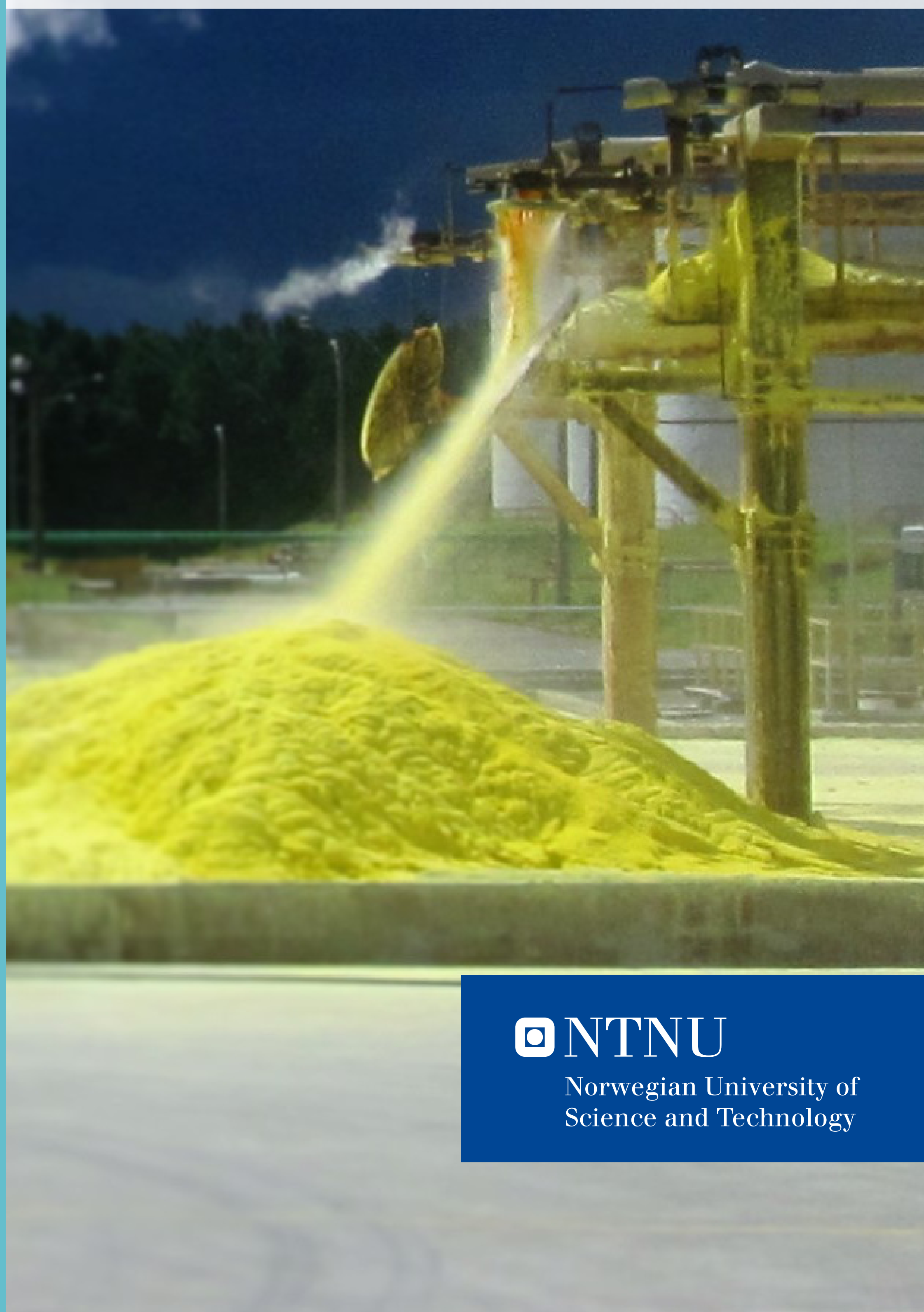
Department of Chemical Engineering 2016

With annual report 2015

Department of Chemical Engineering



NTNU
Norwegian University of
Science and Technology

Title: Environmental protection in practice. Sulfur (S) needs to be removed from oil and gas to reduce corrosion and avoid acid rain caused by SO_2. This photo is from a refinery that the students visited in Brazil. The yellow stuff is elementary sulfur which was removed from the oil by the catalytic Claus process. Most of the sulfur is used to make sulfuric acid, which again is mostly used for fertilizer production. The sulfur finally ends up as calcium sulfate (gypsum).

DEPARTMENT OF CHEMICAL ENGINEERING, NTNU

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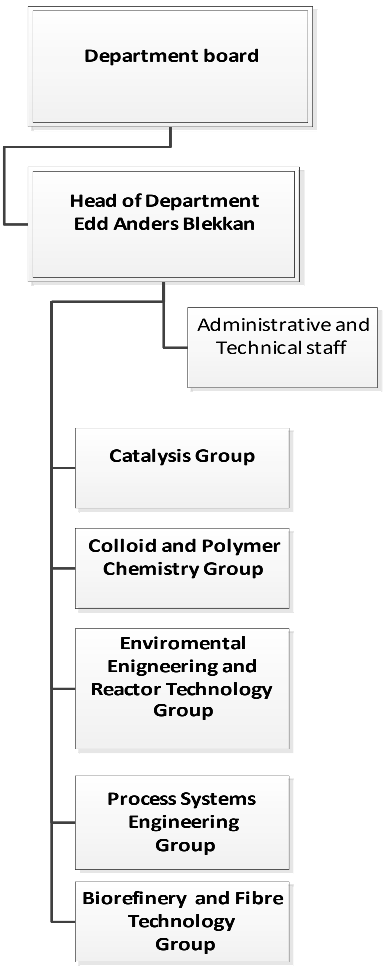
HEAD OF DEPARTEMENT

Professor Edd A. Blekkan

DEPUTY HEADS OF DEPARTEMENT

Professor Jens-Petter Andreassen

Professor Sigurd Skogestad



DEPARTMENT BOARD

EXTERNAL MEMBERS
Hanne Wigum, Statoil Research Centre Trondheim
Deputy: Morten Rønnekleiv, Statoil Research Centre Trondheim
Ole Wærnes, SINTEF Materials & Chemistry
Deputy: Philip A. Reme, Paper and Fibre Research Institute

INTERNAL MEMBERS
Associate Professor Hanna Knuutila
Professor Hilde Johnsen Venvik
Professor Magne Hillestad
Senior Executive Officer Torgrim Mathisen
PhD Marie Døvre Strømsheim
Student Therese Bache
Student Hanne Betten
Deputies:
Professor Gisle Øye, Professor Magnus Rønning, Professor Heinz A. Preisig.
Staff Engineer Karin W. Dragsten

STAFF

ADMINISTRATIVE STAFF
Head of Administration Tom Helmersen
Higher Executive Officer Martha Karin S. Bjerknes
Higher Executive Officer Hege Johannessen
Higher Executive Officer Lisbeth B Roel
Controller Ling Lin
Senior Executive Officer Torgrim Mathisen
HR Consultant Oddny Sagmo

TECHNICAL STAFF
Engineer Harry Brun
Senior Engineer Camilla I. Dagsgård
Staff Engineer Karin W. Dragsten
Head Engineer Gøril Flatberg
Engineer Arne Fossum
Staff Engineer Bicheng Gao
Head Engineer Mikael Hammer
Engineer Odd Ivar Hovin
Staff Engineer Jan Morten Roel
Staff Engineer Kine Skjærbusdal
Staff Engineer Erland Strendo
Engineer Frode Sundseth
Head Engineer May Grete Sætran
Senior Engineer Gunn Torill Wikdahl

CONTENTS

INTRODUCTION

By Edd. A. Blekkan (Head of Departement) and Jens-Petter Andreassen (Deputy Head of Departement)

2015 was another good year for the Chemical Engineering department. Our mission is to deliver excellent research and provide educational programs of high quality and with a high standing both nationally and internationally. I hope this report demonstrates that we deliver on all counts!

The aim of this report is to give an overview of the activity in 2015 as well as to provide some more general information about the department. We hope you find it useful.

The history of the department goes back to the 1940s, when the university (at that time called Norwegian Institute of Technology, NTH) appointed Chairs (each heading a department) in Pulp and Paper chemistry (1946), Chemical Engineering (1949) and Industrial Chemistry (1950). Pulp and Paper was merged with Chemical Engineering in 1986, and following the establishment of NTNU (1996) Chemical Engineering and Industrial Chemistry merged in 1999 into the Chemical Engineering department (Institutt for Kjemisk Prosessteknologi) we know today.

Chemical Engineering is about turning raw materials into useful products, such as the energy that fuel our lives, the materials we use and clothes we wear, food and drink we consume and medications we take. This is done by applying and realizing the potential of basic chemistry and biology, in industrial applications as well as environmental protection. Chemical engineers design, build and operate the units and plants that make products, they help to manage the world's resources, protect the environment and ensure that health and safety standards are met. The present day approach to this is to try to understand the processes on all scales, from the detailed atomic and molecular understanding of the chemistry and biology involved (nano-scale and smaller), up to the macro- and mega scales (whole industrial plants or bigger systems). That puts our field on the interface between science and technology, we need a solid scientific basis in order to develop good and sustainable engineering solutions. We work on the basics, such as colloid chemistry, catalytic phenomena, thermodynamics, drops, particles, biomass as well as oil and gas. Equally important is the development of materials (catalysts, membranes, solvents, sorbents, filters etc.), and solutions (reactors, separators, columns, processes). All this is assisted by modelling, simulation, optimization and process control. Together these areas of work constitute "chemical engineering", and you will find examples of all of these areas in our department and in this report.

A key purpose for our department is to support the Norwegian process industry, both through research and development, and through the education of highly qualified candidates. This demands a good understanding of the requirements in industry, and good industrial relations are necessary in order to perform research of relevance and high quality. A strong link between the research and teaching ensures that our students carry a solid competence and new knowledge into society. Having a strong international profile, in terms of staff, students and international collaboration is an important prerequisite to be successful.

A key metric for us is the research output, expressed by the number of graduated PhD candidates and journal publications. These numbers have been very high for the last few years. The number of credited publications in international journals was 121, compared to 157 in 2014 and 166 in 2013, on average this corresponds to around 6-8 papers per permanent academic staff per year, which is a very high output in an engineering subject. About 1/3 of the papers are registered at "level 2", i.e. in the most prestigious journals with the highest impact. Furthermore, 7 PhD candidates graduated in 2015, a bit lower than the average output of around 18 per year (2011-14). The average time to complete a PhD is about 4-5 years (including teaching duties and leaves of absence), and most of the candidates that start a PhD completes the degree. The quality of the research is of course very important but harder to measure. Many of our senior scientists are highly cited and recipients of professional awards nationally and internationally. It is also very encouraging that younger members of staff get acknowledged. Dr. Jannike Solsvik was awarded the DKNVS (Royal Norwegian Society of Sciences and Letters) price for young scientists (natural sciences) for 2015 in a ceremony held in March 2016.

The Department is located in chemistry buildings K-IV and K-V, experimental halls C and D and in the PFI-building. Our buildings date back to 1957/58 (K-V/Exp. Halls) and 1965 (K-IV). Most of the buildings have been renovated and modernized in recent years, providing the department with excellent laboratory facilities and modern offices. The last facility to be upgraded was hall C, where our largest pilot experimental rigs including the rigs for amine based CO_2 capture is located. Only the K-V building is now awaiting renovation, and in the meantime the experimental activities in this building is kept at a minimum in order to maintain good HES standards.

Our buildings, from the right: K4, K5, Experimental halls and the PFI-building (blue)

FACTS ABOUT THE DEPARTEMENT

The Department of Chemical Engineering is located at the Gløshaugen campus_of the Norwegian University of Science and Technology (NTNU) in Trondheim. NTNU is the only university in Norway that awards engineering degrees in all areas.

The Department offers a 5-year integrated master of science program leading to the degree of *sivilingeniør* (MSc) in Chemical Engineering. Most of the students start at NTNU in their first year, but about 10 to 20% enter in the fourth year based on a 3-year engineering Bachelor degree from Norwegian colleges. In addition, we offer a 2-year International Master Program in Chemical Engineering, also entering into the 4th year of the integrated programme. On top of this we offer a 3-year doctoral program leading to a PhD degree in Chemical Engineering. The Department can trace its roots back to 1910 when the Norwegian Institute of Technology (NTH) started up in Trondheim with engineering chemistry as one of the seven majors. After the Second World War, three applied Departments were formed, Pulp and Paper Chemistry (*Treforedlingskjemi*, 1946), Chemical Engineering (*Kjemiteknikk*, 1949) and Industrial Chemistry (*Industriell kjemi,* 1949). These were merged to the present Department of Chemical Engineering (*Kjemisk prosessteknologi*) in 1999.

The main objectives of the Department are:

Education. Offer a Master Degree in Chemical Engineering which is internationally recognized and makes the candidates attractive on the labour marked.

1. *Research*. Research shall be on an international level, and in some areas internationally leading.

2. The Department shall be attractive in order to recruit the best candidates, including academic faculty, PhD students and undergraduate students. The social environment shall be very good so that everyone feels welcome.

The permanent staff in 2015 included:

- 18 technical/administrative
- 21 academics, including 13 Professors and 8 Associate Professors (*Førsteamanuensis*)
- 7 Adjunct Professors (*Professor II*) (20% *position)*
- 75 PhD students
- 30 Post docs. and researchers

The Department also houses 6 Professor emeriti, and several visitors in addition to a large SINTEF group.

STUDENT PRODUCTION

Year	MSc	PhD
2010	31	16
2011	32	25
2012	46	14
2013	67	15
2014	66	19
2015	42	7

MSC STUDENTS 2015/16

5th year	66 (incl. 9 International Master students)
4th year	51 (incl. 12 International Master students)
3rd year	25

NEW PHD STUDENTS (EXCHANGE STUDENTS NOT INCLUDED)

2010	17
2011	12
2012	13
2013	11
2014	15
2015	23

NEW POST DOCS. /SCIENTISTS

2010	6
2011	7
2012	6
2013	10
2014	5
2015	5

CHAPTER 2 - RESEARCH

CATALYSIS

Academic staff
Professor Edd A. Blekkan
Professor De Chen
Professor Magnus Rønning
Professor Hilde J. Venvik
Adjunct professor Kjell Moljord
Adjunct professor Erling Rytter
Professor Emeritus Anders Holmen

Post Docs./Researchers
Auvray, Xavier (from 12.01.2015)
Chen, Qingjun (from 01.06.2015)
Cognigni, Andrea
Duan, Xuezhi (until 25.11.2015)
Gil Mattelanes, Maria Victoria (from 01.09.2015)
Gunawardana, Daham Sanjaya
Ledesma Rodrigues, Cristian
Lou, Fengliu (04.12.2015)
Muthuswamy, Navaneethan (until 31.03.2015)
Patanou, Eleni
Peña Zapata, Diego Alexander
Tsakoumis, Nikolaos
Zhou, Haitao (until 31.01.2015))

PhD candidates
Baidoo, Martina Francisca
Buan, Marthe Emelie Melandsø
Dadgar, Farbod
Fenes, Endre (from 07.09.2015)
Gavrilovic, Ljubiša
Guo, Xiaoyang (from 12.01.2015)
Hjorth, Ida
Li, Yahao
Liland, Shirley
Østbye Pedersen, Eirik
Qi, Yanying
Salman, Ata ul Rauf (from 12.10.2015)
Strømsheim,Marie Døvre
Udani, Charitha
Van der Wijst, Cornelis G.
Volynkin, Andrey (until 01.12.2015)
Wang, Xuehang
Wang, Yalan (from 18.08.2015)
Wycisk, Michael
Yeboah, Isaac (from 24.08.2015)

Technical staff
Karin Wiggen Dragsten
Cristian Ledesma Rodriguez

Guests
Associate professor Ikko Mikami, Tokai University, Japan
Kuiyi You,
Esther Acha, University of the Basque Country, Bilbao, Spain
Di Wang,
Gonzalo Esteban, Instituto Nacional del Carbón, INCAR-CSIC, Spain
Associate professor Ivan Bogoev, Institute of Catalysis, Bulgarian Academy ogf Sciences, Bulgaria
Cui Ting

PROFILE

The research and teaching in catalysis, reaction kinetics, petrochemistry and related subjects is organised in the Catalysis Group at the Department of Chemical Engineering, NTNU. This is the largest catalysis group in Norway and the main arena for education of PhD and MSc candidates for Norwegian industry and research institutes. The group consists of four permanents faculty members, approximately 20 PhD students and 5-10 postdoctoral fellows. Every year 10-15 MSc students graduate from the Catalysis Group.

The group is an integrated NTNU/SINTEF research laboratory where NTNU-staff collaborate and share facilities with researchers employed by the Oil and Gas Process Technology Department in SINTEF. This collaboration was recognised by NTNU and SINTEF as a Strong-Point Centre (1998) and is formalised through the KINCAT Gemini centre (NTNU/SINTEF twin research centre). Personnel from the two organisations work together and participate in teaching and research. The group participates extensively in international networks and has close collaboration with a number of universities and research groups inside and outside the EU. The research is funded by the Norwegian Research Council, EU, Norwegian and international industry and other sources, and spans from fundamental studies of ideal surfaces to studies of real catalysts and process development work in small pilot plants.

The Catalysis Group was a research partner in a Centre for Research-based Innovation (Innovative Natural Gas Processes and Products – inGAP) in the period 2007-2015.

Since 2015, the Catalysis Group is heading a new Centre for Research-based Innovation: industrial Catalysis Science and Innovation (iCSI) – for a competitive and sustainable process industry. The main objective of iCSI is to boost industrial innovation and competitiveness as well as to provide efficient, low-emission process technology. The centre director is Professor Hilde J. Venvik.

AREAS OF RESEARCH

A description of the Catalysis Group as well as further details of all the projects, are given in our Annual Report (KinCat).

INDUSTRIAL PROCESS CHEMISTRY

In the iCSI centre, the group is working with industrial partners to improve catalysts and associated technology applied to the following industrial processes:

Production of nitric acid (HNO_3) from ammonia (NH_3)

Synthesis of polyvinylchloride (PVC) produced by polymerization of the monomer vinyl chloride (VCM)

Improve the performance of existing formalin production process technology which is based on the catalytic oxidation of methanol to formaldehyde

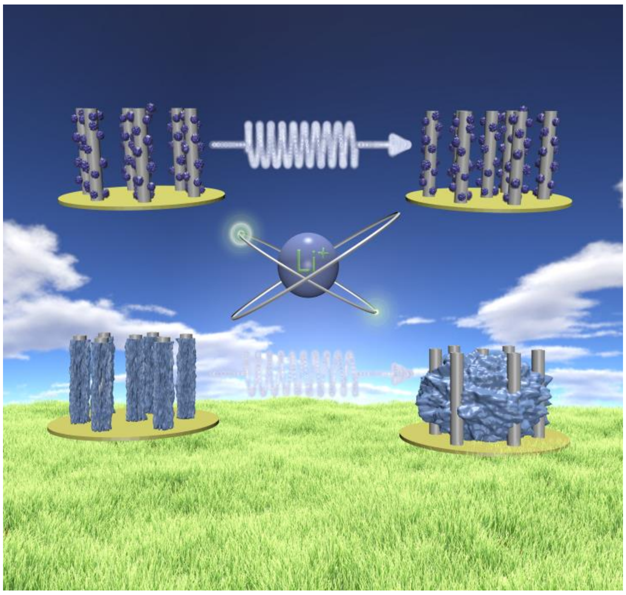
The fact that 85-90% of all chemical production is catalysis based, illustrates the importance of catalysis to the economic growth and the life-standard developed over the previous century. By optimizing the catalytic process, energy consumption and cost in industrial processes will be reduced. Catalysis is also key to enhancing selectivity, an important principle of green chemistry, since it reduces the formation of by-products and waste as well as the energy consumption.

DESIGN AND PREPARATION OF NEW CATALYSTS AND SUPPORTS

The catalytically active material is the key to any catalytic process, and the preparation of these, highly specialized functional materials is an important industry. Understanding the processes involved in the preparation, and developing improved methods are therefore central research areas. We work with new methods for the preparation of supports and catalysts, as well as the preparation and use of structured, mesoporous supports. Other areas include core-shell particles and size and shape-control of metal particles.

CARBON NANOMATERIALS

Carbon nanofibres (CNF) have several interesting properties such as high resistance to strong acids and bases, high electric conductivity (similar to graphite), relatively high surface area and high mechanical strength. These unique properties lead to a large number of applications, such as catalyst supports, selective sorption agents, energy storage, composite materials, nano-electric and nano-mechanical devices, as well as field emission devices. The programme includes synthesis of carbon nanofibres and nanotubes of different morphology and the use of CNF/CNT in applications such as heterogeneous catalysis, fuel cells and conversion and storage of energy. This is done in collaboration with other groups at NTNU, SINTEF and Norwegian industry. Replacing noble metals using doped carbon nanomaterials in fuel cells, dehydrogenation reactions and in water treatment have been explored in a European project coordinated by the Catalysis group at NTNU.



Carbon nanomaterials in energy storage

NEW REACTOR CONCEPTS AND STRUCTURED SUPPORTS

Emerging reactor technologies such as microstructured reactors and (catalytic) membrane reactors are being developed and tested.

Examples of microstructured reactors (Photo: Thor Nielsen)

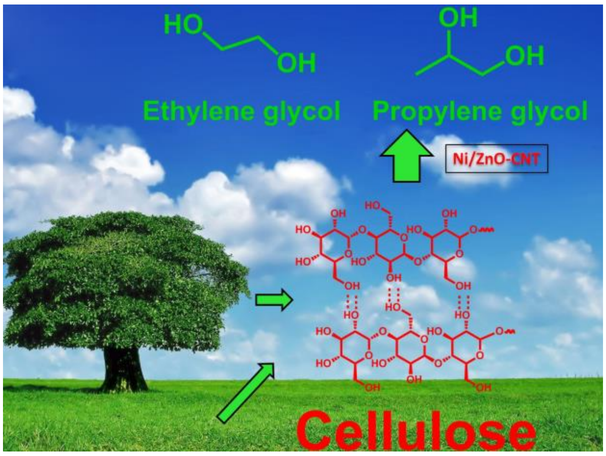
PHOTOCATALYSIS

Accelerated environmental pollution on a global scale has drawn attention to the need for totally new environmentally friendly and clean chemical technologies. The application of photocatalysis to reduce toxic agents in air and water by developing catalysts that can utilise clean and abundant solar energy and convert it into useful chemical energy is a promising challenge. Photocatalysts that can operate at ambient temperature without producing harmful by-products are ideal as environmentally sound catalysts. For such systems to be considered in large-scale applications, photocatalytic systems that are able to operate effectively and efficiently using sunlight must be established. Hydrogen can be produced by photoinduced reforming of organic compounds, including methane and alcohols. Furthermore, the photoreduction of carbon dioxide into useful chemicals is a desirable prospect. It is essential to convert CO_2 into useful substances that are common feedstocks for the production of other chemicals (C_2-C_{3+}, alcohols, etc.).

Photocatalytic reactor system.

CONVERSION OF LIGNOCELLULOSIC BIOMASS TO CHEMICALS AND FUELS

The research is focused on catalytic aspects of thermochemical conversion, such as bio-oil upgrading, syngas cleaning and composition adjustment, residual hydrocarbon reforming and Fischer-Tropsch synthesis. Due to the declining reserves and environmental effects of fossil resources, a transition to renewable carbon sources is important. Lignocellulosic biomass, such as trees, is the most abundant biomass and one of the most promising renewable carbon sources.



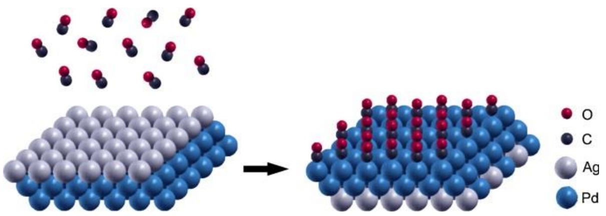
Conversion of biomass into useful chemicals

NATURAL GAS CONVERSION

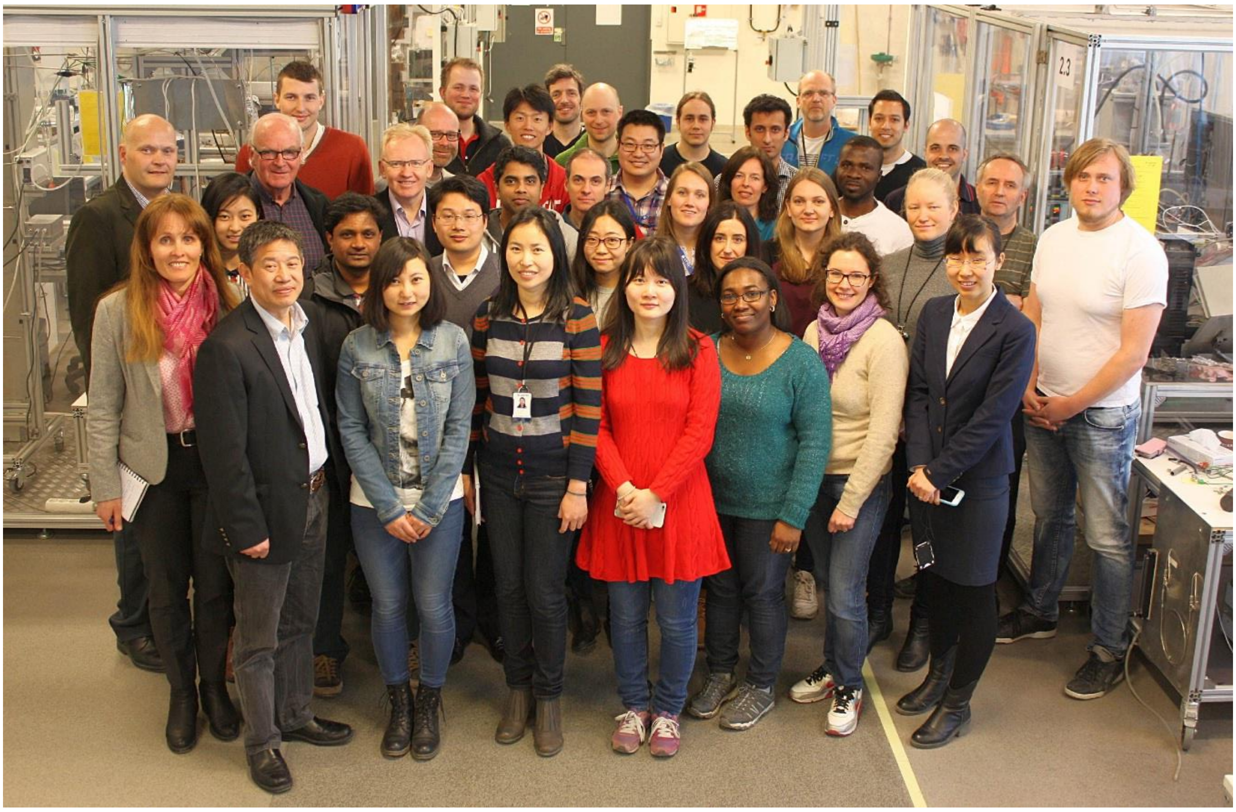
Natural gas is an abundant hydrocarbon fuel and chemical feedstock, and utilizing this resource with minimum environmental impact is a major challenge to catalysis. The main goal is to study catalytic processes for conversion of natural gas to chemicals and fuels including hydrogen. The work includes production of synthesis gas, Fischer-Tropsch synthesis, and dehydrogenation of C_2-C_4 alkanes. The work is carried out in close collaboration with international industry and SINTEF.

FUNDAMENTAL STUDIES IN HETEROGENEOUS CATALYSIS

Several experimental techniques are used to study the details of solid catalysts. We are working together with Department of Physics on the use of Transmission Electron Microscopy and Scanning Tunnelling Microscopy. We focus on characterisation of catalysts at working conditions (*in situ* characterisation) and for this purpose we are using the European Synchrotron Radiation Facility in Grenoble. We have in-house facilities for *in situ* IR and Raman spectroscopy. Steady State Isotopic Transient Kinetic Analysis (SSITKA) and the Tapered Element Oscillating Microbalance (TEOM) are powerful techniques for studying important phenomena such as reaction kinetics, mechanisms, catalyst deactivation, diffusion in porous materials and adsorption, absorption and desorption.



Adsorption of CO on a Pd_3Ag (111) model surface, studied using density functional theory (DFT) calculations.



***4th row:** Ljubisa Gavrilovic, Håkon Bergem, Endre Fenes, Xiaoyang Guo, Torbjørm Gjervan, Bjørn Christian Enger, Yahao Li, Eirik Pedersen, Ata Salman, Rune Myrstad, Diego Alexander Pena Zapata*

***3rd row:** Magnus Rønning, Di Wang, Anders Holmen, Edd Anders Blekkan, Kumar Rajan Rout, Andrea Cognigni, Karin Wiggen Dragsten, Camilla Otterlei, Shirley Elisabeth Liland, Isaac Yeboah, Cristian Ledesma Rodriguez, Rune Lødeng*

***2nd row:** Hilde Venvik, Daham Gunawardana Sanjaya Vidana, Qingjun Chen, Cui Ting, Victoria Gil Matellanes, Mari Helene Farstad, Cornelis van der Wijst*

***1st row:** De Chen, Yalan Wang, Jia Yang, Xuehang Wang, Martina Francisca Baidoo, Estelle Vanhaecke, Yanying Qi*

***Not present**: Charitha Udani, Eleni Patanou, Erling Rytter, Farbod Dadgar, Haakon Rui, Hilde Bjørkan, Ida Hjort, Ingeborg-Helene Svenum, Kuiyi You, Marie Døvre Strømsheim, Marthe Emelie Buan, Michael Marcus Wycisk, Nikolaos Tsakoumis, Svatopluk Chytil, Xavier Auvray*

COLLOID- AND POLYMER CHEMISTRY

UGELSTAD LABORATORY

Academic staff

Professor Johan Sjöblom
Professor Gisle Øye
Associate Professor Brian A. Grimes
Associate Professor Kristofer Paso
Adjunct Professor Hans Jürg Oschmann
Adjunct Professor Roar Skartlien
Associate Adjunct Professor Martin S. Foss
Professor Emeritus Arvid Berge
Professor Emeritus Preben C. Mørk

Reseachers

Gawel, Bartolomiej (until 19.12.2015)
Simon, Sébastien

Post docs

Norrman, Jens
Nourani, Meysam (until 16.10.2015)
Rodionova, Galina
Wei, Duo (until 12.06.2015)

PhD candidates

Bandyopadhyay, Sulalit
Bertheussen, Are (from 01.09.2015)
Bin Ismail, Ahmad Shamsulizwan
Dudek, Marcin (from 17.08.2015)
Kurniawan, Muh
McDonagh, Birgitte Hjelmeland (until 10.12.2015)
Mehandzhiyski, Aleksandar
Molnes, Silje
Pradilla Ragua, Diego Camilo
Rodriguez, Sandra Fabia (from 27.05.2015)
Ruwoldt, Jost (from 12.10.2015)
Subramanian, Sreedhar
Tichelkamp, Thomas (until 04.09.2015)

Laboratory Manager

Dagsgård, Camilla I.

Technical staff

Gao, Bicheng
Sætran, May Grete

THE MAIN PURPOSE IS TO RAISE THE NATIONAL LEVEL OF COLLOIDAL SCIENCE.

The Ugelstad Laboratory is a modern educational, research and development laboratory within the field of colloid, polymer and surface chemistry.

In order to attract the best and most motivated students and researchers, the laboratory has invested in new and modern instrumentation. Diploma and PhD studies are offered within the field of colloid, polymer and surface chemistry, often in close collaboration with industrial companies. The aim is to educate highly qualified candidates for industrial positions. The laboratory also participates in international exchange programs, and hosts internationally renowned guest researchers and lecturers.

The Ugelstad Laboratory is sponsored by industrial companies, the Research Council of Norway (NFR), research institutes and NTNU. All the members are annually invited to a presentation of the recent research activities at the laboratory. This is combined with the Ugelstad Lecture, where invited scientists lecture within the field of colloid, polymer and surface chemistry.

The laboratory specializes in surfactant chemistry and its technical applications, emulsions and emulsion technology, water management, flow assurance, modelling of heterogeneous systems and separation technology.

Applications include crude oil production and processing wood-based fibers, EOR and material science.

Research Activities: In the following paragraphs, selected ongoing research programs for 2015 are briefly described. For a complete description of the research activities at the Ugelstad Laboratory, please visit our web page:
www.chemeng.ntnu.no/research/polymer/ugelstadlab

RESEARCH PROGRAM

NEW STRATEGY FOR SEPARATION OF COMPLEX WATER-IN-CRUDE OIL EMULSIONS: FROM BENCH TO LARGE SCALE SEPARATION, PETROMAKS 2 (2016-2019)

Water-in-crude oil emulsions (w/o) are ubiquitous in the petroleum production industry and they need to be processed to obtain anhydrous oil and pure water. As environmental regulations become more rigorous (OSPAR), it is of outmost importance to improve oil-water separation technology in order to successfully process increasingly complex production fluids. That is why this new project aims to improve the knowledge of water-oil separation processes and to develop new separation strategies by focusing on two aspects:

Better understand the systems problematic in oil-water separation namely the formation of complex multi-component interfaces around droplets and the dense-packed layers with high water content (DPL). The complex interfacial layers will be characterized by state-of-the-art techniques like ellipsometry, Quartz Crystal Microbalance (QCM), interfacial rheology in shear and dilation, NMR, Film drainage experiments, Isothermal Titration Technology (ITC), FT-ICR-MS and neutron reflectometry. In addition to this experimental work, dissipative particle dynamics (DPD) modelling will be carried out to better understand structure of these systems.

Combines electrocoalescence and chemicals to improve oil-water separation by performing experiments at various scales followed up by modelling. The new destabilizing agent classes will be developed in collaboration with chemical vendors (AkzoNobel and NalcoChampion). These demulsifiers will be combined with electrocoalescers and tested in large scales at Wärtsilä Oil and Gas facilities.

The project will have Ugelstad Laboratory as host institution with Prof. Johan Sjöblom as project manager and will be conducted in collaboration with University of Alberta, Canada (Prof. Zhenghe Xu), Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland (Prof. Jan Vermant), and IFE (Prof. Roar Skartlien and Kenneth Knudsen) with a strong implication from industrial sponsors especially Wärtsilä Oil and Gas (Drs. Morad Amarzguioui and Erik Bjørklund). The project is funded by the Norwegian Research Council via a Petromask II grant and by the following industrial sponsors: AkzoNobel, NalcoCampion and Wärtsilä Oil and Gas. This project will educate 3 PhD candidates and 1 post-doctor as well as well as several master students.

INFLUENCE OF PRODUCTION AND EOR CHEMICALS ON PRODUCED WATER QUALITY - FUNDAMENTAL KNOWLEDGE OF THE FLUIDS FOR IMPROVED PRODUCED WATER MANAGEMENT, PETROMAKS 2 (2016-2020)

The overall goal of the project is to investigate how production and enhanced oil recovery (EOR) chemicals influence produced water quality and treatment. Production chemicals giving rise to poor produced water quality is already an issue within the petroleum industry, while the effects of EOR chemicals on the water quality will increasingly become a challenge as chemical flooding methods are likely to emerge in the years to come. There is, however, a lack of systematic investigations focusing on how the use of the various chemicals affects the produced water quality. Fundamental studies of synergies between indigenous and added components in produced water, the resulting interfacial phenomena and ultimately the implications for produced water treatment are areas of research which will be addressed in this project. The studies will range from small-scale interfacial studies to pilot-scale testing of produced water treatment units, aiming at revealing underlying mechanisms affecting produced water quality and produced water treatment efficiency.

2 PhD candidates 1 post.doc and several master students will be educated within the project. The industrial partners are Statoil, Total and Schlumberger. In addition, the Research Council of Norway will finance the project.

SFI SUBPRO: SUBSEA PRODUCTION AND PROCESSING CENTRE (2015-2022)

Subsea production and processing is a key technology for exploitation of Norwegian and international oil and gas resources. New solutions are needed to reduce operation and development cost, to increase the recovery factor, to reduce implementation time for field developments, and to allow development of new more demanding fields, such as in the Northern areas and the Barents Sea. To overcome this challenge, the centre for innovation (SFI) “subsea production and processing” SUBPRO has been set up at NTNU. It gathers the production and quality engineering, the petroleum Engineering applied geophysics and chemical engineering departments including Ugelstad Laboratory. It aims to become a leading international subsea research centre that provides top quality candidates, knowledge, innovations and technology in partnership with the most important industrial players in the field

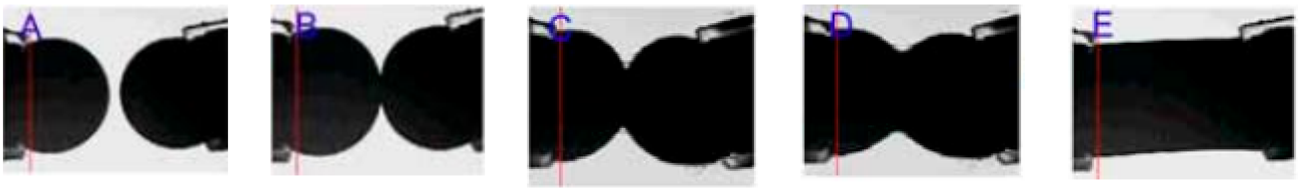


Figure: Route of coalescence of two oil droplets determined by a drop-bubble micropipette setup.

A) Drops approachin

B) Thinning of the aqueous film between the droplets

C) Breakage of the film

D) Merging of the drops

E) Completely merged drops

JIP ASPHALTENES: IMPROVED MECHANISMS OF ASPHALTENE DEPOSITION, PRECIPITATION AND FOULING TO MINIMIZE IRREGULARITIES IN PRODUCTION AND TRANSPORT (NFR PETROMAKS 2014 – 2017)

Asphaltenes represent heavy polar colloidal fraction in crude oils. Due to pressure variation, processing and production conditions of different crude oils, asphaltenes can precipitate and form organic deposits in oil reservoirs, in wells and on equipment and pipe walls and induce fouling in general. These deposits can cause serious and costly irregularities in production and transport of oil. Several models have been proposed to explain these irregularities but they all suffer from inaccurate asphaltene chemistry. It is by now evident that in order to fully understand and account for the above-mentioned phenomena, the effect of the polydisperse functionality of the asphaltenes must be understood.

In order to follow up the objective, the project will combine small scale tests both at atmospheric and elevated pressures, modelling and capillary loop tests. Finally based on the accumulated knowledge, chemical modifications together with inhibitors will be developed in order to minimize the molecular affinity to pipe surfaces and their interactions in solution.

This project is a collaborative effort between the Ugelstad laboratory, University of Alberta (Canada), University of Pau (France), University of Paraná (Curitiba, Brazil) and several industrial partners.

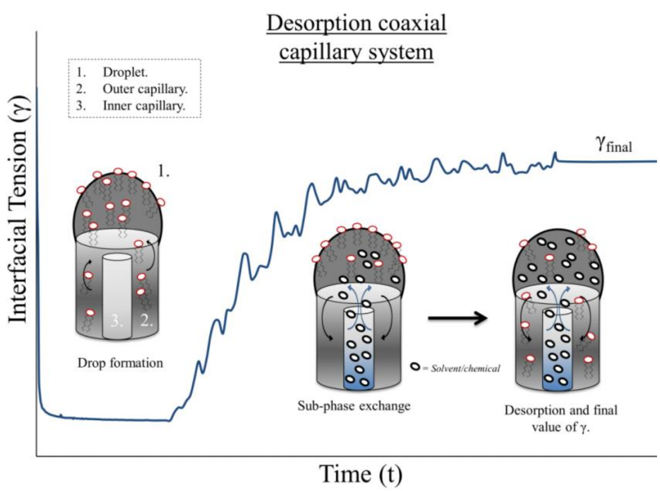


Figure: Schematic of the coaxial capillary system used for desorption studies experiments. A droplet (1) of constant volume is formed via an outer capillary (2) and is let to equilibrate for a fixed time. The predetermined volume of solvent of chemical species is pumped via an inner capillary (3) at a given rate. The interfacial tension is continuously measured through all steps.

A COMBINED SURFACE-COLLOID CHEMICAL AND ROCK-FLUID INTERACTION APPROACH TOWARDS MORE EFFICIENT ENHANCED OIL RECOVERY STRATEGIES (NFR PETROMAKS, 2012 – 2015)

The objective of the project is to provide essential knowledge of how surfactants can improve low salinity water flooding processes by also considering indigenous crude oil components. The studies range from molecular level to fluid-rock interaction and dynamic displacement studies.

The project is a collaborative effort between Ugelstad Laboratory, Department of Petroleum Engineering and SINTEF Petroleum Research.

Figure: Phase behaviour of IFT of crude oil and solution of surfactant 0.068 and 0.410 mol/L NaCl (increasing form left to right). All IFT values are given in units of 10-6 N/m.

FUNCTIONALIZED NANOPARTICLES TO IMPROVE CRUDE OIL QUALITY (VISTA FUNDING 2015-2017)

The deposition of metal naphthenates can cause operational and environmental problems during crude oil production and processing. The main goal of this project is to establish new methods for both preventing formation and facilitating removal of naphthenic acids responsible for formation of the metal naphthenates by using magnetic nanoparticles. The newly developed methods will be based on the application of magnetic nanoparticles modified with certain chemical groups for extraction of the naphthenic acids before formation of the metal naphthenates (mitigation strategy) as well as removal of the metal naphthenates (remediation strategy). The nanoparticles will be designed according to their affinity to the carrying phase (oil, water, or interface). The methodology will bring concepts with the following advantages:

Nanoparticles will be recovered at the end of extraction, regenerated and recycled.

No toxic chemicals will be lost into oil or produced water due to material recovery at the end of the process.

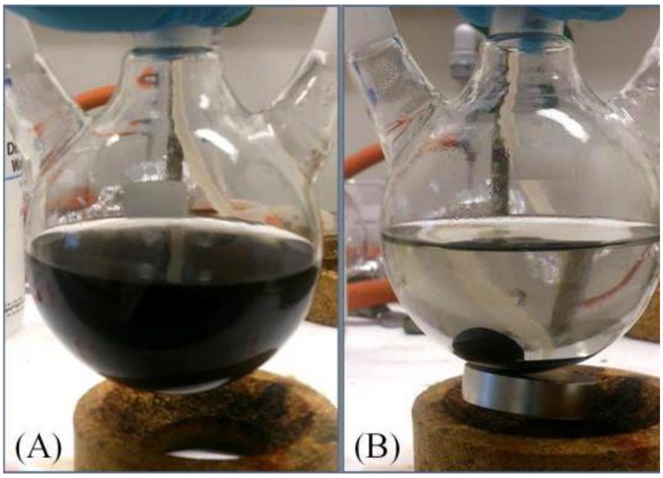


Figure: The synthesized Fe3O4 MNP before (A) and after applying a magnet beneath the flask (B).

NEXT-GENERATION WAX INHIBITORS FOR THE OIL AND GAS INDUSTRY (VISTA FUNDING 2015-2017)

Heavy crude oils often contain waxes that can form large, volume spanning networks upon crystallization, effectively forming a strong gel that inhibits flow in pipelines even at relatively low wax contents. This is avoided during normal flow by the continuous breakdown of this gel network under flow, but during operational stops this gel network can result in a serious restart problem.

The object of this project is developing new mechanism for wax inhibition in heavy oils by morphological modification of silica nanoparticles, trying to avoid major reliance on chemical modification and toxic chemicals. The major benefits of this new technology include low dosage rates, environmental friendliness by keeping the nanoparticles in the oil phase, and potential reuse of the nanoparticles. The nanoparticles should work by optimizing entropic repulsion and modifying wax crystallization.

The project uses rheology, differential scanning calorimetry and quartz crystal microbalance to evaluate nano-particle formulation effect and effectiveness on waxy oil gels, and aims to further evaluate the environmental impact of using such nano-particles on produce water, emulsions and sustainability of the formulations.

CO_2 CAPTURE IN CONFINED SURFACTANT GEOMETRIES (NFR AND GASSNOVA)

A new collaborative project to use liquid crystals for CO2 capture, transport and storage is being performed between Ugelstad Laboratory and University in Bergen. The project is financed by CLIMIT, which is a collaboration managed jointly between the Research Council of Norway and Gassnova. The idea is to use liquid crystal geometries to provide tailored internal environments to capture CO2, and retain the CO2 inside the liquid crystals for facilitated transport and also storage in geologic acquirers. The liquid crystals provide a primary thermodynamic sealant mechanism for CO2, assuring continued storage in the case of caprock fracture.

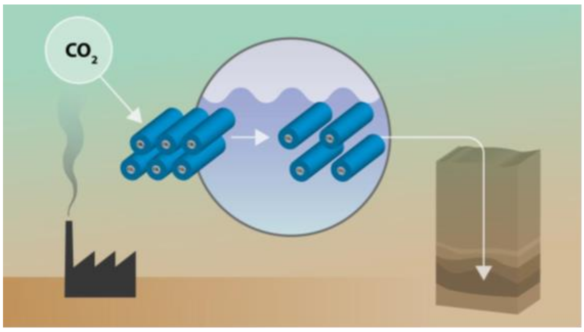


Figure : CO2 capture, transport and storage using liquid crystal technology (Illustrasjon Eivin Vetle).

NORCEL: THE NORWEGIAN NANOCELLULOSE TECHNOLOGY PLATFORM (NFR 2013-2018)

The vision of the NORCEL project is to develop an internationally leading research platform for production, modification and control of morphology, chemistry and three-dimensional structures of nanocellulose at a fundamental level. One of the applications in focus in this project is enhanced oil recovery (EOR), and rheology of nanocellulose dispersions is a key factor in this respect. The project is led by PFI and has both national and international partners. The project is funded by the

Research Council of Norway through the NANO2021 Program.http://www.pfi.no/New-Biomaterials/Projects/NORCEL/

GREENEOR: GREEN HIGH PERFORMANCE SYSTEMS FOR ENHANCED OIL RECOVERY (NFR PETROMAKS 2014-2016)

Enhanced oil recovery is also the topic of the newly started project GreenEOR: Green high performance systems for Enhanced Oil Recovery.The objective of the GreenEOR project is to contribute to enhanced oil recovery in a sustainable manner, by developing a novel series of green fluids for chemical EOR applications based on nanocellulose, alone or in combination with other EOR surfactants. The project is led by PFI and the R&D partners in the project are PFI, NTNU – Department of Petroleum Engineering and Applied Geophysics and NTNU – Ugelstad Laboratory. The project is funded by the Research Council of Norway through the Petromaks 2program.
http://www.pfi.no/NewBiomaterials/Projects/GreenEOR/

NANOVISC: DEVELOPMENT OF HIGH-PERFORMANCE VISCOSIFIERS AND TEXTURE INGREDIENTS FOR INDUSTRIAL APPLICATIONS BASED ON CELLULOSE NANOFIBRILS (CNF).

Ugelstad Laboratory collaborates with Pulp and Fiber Institute (PFI) in the NanoVisc project: Development of high-performance viscosifiers and texture ingredients for industrial applications based on Cellulose Nanofibrils (CNF). The project is collaboration between Ugelstad Laboratory, PFI and Innventia as research partners, and Borregaard AS, Stora Enso, Mercer, Mills DA and Norcem as industrial partners. The effect of CNF surface chemistry and morphology on rheology will be studied as a function of different external parameters such as salinity, temperature and the presence of co-solutes. The application of CNF as rheology modifier for emulsions and cements will also be considered.

SMART AND MULTIFUNCTIONAL CORE-SHELL NANO-PARTICLES (NPS) FOR DRUG DELIVERY. (2012-2016)

Core-shell nano-particles (NPs) represent a new class of materials, possessing tunable multifunctional properties for which they find wide applications in electronics, catalysis, separations, drug delivery and medical diagnostics. The field of medical diagnostics and drug delivery is one of the most important application fields of such nano-constructs. This comes with the need to unite various functionalities like contrasting, targeting, imaging into a single nanostructured system, integrating the strengths of individual modalities in order to produce multifunctional constructs.

The project aims at synthesizing and characterizing core-shell NPs suited to targeted drug delivery applications. The optimized NPs would therefore be screened for surface functionalization with multiresponsive block copolymers, synthesized in-house to target drugs and small molecules. These nano-constructs will be tested in regards to magnetic resonance imaging (MRI) contrast agent, targeted drug delivery and other pertinent applications. These nanomaterials will have multifunctional applications in diagnostic and therapeutic fields.

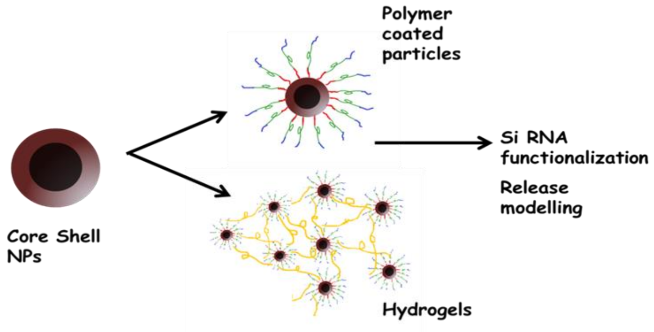


Figure: Schematic overview of the project Smart and multifunctional core-shell nano-particles (NPs) for drug delivery.

***1st row**: Sulalit Bandyophadhyay, Muh Kurniawan, Silje Molnes, May Grete Sætran, Brian Grimes, Gisle Øye*

***2nd row**: Camilla I. Dagsgård, Anuvansh Sharmak, Ahmad Shamsulizwan Bin Ismail, Sandra Rodriguez Fabia, Johan Sjöblom, Trygve Jakobsen, Ragnhild Aaen, Kristofer Paso*

***3rd row**: Marcin Dudek, Diego Pradilla, Jens Norrman, Bicheng Gao, Aleksandar Mehandzhiyski, Sebastien Simon, Jost Ruwold, Are Bertheussen, Arnt Ove Jektvik Olsen*

PROSESS SYSTEMS ENGINEERING

Academic staff
Professor Sigurd Skogestad
Professor Heinz A. Preisig
Associate professor Tore Haug-Warberg
Associate professor Nadav Bar
Associate professor Johannes Jäschke
Adjunct professor Krister Forsman (Perstorp, Sweden)
Professor emeritus Terje Hertzberg

Post Doc
Suwartadi, Eka (from 01.09.2015)
Backi, Christoph J. (from 01.09.2015)
Jahanshahi, Esmaeil (20% from 01.09.2015)

PhD candidates
Birgen, Cansu (from 01.07.2015)
Bouza, Pablo Julian
Das, Tamal (from 30.03.2015)
de Oliveira, Vinicius (unitil 29.04.2016)
Doni Jayavelu, Naresh (until 26.03.2015)
Elve, Arne Tobias (from 01.10.2015)
Grimholt, Chriss Karolius, Sigve (from 01.05.2015)
Minasidis, Vladimiros L.
Reyes Lua, Adriana
Skancke, Jørgen
Straus, Julian
Verheyleweghen, Adriaen (from 10.08.2015)

Guests
Le Roux, Derik, (visiting PhD from Univ. of Pretoria, South Africa, 02May-05Jul)
Qian, Xing (visiting PhD from Tianjin Univ., China, from 29.08)
Sun, Bo, visiting PhD from Shanghai Jiao Tong University, China (until 23 Oct. 2015)
Paksiova, Daniela (visiting PhD from STUBA, Slovakia, 03.09-19.12)
Bisgaard, Thomas (visiting PhD from DTU, Denmark, 03.08-30.10)
Pedersen, Simon (visiting PhD from Aalborg Univ., Denmark, 02.10-28.11)
Soltesz, Kristian (visiting postdoc from Lund, Sweden, 07.09-18.09)
Sutil, Mario (visiting researcher from Univ. of Salamanca, Spain, 15.07-29.07)

PROFILE:

Process systems engineering deals with the overall system behaviour, and how the individual units should be combined and operated to achieve optimal overall performance. Important topics are process modelling on all scales, operation and control, design and synthesis, and simulation, statistics and optimization. The group closely cooperates with other systems-oriented departments at the university, including Engineering Cybernetics, Energy and Process Engineering and Industrial Ecology, and also with SINTEF. The process systems engineering activity at NTNU (PROST) holds high international standards and was already in 1994 recognized as a strong-point centre, both by NTNU and SINTEF.

PROCESS CONTROL ACTIVITIES

Industrial use of advanced process control increases rapidly, and candidates who combine process knowledge and control expertise are in high demand in industry. Control is an enabling technology, thus basic for any industry-based society. The use of advanced control is transforming industries previously regarded as "low-tech" into "high-tech". In process control (Sigurd Skogestad, Johannes Jäschke, Heinz Preisig and Krister Forsman), the objective of the research is to develop simple yet rigorous tools to solve problems significant to industrial applications.

Up to now, the design of the overall "plant-wide" control structure has been based on engineering experience and intuition, whilst the aim has been to develop rigorous techniques. The concept of "self-optimizing control" provides a basis for linking economic optimization and control (Sigurd Skogestad). For example, for a marathon runner, the heart rate may be a good "self-optimizing" variable that may be kept constant in spite of uncertainty. Control is done in a hierarchical construct. At the bottom of the hierarchy, the main issue is to "stabilize" the operation and follow the setpoints provided by the layer above. Further up in the hierarchy one finds optimising control co-ordinating the control of units and plants. A special case is sequential control, which is used to implement recipes in batch operations but also is the basics of handling start-up and shut-down as well as all fault and emergency handling. Another important concept is controllability, which links control and design. Here the main focus is on applications, which currently include reactor and recycle processes, distillation columns, gas processing plants, cooling cycles including liquefied natural gas (LNG) plants, low-temperature polymer fuel cells and anti-slug control. Small-scale experimental rigs have been built to study anti-slug control and novel distillation arrangements. In most cases, control is an "add-on" to enable and improve operation, but the anti-slug rig demonstrates how control in some cases can be used to operate the system in a completely different manner

SFI ON SUBSEA PRODUCTION AND PROCESSING (SUBPRO)

Subsea production and processing is a key technology for exploitation of Norwegian and international oil and gas resources. New solutions are needed to reduce operation and development cost, to increase the recovery factor, to reduce implementation time for field developments, and to allow development of new more demanding fields. The research in our group is focused on developing methods for enabling safe, reliable and economic operation of such systems. This includes development of simplified process models that are suitable for optimization and control, as well as methods for optimizing operation and estimating important unmeasured variables.

The term “SFI” stands for “senter for forskningsdrevet innovasjon” or “center for research-based innovation» and our Department (IKP) was by the Norwegian Research Counsil awarded two such centers with start in 2015. The process systems group is heavily involved in SUBPRO, which also has a very strong industrial support from four oil companies and (Engie, Lundin, Shell and Statoil) and three vendor companies (ABB, Aker Solutions, and DNVGL). The total annual budget is about 33 million NOK and the program is planned to run for 8 years, from 2015 to 2023. One the senior level the following people are involved from our group:

- Professor Sigurd Skogestad is the Director of SUBPRO.
- Associate professor Johannes Jäschke’s position on subsea processing is funded by DNVGL who is a partner in SUBPRO.
- Jon Lippe (associate member of the system’s group) is Project Coordinator in SUBPRO
- Gro Mogseth (associate member of the system’s group) is Technical Coordinator in SUBPRO

Most of the SUBPRO funding goes to research at NTNU, with about 20 PhD students and postdocs engaged at any given time. From our group this includes the following PhD students and postdocs and projects:

1. Christoph Backi (postdoc). Model library for dynamic simulation and control
2. Tamal Das (PhD student). Estimation of un-measurable variables
3. Adriaen Verheylewegen (PhD student). Control for extending component life.
4. Dinesh Krishnamoorthy (PhD student from Aug. 2016). Production optimization

We also work closely with several other NTNU groups in the project, including the control group at the Department of Production and Quality Engineering (Professor Olav Egeland and Associate Professor Christian Holden). The goal of the project is to perform high-class research, which can form the basis for innovation within the companies. The currently low oil prices have made it even more important to come up with new and cost effective solutions. Subsea installations are special because it is costly and difficult to perform maintenance and modifications, and because of their remoteness. In terms of operation this means that robustness and autonomy are more important.

PROCESS MODELLING BEHAVIOURS

The centre piece of process systems engineering is the model. Modelling is generally seen as a difficult and time consuming operation. The step-wise approach developed in this group has transformed the art of modelling into a nearly procedural operation, which has been captured in a program environment (Preisig). The modelling operation is thereby lifted up from writing equations to choosing concepts and mechanisms. The equations are then generated and assembled automatically taking the applicable equations from a data base that has built applying mechanistic descriptions where ever applicable. Multi-scale modelling is supported by enabling order-of-magnitude assumptions, which automatically induce model reduction thereby eliminating structure-related mathematical problems. The overall objective in the group is to develop efficient object-oriented software tools that implement this method and assist in developing consistent and structurally solvable process models on different scales that match the particular application. The technology is physics-based with extensions to allow for grey-box modelling. It aims at replacing various graphical interfaces to simulators and generates code for the major chemical engineering simulators such as gProms, Matlab, Modelica etc. but will also be able to generate stand alone, application-tailored simulators. The fourth generation of a high-level modelling tool (Preisig) incorporates object-oriented tools for efficient thermodynamic modelling, which extend into the efficient computation of thermodynamic information. Rather than a traditional implementation of activity or fugacity coefficients, emphasis is put on the use of structured equation sets governed by thermodynamic consistency rules (Haug-Warberg).

The thermodynamic models are implemented in symbolic form with automatic differentiation capabilities and serves as the basis of several industrial strength simulations (YASIM, CADAS) and energy accounting tools (HERE) in co-operation with Statoil, Hydro and Yara (Haug-Warberg). A primary aspect of thermodynamic (and other physics) modelling is the required consistency of physical units. We have a procedure to obtain self-consistent models, including automatic generation of gradients. This technique has so far been tested up to sixth order gradients, which are needed for higher-order critical point calculations.

In cooperation with Yara AS we have implemented a thermodynamic stream calculator "Yasim". It has a gentle learning curve using the familiar Excel worksheet interface whilst using state-of-the-art thermodynamic methods. All model information including mass balances, energy balances, chemical and phase equilibrium relations are defined in symbolic form. Differentiations are done in symbolic form. These properties add unsurpassed flexibility to Yasim that is not found in any other software of its kind. The ease of use should make it ideally suited for training and use in an industrial environment.

MULTI-SCALE MATERIALS MODELLING

The MoDeNa project, which NTNU (Preisig) is coordinating, is part of EC's Framework 7 program. MoDeNa stands for **Mo**delling of morphology **De**velopment of micro- and **Na**nostructures and is part of an EC cluster consisting of 4 + 1 projects: Deepen (Tyndal, Irland), MMP (TNO, Netherlands), NanoSim (SINTEF), SimPhoNy (Fraunhofer, Germany) plus a fifth associated member ICMEg (RWTH, Aachen). The cluster's objective is to generate a platform for the materials modelling for process and product design, which in the long run extends to operations, thus control on all scales The MoDeNa consortium includes UNITS (Trieste, Italy) for nanoscale modelling, VSCHT (Prague, Czech Republic) for mesoscale modelling, Uni Stuttgart (Germany) for thermodynamic properties, TUE (Eindhoven, Netherlands) for micro-scale fluid properties, POLITO (Turin, Italy) for macroscopic flow, Wikki (London, GB) for the platform, BASF (Ludwigshafen, Germany) for the cases of thermoplastic Polyurethane and Polyurethane foams. IMDEA (Madrid, Spain) for the modelling of the mechanical properties, whilst DIN (Berlin, Germany) is together with NTNU attempting to define a standard for the representation of mathematical models. NTNU is the coordinator and responsible for the generic organisation of the models, workflows, data models and data storage as well as the systematic generation of surrogate models, which involves a loop of design of experiments – detailed model simulations – fitting of the surrogate model – quality assessment and if necessary an improved design of experiments.
Preisig is also member of EMMC, the EC's European Materials Modelling Council.

MODEL-PROCESS INTERFACE

The model generally needs to be fitted to experimental data, and the group has always had a strong focus on statistical methods and experimental design (Hertzberg). Although Professor Hertzberg retired in 2007, he is still active in this area, and in particular, in mentoring.

SYSTEMS BIOLOGY

The system biology activity in the group is rather new, and we here provide a more detailed status on it. Whereas the rest of the Process Systems engineering group looks at any process, whether it is a large industrial scale process or a smaller parts of the process, and strive to model, optimize and control it, the systems biologist in the group (Nadav Bar and coworkers) use similar tools to achieve the same in processes from the world of biology. This includes understanding the biological system, modelling it qualitatively and quantitatively, analysing the models to find hidden properties, and ultimately developing control applications in order to drive the system towards more desired objectives. We use mathematical and computer tools, and we rely on the cooperation with our partners for experimental results. The activities in system biology aee presently in four main research areas:

BAT BEHAVIOUR.

In corporation with two groups from Israel, (Nachem Ulanovsky at the Weizman institute, and Yossi Yovel at Tel Aviv University) we developed a dynamic model that describe the flight pattern of the bat that wants to catch a moving target (insect). We found that that the bat uses a controller with derivative control effect. However, this amplifies the noise and reduces the ability to detect the target while flying, increasing the chance to lose its food.

AQUACULTURE MODELLING (BAR)

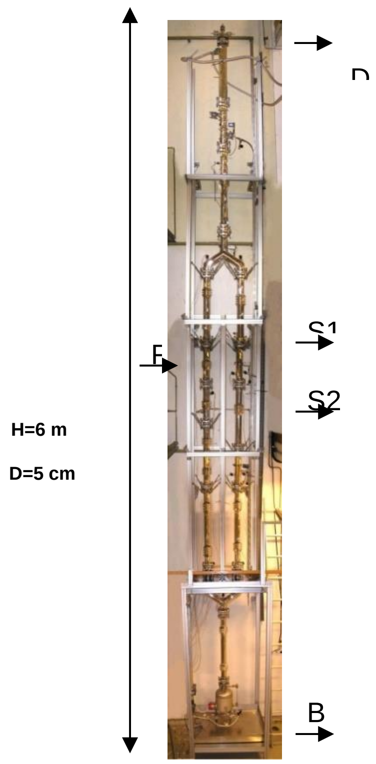
This project is directed towards several of the main goals of the Norwegian research Council, aquaculture program. The activity in the group focuses on two main subjects: 1) Healthy fish, with the goal to fight fish parasite through modelling the interaction fish-lice, and 2) Fish Feed, with the goal to create an optimal feed which reduces the environmental load while maintaining optimal fish growth. An application to the Research Council, in corporation with UiB, Bergen, was send in April, and two more grant applications will be sent in September. The Aquaculture modelling project extends the activity to include also modeling of hunger and feed intake, a very important factor in fish growth and a significant factor in the aquaculture activity and its economic benefits. We wish to be able to control the appetite of the fish in rearing conditions (such as Salmon) through the effect of the balance of the food ingredients, without adding any artificial additives such as hormones. Since this industry produces very large quantities of fish every year, even a small increase in daily feed intake will result in a massive increase in fish production and large profits to both the feed manufacturers and the fish farmers.

PREDICTION OF GENE EXPRESSION.

This project started in cooperation with the other system biology groups at the Faculty, namely those of Martin Kuiper (Department of Biology) and Svein Valla (Department of Biotechnology). Using bioinformatics tools, we want to show how the bonds between the DNA and the mRNA are correlated to gene regulation. During 2011 we conducted experiments at the Department of Biotechnology. The expression data acquired enables us to compare the simulations and conclude about the mechanisms involved. The project involves Jørgen Skancke, who is planned to finish his PhD work in the summer of 2016.

EQUIPMENT IN THE SYSTEMS GROUP

The Kaibel distillation column (see picture), which is currently being reassembled, is 6-meter-high and 5 cm in diameter and can be used to study "thermally coupled" columns, including the three-product Petlyuk column and the four-product Kaibel column. Dr. Ivar Halvorsen from SINTEF and Sigurd Skogestad manage this integrated distillation project. An automatic drink robot is used for demonstration purposes and to study sequence control based on automata theory (Heinz Preisig). In ddition, we have extensively used our two-phase “mini-loop” to test anti-slug control strategies. The group also has a control teaching laboratory, which includes three thermal/air flow processes, a pseudo flash and a mixing process.



Kaibel Distillation column

***1st row**: Åge Johansen, Siri Hansen, Heinz Preisig, Nadi Bar, Johannes Jäschke, Tamal Das, Sigurd Skogestad*
***2nd row**: Torstein Bishop, Ingvild Sørlie, Morten Aulin Moen, Anders Leirpoll, Christoph Backi, Julian Straus, Pablo Bouza, Iosif Pappas, Adriana Reyes Lua*
***3rd row**: Sigve Karolius, Arne Tobias Elve, Rotimi Bayode Famisa, Jan Sulc, Abel Tenu Mekonnen, Eka Suwartadi, Martin Gensor, Prathak Jienkulsawad, Qian Xing, Erqiang Wang*
***4th row**:Tore Haug-Warberg, Cansu Birgen, Adriaen Verheyleweghen, Alexander Leguizamón*

ENVIRONMENTAL ENGINEERING AND REACTOR TECHNOLOGY

Academic staff
Professor Hallvard Svendsen
Professor May-Britt Hägg
Professor Hugo A. Jakobsen
Professor Magne Hillestad
Professor Jens-Petter Andreassen
Associate Professor Hanna Knuutila
Associate Professor Liyuan Deng
Adjunct Professor Jon Samseth
Adjunct Professor Jana P Jakobsen
Professor Emeritus Olav Erga

Scientists
Hartono, Ardi
He, Xuezhong
Lindbråthen, Arne

Post Docs
Ansaloni, Luca (from 05.01.2015)
Guitierrez, Maria Teresa Guzman,
Gupta, Mayuri
He, Xuezhong
Ma, Xiaoguang
Rafiq, Sikander
Romero-Nieto, Daniel
Rout, Kumar Ranjan
Solsvik, Jannike

PhD candidates
Bernhardsen, Ida M. (from 17.08.2015)
Broby, Margrethe
Dai, Zhongde
Dalane, Kristin (from 17,08.2015)
Enaasen, Nina (until 04.09.2015)
Fytianos, Georgios
Guerrero Heredia, Gabriel
Helberg, Ragne M. Lilleby (from 13.04.2015)
Herø, Eirik Helno (from 10.08.2015)
Jahan, Zaib (from 12.02.2015)
Jonassen, Øystein
Majeed, Hammad Mehdizadeh, Hamid
Putta , Koteswara Rao
Saeed, Muhammad (until 31.08.2015)
Seglem, Karen Nessler
Shoukat, Usman
Skylogianni, Eirini (from 07.10.2015)
Trollebø, Anastasia
Uçar Şeniz
Usman, Muhammad
Vik, Camilla Berge
Wang, Lijuan
Zhang, Yanwei

Technical staff
Flatberg, Gøril
Hammer, Mikael

Guests
Cristina Perinu TELEMARK UNIVERSITY COLLEGE
Federico II, Italy
Monica Garcia, University of Surrey

PROFILE

Environmental engineering and reactor technology is the largest research group in the department. The work done in the group covers activities from fundamental modelling to process simulations and design as well as experimental work related to sour gas removal, crystallization and experimental studies related to droplet behaviour.

The group members participate and lead many EU- and national project and have close collaboration with other research institutions (for example SINTEF) and industry. One example of involvement of our group in large research projects is SFI SUBPRO - Subsea production and processing – where the group activities are related to dehydration of natural gas using membranes, combined H_2S and hydrate control and investigating of fluid particle breakage. Another example is the participation in ECCSEL: European Carbon Dioxide Capture and Storage Laboratory infrastructure. Large part of the laboratory infrastructure in the group is part of ECCSEL.

At present, the main activities in the group are within

- Chemical Reactor Research
- Acid gas removal with absorption
- Crystallization and particle design
- Membrane research
- Process design

Project and MSc student can be involved in all areas of our work.

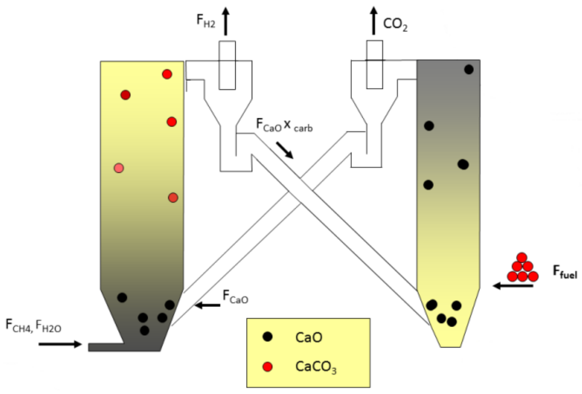
CHEMICAL REACTOR RESEARCH

The activity on reactor engineering has been concentrated in fields directly supporting the design and development of chemical reactors and reactive separations. The most important research areas are:

- Mathematical modeling of chemical reactors.
- Multiphase flow modeling.
- Design of novel solution methods and algorithms.
- Experimental analyses of fluid flow, fluid particle coalescence and breakage, CO_2 sorption by adsorbents and heat- and mass transfer in chemical reactors.
- Experimental validation of numerical models.
- Analysis and design of reactors for environmentally friendly chemical processes.

The research in these fields comprises both experimental and theoretical studies, but emphasis is placed on modeling, development of numerical methods and in-house software for multi-phase reactor simulations.

The simplest models considered are normally implemented in the programming language Matlab, whereas the computationally demanding models are implemented in FORTRAN 90 and C++. Application areas are special chemicals reactors, polymer production, sorption enhanced steam methane reforming, conventional synthesis gas and methanol synthesis, membrane reactors, wood gasification and chemical looping combustion.



A circulating fluidized bed reactor used for studies of sorption enhanced steam methane reforming (SE-SMR).

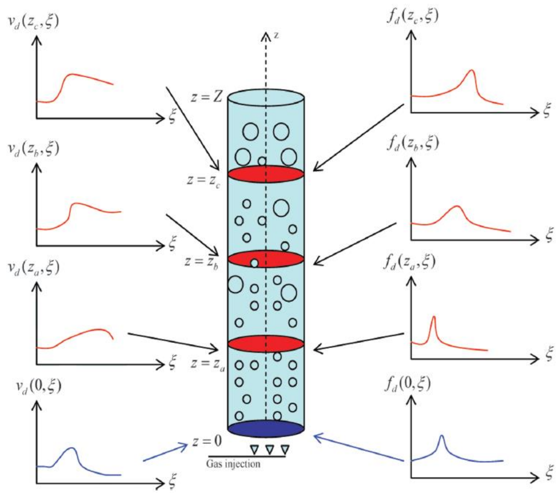
Educationally the main objective of our group is to educate MSc for the Norwegian industry and to raise the national scientific competence in our field of research through PhD studies.

RESEARCH ACTIVITIES

The most important research projects are described in the following paragraphs. For a more comprehensive description, see: (www.ntnu.no/kjempros/miljoreaktor)

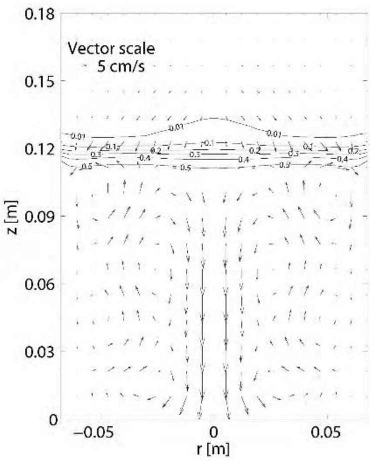
MODELING OF MULTI-PHASE REACTORS

We have for more than 20 years been developing in-house CFD codes for simulating multiphase flows in chemical reactors. Lately, our main focus has been put on developing modules for bubble/droplet break-up and coalescence within the population balance equation (PBE) framework.



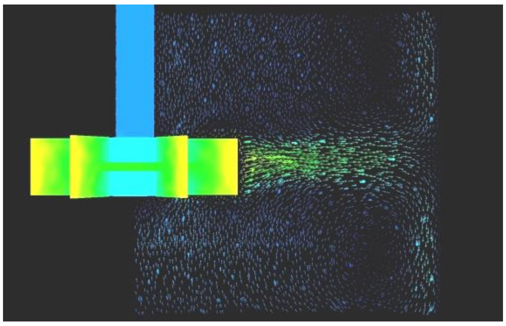
A cold flow bubble column used for studies of bubble breakage and coalescence mechanisms.

The PBEs are solved accurately by efficient spectral and spectral-element methods designed for this particular purpose.



Flow pattern in a bubbling fluidized bed.

We are also investigating the performance of chemical reactive systems like fluidized beds, fixed bed reactors and agitated tanks. At present we are working with the design of suitable reactors for sorption enhanced reaction processes (SERP) like steam reforming with absorbents for CO_2. Moreover, we are performing investigations of the chemical looping reforming and combustion processes.



Simulation of the flow pattern from a turbine impeller.

The conventional 1D and 2D steady-state reactor models are normally run on standard PCs whereas the more computationally demanding dynamic 2D and 3D single and multiphase flow simulations are run on the national super-computers located at the university.

ADVANCED MODELING AND SIMULATION OF CHEMICAL- AND BIOCHEMICAL REACTORS

The activity in this area is mainly founded by the Norwegian Research Council through the GassMaks program. The work in this project is focused on modeling of chemical reactors like fixed packed bed-, bubble column-, and fluidized bed reactors by the complete multifluid model containing a population balance equation for the fluid particle size distribution for the multiphase reactors. The model equations are solved by the modern least squares spectral element method. In the next phase of the project the novel in-house codes will be applied analyzing the chemical reactor processes utilizing natural gas as feedstock.

One such activity is related to the modeling, implementation and simulation of the Fischer-Tropsch process operated in a slurry bubble column producing diesel using natural gas and biomass as feedstock. For this purpose, we are employing a combined multifluid-population balance model for the reactive three-phase system. The model equations are solved by the modern least squares spectral method. A new activity in the group is related to the utilization of biochemical processes that are mass transfer limited thus the bubble size distribution is of outmost importance. Hence, combined multifluid-population balance model is applied for these processes as well. Further information on this activity is outlined at:

http://www.ntnu.edu/web/ntnu-biotechnology/ntnu-bioreactor-design-and-operation.

EXPERIMENTS ON FLUID PARTICLE BREAKAGE (SUBPRO)

For the reactor group the main activity in this SFI program is the experimental investigating of fluid particle (i.e., bubbles and droplet) breakage (and coalescence). A novel experimental facility is under construction for high speed imaging of single particle breakage events, Fig. x. The goal is to determine parameters like the mother particle size, the number of daughters produced in a single breakage event, the breakage time, breakage probability, the size distribution of the daughter particles. These are important functions in a population balance closure model for describing the breakage phenomena.

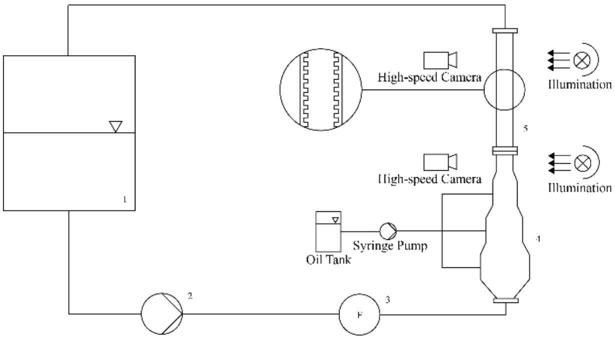


Fig. X Experimental facility for single particle breakage investigations.

ACID GAS REMOVAL BY ABSORPTION

Removal of acid gases, like CO_2 and H_2S using chemical absorbents is a commercial technology used for decades. However novel, environmentally friendly solvents with low energy requirement during solvent regeneration are needed. Our work is concentrated along two axes, one studying CO_2 capture from off gases from fossil fuel power plants as well as from the iron and steel-making industry, and the other directed toward the removal of acid gases from natural gas.

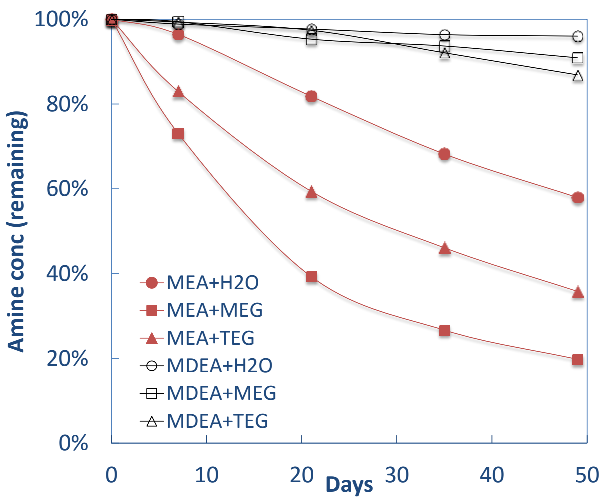
We have experience with theoretical screening by use of computational chemistry, experimental screening and solvent development, characterization of equilibria, thermal properties, transport properties and kinetics and testing in a laboratory pilot plant. In parallel we develop rigorous thermodynamic models and improved models for combined mass and heat transfer. In addition, we have developed together with CO_2 Capture Process Technology group at SINTEF MK a full rate based simulator for the whole absorption/desorption process, CO2SIM. Surplus to these activities, we have been working on solvent degradation and corrosion as well as environmental issues.

We have many research projects in this area funded by the Research Council of Norway, the industry, and the European Union. Our work is concentrated along two axes, one studying CO_2 capture from off gases from fossil fueled power plants and industry, and the other directed toward the removal of acid gases from natural gas. We were heavily involved in EU FP6 projects, e.g CASTOR and CAPRICE. This work continued in the EU FP7 CESAR and as coordinator of the EU FP7 iCap project. Currently we are partner in the OCTAVIUS and HiPerCap projects. Of the current national projects on CO_2 capture, the largest is *SOLVit*, a JIP with Aker Solutions and SUBPRO. Furthermore, we leading national project *3rd Generation membrane contactors* (3GMC), and are partner in following two national projects: *Low energy penalty solvents* (LEPS) and *Magnetic separation of CO_2 through sorption on magnetic hybrid nanoparticles* (CARBOMAG).

COMBINED SUBSEA HYDRATE CONTROL AND H_2S REMOVAL (SUBPRO)

Pipelines used to transport produced gas have quality restrictions related to content of water, CO_2, H_2S and heavy hydrocarbons. If these requirements cannot be met, oil wells may need to be closed. Today on a typical platform water is removed by Triethylene glycol and amine processes are used to remove CO_2 and H_2S. In addition to this Monoethylene glycol is used for hydrate control in the well flowlines, giving in total 3 different chemical systems with separate absorption and regeneration equipment. Simplifying the chemical systems or moving equipment and process elements subsea could be a way to ensure better energy efficiency and utilization of the resources.

We are working on developing a new regenerative process where both hydrate formation is controlled and H_2S removed. Since this would be a regenerative process significantly higher concentrations of H_2S could be treated than normally is the case with scavengers.

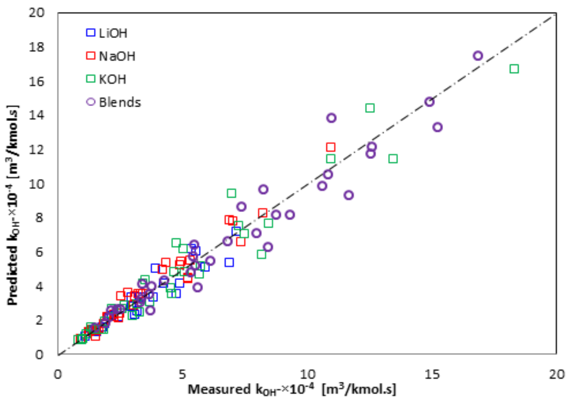


Amine concentration as a function of time during thermal degradation experiments.

CO_2 CAPTURE FROM EXHAUST GASES AND NATURAL GAS SWEETENING

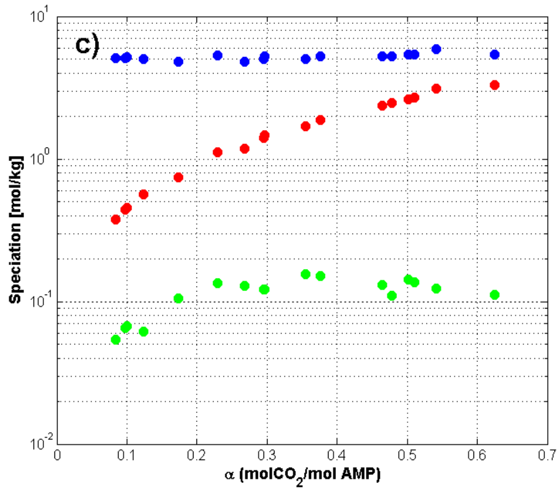
The work we do involves all steps from theoretical screening of new absorbents by use of computational chemistry, through experimental screening, testing of environmental properties, characterization of equilibrium, thermal properties, transport properties and kinetics, degradation rates and mechanisms up to testing in laboratory scale pilot plants. We have also studied nitrosamine decomposition with UV-light on pilot scale. In parallel with the experimental work we develop models ranging from simple models for physical properties to rigorous kinetic and thermodynamic models, based on the electrolyte NRTL and extended UNIQUAC model frame-works.

Below some examples of work, we are doing are shown. The next figure shows measurements and model representation of the reactions kinetics of LiOH, NaOH, KOH and blends of hydroxide and carbonates.



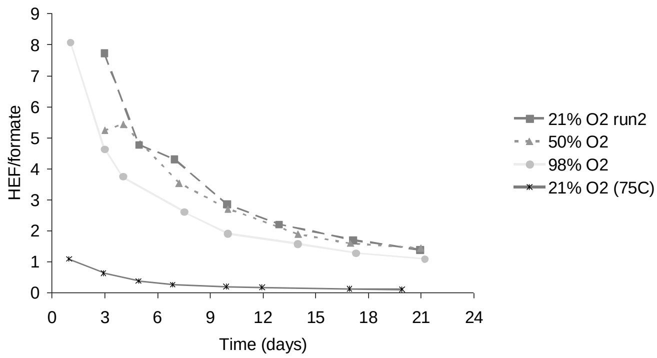
PARITY PLOT FOR THE POHORECKI AND MONIUK'S (1988) MODEL WITH REFITTED PARAMETERS AND EXPERIMENTAL DATA.

The figure below shows results from NMR measurements in the CO_2-loaded AMP system. For the first time the formation of AMP-carbamate was reported and the carbamate constant determined.

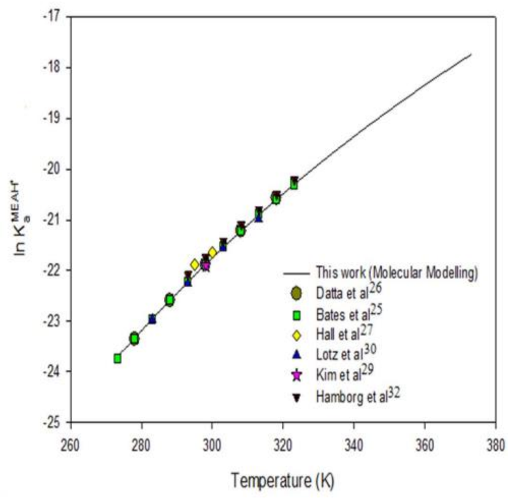


Liquid speciation determined directly by 13C NMR spectroscopy for AMP-CO2-H2O system at: c) 45 °C. ●, AMP/AMPH$^+$;●, HCO_3^- / CO_3^{2-} ; ●, AMPCO2.

Degradation of absorbents is of great concern and we work on identification of degradation products and reaction mechanisms. In the figure below results from oxidative degradation measurements show how the HEF formation is compared to formate changes over time.

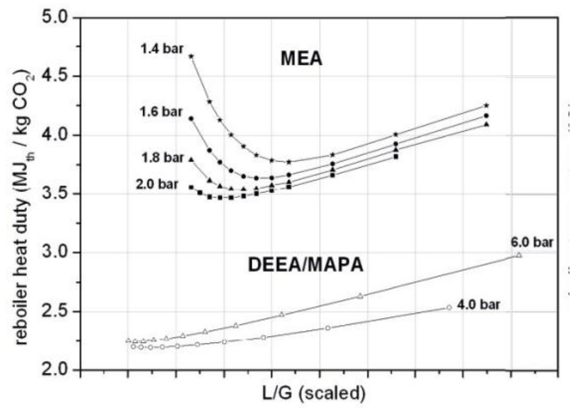


HEF/formate molar ratio for the experiments at different oxygen concentration (21-98%) and temperatures (55-75 °C).

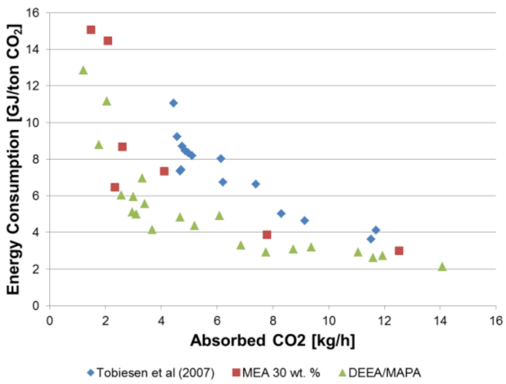


Molecular modeling results of the protonation constant, and heat of protonation of MEA compared to experimental results.

In the iCap project a new liquid/liquid solvent system was simulated in CO2SIM and tested in pilot runs. In the figure below the predicted specific reboiler duty in this system is compared with MEA, and some results from the pilot campaign are shown.



Results from CO2SIM.



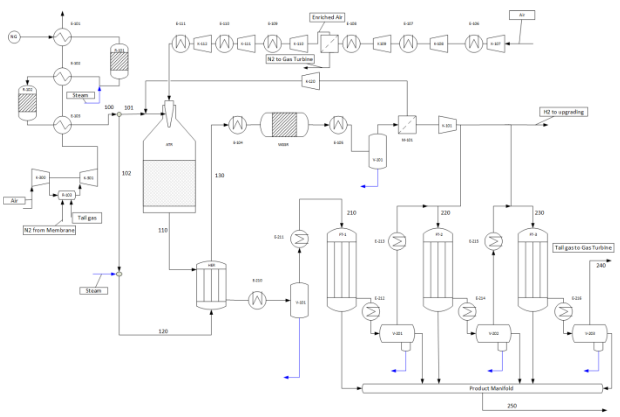
Experimental specific reboiler duty from the lab-pilot for DEEA/MAPA system and for 30wt% MEA.

PROCESS DESIGN

A process design is to a large extent a consequence of developments on catalyst, choice of reaction routes, selection of solvent system, fluid type etc. At this level of development, the structure of the chemical system and the kinetics are determined. Much research is focused on these topics because even incremental improvements may have large economic consequences. The next major step is to find a suitable reactor and process in which to deploy the system on a larger scale. The traditional way of doing design of new processes is by selecting reactor type and process configuration based on comparison to a similar known system. Design choices are often made on the basis of past experience or trial-and-error using laboratory tests and repeated simulations. These activities are necessary. However, it is not likely that the traditional way alone will lead to the best possible process configuration and design. Complementary tools and methods are needed to lead the design engineer onto the path of optimal design. Deviations from the optimal design will lead to unnecessary loss of product yield, unnecessary large volumes and loss of energy. Within the conceptual process design activity some of the most important choices are made, which have large consequences on the profitability and environmental loads of the final process technology. According to Douglas (1988) the conceptual design of an integrated plant can be broken down into a hierarchy of decisions and organized into different levels of activities. Among the levels of activities are reactor-separator-recycle structures, heat integration, and separation train sequence design. A method in focus here is a systematic procedure based on shortcut models. A path is a line of production on which basic operations or functions take place. Reactants pass through a series of functions or basic operations to form the desired products. The basic operations are represented by design functions on the volume path. The design functions are fluid mixing (dispersion), distribution of extra feed points, distribution of heat transfer area and coolant temperature, catalyst dilution distribution and more. The conceptual reactor design problem is solved as an optimal control problem. Parameterization of the design functions and the state variables are applied. The realization is a staged process string of multifunctional units.

GASSMAKS – IMPROVED PROCESS DESIGN AND OPERATION OF NATURAL GAS CONVERSION TECHNOLOGIES

A novel process concept is proposed for converting natural gas to liquid Fischer-Tropsch products. An autothermal reformer with enriched air as oxidant is applied for synthesis gas (syngas) production, and because of the inert nitrogen a once-through Fischer-Tropsch synthesis is the preferred option. In order to maximize the syngas conversion and the production of heavy hydrocarbons, a staged reactor path with distributed hydrogen feed and product withdraw is proposed. The hydrogen is produced by steam methane reforming in a heat exchange reformer (gas heated reformer), heat integrated with the hot effluent stream from the autothermal reformer. Tail gas from the last Fischer-Tropsch stage is sent to a gas turbine for power production. The hot exhaust gas from the gas turbine is used for natural gas preheating. The process is autonomous in the sense that it is self-sufficient with power and water, and therefore well suited for production in remote locations such as a floating production unit. The process concept is simple and inexpensive since cryogenic air separation and fired heaters are not required. For the Fisher-Tropsch synthesis, both the conventional shell and tube fixed bed reactors and microchannel reactors are considered and compared. The carbon efficiencies for a once-through synthesis are calculated to be 57 and 62 % for the fixed bed and microchannel reactors, respectively. The part of the energy that ends up in the product is 45 and 50 % for the fixed bed and microchannel reactors. However, the fixed bed alternative produces more energy as steam and power for export.



Results from CO2SIM.

MEMBRANE RESEARCH

MEMBRANES FOR GAS SEPARATION AND OSMOTIC PROCESSES

Memfo = Membran Forskning (Membrane Research)

The membrane research programs have extensive activities on basic membrane material development, as well as membrane gas separation processes, modelling and simulations. The main focus for the research is CO_2 capture by membranes (from flue gas, natural gas sweetening, biogas upgrading) and hydrogen recovery from various mixed gas streams. In addition to this energy focused gas applications, there is also ongoing research on membranes for other gas mixtures and liquid separation The membrane materials in focus are various types of polymers, nano-composites, carbon membranes, and modified glass membranes.

The group has several well equipped laboratories available for the membrane research; both for membrane material development as well as membrane characterization. The membrane research on CCS is especially strong, and completes the research on CCS activities within the Environmental engineering and reactor technology group.

The international network is extensive, with co-operation both within EU-projects, USA, China, Japan, the Nordic countries and Russia.

BRIEF DESCRIPTION OF SAMPLE GAS SEPARATION PROJECTS

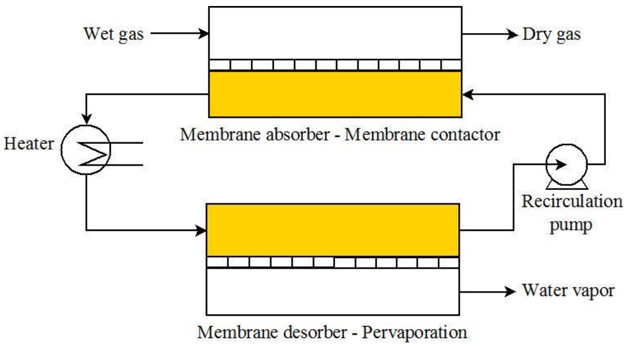
NORCEM-ECRA/NFR PROJECT

This is a project with pilot-scale demonstration of fixed-site-carrier membranes for CO_2 capture from the flue gas in Norcem cement industry by collaboration with DNV GL and Yodfat Engineers. This project comprises two phases: a feasibility phase and phase for execution. The feasibility phase is to test and document the membrane performance and durability over at least 6 months of exposure in the flue gas in Brevik cement kilns, while phase of execution is to design and construct large modules for a two-stage FSC-membrane system, and to prove the performance as expected from process simulation and additionally to document the membrane durability by exposed to the flue gas of Brevik cement kilns over 24 months.

BIP GASSMAKS/ NFR PROJECT NAGAMA

The project started late 2011 ended in 2015. The objective has been CO_2 removal from high pressure natural gas streams using a polymeric blend membrane; using as one of the polymers in the blend the patented PVAm facilitated transport membrane – other materials suitable for high pressure applications are also considered. The project includes material development, pilot construction, durability tests and simulations. The main challenge in this project is to maintain the good performance at high pressures (→100 bar). Advanced high pressure test rigs have been built, one for permeation tests and one for durability tests. Special restrictions for HMS are very important in this operating range. Industrial partners are Statoil and Petrobras.

Bundle of hollow fibre membranes in an industrial module–packing densities can be up to 30 000 m2/m3



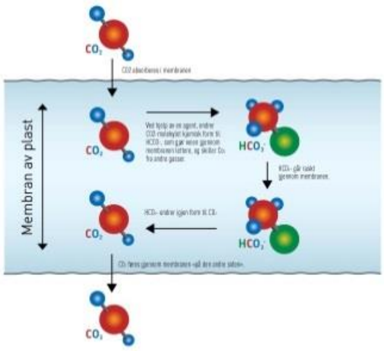
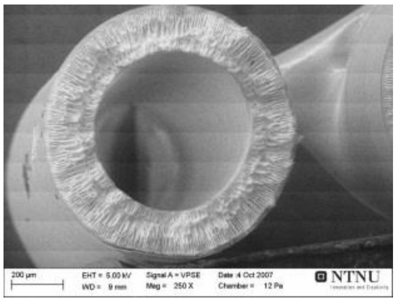


Illustration of the mechanism in the patented CO2 facilitated transport membrane



SEM-picture showing a membrane. D0-DI: 1-6 mm cut though a hollow fibre

KMB PETROMAKS / NFR A GREEN SEA

The project started in 2010, and Sintef Energy is the coordinator and ended in 2015. The project has had activities within four alternative technologies for natural gas sweetening. Memfo's activity within the project has been to development of a nanocomposite membrane material for a membrane contactor There were two PhD-students in the project, one within Memfo.

MCIL-CO_2 / NFR /CLIMIT

The project started in the middle of 2012 with focus on the development of a novel membrane contactor process using ionic liquids as absorbents for pre-combustion CO_2 capture. The project is scheduled for 4 years and finances 2 PhD-students within Memfo. The research activities include (1) build up a lab scale setup and simulation modules to demonstrate the proposed process and (2) provide knowledge and experimental data for the further up-scaling of the process. In 2013 two exchange PhD students from the project partner also contribute to this project in the development of ionic liquid based solvent.

NANOMBE / NFR /NANO2021

This project started from Fall 2014 and will last for 4 years. The aim of this project is to develop nanocomposite membrane containing bio-nanofibers and mimic enzyme for CO_2 separation, which can significantly increase the separation performance and reduce the energy penalty for CO_2 capture from power plant flue gas (CO_2/N_2 separation) and to upgrade biogas (CO_2/CH_4 separation). The nano-materials developed in this project is based on a bio-product from one of Norway's most important natural resources, i.e. trees, which increases value creation based on natural resources. Three PhD students are currently working in this project.

OMPA / NFR/ BIP STATOIL

The project started in 2012 and planned for 3years. The principal objective has been to develop an autonomous valve based on the principle of pressure retarded osmosis (PRO), so that it is able to close off the water producing zones in the well while other parts of the well continue to produce oil/gas. The main focus for Memfo has been to develop a suitable forward osmotic membrane that can withstand the harsh environmental conditions in a given well. Two postdoc researchers work in this project in 2015. The specially designed osmotic membrane for OMPA has been developed from chemically and thermally stable polymeric materials.

VARIOUS PROJECTS ON NANOCOMPOSITES

The group has additionally several smaller research projects focusing on development of hybrid materials; in 2015 four PhDs have been involved in this topic, including an application of nanocomposite membrane in membrane contactor using mimic enzyme as promotor for CO_2 absorption.

The Memfo researchers work very much as a team in addition to be dedicated to individual projects. Hence the simulation of processes is handled whenever needed by those who have the competence. Likewise; the concern for environmental issues, leads to the focus also on biogas upgrading to vehicle fuel quality (biomethane). Carbon membranes has proved to be suitable for upgrading of biogas; documented by experiments and discussed in publications.

SEVERAL PROJECTS ON MEMBRANE CONTACTORS

The group has also been involved in several projects on membrane contactors, including a postdoc working in 3GMC (NFR/CLIMIT) project focusing on the non-porous membrane contactor, one PhD on membrane contactor using green solvent promoted by mimic enzyme, and one PhD working on membrane contactor for high pressure natural gas sweetening (The GREEN SEA project).

EU-PROJECT HIPERCAP (COORDINATED BY SINTEF)

The membrane group is very active in the above mentioned EU-project, contributing both with development of hybrid facilitated membrane as well as supported ionic liquid membranes. The project focus on various technologies for CO2 capture from flue gas.

MEMBRANE AND MEMBRANE CONTACTOR FOR SUBSEA SEPARATION

The petroleum industry has a goal to move oil and gas production and processing to subsea when more advantageous than top side solutions, and one of the main processing step in natural gas processing is dehydration. The objective for this project is to evaluate a new membrane process design for subsea natural gas dehydration to reach pipeline specifications and simultaneously prevent problems caused by the presence of water in natural gas such as hydrate formation, slug flow, corrosion and erosion in pipes and process equipment. To evaluate the membrane dehydration process, modelling and process simulation will be conducted. The two membrane modules will be modelled and verified before they are implemented into HYSYS for an overall process design evaluation and optimization. With a verified and optimized process simulation model a feasibility study of the membrane dehydration process can be reported. In a later stage there will be a need for verification of models through experimental testing.

Preliminary process design for closed loop membrane dehydration with glycol. Water from wet natural gas is absorbed into the glycol in a membrane contactor, and glycol regeneration with pervaporation where the water is removed from the rich glycol.

INNOVATION PROJECTS ON PILOT SCALE (GASSNOVA)

Two large innovation projects started up in 2015, and experimental pilot rigs were built for testing at NORCEM cement plant in Brevik, and at Tiller in Trondheim. The focus for both projects are CO_2 capture from flue gas, and with the goal of bringing the membrane technology closer to commercialization by scaling up and testing under real process conditions. The feasibility phase is to test and document the membrane performance and durability over several months.

1st row: Mohammad Ostadi, Maria Gutierrez, Xuezhong He, Putta Koteswara, Cristina Perinu, Monica Garcia, Erini Skylogianni, Ardi Hartono, Liyuan Deng, Mayuri Gupta, Kristin Dalane
2nd row: Usman Shoukat, Georgios Fytianos, Eirik H. Herø, Luca Ansaloni, Yuanwei Zhang, Hammad Majeed, Arne Lindbråten, May-Britt Hägg, Magne Hillestad, Muhammad Usman, Hugo Jakobsen, Ida Bernhardsen, Karen N. Seglem, Ina Beate Jenssen, Ragna Marie Helberg, Margrethe Broby, Jens- Petter Andreassen, Jing Shi, Eva Baumeister, Xiaoguang Ma, Hanna Knuutila, Zhongde Dai

BIOREFINERY AND FIBRE TECHNOLOGY

Academic staff
Professor Øyvind W. Gregersen
Associate Professor Størker Moe
Adjunct Professor Kristin Syverud
Professor Emeritus Torbjørn Helle

Post Docs.
Celaya Romeo, Javier (from 06.10.2014)

PhD candidates
Ottesen, Vegar
Torstensen, Jonathan Økland
Aaen, Ragnhild (from 24.08.2015)
Jakobsen, Trygve (from 26.11.2015)

Guests
Molnes, Silje Nedland
Jan Hill, (15.03.2013 – 30.06.2015)

TEACHING

The Biorefinery and Fiber Technology group educate chemical engineers and PhDs for the Norwegian pulp, paper and biorefinery industry. The estimated need from the industry is 4-6 engineering graduates and about 2 PhD candidates per year. We have now developed the curriculum of our courses in the 4th and 5th year to include bioenergy and biorefinery concepts on an equal basis with pulp and paper. This reflects a similar change in our research focus and starting industrial development. During 2013-2014 we initiated a closer teaching cooperation with the department of biotechnology within the combined area of biorefinery and biochemical engineering. Biorefinery related topics are now offered to students from both biotechnology and chemical engineering, with packages of electable subjects designed for both classes of students. We have revised the contents of the “Biorefinery and fibre technology” course to make it as useful as possible for this new cooperation.

PARTNERS

The Biorefinery and Fibre technology group, Paper and Fibre Research Institute (PFI) and parts of the Ugelstad laboratory (colloid and surface chemistry) are located in the same building on the NTNU Gløshaugen campus and are working in close cooperation. In addition, Sintef, Innventia (Stockholm), UIB, Åbo Akademi and MIUN (Sundsvall) are important research partners. We also cooperate closely with industry partners such as Norske Skog, Borregaard AS Peterson and Statoil.

RESEARCH

Our research is focused on bioenergy/biorefinery, improvements in the pulp and paper process and on improved end product quality. Our main research activity is done through PhD and Post Doc. fellows. Examples are:

- Optimal pre-treatment for the hydrolysis of lignocellulose for biofuel and biorefinery processes
- Formation of inhibitory degradation products during pretreatment and depolymerisation of lignocellulose for biofuel and biorefinery processes
- Barrier properties of nanocelluloseand chemically modifiednanocellulose.
- Interaction between nanocellulose and the other components in the papermaking furnish.
- 2D and 3D characterisation of polymer composites containing nanocellulose.
- Swelling and strength properties of nanocellulose composite materials
- Transport properties of polymer materials containing nanocellulose.
- Nanocellulose as a rheology modifier
- Nanocellulose for increased oil recovery

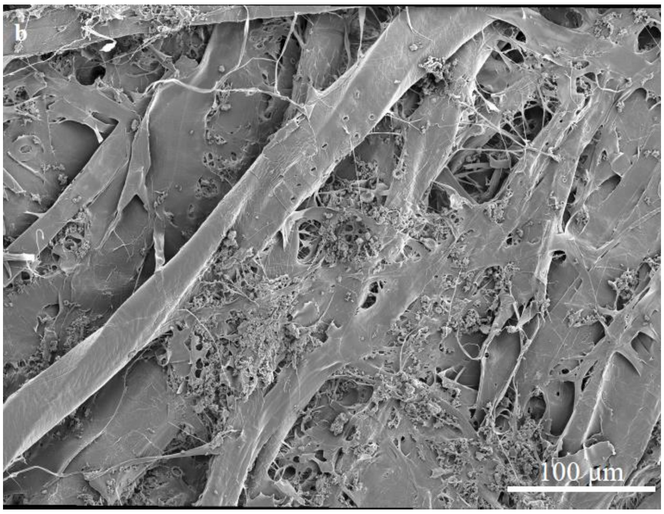


Figure: A paper surface with ground calcium carbonate that has been partly agglomerated by nanocellulose. (Photo: V. Ottesen, NTNU)

A main focus is to establish new research projects.

Currently we work in several research projects funded from the Nano 2021 program of NFR, Petromax 2. In 2013 the NORCEL project was started with Kristin Syverud (PFI/NTNU) as project manager. The project aims at developing tailored nanocellulose materials for application in medicine, papermaking and oil production. Vegar Ottesen and Silje N. Molnes (UiS) are PhD fellows in this project.

During 2014 one new research project, NanoMBE was established together with Liyuan Deng from the Environment and reactor group at IKP as project manager and PFI as the third project partner. The project has three PhD students and aims at developing improved polymer-nanocomposite membranes for gas separation. Jonathan Torstensen is a PhD fellow in this project.

During 2015 the project “Green high performance systems for Enhanced Oil Recovery” was started. The project is led by PFI. Reidun Cecilie Grønfur Aadland work with nanocellulose in enhanced oil recovery (EOR)

The related project “Development of high-performance viscosifiers and texture ingredients for industrial applications based on Cellulose Nanofibrils (CNF)” was also started in 2015.Ragnhild Aaen is a PhD-student in this project, working on rheological properties of cellulose nanofibrils

We are also a partner in the Norwegian biorefinery laboratory project (NorBioLab: http://www.pfi.no/Biorefinery/Biorefinery-Projects/NorBioLab/) which is a national laboratory for biorefining. This involves the development of processes for sustainable conversion of Norwegian land and sea-based biomass into new, environmentally friendly biochemicals, biomaterials and bioenergy products. This infrastructure gives us new research possibilities for converting lignocellulose to chemicals, materials and fuel.

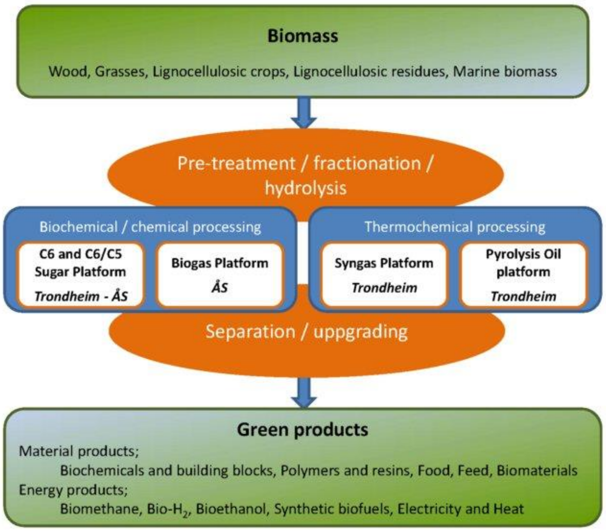


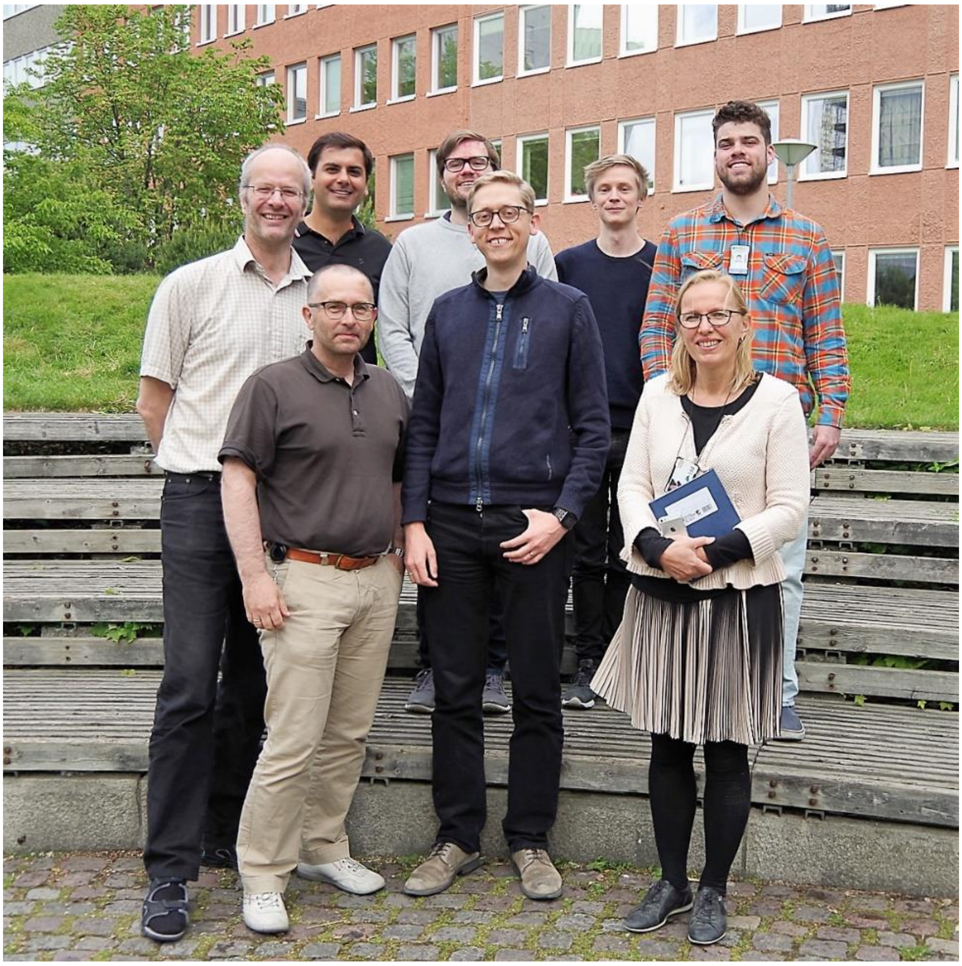
Figure: The equipment in the NorBioLab project covers all the most relevant conversion routs from biomass go green products.

TRENDS

During the last 10 years the focus of our research has shifted from exclusively pulp and paper to including research on bio-fuel, nanocellulose and bio-composite materials. Cellulose based particles in film and composite materials can give better oxygen barrier and mechanical properties to the materials. An overall goal in this research is replacing non-renewable packaging materials (plastics, aluminium foil) with cellulose based (renewable) materials. The research and application areas for nanocellulose have been much extended. The group is active in research on production, modification, application as filter material, barrier material, wound dressing, membrane materials and additive for oil production.

Biofuel manufacturing processes are regarded as a first stage in the development of biorefinery processes for the manufacture of energy, chemicals and materials from renewable resources. Together with PFI we are conducting research on the use of wood and agricultural waste materials for the production of biofuel and chemicals.

The short-term goal is cost-effective production of bio-oil and fuel ethanol from wood, while the long-term goal is the development of a viable biorefinery industry based on domestic or foreign non-fossil raw food.



***1st row**: Størker Moe, Vegar Ottesen, Kristin Syverud*
***2nd row**: Øyvind Gregersen, Bilal Niazi, Henrik Riis, Erik Roede, Jonathan Ø. Torstensen*
***Not present:** Ragnhild Aaen, Trygve Jakobsen, Javier Celaya Romeo*

CHAPTER 3 – PUBLICATION –

PUBLICATION IN REFEREED JOURNALS

1. **Agnihotri, Swarnima; Johnsen, Ingvild Andersen; Bøe, Maren Seljenes; Øyaas, Karin; Moe, Størker.**
Ethanol organosolv pretreatment of softwood (Picea abies) and sugarcane bagasse for biofuel and biorefinery applications. *Wood Science and Technology* 2015 ;Volum 49.(5) s. 881-896

2. **Auvray, Xavier; Olsson, Louise.**
Stability and activity of Pd-, Pt- and Pd–Pt catalysts supported on alumina for NO oxidation. *Applied Catalysis B: Environmental* 2015; Volum 168-169. s. 342-352

3. **Bar, Nadav; Skogestad, Sigurd; Marçal, Jose M.; Ulanovsky, Nachum; Yovel, Yossi.**
A Sensory-Motor Control Model of Animal Flight Explains Why Bats Fly Differently in Light Versus Dark. *PLoS biology* 2015 ;Volum 13.(1)

4. **Bardet, Raphael; Reverdy, Charlene; Belgacem, Naceur; Leirset, Ingebjørg; Syverud, Kristin; Bardet, Michel; Bras, Julien.**
Substitution of nanoclay in high gas barrier films of cellulose nanofibrils with cellulose nanocrystals and thermal treatment. *Cellulose (London)* 2015 ;Volum 22.(2) s. 1227-1241

5. **Bi, Jiebin; Yang, Fan; Harbottle, David; Pensini, Erica; Tchoukov, Plamen; Simon, Sebastien Charles; Sjøblom, Johan; Dabros, Tadek; Czarnecki, Jan; Liu, Qingxia; Xu, Zhenghe.**
Interfacial Layer Properties of a Polyaromatic Compound and its Role in Stabilizing Water-in-Oil Emulsions. *Langmuir* 2015 ;Volum 31.(38) s. 10382-10391

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Mechanistic studies of cobalt-catalyzed Fischer-Tropsch synthesis by a combined approach of DFT calculations, kinetic isotope effect and kinetic analysis. 24th North American Catalysis Society Meeting; 2015-06-14 - 2015-06-19

80. **Rafiq, Sikander; Sarfraz, Mohammad Vahid; Rival, Nicolas; Simon, Christian; Hagg, May-Britt.**
Development of Novel Nano-Composite Membranes for CO_2/N_2 Separation. Euromembrane 2015; 2015-09-06 - 2015-09-10

81. **Romero Nieto, Daniel; Lindbråthen, Arne; He, Xuezhong; Hagg, May-Britt; Sandru, Marius; Kim, Taek-Joong.**
CO_2 removal from fluegas using a novel FSC-Membrane, Going from lab to pilot scale. CLIMIT SUMMIT; 2015-02-24 - 2015-02-25

82. **Roussanaly, Simon; Anantharaman, Rahul; Lindqvist, Karl Erik Artur; Jakobsen, Jana Poplsteinova; Zhai, Haibo; Rubin, Edward M.**
Membrane properties required for post-combustion CO_2 capture at coal-fired power plants. Pittsburgh Coal Conference; 2015-10-05 - 2015-10-08

83. **Roussanaly, Simon; Anantharaman, Rahul; Lindqvist, Karl Erik Artur; Jakobsen, Jana Poplsteinova; Zhai, Haibo; Rubin, Edward M.**
Membrane properties required for post-combustion CO_2 capture at coal-fired power plants. Trondheim Carbon Capture and Storage Conference; 2015-06-16 - 2015-06-18

84. **Rønning, Magnus.**
Celebrating 20 Years of Catalyst Characterisation Development, SNBL 20 Years Anniversary Workshop; 2015-05-28 - 2015-05-29

85. **Rønning, Magnus.**
FREECATS: Doped carbon nanostructures as metal-free catalysts. CRM InnoNet 3rd Innovation Network Workshop; 2015-02-11

86. **Rønning, Magnus.**
Replacing platinum group metals with N-doped carbon nanomaterials in the oxygen reduction reaction, Aalto University; 2015-04-10

87. **Rønning, Magnus; Buan, Marthe Emelie Melandsø; Muthuswamy, Navaneethan; Chen, De.**
Nitrogen-doped carbon nanomaterials as alternative catalysts for the Oxygen Reduction Reaction. Norwegian Catalysis Symposium; 2015-12-03 - 2015-12-04

88. **Samseth, Jon.**
Kjernekraftulykker med fokus på Fukushima. Medlemsmøte; 2015-03-18

89. **Sharma, Anuvansh; Bandyopadhyay, Sulalit; Alvi, Muhhamad Awais Ashfaq; Raju, Rajesh; Glomm, Wilhelm.**
Modelling the Swelling-Collapse Behaviour of Nano Systems Showing Phase Transition. Nano@ Symposium 2015; 2015-11-11

90. **Sjøblom, Johan; Dagsgård, Camilla Israelsen; Sætran, May Grete; Gao, Bicheng.**
Influence of HPAM on W/O Emulsion Separation Properties. Tekna Separation Technology Conference; 2015-09-23 - 2015-09-24

91. **Solsvik, Jannike; Jakobsen, Hugo Atle.**
On the Extension of the Fluid Particle Breakup Models for the Entire Range of Scales of Turbulence. ECCE10+ECAB3+EPIC5; 2015-09-27 - 2015-10-01

92. **Stenius, Per Johan; Gestranius, Marie; Sjøblom, Johan.**
Stabilization of emulsions (and foams) with nanocellulose materials. Smart and green interfaces: Fundamentals and diagnostics (SGI-FunD); 2015-10-29 - 2015-10-31

93. **Strømsheim, Marie Døvre; Svenum, Ingeborg-Helene; Borg, Anne; Venvik, Hilde Johnsen.**
Model Systems for Co Fischer-Tropsch catalysts. EuropaCat XII; 2015-08-30 - 2015-09-04

94. **Strømsheim, Marie Døvre; Svenum, Ingeborg-Helene; Borg, Anne; Venvik, Hilde Johnsen.**
Model Systems for Co Fischer-Tropsch catalysts: STM investigations of alkali metal on Co single crystal surfaces. The 31st European Conference on Surface Science (ECOSS31 Barcelona); 2015-08-31 - 2015-09-04

95. **Svendsen, Hallvard Fjøsne.**
Activity based kinetics for CO_2 absorption. Gjesteforelesning; 2015-02-17

96. **Svendsen, Hallvard Fjøsne.**
CO_2 capture by absorption: 20 years of R&D. BIGCCS GA; 2015-09-23

97. **Svendsen, Hallvard Fjøsne.**
CSS: et essensielt element I kampen mot global temperaturøkning. Pool til Paris; 2015-09-14

98. **Svenum, Ingeborg-Helene; Vicinanza, Nicla; Herron, Jeffrey A.; Peters, Thijs; Bredesen, Rune; Mavrikakis, Manos; Venvik, Hilde Johnsen.**
Surface Phenomena Affecting the Performance of Pd-Ag Alloys. EuropaCat XII; 2015-08-30 - 2015-09-04

99. **Syverud, Kristin.**
Ikke bare et tre: Nanocellulose innerst i kroppen og på havets bunn. Næriongslivsdagen 2015; 2015-04-21

100. **Syverud, Kristin.**
Ten years of nanocellulose research at PFI, keynote presentation. COST Action FP1205; 2015-03-10 - 2015-03-11

101. **Syverud, Kristin; Chinga-Carrasco, Gary; Pettersen, S; Draget, K.**
Controlling the elastic modulus of cellulose nanofibril hydrogels – scaffolds for potential in tissue engineering. 249th ACS National Meeting & Exposition; 2015-03-22 - 2015-03-26

102. **Syverud, Kristin; Heggset, Ellinor B.; Chinga-Carrasco, Gary.**
Temperature stability of nanocellulose dispersions, EPNOE. International polysaccharide conference; 2015-10-19 - 2015-10-22

103. **Tichelkamp, Thomas; Nourani, Meysam; Hosseinzade Khanamiri, Hamid; Stensen, Jan Åge; Torsæter, Ole; Øye, Gisle.**
The effect of water composition on interfacial properties and oil recovery when surfactants are combined with low salinity water. IEA Collaborative Project 36th EOR Workshop & Symposium; 2015-09-07 - 2015-09-11

104. **Trinh, Thuat; Kjelstrup, Signe; Hagg, May-Britt.**
AN ATOMISTIC STRUCTURE OF CARBON MEMBRANES FROM GENETIC ALGORITHM AND REACTIVE FORCE FIELD STUDY. The 8th Trondheim CCS Conference; 2015-06-16 - 2015-06-18

105. **Usman, Muhammad; Hillestad, Magne; Deng, Liyuan.**
Mass and heat transfer study in a membrane contactor using ionic liquid based solvent for pre-combustion CO_2

capture. Euromembrane; 2015-09-06 - 2015-09-10

106. **Venkatraman, Vishwesh; Gupta, Mayuri; Foscato, Marco; Jensen, Vidar Remi; Svendsen, Hallvard Fjøsne; Alsberg, Bjørn Kåre.**
Evolutionary de Novo Design of Absorbents for CO_2 Capture. CLIMIT SUMMIT 2015; 2015-02-24 - 2015-02-25

107. **Venkatraman, Vishwesh; Gupta, Mayuri; Foscato, Marco; Jensen, Vidar Remi; Svendsen, Hallvard Fjøsne; Alsberg, Bjørn Kåre.**
Evolutionary de novo design of absorbents for CO_2 capture. Trondheim Conference on CO2 Capture, Transport and Storage; 2015-06-16 - 2015-06-18

108. **Venkatraman, Vishwesh; Gupta, Mayuri; Foscato, Marco; Jensen, Vidar Remi; Svendsen, Hallvard Fjøsne; Alsberg, Bjørn Kåre.**
Evolutionary de novo design of absorbents for CO_2 capture. International Symposium on Green Chemistry; 2015-05-03 - 2015-05-07

109. **Østbye Pedersen, Eirik; Svenum, Ingeborg-Helene; Blekkan, Edd Anders.**
Co-Mn Catalysts for Fischer-Tropsch Production of Light Olefins. 24th North American Catalysis Society Meeting; 2015-06-14 - 2015-06-19

110. **Østbye Pedersen, Eirik; Svenum, Ingeborg-Helene; Blekkan, Edd Anders.**
Fischer-Tropsch Production of Light Olefins by Mn promoted Co/Al_2O_3 Catalysts. 15th Norwegian Catalysis Symposium; 2015-12-03 - 2015-12-04

111. **Øye, Gisle.**
Offshore Petroleum production – an overview of interfacial and colloid chemical phenomena in various process stages. Jadavpur University; 2015-12-15

112. **Øye, Gisle.**
Produced water treatment during offshore petroleum production - the influence of interfacial phenomena. Calcutta Regional Centre of Indian Institute of Chemical Engineers (IICHE); 2015-12-14

MEDIA CONTRIBUTIONS AND REPORTS

1. **Bar, Nadav.**
En dynamisk systembiologimodell forklarer forskjellen på flaggermusens flyvning i dagslys og mørket. Schrødingers katt, NRK [TV] 2015-05-19

2. **Bar, Nadav.**
Slik flyr en flaggermus. Gemini [Fagblad] 2015-05-28

3. **Benjaminsen, Christina; Skancke, Jørgen.**
Oljedråper avslører miljøpåvirkning etter utslipp. Gemini.no [Internett] 2015-03-26

4. **McDonagh, Birgitte Hjelmeland.**
Schrødingers Katt, Øyeblikket; Oppvask. http://tv.nrk.no/serie/oeyeblikket [Internett] 2015-02-04

5. **McDonagh, Birgitte Hjelmeland; Jansrud, Line.** Hva er såpe? Newton [TV] 2015-04-19

6. **Rønning, Magnus.**
Audi lager diesel av CO_2 og vann - kan bli billigere enn vanlig drivstoff. Teknisk Ukeblad [Fagblad] 2015-04-28

7. **Syverud, Kristin.**
Dyrker nye kjever av trevirke. Forskning.no [Internett] 2015-03-21

8. **Syverud, Kristin.**
Med råstoff fra skogen Fra innerst i kroppen til havets bunn. www.regjeringen.no [Internett] 2015-07-15

9. **Syverud, Kristin.**
Norske forskere skal finne ut om trefibre kan presse ut mer olje av reservoarene. Teknisk ukeblad [Fagblad] 2015-02-21

CHAPTER 4 - EDUCATION – MASTER IN CHEMICAL ENGINEERING

The Chemical Engineering specialization for the 5-year domestic integrated master program starts in the third year with basic technological courses in Separation Technology, Reaction Engineering, Thermodynamics, Process Design, and Process Modelling. In the last two years the students choose between different specialized chemical engineering courses that lead to project work and master thesis within 5 specializations: Catalysis, Colloid and Polymer Chemistry, Environmental Engineering and Reactor Technology, Process Systems Engineering, and Biorefinery and Fibre Technology.

The same course package is offered to our International master program in chemical engineering and to students with a bachelor degree in a relevant area from domestic universities/colleges. The goal of all our education is a Master (MSc) at a high international level in Chemical Engineering.

The degree provides the candidates qualifications for jobs in a wide range of industries, as well as the public sector and in research. It is also the basis for admission to PhD-studies in Chemical Engineering

COURSE CODE	COURSE TITLE	CREDITS	YEAR	PASSED
TKP4100	Fluid Flow and Heat Transfer	7.5	2	64
TKP4105	Separation Technology	7.5	3	67
TKP4106	Process Modelling	7.5	3	31
TKP4110	Chemical Reaction Engineering	7.5	3	94
TKP4115	Surface and Colloid Chemistry	7.5	3	89
TKP4120	Process Engineering	7.5	1	155
TKP4130	Polymer Chemistry	7.5	4	34
TKP4135	Chemical Process System Engineering	7.5	4	5
TKP4140	Process Control	7.5	4	54
TKP4145	Reactor Technology	7.5	4	7
TKP4150	Petrochemistry and Oil Refining	7.5	4	30
TKP4155	Reaction Kinetics and Catalysis	7.5	4	58
TKP4160	Transport Phenomena	7.5	4	34
TKP4165	Process Design	7.5	4	38
TKP4170	Process Design, Project (autumn)	7.5	4	38
TKP4171	Process Design, Project (spring)	7.5	4	3
TKP4175	Thermodynamic Methods	7.5	3	41
TKP4180	Bioenergy and Fiber Technology	7,5	4	4
TKP4185	Nuclear Power, Introduction	7,5	4	11
TKP4190	Fabrication and Applications of Nanomaterials	7,5	4	15
TKP4195	System Modeling and Analysis in Biology	7,5	4	5
TKP4510	Catalysis and Petrochemistry, Specialization Project	15	5	16
TKP4511	Catalysis and Petrochemistry, Specialization Project	7,5	5	-
TKP4515	Catalysis and Petrochemistry, Specialization Course	7,5	5	17

TKP4520	Colloid and Polymer Chemistry, Specialization Project	15	5	9
TKP4521	Colloid and Polymer Chemistry, Specialization Project	7,5	5	2
TKP4525	Colloid and Polymer Chemistry, Specialization Course	7,5	5	9
TKP4530	Reactor Technology, Specialization Project	15	5	10
TKP4531	Reactor Technology, Specialization Project	7,5	5	-
TKP4535	Reactor Technology, Specialization Course	7,5	5	12
TKP4550	Process Systems Engineering, Specialization Project	15	5	9
TKP4551	Process Systems Engineering, Specialization Project	7,5	5	1
TKP4555	Process Systems Engineering, Specialization Course	7,5	5	9
TKP4560	Paper and Fibertechnology, Specialization Project	15	5	-
TKP4561	Paper and Fibertechnology, Specialization Project	7,5	5	-
TKP4565	Paper and Fibertechnology, Specialization Course	7,5	5	0
TKP4850	Experts in Team, Biofuels – A good Solution?	7,5	4	25
TKP4852	Experts in Team, CO_2 Capture	7,5	4	22
TKP4900	Chemical Process Technology, Master Thesis	30	5	66

MASTER THESIS AND MASTER STUDENTS

Alvi, Muhammad Awais Ashfaq

Polymer-Nanoparticle Hybrids For Drug Delivery Applications

Supervisor: Wilhelm Robert Glomm

Amundsen, Paul Magne

Calorimetric measurements with CO2 capture solvents

Supervisor: Hallvard Fjøsne Svendsen

Barsnes, Anne Helene

Nitrogen-Doped Carbon Nanofibers as Pt-Free Catalyst in the Oxygen Reduction Reaction

Supervisor: Magnus Rønning

Bernhardsen, Ida Mortensen

Removal of SO2 from Flue Gas

Supervisor: Magne Hillestad

Bertheussen, Are

Isolation, Characterization and Prediction of Calcium Naphthenates in High Acid Crude Oils

Supervisor: Johan Sjöblom

Bland, Martin Jonathan

Optimisation of an Ammonia Synthesis Loop

Supervisor: Sigurd Skogestad

Dalane, Kristin

Once-Through Gas-to-Liquid Process Concept for Offshore Applications

Supervisor: Magne Hillestad

Elve, Arne Tobias

Ontology Design for Representation of mathematical Models

Supervisor: Heinz A. Preisig

Eraker, Øyvind Juvkam

Pressurized Reduction of Cu-ZnO Water-Gas Shift Catalysts in Presence of Water

Supervisor: Magnus Rønning

Fenes, Endre

Kinetic Study of the Oxychlorination Process

Supervisor: De Chen

Finvold, Adrian Støbakk

Adaptive Control for Severe Slugging Mitigation

Supervisor: Sigurd Skogestad

Forthun, Linn-Therese M

Simulation and Model Verification of the Dynamic and Steady State Behavior of the CO2 Capture

Plant at TCM.

Supervisor: Magne Hillestad

Hemminghytt, Thomas Støme

Multifunctional proppants for enhanced oil production from shales

Supervisor: De Chen

Hole, Nils-Olav Andersen

Effects of Potassium and Copper Promoters on Iron Fischer-Tropsch Catalysts

Supervisor: Hilde Johnsen Venvik

Huang, Huang

Experimental Study of CO2 Solubility in Ionic Liquids and Polyethylene Glycols

Supervisor: Liyuan Deng

Hwang, Jihye

Initial stages of metal dusting corrosion

Supervisor: Hilde Johnsen Venvik

Iglesias Gonzalez, Hector

Photocatalytic H2-production through photo-reforming of hydrocarbons

Supervisor: Magnus Rønning

Jakobsen, Angela

Destabilization of crude oil emulsions by combining chemicals and electric fields

Supervisor: Johan Sjöblom

Jensen, Lise Saue

Cu-Promoted Fe-Based Catalyst for Biomass-Derived Synthesis Gas for the Fischer-Tropsch Synthesis

Supervisor: Magnus Rønning

Lello, Anne Brit

Fabrication and characterization of Solid Lipid Nanoparticles and Nanostructured Lipid Carriers.

Supervisor: Wilhelm Robert Glomm

Linnestad, Kasper

Model predictive control of a polyolefin reactor

Supervisor: Magne Hillestad

Matovu, Fahad

Modelling and Optimization of Compact Sub-sea Separators

Supervisor: Johannes Jäschke

Morken, Siri Foss

One-pot Conversion of Biomass to Chemicals on Ni-Cu/ZnO Based Catalysts

Supervisor: De Chen

Nisja, Trine

The Influence of Salts with Different Cation Valency on Oil-in-Water Emulsion Stability

Supervisor: Johan Sjöblom

Nyeng, Ingrid

Modeling of a 1,2-Dichloroethane Cracker

Supervisor: Tore Haug-Warberg

Paereli, Sergiu

Sorption of hydrogen chloride on solid sorbents

Supervisor: Edd Anders Blekkan

Rennemo, Rune

Vapor-Liquid Equilibria of Bicarbonate Forming Solvents for Post-Combustion CO2 Capture: Experimental and Modeling

Supervisor: Hanna Knuutila

Ronander, Mia Elise

Magnetic Nanoparticles for Extraction of Naphthenic Acids from Model Oil

Supervisor: Johan Sjöblom

Rui, Haakon Marius Vatten

Synthesis and characterisation of tungsten carbide

Supervisor: De Chen

Salman, Ata ul Rauf

Surface Modified γ-Alumina Supports For Cobalt Fischer-Tropsch Catalysts

Supervisor: Magnus Rønning

Sonerud, Kjetil Bohman

Thermodynamic Analysis of Heat and Mass Transfer Using Entropy Production Formalism

Supervisor: Tore Haug-Warberg

Spinu, Dmitri

Kinetic study of ferrous sulfate and copper monosulfide oxidation in aqueous sulfate solution by molecular oxygen

Supervisor: Hallvard Fjøsne Svendsen

Straume, Hanne Marie

Cobalt/Manganese Oxide Nanoparticles for Enhanced Olefin Production in Fischer-Tropsch

Supervisor: De Chen

Sørvik, Linn Cecilie

Investigations of PdAu membranes and model systems for production of pure hydrogen

Supervisor: Hilde Johnsen Venvik

Torvik Jenssen, Astri Karin

Catalytic conversion of oxygenates to fuels

Supervisor: De Chen

Tyvold, Preben Fürst

Modeling and Optimization of a Subsea Oil-Water Separation System

Supervisor: Jäschke Johannes

Verheyleweghen, Adriaen

Modelling and Simulation of a Two-Stage Refrigeration Cycle

Supervisor: Jäschke Johannes

Wigum, Stine Hagen

Nickel and Iron Poisoning of Copper Based Methanol Synthesis Catalysts

Supervisor: Magnus Rønning

Witzøe, Trine

Simulation of Pilot Data with Aspen Plus

Supervisor: Hanna Knuutila

Yeboah, Isaac

Characterization and Thermal/Catalytic Upgrading of Kerogen in a Green River Oil Shale

Supervisor: De Chen

5TH YEAR STUDENTS 2015/201 TOTAL 66, 31 FEMALE AND 35 MALE

Andenes, Sigmund
Apan, Shawn Christopher
Arif, Asad
Bache, Therese
Bakke, Bjørnar
Berry, Joshua
Bishop, Torstein Alexander
Bjørkedal, Ole Håvik
Chowdhury, Debasish
Ekholdt, Rakel Johanne
Emhjellen, Morten Thomas
Engh, Mathias
Erevik, Tor Olav Høva
Famisa, Rotimi Bayode
Fyllingsnes, Regina Lopez
Garmann, Ingelin
Ge, Wei
Hansen, Siri Kildal
Hauge, Astri Brugrand
Haugsten Hansen, Kristian
Hope, Terje Mongstad
Hovd, Benedicte
Haarseth, Pia Kristine
Jernslett, Martin
Johansen, Åge
Krokvik, Iris Renate Tøkje
Larsen, Annemari Løberg
Leguizamon, Alexander
Leirpoll, Anders Tyseng
Lervold, Stine
Lid, Mads Alexander
Lilleng, Mari Iselin
Lingelem, Hans-Ulrik

Lundgren, Mathias Kristoffer
Lund-Johansen, Ragnhild B.
Lædre, Torstein
Mekonnen, Abel
Melle, Ørjan Nymark
Meyer, Marthe
Moen, Ann Kathrin
Moen, Morten Aulin
Mundal, Ingvild
Nannestad, Åsne Daling
Naustdal, Vegard Andreas
Nautnes, Ragnhild
Nazarpour Alizad, Rasa
Neteland, Marte
Nielsen, Henriette
Nøkleby, Christina
Olsen, Arnt Ove Jektvik
Ruud, Anniken Amos
Sandvik, Helene Mørkkåsa
Sharma, Anuvansh
Skjervold, Vidar Torarin
Solvoll, Anne Marthe
Storrvik, Hanna Marie
Strand, Mikael
Strømsnes, Lars Moen
Sveen, Ruth Elisabeth
Sørensen, Tor Erik
Sørlie, Ingvild Marie
Tapio, Lene Katrin
Westbye, Alexander
Wiker, Ellinor Sofie Smith
Yousaf, Bilal
Aas, Elin Cecilie Ristorp

4TH YEAR STUDENTS 2015/2016 TOTAL 51, 18 FEMALE AND 33 MALE

Andersen, Anders Galland
Baumgarten, Bjørn
Betten, Hanne Kalvøy
Baalsrud, Gaute Tessand
Dlima, Melissa Florine
Edvardsen, Johan Christian

Erstad, Ramn
Gangstad, Sanna Henøen
Gebremariam, Solomon Kahsay
Gjøby, Julie Marie
Gjørtz, Kristoffer A.
Hambro, Carl Johan
Hansen, Stine
Hauge, Marta Westad
Heuch, Cathrine Ro
Hines, Mona Aufles
Hyrve, Signe Marit
Høgstad, Jon
Iversen, Per Sverre
Josefsen, Natalie Therese
Kjellstrøm, Tomas Tungen
Kjetså, Ellen
Krog, Halvor Aarnes
Kure, Ida Kristina
Kaalstad, Petter
Langfjæran, Sebastian
Lems, Eva Marieke
Linga, Åsmund
Lund, Marlene Louise
Løining, Vilde Stangeland
Ma, Jianyu
Markussen, Petter B.
Martem, Hugo
Mawanga, Moses
Moen, Morten Aulin
Panneer Selvam, Arun Kumar
Pettersen, Even
Raghunathan, Karthik
Rutkowski, Gregory
Samuelsen, Eirik
Skodvin, Daniel
Soundaranathan, Mithushan
Suciu, Sandra
Thombre, Mandar
Tofte, Sondre Waage
Torp, Eirik Hjalmar
Tysseland, Amalie
Wang, Kun
Yu, Junbo
Zahraee, Znar
Zotica, Cristina Florina

3RD YEAR STUDENTS 2014/2015 TOTAL 25, 11 FEMALE AND 14 MALE

Abdullahi, Najma Ali
Amundsen, Hans Sigurd
Andreassen, Vilde Elin
Gremmetsen, Henrik Jenssen
Gullberg, Rebecca Maria Birgitte
Haugberg, Oliver Sale
Hauge-Iversen, Hallvard
Heggheim, Sindre Johan
Holck, Haakon Eng
Ims, Julie Berge
Krogstad, Dag Svenningsson
Larsen, Emilie Wattø
Lilleng, Ane Sofie
Lønning, Askild Johannes
Mageli, Eskild Ruud
Magnø, Hilde Scherven
Nilsen, Karoline Aase
Rasmussen, Julie Kristine Bonnevie
Reed, Marius
Save, Jonas Steidel
Sollund, Erling Olav
Sundli, Eline Nesdal
Yahia, Sarry Haj
Østrådt, Beate Meisland
Øyen, Sindre Bakke

INTERNATIONAL MASTERSTUDENTS (MSCHEMENG) AUTUMN 2015, TOTAL 16, 4 FEMALE AND 12 MALE

Andersen, Anders Galland, Norge
Baumgarten, Björn Frederik, Tyskland
Dlima, Melissa Florine, India
Gebremarian, Solomon Kahsay, Etiopia
Kaalstad, Petter, Norge

Kjetså, Ellen, Norge
Ma, Jianyu, Kina
Mawanga, Moses, Uganda
Panneer Selvam, Arunn Kumar, India
Raghunathan, Karthik, India
Rutkowski, Gregory, USA
Suciu, Sandra-Paula, Romania
Thombre, Mandar Nitin, India
Wang, Kun, Kina
Yu, Junbo, Kina
Zotica, Cristina Florina, Romania

TWO YEAR DOMESTIC MASTER DEGREE PROGRAM AUTUMN 2015, TOTAL 8, 2 FEMALE AND 6 MALE

Baalsrud, Gaute Tessand
Bråtveit, Ole Christian
Dyrli, Kristine
Gjørtz, Kristoffer Andersen
Hines, Mona Aufles
Kjellstrøm, Tomas Tungen
Lislelid, Robert
Martem, Hugo Sundkjer

STUDENT MOBILITY

18 EXCHANGE STUDENTS VISITED OUR DEPARTMENT (8 FEMALES AND 10 MALES)

NAME	UNIVERSITY/COUNTRY	GROUP LOCATED
Betzenbichler, Franziska	Universty of Munich, Germany	Catalysis Group
Caux, Marine Adelaide	Claud Bernard University, Lyon, France	Catalysis Group
Coudrais, Guillaume J.	University of Lorraine, Nancy, France	Colloid and Polymer Group
Mouillat, Baptiste	INSA, Lyon, France	Process System Engineering
Dugard, Alain Patrice	INSA, Lyon, France	Process System Engineering
Falkenberg, Martin	Aachen University of Technology, Germany	Environmental and Reactor Technology Group
Ferrer Montanes, Laura M.	University of Saragossa, Spain	Colloid and Polymer Group
Galimberti, Marco	Polytecnico di Milano University, Italy	Environmental and Reactor Technology Group
Iglesias Golzalez, Hector	University of Valladolid, Spain	Catalysis Group
Lunardon, Adeline	University of of Lorraine, France	Colloid and Polymer Group
Maerten, Sophie	University of Mons-Halnaut, Belgium	Environmental and Reactor Technology Group
Nieto-Sandoval Rodriguez, Julia	Autonomous University of Madrid, Spain	Catalysis Group
Parmentier, Tanja	Utrecht University, The Netherlands	Catalysis Group
Pilar Mores, Monica	University of Saragossa, Spain	Colloid and Polymer Group
Riviere, Maxime Jaques	University Claude Bernard, Lyon, France	Catalysis Group
Smits, Nick	Ghent University, Belgium, Belgium	Colloid and Polymer Group
Thombre, Mandar Nitin	Birla Institute of Technology and Science, India	Process System Engineering
Vangaever, Stijn	Ghent University, Belgium	Colloid and Polymer Group

15 STUDENTS FROM OUR DEPARTMENT (7 FEMALES AND 8 MALE) ON EXCHANGE IN 2014

NAME	TO INSTITUTION	PROGRAM	PERIOD
Andenes, Sigmund	University of California, Santa Barbara, USA	Bilateral	01.08.13 – 30.06.14
Bernhardsen, Ida M.	University of New South Wales, Australia	Bilateral	01.08.13 – 30.06.14
Bishop, Torstein A.	University of California, Santa Barbara, USA	Bilateral	29.09.14 – 12.06.15
Bland, Martin Jonathan	University of California, Santa Barbara, USA	Bilateral	01.08.13 – 30.06.14
Emhjellen, Morten T.	University of California, Santa Barbara, USA	Bilateral	29.09.14 – 12.06.15
Lædre, Torstein	University of California, Santa Barbara, USA	Bilateral	29.09.14 – 12.06.15
Lingelem, Hans-Ulrik	University of New South Wales, Australia	Bilateral	01.07.14 – 01.06.15
Melle, Ørjan Nymark	University of New South Wales, Australia	Bilateral	01.07.14 - 01.06.15
Nyeng, Ingrid	University of California, Santa Barbara, USA	Bilateral	01.08.13 – 30.06.14
Sandvik, Helene M.	University of California, Santa Barbara, USA	Bilateral	29.09.14 – 12.06.15
Sørlie, Ingvild Marie	University of California, Santa Barbara, USA	Bilateral	20.08.14 – 20.05.15
Sørvik, Linn Cecilie	California State University, USA	Individ	01.01.14 – 30.06.14
Tapio, Lene Katrin	University of KwaZulu-Natal, Durban, South Africa	Bilateral	01.02.14 – 30.06.14
Tyvold, Preben Fürst	University of California, Santa Barbara, USA	Bilateral	22.09.13 – 13.06.14
Witzøe, Trine	University of California, Santa Barbara, USA	Bilateral	06.01.14 - 13.06.14

Some of the masterstudents in 2015.
1st row: Kristin Dalane, Trine Witsøe, Ida M. Bernhardsen and Lise Saue Jensen
2nd row: Kasper Linnestad, Martin Bland, Åsne Daling Nannestad, Linn-Therese Forthun
3rd row: Nils Olav Hole, Adriaen Verheyleweghen, Preben Fürst Tyvold

PHD IN CHEMICAL ENGINEERING

The Department of Chemical Enginerring offers a PhD-programme, which gives a higher education within the field of Chemical Engineering.

The PhD program in Chemical Engineering will provide training in how to generate and publish new knowledge in the field, as well as help strengthen the catidates acdemic horizont in Chemical Engineering.

The PhD proggram in Chemical Engineering are connected to the Departments research groups:

- Catalysis
- Colloid- and Polymerchemistry
- Process- Systems Engineering
- Environmental Engineering and Reactor Technology
- Biorafinery and Fibre Technology

PHD COURSES GIVEN AT DEPARTMENT OF CHEMICAL ENGINEERING:

COURS CODE	COURSE TITLE	CREDITS	PASSED	SEMESTER
KP8091	Advanced Chemical Engineering	7.5	1	Spring 14
KP8100	Advanced Process Simulation	7.5	1	Fall 14
KP8102	Lignocellulosic Chemistry	7.5	-	Fall 15
KP8105	Mathematical Modelling and Model Fitting	7.5	8	Fall 15
KP8106	Gas Cleaning with Chemical Solvents	9.0	1	Spring 14
KP8107	Advanced Course in Membrane Separation Process	9.0	-	Spring 14
KP8108	Advanced Thermodynamics: With applications to Phase and Reaction Equilibria	9.0	-	Spring 15
KP8110	Membrane Gas Purification	9.0	5	Spring 15
KP8115	Advanced Process Control	7.5	5	Fall 14
KP8128	Advanced Reactor Modelling	12.5	1	Spring 14
KP8129	Colloid Chemistry for Process Industry	7.5	-	Spring 14
KP8130	Systembiology, Modelling and Analysis	7.5	-	Fall 15
KP8131	Crystallization and Particle Design	7.5	-	Spring 15
KP8132	Applied Heterogeneous Catalysis	7.5	9	Spring 14
KP8133	Characterization of Heterogeneous Catalysts	7.5	-	Fall 14
KP8134	Surfactants and Polymers in Aqueous Solutions	7,5	2	Fall 14
KP8135	Surface, Colloid and Polymer Chemistry Special Topics	7.5	2	Spring 14

KP8136	Modelling of Catalytic Reactions	7.5	-	Spring 14
KP8137	Design and Preparation of Catalytic Materials	7.5	8	Spring 15
KP8901	Chemical Process System Engieering	7.5	-	Spring 14
KP8902	Reactor Technology	7.5	2	Spring 14
KP8903	Reaction Kinetics and Catalysis	7.5	4	Fall 14
KP8904	Transport Phenomena	7.5	3	Fall 1
KP8905	Surface- and Colloid Chemistry	7.5	6	Spring 14

PHD- THESIS 2015 – 7 STUDENTS: 2 FEMALE AND 5 MALE

Dam, Anh Hoang.
Bimetallic Catalyst System for Steam Reforming. Supervisor: De Chen

Doni Jayavelu, Naresh.
Integrative Systems Biology Approaches for Analyzing High-Throughput Data. NTNU, Trondheim: Institutt for kjemisk prosesseknologi 2015 (ISBN 978-82-326-0796-9) 170 s. Supervisor: Nadav Bar

Flø, Nina Enaasen.
Post-combustion absorption-based CO2 capture: modeling, validation and analysis of process dynamics. Supervisor: Magne Hillestad

McDonagh, Birgitte Hjelmeland.
Multifunctional Nanoparticles for Bioimaging. NTNU Suprvisor: Wilhelm R. Glomm

Saeed, Muhammad.
Development of Mimic Enzyme-based Membrane and Membrane Contactor for CO2 capture. Supervisor: Liyuan Deng

Tichelkamp, Thomas.
The Effect of Calcium Ions on Oil-Brine-Surfactant Interfacial Properties and the Relation to Surfactant Enhanced Oil Recovery at Low Salinity. Supervisor: Gisle Øye

Volynkin, Andrey Sergeevich.
The role of carbon supports in platinum catalyzed hydrogenation/dehydrogenation model reactions. Supervisor: Edd A. Blekkan

PHD STUDENT EXCHANGE

Georgios Fytianos Univerity of Tokyo, Japan

SEMINARS AND MEETINGS ORGANIZED BY THE DEPARTMENT IN 2015

SEMINARS IN PROCESS CONTROL

18.03.2015
Kristian Soltesz
The PID auto-tuner revisited

12.05.2015
Johan Derik le Roux
Cost and benefit of model-based control in the comminution industry.

18.09.2015
Celso J. Munaro
Fault detection and isolation via causality detection

30.11.2015
Matias Hultgren, University of Oulu:
Integrated control and process design and plantwide control in the circulating fluidized bed boiler.

12.11.2015
Professor Miroslav Fikar, Slovakia
Modelling, Control, and Optimisation of Batch Membrane Processes

SEMINARS IN BIOREFINERY AND FIBER TECHNOLOGY

10.11.2015
Nordic pulp and paper symposium (Nordisk treforedlingsymposium)
NTNU, Biorefinery and Fiber Technology arranged with PFI AS and Paper Industry Technical Association. There were about 45 participants from research and industry.

SEMINARS IN ENVIROMENTAL ENGINEERING AND REACTOR TECHNOLOGY

12-13. april 2015
Seminar in HiperCap project; GA (General Assemmbly) and TM (technical Meetings).
It was approximately 30 participants to these meetings.
(Hipercap = Hihg Performance Capture, EU-grant £ 60855

HEALTH, SAFETY AND ENVIRONMENT (HSE)

HSE STATUS AT IKP

SAFETY INSPECTIONS

The annual safety inspection was carried out as usual. For the first time, this year the report deals with challenges and areas for improvements related to the entire field of health, safety and environment. We were required to report on the status following the survey on the work environment, the work to reach work environment targets and users' behavior in the laboratories. We were also required to describe the implementation and documentation of the HSE training in the department.

FULL SCALE TEST IN K5

A new gas alarm system is installed in building K5. Representatives from engineering consultants Rambøll, NTNU operations division and the department were present when the full scale test of the system was performed. All functions such as warning lights, sound alarms and display were tested. The few errors revealed have been corrected.

FIRE INSPECTION

The annual fire inspection was carried out by the municipal fire department, Trondheims Brann og Redningstjeneste. No major issues requiring improvements were revealed, only minor technical discrepancies were discovered.

INCIDENTS AND DISCREPANCIES REPORTING

We received about 40 reports about incidents and discrepancies in 2015. The majority of these are reported as less important, while three incidents were classified as serious. The Department encourages its employees to report any incidents and discrepancies, however small.

TRAINING

Anyone who is going to get access to our laboratories, apparatus and workshops are obliged to attend both a general and a site specific HSE training course. The training is documented and everyone who attends the general HSE training receives a diploma.

NTNU has introduced an exposure register. Everyone working with chemicals registered to pose a risk, as illustrated with official hazard statements in the figure below, have to register in this exposure register. Key personnel at the Department have received training on how to use the register

Risk phrase (R-phrase)
R46 May cause heritable genetic damage
R45 May cause cancer
R49 May cause cancer by inhalation

Hazard statements (H statements)
H340 May cause genetic defects
H350 May cause cancer
H350i May cause cancer by inhalation

GENERAL PERSPECTIVES

The laboratories appear very presentable since the research groups have good tidying routines.

The persons in charge of the laboratories, safety representatives and HSE-coordinator meet regularly in order to elaborate the procedures and to improve the HSE training.

In June 2015 the EU regulation on classifying, labelling and packing of chemicals, CLP, were introduced. A fair amount of our chemicals did not meet the requirements in the regulations and were disposed.

CHAPTER 5 – ORGANIZATION AND ECONOMY

ORGANIZATION (ILLUSTRATION SEE COVER PAGE)

The Department Board is the highest decision-making body. The Boards mandate is to make decisions regarding strategy and budget. The Board shall have 2 meetings each year. It consists of two external members, three members from the scientific staff, administrative staff, temporary scientific staff (PhD's, Post Doc's) and students. The board is elected for 4 years. The Head of Department is chair of the board. Head of Department is Professor Edd Anders Blekkan, employed in 2013 for a four-year period. The scientific staff is divided in to five research groups. Each research group has a representative in the management team. The management team has also representatives from the PhD's, the students and technical staff. The management team meets every second week and discusses running matters, and gives advice to the Head of Department.

In addition to the scientific staff the department has 23 persons in a technical and administrative staff to support teaching and research of all the research groups.

ADMINISTRATIVE RESPONSIBILITIES OF FACULTY

Faculty Educational Committee (Department representatives)	Professor Jens-Petter Andreassen Deputy: Edd Anders Blekkan
Faculty Research Committee (Department representatives)	Professor Sigurd Skogestad Deputy: Professor Hugo Atle Jakobsen
Study Program Chemical Engineering and Biotechnology (Industriell kjemi og bioteknologi) (Department representatives)	Professor Jens-Petter Andreassen Deputy: Liyan Deng
Exchange of Norwegian students taking courses abroad (approval of course program), and approval of course program for visiting exchange students.	Professor Jens-Petter Adreassen
International Master program	Associate Professor Liyan Deng and Higher Executive Officer Hege Johannessen

DEPARTMENT ECONOMY

The department has three main sources of income:

- Regular funds from the University and coverage of cost due to research financed by external sources.
- Strategic funding from the University
- External projects.

In terms of external funds, including contributions from the research Council and industry, the portfolia has been fairly stable but raised some in 2015 (shown in table 2). We were in 2015 awarded with two cetras for research based innovation. These two large projects each over 200 million NOK in total budget will contribute largely to our portfolio for the next 8 years. The regular funds from the University were about 34 million NOK in 2015. These funds are mainly used for salaries to permanent staff, equipement, regular operations of the department and contribution to research projects. New practice in distributing contribution and cost from external research blows up both the income and expence side of the economy. The surplus in 2015 was caused by restrictions from University to employ new or replace staff, postponed investments in infrastructure and more contribution from external projects than budgeted.

More details are shown in Table 1.

Accounts	2013	2014	2015
Income:			
University funding and coverage of expenses from external activities	44 742 000	45 326 000	70 333 000
Sum income	44 742 000	45 326 000	70 333 000
Expenses:			
Wages	35 672 000	35 808 000	34 877 000
Investment	388 000	1 722 000	2 414 000
Operating expenses	5 363 000	4 492 000	11 104
NTNU contribution to ext. projects	623 000	2 836 000	15 197 000
Sum expenses	42 046 000	44 858 000	63 592 000
Result	2 696 000	468 000	6 741 000

Table 1. Department's income from University and spending.

EXTERNAL FUNDING

In addition to the University funding shown in Table 1, the Department have a substantial income from external contributors, approx 84 million NOK. Details are shown in Tables 2. In 2015 the external contributions raised from 68,5 to 84,3 million NOK. It seems that several of the new academic staff also are able to attract projects. The majority of the external funds are spent on salary for PhD candidates and Post Docs. The main contributor to the external research activity is The Norwegian Research Council (NRC). Most of these projects are hosted by The Department, but the second largest external source is NRC projects where we contribute as a third party. The level of funding from commissioned research have been modest the last years. The funding from EU has been in the range 3 – 6 MNOK/year, and in 2015 it raised to 5,6 MNOK. NTNU wish to increase the EU-research and we manage to do so in 2015. Many of the projects both for NRC and others are co-founded by public funding and industry funding. The industry partners are from Europe, North and South America and Asia.

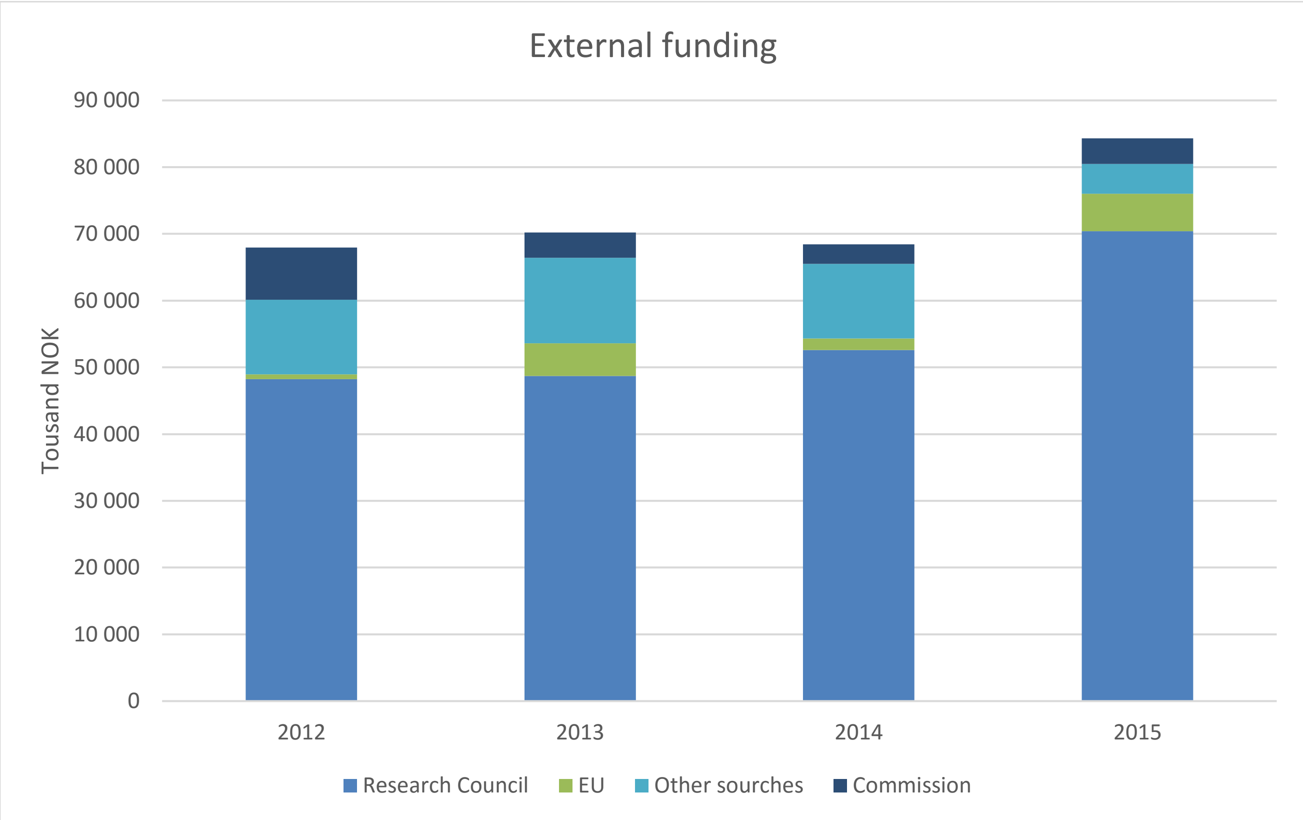

Table 2 Sources of external funding

STRATEGIC FUNDS FROM UNIVERSITY

The third source of income is strategic funding from the Minestry, this is earmarked funds to support teaching, research and academic profile. These funds are ment to finance PhD or Post Doc positions and to aquire scientific equipement. But also to support self-financing in external project of strategic interest.

The funds we receive are mostly used to cover self-financing of projects we take part in that are of strategic interest for NTNU. The budget for the segment was approx. 3,2 MNOK in 2015.

AWARDS IN 2015

In april 2015 Sigurd Skogestad was appointed honorary member of the NFA (Norwegian Association for Automation)

Department of Chemical Engineering

CONTACT

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