boreskov, Catalysis in Sulphuric Acid Production, Goskhimizdat (in Russian), Moscow, 1954, p. 348]. In recent years these catalysts have also been used to clean flue gases and other SO2-containing, industrial off-gases. In spite of the importance and long utilization of these industrial processes, the catalytic active species and the reaction mechanism have been virtually unknown until recent years.

It is now recognized that the working catalyst is well described by the molten salt/gas system M2S2O7-MHSO4-V2O5/SO2-O2-SO3-H2O-CO2-N2 (M=Na, K, Cs) at 400-600 degrees C and that vanadium complexes play a key role in the catalytic reaction mechanism.

A multiinstrumental investigation that combine the efforts of four groups from four different countries has been carried out on the model system as well as on working industrial catalysts. Detailed information has been obtained on the complex and on the redox chemistry of vanadium. Based on this, a deeper understanding of the reaction mechanism has been achieved. (C) 1999 Elsevier Science B.V. All rights reserved.

Redox Equilibria in SO2 Oxidation Catalysts

General information
Publication status: Published
Organisations: Department of Chemistry, Boreskov Institute of Catalysis SB RAS, University of Patras
Contributors: Lapina, O. B., Bal'zhinimaev, B., Boghosian, S., Eriksen, K. M., Fehrmann, R.
Pages: 469
Publication date: 1999
Peer-reviewed: Yes

Publication information
Journal: Catalysis Today
Volume: 51
Issue number: 3-4
ISSN (Print): 0920-5861
Ratings:
Scopus rating (1999): SJR 1.373 SNIP 1.437
Original language: English
DOIs:
10.1016/S0920-5861(99)00034-6
Source: orbit
Source-ID: 174117
Research output: Contribution to journal › Journal article – Annual report year: 1999 › Research › peer-review

Sulfato Complex Formation of V(V) and V(IV) in Pyrosulfate Melts Investigated by Potentiometry and Spectroscopic Methods

General information
Publication status: Published
Organisations: Department of Chemistry
Contributors: Rasmussen, S. B., Eriksen, K. M., Fehrmann, R.
Thermal and Conductometric Investigations and Phase Diagram of the Rb2S2O7-V2O5 System

Organisations: Department of Chemistry, Université de Provence
Contributors: Abdoun, F., Hatem, G., Gaune-Escard, M., Eriksen, K. M., Fehrmann, R.

Thermal Properties of the Compounds and Binary Systems, M2S2O7, MHSO4, M2S2O7-MHSO4, M2S2O7-V2O5 (M=Na, K, Rb, Cs).

Organisations: Department of Chemistry, Université de Provence
Contributors: Hatem, G., Gaune-Escard, M., Eriksen, K. M., Fehrmann, R.

Coductivity, NMR Measurements and Phase Diagram of the K2S2O7-V2O5 System

Organisations: Department of Chemistry, Hempel A/S, Université de Provence, Boreskov Institute of Catalysis SB RAS
Conductrometric, density and thermal measurements of the M2S2O7 (M = Na, K, Rb, Cs) salts

Physico-chemical properties, such as densities, conductivities, enthalpies of phase transitions and melting points, have been measured and summarised for the alkali pyrosulphates Na2S2O7, K2S2O7, Rb2S2O7, Cs2S2O7. The densities of the molten pyrosulphates could be expressed by the linear expression \( \rho = A + B(T - T_m) \) where \( T_m \) is the middle temperature of the temperature range measured, i.e. from the melting point and up to 550 degrees C at the maximum.

The specific conductivities of the molten pyrosulphates have been expressed by the equation \( \rho = A + B(T - T_m) + C(T - T_m)^2 + D(T - T_m)^3 \) in the temperature range from the melting point and up to 500 degrees C at the maximum. From these measurements also the activation energy for the equivalent conductivity of the alkali cations in the melts could be calculated and compared to the analogous alkalisulphates.

By calorimetric investigations of the alkali pyrosulphates the temperatures of fusion, the enthalpies and entropies of fusion and possible solid-solid transitions together with the molar heat capacities of the solid and liquid pyrosulphates at 300-800 K, have been obtained and discussed in relation to the conductrometric measurements and the few related previous investigations. (C) 1998 Elsevier Science B.V.

Diagramme d'Equilibre des Phases du Systeme NaHSO4-Na2S2O7 et Grandeur Thermodynamiques d'Exces

Electrochemical and Spectroscopic Study on V(V) and V(IV) Sulfate Complex Formation in Pyrosulfate Melts.
Pollution Control by Catalysis: Final Report

General information
Publication status: Published
Organisations: Department of Chemistry
Contributors: Eriksen, K. M., Fehrmann, R.
Number of pages: 35
Publication date: 1998

Spectroscopic and Electrochemical Investigations on the M2SO4-V2O5 System (M=Alkali) and Characterization of Compounds

General information
Publication status: Published
Organisations: Department of Chemistry, Georgia Institute of Technology, University of Patras
Contributors: Schmidt, D. S., Wnnick, J., Boghosian, S., Fehrmann, R., Eriksen, K. M.
Pages: 491-498
Publication date: 1998

Host publication information
Title of host publication: Molten Salts XI
Place of publication: Pennington, N.J.
Publisher: The Electrochemical Society
Source: orbit
Source-ID: 170637
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 1998

Thermodynamics and Complex Formation in Pyrosulfate Melts

General information
Publication status: Published
Organisations: Department of Chemistry, Université de Provence
Pages: 63-64
Publication date: 1998

Host publication information
Title of host publication: Proceedings of the International Terje Østvold Symposium
Place of publication: Trondheim, Norway
Publisher: Norwegian University of Science and Technology
Source: orbit
Source-ID: 170684
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 1998

Catalytic Activity and Deactivation of SO2 Oxidation Catalysts in Simulated Power Plant Flue Gases

General information
Publication status: Published
Organisations: Department of Chemistry, Imperial College London, Foundation for Research and Technology-Hellas
Contributors: Masters, S. G., Chrissanthopoulos, A., Eriksen, K. M., Boghosian, S., Fehrmann, R.
Pages: 16-24
Publication date: 1997
Peer-reviewed: Yes
Electrochemical and Spectroscopic Study on V(V) and V(IV) Sulfate Complex Formation in Pyrosulfate Melts

General information
Publication status: Published
Organisations: Department of Chemistry
Contributors: Fehrmann, R., Eriksen, K. M.
Publication date: 1997

Host publication information
Title of host publication: Book of Abstracts
Source: orbit
Source-ID: 168805
Research output: Chapter in Book/Report/Conference proceeding ➔ Article in proceedings – Annual report year: 1997 ➔ Research

Formation of Oxosulfato Complexes of Vanadium in Pyrosulfate and Sulfate Melts

General information
Publication status: Published
Organisations: Department of Chemistry
Contributors: Fehrmann, R., Eriksen, K. M., Rasmussen, S. B.
Publication date: 1997

Host publication information
Title of host publication: Book of Abstracts
Source: orbit
Source-ID: 168810
Research output: Chapter in Book/Report/Conference proceeding ➔ Article in proceedings – Annual report year: 1997 ➔ Research

High Temperature Multinuclear NMR Studies of the Melts M2S2O7-V2O5 (M=K,Na, Cs)

General information
Publication status: Published
Organisations: Department of Chemistry, Boreskov Institute of Catalysis SB RAS
Contributors: Lapina, O. B., Mastikhin, V., Terskikh, V. V., Eriksen, K. M., Fehrmann, R.
Publication date: 1997

Host publication information
Title of host publication: Book of Abstracts
Source: orbit
Source-ID: 168804
Research output: Chapter in Book/Report/Conference proceeding ➔ Article in proceedings – Annual report year: 1997 ➔ Research

High Temperature NMR Studies of the Glass-Crystal Transition in the Cs2S2O7-V2O5 System

General information
Publication status: Published
Organisations: Department of Chemistry, Boreskov Institute of Catalysis SB RAS
Contributors: Lapina, O. B., Terskikh, V. V., Shubin, A. A., Mastikhin, V., Eriksen, K. M., Fehrmann, R.
Pages: 9188-9194
Publication date: 1997
Peer-reviewed: Yes
Hysteresis Phenomena in Sulfur Dioxide Oxidation over Supported Vanadium Catalysts

Model Systems of SO2 Oxydation Catalysts: Thermal, Spectroscopic and Electrochemical Characterization

Multinuclear NMR Studies of the Glass - Crystal Transition in V2O5 - Cs2S2O7 System

Phase Diagram of the K2S2O7-V2O5 and Rb2S2O7-V2O5 Systems
Phase Transitions in Model Systems for SO2 Oxidation

Progress on the Mechanistic Understanding of SO2 Oxidation Catalysts

Spectroscopic Investigation of SO2 Oxidation Catalysts
Structure and Properties of SO2 Oxidation Catalysts

General information
Publication status: Published
Organisations: Department of Chemistry, Imperial College London, Foundation for Research and Technology-Hellas
Contributors: Fehrmann, R., Eriksen, K. M., Nielsen, K., Masters, S. G., Boghosian, S.
Number of pages: 831
Publication date: 1997

Host publication information
Title of host publication: Book of Abstracts Vol. 2
Place of publication: Krokow
Publisher: Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences
Source: orbit
Source-ID: 168808

Conductivity, NMR, Thermal Measurements and Phase Diagram of the K2S2O7-KHSO4 System.

General information
Publication status: Published
Organisations: Department of Chemistry, Université de Provence, Boreskov Institute of Catalysis SB RAS
Pages: 10771-10778
Publication date: 1996
Peer-reviewed: Yes

Publication information
Volume: 100
Issue number: 25
Original language: English
Source: orbit
Source-ID: 166476

Crystal Structure and Spectroscopic Characterization of the Mixed Valence V(IV)-V(V) Compound K6(VO)4(SO4)8

General information
Publication status: Published
Organisations: Department of Chemistry
Contributors: Eriksen, K. M., Nielsen, K., Fehrmann, R.
Pages: 480-484
Publication date: 1996
Peer-reviewed: Yes

Publication information
Volume: 35
Issue number: 2
Original language: English
Source: orbit
Source-ID: 166469

Deactivation, Hysteresis Phenomena and Crystallization Modelling of SO2 Oxidation Catalysts.

General information
Publication status: Published
Molten Salt Catalysts for Sulfuric Acid Production and SO2 Removal From Flue Gas: Final Technical Report

Physico-Chemical and Structural Properties of DeNOx - and SO2-Oxidation Catalysts.

Physico-Chemical and Structural Properties of DeNOx and SO2 Oxidation Catalysts

Commercial catalysts for NOx removal and SO2 oxidation and their model systems have been investigated by spectroscopic, thermal, electrochemical and X-ray methods. Structural information on the vanadium complexes and compounds as well as physico-chemical properties for catalyst model systems have been obtained. The results are discussed in relation to proposed reaction mechanisms.

General information
Publication status: Published
Organisations: Department of Chemistry, Department of Chemistry, BP plc, Foundation for Research and Technology-Hellas
Contributors: Masters, S. G., Oehlers, C., Nielsen, K., Eriksen, K. M., Fehrmann, R., Boghosian, S., Chrissanthopoulos, A.
Number of pages: 1,140
Publication date: 1996

Host publication information
Title of host publication: Abstract Book
Place of publication: Pennington,NJ
Publisher: The Electrochemical Society
Source: orbit
Source-ID: 166801
Research output: Chapter in Book/Report/Conference proceeding → Article in proceedings – Annual report year: 1996 → Research

Organisations: Department of Chemistry, BP plc, Boreskov Institute of Catalysis SB RAS
Publication date: 1996

Host publication information
Title of host publication: Book of Abstracts
Place of publication: Åbo,Finland
Publisher: The Association of Finnish Chemical Societies
Source: orbit
Source-ID: 166817
Research output: Chapter in Book/Report/Conference proceeding → Article in proceedings – Annual report year: 1996 → Research

Organisations: Department of Chemistry, Department of Chemistry, BP plc, Foundation for Research and Technology-Hellas
Contributors: Masters, S. G., Oehlers, C., Nielsen, K., Eriksen, K. M., Fehrmann, R., Boghosian, S., Chrissanthopoulos, A.
Number of pages: 567
Pages: 74-79
Publication date: 1996

Host publication information
Title of host publication: Molten Salts X
Place of publication: Pennington,NJ

General information
Publication status: Published
Organisations: Department of Chemistry, Boreskov Institute of Catalysis SB RAS
Publication date: 1996

Host publication information
Title of host publication: Abstract Book
Source: orbit
Source-ID: 166830
Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 1996

The Cs2S2O7-V2O5 Catalyst Model Melt System: 51V and 133Cs NMR Measurements at High Temperature.

General information
Publication status: Published
Organisations: Department of Chemistry, Boreskov Institute of Catalysis SB RAS
Contributors: Lapina, O. B., Terskikh, V., Eriksen, K. M., Fehrmann, R.
Publication date: 1996

Host publication information
Title of host publication: Book of Abstracts
Place of publication: Åbo,Finland
Publisher: Association of Finnish Chemical Societies
Source: orbit
Source-ID: 166808
Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 1996

ESR-Investigations of Sulfuric Acid Catalyst Deactivation

General information
Publication status: Published
Organisations: Department of Chemistry, Energy and Materials
Contributors: Eriksen, K. M., Fehrmann, R., Bjerrum, N.
Pages: 263-265
Publication date: 1991
Peer-reviewed: Yes

Publication information
Journal: Journal of Catalysis
Volume: 132
ISSN (Print): 0021-9517
Original language: English
Source: orbit
Source-ID: 248624
Research output: Contribution to journal – Journal article – Annual report year: 1991

Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 1996

Research output: Contribution to journal – Journal article – Annual report year: 1991

Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 1996

Research output: Contribution to journal – Journal article – Annual report year: 1991

Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 1996

Research output: Contribution to journal – Journal article – Annual report year: 1991