Annual Report 2007
Nordic Graduate School of
Biofuel Science and Technology
BiofuelsGS-2

Chalmers University of Technology, Sweden

Technical University of Denmark, Denmark

Norwegian University of Science and Technology, Norway

Åbo Akademi University, Finland

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Preface

The Nordic Graduate School in Biofuels Science and Technology – Phase 2 (BiofuelsGS-2) is a post-graduate programme operated jointly by the four universities Chalmers University of Technology (CTU), Sweden, Technical University of Denmark (DTU), Denmark, Norwegian University of Science and Technology (NTNU), Norway, and Åbo Akademi University (ÅAU), Finland. BiofuelsGS-2 is a direct continuation to the former Nordic graduate school "biofuelsGS", which was established in 2003. BiofuelsGS-2 is funded by the Nordic Energy Research for the period of four years, starting the 1st of January 2007, ending the 31st of December 2010.

The members of the school board are Professors Bo Leckner (CTU), Kim Dam-Johansen (DTU), Johan Hustad (NTNU) and Mikko Hupa (ÅAU), who is also acting as chairman. The co-ordinator of the school is Dr. Bengt-Johan Skrifvars (ÅAU). The coordination office is located at Åbo Akademi University in Turku, Finland and the coordinating assistant is Mrs Anne-Leena Gröning (ÅAU). A team of three senior researchers is additionally tightly cooperating with the coordination to organize the program, planned to be performed in BiofuelsGS-2. The team consists of Dr. Flemming Frandsen (DTU), Dr. Henrik Thunman (CTU), and Dr. Øyvind Skreiberg (NTNU).

This 1st year's BiofuelsGS-2 annual report reviews the progress of and plans for students in the school. Some of them participated in the former school and have been accepted to the new school to finalize their studies. These students report their progress. The rest of the students are new doctoral students who have started their studies during 2007. These students report only their plans in this 1st annual book. Furthermore, the annual report provides general information about the BiofuelsGS-2 as well as of the participating universities.

We whish all students, supervisors and board members of the new BiofuelGS-2 a pleasant, intensive and fruitful collaboration during the coming active years of the school.

BiofuelsGS-2
Coordination Team

1. About BiofuelsGS-2

The goal of the new Graduate School, the BiofuelsGS-2, is to continue to raise the esteem and quality of the doctoral training within the Nordic universities in the area of biomass and waste conversion to fuels, heat and power. The graduate school aims also at providing the basic scientific and technical knowledge to solve problems related to conversion of biofuels. This is achieved by collaboration in post-graduate course arrangements, shared student supervision by student and supervisor visits between the base universities, and intensive industry-academia networking.

The BiofuelsGS-2 will consist of 8 students (partly funded directly by the school, partly funded by other sources) and their supervisors. Also, additional students from the four partners are given the possibility to participate with funding from other sources.

The individual courses of the biofuelsGS are advertised broadly and are open to students in all Nordic universities.

In summary, the School activities include:

- Tailor-made study and research plans for all participating students, including study and research visits at other Nordic universities.
- Intensive courses organized directly by the school: 1 per year in key topics of biofuel conversion science and technology, provided by the senior researchers and professors within the participating universities or by invited lecturers from industry.
- Intensive courses organized by others: Additional 1-4 per year provided by cooperating partners to BiofuelsGS-2 such as the Danish Graduate School of Chemical Engineering, "Molecular Product and Process Technology (MP2T)", the Finnish Graduate School in

Chemical Engineering (GSCE) and the Swedish post-graduate training program CeCost.

- Annual seminars where the students present their work and discuss with each other.
- An Annual Book published at the annual seminars, consisting of progress reports by the students of the School.

2. Activities 2007

BiofuelsGS-2 was initiated the 1st of January 2007. A first steering group meeting was held the 22nd of Jan. during which it was cleared that BiofuelsGS-2 has received financing for a period of four years. The contractual negotiations were initiated immediately and by end of March all necessary contracts were accepted and signed.

The main activity during the first half year of the school has been to plan the program of the school and to appoint students to the school. 8 PhD students from the Nordic partner universities have been so far appointed. They present all their doctoral plans and progress in this book. The recruitment continues.

A web-site for BiofuelsGS-2 has been established; http://www.abo.fi/biofuelsGS-2. Through this site information about the program such as courses, meeting and seminars, is delivered. The site will also provide a description of the school and a presentation of the participants.

An important part of the activities in the school is the annual seminar of the school. In writing moment it seems that most of the participants in the school will join the coming 1st annual seminar, which will be held in the Turku region (Kimito) in Finland with ÅAU as host, the 26th – 28th of September.

Two courses are planned to be held in the fall of 2007. The first will be held in Turku, Finland at Åbo Akademi University the 22nd – 26th of October; ”Chemistry in combustion processes part II”. Registration is required before October 15.

The second course during the fall will be held in Gothenburg at Chalmers, the 19th – 23rd of November; ”Thermal conversion of solid biomass and wastes”. Registration is required before October 30.

2. Participating universities:

Åbo Akademi University (ÅAU), Finland

Process Chemistry Centre

The Process Chemistry Centre at Åbo Akademi (PCC) is a research centre active in the field of chemical engineering. It has four major focus areas of which one is combustion and materials chemistry research. The PCC was granted the status of "Center of Excellence" by the Academy of Finland the first time in the year 2000 and has renewed this status in 2006. The status of "Center of Excellence" will continue until 2011. The PCC studies physico-chemical processes at the molecular level in environments of industrial importance, in order to meet the needs of tomorrow's process and product development. This mission statement is realized in the combustion and materials chemistry research in two subdivided themes:

- Combustion
  - Modelling
  - Experimental
- Materials
  - Biomaterials
  - Conventional

Åbo Akademi University has been active in the area of combustion and materials chemistry since 1974. Work performed has included both basic research and trouble-shooting cases. At present some 40 people are actively involved in the combustion and materials chemistry research. 6 of these are post-doc level full time researchers. Presently there are 15 research projects dealing with various aspects of chemistry in combustion and/or gasification. In all, the PCC consists of some 130 researchers.

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Chalmers University of Technology (CTU), Sweden

Department of Energy and Environment

The department consists of several sections, among them a research group dealing with energy conversion. The research group which is of interest for the present activity, the division of Energy Conversion, works with combustion devices and conversion (drying, devolatilization, combustion and gasification) of solid fuels, biofuels and wastes with respect to efficiency, reliability and environmental performance. The combustion technologies of primary interest are fixed and fluidized bed. The department operates one of the largest research plants available in Europe (in the world, except China), a $12MW_{th}$ circulating fluidized bed boiler. The academic staff of the division of Energy Conversion consists of 3 professors, 3 associate professor, 1 assistant professor, lecturers and doctoral students.

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Technical University of Denmark (DTU), Denmark, Combustion and Harmful Emission Control (CHEC) Research Center

The CHEC (Combustion and Harmful Emission Control) Research Centre, at the Department of Chemical Engineering of the Technical University of Denmark, carries out research in fields related to chemical reaction engineering and combustion, focusing on high-temperature processes, formation and control of harmful emissions, and particle technology. CHEC has achieved international recognition through a combination of experimental techniques and modelling. Laboratory experiments provide detailed and accurate data on chemical and physical processes in the systems studied. The data is subsequently interpreted by mathematical modelling based on chemical kinetics, chemical reaction engineering, multi-phase and component thermodynamics, and fluid dynamics.

The CHEC laboratories are well equipped and include equipment for gas adsorption and mercury porosimetry, particle size distribution, simultaneous thermogravimetric and differential scanning calorimetric, Fourier transform IR, high-temperature light microscopy, and ash viscosity measurements. The laboratories also include a lab-scale wet flue gas desulphurization column, a SCR test-rig, and a number of reactors from lab to pilot-scale, used to characterize and investigate fixed-bed, entrained flow and fluid bed combustion processes, emissions, ash formation, deposition and corrosion.

The CHEC Research Centre has staff personnel of about 40, including 7 professors/associate professors, and about 20 PhD students.

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Norwegian University of Science and Technology (NTNU), Norway
Department of Energy and Process Engineering

The Department of Energy and Process Engineering has a total of 150 employees, including approximately 80 PhD students. We have an extensive contact net, and our Master students are employed by both industry and public administration. Our research is applied by offshore and onshore industry, by consulting companies, for energy advisory services, by engineering companies and public administration.

The Department of Energy and Process Engineering at the Norwegian University of Science and Technology is an international know-how organization. The Department aims at being a driving force within education and research comprising the total energy chain - from electricity/heat production to end-use in industry and buildings. Our activities include systems based both on natural gas and renewable energy. Pollution problems connected to the general environment and to the indoor/residential environment is an important part of this work. We also perform research on industrial process technology in a wider sense, including refining of Norwegian raw materials into superior and competitive products.

Our business concept is to develop and communicate knowledge, thus contributing to added value and improvement of society. Our target is to be a premise provider to the authorities and an innovation resource unit for the Norwegian industry within our fields of science. By ensuring that Norwegian industry and the public authorities have access to knowledge of a high international level, we contribute to the solution of important issues in the society.

The Department has four specialist groups:

- Thermal Energy
- Industrial Process Technology
- Energy and Indoor Environment
- Fluids Engineering

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4. Organisation of biofuelsGS

4.1 Board

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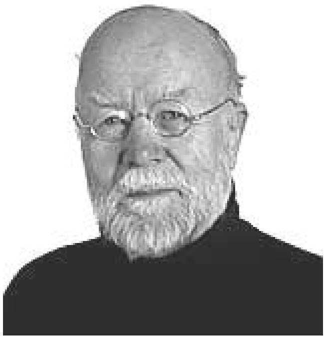
I am Professor in Inorganic Chemistry at the Åbo Akademi Process Chemistry Centre. My team's research activities deal with detailed laboratory studies and advanced modeling of the chemical aspects in various types of combustion systems, such as fluidized bed boilers, pulping industry spent liquor recovery boilers etc.
I also have an interest in ceramic materials for various applications. Since 2006 I am also the Dean of our Technical Faculty at Åbo Akademi.



Professor Bo Leckner

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I am professor in energy conversion technology at Chalmers University of Technology. I have mostly been working with questions related to combustion of solid fuels, combustion devices, and a number of different subjects ranging from reduction of emissions to heat and mass transfer. Much work has been connected to fluidized bed combustion.

Professor Kim Dam-Johansen

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Professor in Combustion and Chemical Reaction Engineering. Head of Department of Chemical Engineering, Technical University of Denmark, Director of the CHEC (Combustion and Harmful Emission Control) research centre dealing with:

- High-temperature processes
- The formation and control of harmful emissions
- Particle technology
- Chemical product design

Professor Johan E. Hustad
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My main research area is thermal conversion of solid, fluid and gaseous fuels to heat and electricity with focus on energy, economy, safety and the environment:

- Combustion and gasification technologies for biomass fuels and solid refuse-derived fuels in several different types of equipments.
- Combustion in diffusion flames, diluted flames, partially premixed flames and premixed combustion for boilers, Stirling Engines, gas turbines and in burners for off-gases from fuel cells (mainly catalytic burners).
- Fluidized bed technology
- Gas cleaning equipment
- Formation mechanisms for different pollutants in combustion
- Prediction, modelling and reduction of pollutants from several combustion technology processes both for land-based and off-shore plants and equipment.

4.2 Coordination

Associate Professor (docent)

Bengt-Johan Skrifvars

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I am an associate professor (docent) in inorganic chemistry in combustion processes at the Åbo Akademi Process Chemistry Centre. My main research activities deal with:

- Ash behaviour and corrosion in energy conversion systems
- Recovery boiler chemistry
- Trace elements emissions

I am also involved in teaching at the university and have the executing responsibility of the basic chemistry course given for all students doing chemistry related studies at the university.

MSc Anne-Leena Gröning

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Parallel to my studies in analytical chemistry at the Åbo Akademi University I worked in several projects connected to environmental analysis. Later I managed to graduate during the years I was at home with my children. After some years of laboratory work in the industry, because of some health problems and the fact that I wanted to have shorter workdays when my children started school, I found my way back to Åbo Akademi.

Today I take part in the administration of the laboratory of analytical chemistry and work as a coordination assistant in three ongoing international projects at the Åbo Akademi Process Chemistry Centre.

Associated Professor Flemming Frandsen

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I graduated as Chemical Engineer from the Department of Chemical Engineering, Technical University of Denmark (DTU), 1991, and received a PhD-degree from the same university on 'Trace Elements from Coal Combustion' in 1995. I have been and is currently involved in several national and international research projects on slagging, fouling and corrosion in utility boilers fired fully or partly by biomass (wood, straw, and others) and waste. I am co-founder of a Nordic Energy Research Program PhD short course on 'Ash and Trace Element Chemistry in Thermal Fuel Conversion Processes'.

List of expertise: Solid fuel ash characterization, biomass and waste, formation of fly ash and combustion aerosols, deposit formation, sintering and agglomeration, high-temperature corrosion, trace element transformations and emissions, deposition probe measurements, and analytical techniques.

Associate Professor Henrik Thunman

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My main research topic is modelling the conversion of solid fuels. However, I have also modelled black liquor conversion during my thesis work for the Master of Science degree in 1994. In 1995 I started to investigate the combustion of solid fuels in a fluidised bed combustor, with the main focus on the fragmentation and attrition processes. In 1997 I changed the direction of the research to combustion of biofuels in fixed beds, a work, which is still ongoing.

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I received my diploma as a mechanical engineer at the Norwegian Institute of Technology (NTH) in Trondheim in 1992, where I finished my PhD thesis on "Theoretical and experimental studies on emissions from wood combustion" in 1997. My work as Research Scientist at the Norwegian University of Science and Technology (NTNU, former NTH) changed in 1998 when I became a Nordic Senior Research Scientist within Nordic Energy Research, on Biomass Combustion. My working background deals with heat engineering and combustion in general, with special emphasis on biomass combustion. Main research topics are emission formation and reduction in combustion (NOx, N_2O, CO, hydrocarbons and particles). This includes both experimental work, from single wood particles to wood logs, and modelling work (empirical, chemical kinetics, CFD). Additionally, I am involved as a lecturer in several courses at NTNU. Furthermore, I am a member of the IEA Bioenergy Task 32 where I represent the Norwegian University of Science and Technology since 1998.

5. Participating student

Daniel Stanghelle

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Research TOPIC	**High temperature filtration**

MAIN SUBJECT	**High temperature filtration in biomass combustion and gasification processes**
SUPERVISORS	Prof. Johan Hustad Prof. Otto Sønju
M.Sc.	July 2004
DOCTORAL STUDIES	
Started	August 2004
To be completed	August 2008

High temperature filtration in biomass combustion and gasification processes

Daniel Stanghelle

Background

The utilization of fossil fuels such as coal, oil and gas are by far the largest contributors to global energy production. However, growing concern for the environment and security of supply have resulted in a renewed interest in utilization of renewable and domestic energy sources. Combustion or gasification of bio-fuels in advanced CHP plants represents an interesting and important alternative in this respect. The utilization of CO_2 neutral biomass fuels requires efficient systems to remove gaseous and particulate emissions.

The Panel Bed Filter (PBF) has the transient behavior of granular filtration and uses surface filtration for particle removal. The PBF is made up of louvered walls that carry and increase the surface (filtration) area of the granular particle bed. The PBF is also well suited for high temperature applications.

Objectives

- Investigate new ideas about louver design to increase the stability of the granular bed material and increase the filtration area.
- Laboratory and full-scale tests of high temperature granular bed filters.
- High temperature filtration study of biomass gasifier gas and the direct integration with SOFC.
- System integration of biomass gasification, high temperature cleaning (particles, sulphur) and power production (SOFC)

Method

Task 1. Build a laboratory scale PBF for continuing the research done by the department. Testing of a new louver design in co-operation with Dr. Squires of Virginia Polytechnic Institute and State University.

Task 2. Testing a PBF for cleaning the flue gas from a small biomass combustion plant in Hadeland, Norway.

Task 3. Continue the high temperature tests on gasifier gas with integration of H_2S removal in Güssing, Austria. The purposes of these tests are to run the gas cleaning smoothly within the premises of a fuel cell (SOFC).

Results:

- A laboratory scale PBF initial test module for a new louver geometry which contains trays has been built and tested with promising results.
- Initial high temperature particle filtration tests have been conducted and demonstrated with an efficiency above 99.9 % with a small PBF (0.5–2 Nm^3/hr) at the Güssing gasifier in Austria.
- The design and building of an up-scaled PBF (20 Nm^3/hr) have been completed. The up-scaled PBF has been tested with good results on the producer gas from the Güssing gasifier.
- A system for cleaning the producer gas at high temperatures and integrating a SOFC has been built and tested in the university laboratory.
- An industrial size PBF filter has been built and installed at Hadeland, Norway. The PBF will remove particles from a biomass boiler for district heating.

Schedule:

Fall 2007

- Filtration with a complete PBF system in Hadeland.
- Laboratory tests with new louver design.
- Contributing to the complete system tests of the BioSOFC system in Austria

Spring 2008

- Writing the thesis

International co-operation in addition to BiofuelGS:

- Dr. Squires, Department of Chemical Engineering, Virginia Polytechnic Institute and State University, USA.
- Technical University of Vienna, Austria.
- Biomasse Kraftwerk Gűssing, Austria.

Articles and Presentations:

- J.E Hustad, Ø. Skreiberg, T. Slungaard, D. Stanghelle, A. Norheim, O.K. Sønju, H. Hofbauer, R. Reich, A. Grausam, A. Vik, I. Wærnhus, J. Byrknes: "BIOSOFC _Technology Development for Integrated SOFC, Biomass Gasification and High Temperature Gas Cleaning – Achievements" (2005) The 14th European Biomass Conference and Exhibition, Paris.
- D. Stanghelle, T, Slungaard and O.Sønju: "Granular bed filtration of high temperature biomass gasification gas" (2007) Journal of Hazardous Materials, Vol 144, pp 668-672

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Research TOPIC	**Wood-pellets based heating centrals**

MAIN SUBJECT	**Improvement in running and maintenance cost of wood-pellets based heating centrals.**
SUPERVISORS	Prof. Johan Hustad
M.Sc.	Cand. Agric. 1996
DOCTORAL STUDIES	
Started	autumn 2006
To be completed	2010

The Ph.D. studies are done in part time combined with a profession as a marketing manager of Bioenergy in Statoil Norge AS.

The studies are financed by Statoil Norge AS.

Improvement in running and maintenance cost of wood-pellets based heating centrals.

Geir Skjevrak

Background

Utilisation of bioenergy for heating purposes (not transportation) is increasing in Norway, opposite to traditional use which only has been wood industry, large district heating and heating stoves in households. Nevertheless the government goals are larger, 4 TWh growth in water based heating (mainly bioenergy) before 2010 (NOU 1998:11).

The refining degree woodpellets have achieved a certain level of utilization in Norway with a use of approximately 45 000 tons per year. This is distributed between approximately 5500 units of pellets stoves and 100 medium size heating centrals (below 3 MW). Complement to this is existent woodchips based heating centrals which also can use woodpellets.

Woodpellets are seen as a necessary degree of refined biomass to reach conversion goals from small- and medium size users of oil and electricity in the stationary sector/heating purposes.

The benefits of wood-pellets, which are important when use in new areas are to be made, are as follows:

- a relatively homogenius fuel
- an easy fuel to trade
- quality standards is established
- very high energy content regarded to volume
- Transportation and handling is done in closed systems with pressure air.
- Wood-pellets is dry, and problems with fungus, air quality in storage-rooms and freezed material is non-existing.
- An easy fuel should increase the possibilities to increase both environmental and economic prestations regarding all convertion technologies.

Woodpellets and biomass in general compete mostly against electricity and to some extent heating oil.

Therefore end-user comfort and perspectives is important to increase use in Norway. Since Norway is a country with a large lack of water-based heating systems, maintenance personell is not used to both boilers and these heating systems. In addition, many installations is using wood-pellets, but the boilers is designed for wet wood-chips with a weak running prestations as a result.

In a holistic view, introduction is not only a technical challenge but also include the operators capability and willingness to use bioenergy.

Objectives

- Investigate the system fuel-heating central- personel introduction and point out potentials for improvement
- What properties should wood-pellets heating plants have to credit a standardized fuel as wood-pellets with higher reliability and lower running costs?
- Investigate and make developments to increase low output and on/off running conditions
- Build and do full scale tests of new concept boiler.

Method

Task 1. Through the discipline systems engineering and a questionnaire investigate the system fuel-heating central-personel and point out potentials for improvement in the whole system.

Task 2. Preliminary: Literature and market study of accessable technology. Development of improvements in cooperation with a technology manufacturer.

Task 3. Preliminary: Build and test of improved concept boiler.

Publications and presentations

Presentations of task 1 is planned to the INCOSE 2008 conference in june. www.incose.org/symp2008

No further presentations is planned at this time.

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TOPIC	**Ablative Flash Pyrolysis of Straw**

MAIN SUBJECT	**Flash Pyrolysis of Straw in Situ**
SUPERVISORS	Prof. K. Dam-Johansen Ass. Prof. Peter A. Jensen
M.Sc.	09/1998
DOCTORAL STUDIES	
Started	08/2004
To be completed	02/2008

Ablative Flash Pyrolysis of Straw

Niels Bech

Background

For a number of years straw has been combusted in biomass boilers. This practice has attracted attention to the number of weaknesses that follow the use of straw as a solid-fuel substitute, especially in the areas of transport, storage, combustion technology, and disposal of ash. Flash pyrolysis represents a technology capable of rectifying or eliminating these shortcomings, and thereby facilitate the increased use of a local CO_2-neutral energy source.

Until now, commercial application of pyrolysis technology has been envisioned as a grid of local pyrolyzer stations with a potential biomass supply area within a 25 km radius. This arrangement will result in a substantial reduction of the potential benefits associated with pyrolysis: Straw still has to be baled and transported to the station, where it must be stored before consumption, and the ash fraction must be disposed off. The economical result is that the difficulties associated with combustion are solved, but the price paid is most likely too high to justify the complication of the added processing step.

This conventional line of thought is anticipated, considering the nature of the known reactor designs, e.g. various fluid bed configurations, transported beds and ablative reactors. These designs either employ a voluminous reactor, or require extensive secondary equipment such as sand conveyors or blowers for fluidization or in-bed char combustion.

In contrast to a stationary pyrolyzer station, a compact agricultural tractor-powered pyrolysis machine, which could be transported between fields on public road, will posses all the potential benefits of the technology. In addition to solving the difficulties associated with straw combustion, there would be no need for baling, and the handling of a liquid would be considerably easier. In addition, the volumetric transport is reduced by 90% and ash could be distributed directly on the field.

The key to a cost-effective mobile flash pyrolysis process of sufficient capacity (say 10,000 kg h^{-1}) is the reactor design. In order to optimize the reactor design, extensive knowledge regarding the complex series of reactions represented by flash pyrolysis is needed. Until recently publicized material on the subject has been scarce, and engineering of pilot plants based on semi-empirical methods or known reactor configurations, not necessarily representing the most advantageous for this application.

For this project, a scientific approach is applied to generate a process design, which through its efficiency could establish straw flash pyrolysis commercially, and thereby enhance utilization of available CO2 neutral energy resources without political intervention of subsidization.

Objectives

I. Identification of suitable reactor technology for mobile operation

II. Construction and operation of a stationary pilot plant

III. Tar combustion trial and business plan development

Method

Task 1. Development of a mathematical model for prediction of the influence of various operating parameters on yield of principal fractions, combined with lab-scale experiments to test two selected reactor configurations. Based on the results of the theoretical and experimental work, the most suitable reactor technology is chosen for further development.

Task 2. Following engineering of the selected reactor technology, a pilot plant is constructed. Operation in bench plant-size will provide valuable operational experience, along with samples of pyrolysis tar.

Task 3. Pyrolysis tar obtained from the bench reactor runs is tested in boiler, and compared to other sources of pyrolysis tar and to conventional heavy fuels. Engineering data for full scale plant and compilation of a business plan are the final results.

Articles and Presentations

Bech, N. In-Situ Flash Pyrolysis of Straw. In: Dam-Johansen, K., Skjøth-Rasmussen, M. (eds.), M.S. Graduate Schools Yearbook 2004, Dept. of Chemical Engineering, DTU, Kgs. Lyngby, 2004, pp. 13-14.

Bech, N. In-Situ Flash Pyrolysis of Straw. In: Dam-Johansen, K., Bøjer, M. (eds.), M.S. Graduate Schools Yearbook 2005, Dept. of Chemical Engineering, DTU, Kgs. Lyngby, 2005, pp. 5-8.

Bech, N., Jensen, P.A., Dam-Johansen, K. Ablative Flash Pyrolysis of Straw and Wood: Bench-Scale Results. Proc 15th European Biomass Conference and Exhibition, Berlin, 7-11 May, 2007 (in press).

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Research TOPIC	**Application of fly ash from solid fuel combustion in concrete**

MAIN SUBJECT	
SUPERVISORS	**Anker Jensen, Kim Dam-Johansen**
M.Sc.	**July 2004**
DOCTORAL STUDIES	**Ph.D.**
Started	**09/2004**
To be completed	**11/2007**

Application of fly ash from solid fuel combustion in concrete

Kim Hougaard Pedersen

Background

Combustion of coal and biomass in the production of electricity generates large amounts of solid materials such as fly ash. The demand for clean and cost effective power generation has increased the motivation for fly ash recycling and today the primary utilization of fly ash is in the concrete manufacture, where it serves as partial replacement for cement.

A high resistance toward freezing and thawing conditions is an important property of concrete in certain areas. This is achieved by having air entrained into the concrete and the amount is controlled by adding special surfactants known as air entraining admixtures (AEAs). These surfactants adsorb strongly to the air-water interface, thus stabilizing the air in the concrete paste.

Utilization of fly ash in concrete is observed to interfere with the air entrainment. Instead of the AEAs being collected at the air-water interface, they are adsorbed by the fly ash and this leads to a decrease in the amount of air entrained. This adsorption is caused by the residual carbon and not the mineral matter of the fly ash.

The regulations for fly ash application in concrete have so far focused on the amount of residual carbon in fly ash. However, in recent years this has shown to be an insufficient criterion for approval of a given fly ash as concrete additive, e.g. problems with air entrainment have been observed with fly ashes having levels of carbon below the limits. Thus, the adsorption of AEAs by the fly ash is not only related with its amount of residual carbon. Studies have shown that the properties such as accessible surface area and surface chemistry of the residual carbon play an important role in the adsorption of AEAs as well.

The worldwide introduction of improved burner technologies in order to reduce NO_x-emissions is believed to be one reason for the reduced fly ash quality. These burner technologies works with hot fuel rich zones to ensure that combustion is carried out under reducing conditions. The residual carbon in fly ashes produced at these combustion conditions is assumed to have a higher AEA adsorption capacity.

Objectives

The aim of this project is to obtain further knowledge of how combustion conditions of pulverized coal influences the fly ash quality for concrete utilization with emphasis on the air entrainment in concrete. Post treatment methods to improve the performance of fly ash in concrete will be investigated as well. Furthermore, since the laboratory test method for determine the fly ash adsorption capacity is not standardized and has a low reproducibility; steps will be taken toward the development of a standardized test method to replace this test.

Method

Task 1: Develop a method which can replace the commonly used laboratory test for determination of fly ash quality. The new test will be based on surface tension measurements on simulated concrete mixtures, where pure surfactants have been added instead of commercial AEAs. The present laboratory test used today is based on visual examination of foam stability and is highly influenced by the varying formulas of commercial AEAs. The new method will reduce the influence of these parameters

Task 2: Conduct combustion experiments with pulverized fuel on different kinds of experimental setups such as a swirl burner and an entrained flow reactor. Characterize the ashes with emphasis on parameters which are important for their performance in concrete. Evaluate the relationship between the combustion conditions and the quality of produced fly ash.

Task 3: Develop a method to post treat fly ash in order to lower the AEA adsorption of the residual carbon. The method will combine thermal and chemical treatment processes and will be evaluated on ashes produced from coal and biomass.

Task 4: Modelling of residual carbon properties during the combustion process of pulverized fuel with emphasis on adsorption of AEAs in concrete.

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TOPIC	**Fixed-bed combustion**

MAIN SUBJECT	**Modeling of combustion of biofuels in grate furnaces**
SUPERVISORS	Assistant Professor Henrik Thunman, Professor Filip Johnsson
M.Sc.	February 2004
DOCTORAL STUDIES	
Started	March 2004
To be completed	February 2009

Modeling of combustion of biofuels in grate furnaces

Sven Hermansson

Background

The use of biofuels for production of heat and power has because of different reasons increased during the last decades. One of the most frequently used techniques for conversion of biofuels into energy is combustion in grate furnaces. Grate furnaces are typically installed in small scale power plants, i.e. plants with production capacity under 20 MW_{th}, because of their benefit in simplicity concerning construction and control systems compared to e.g. fluidized bed boilers. In Sweden there exist around 150 grate furnaces for production of 5 MW_{th} and more, and many more at lower capacities.

The design of grate furnaces, especially the small scale ones, is much dependent upon practical experience. Creating combustion models, both for the conversion in the fuel bed and in the gaseous phase, could give the furnace developers a useful tool for improvement of not only the efficiency and emissions of the furnace but also increasing the flexibility in the use of fuels.

Today, Computational Fluid Dynamics (CFD) is often used when modeling grate furnaces. The most common path is to compute the conversion of the solid fuel in the fuel bed outside the CFD-calculation and link it as a boundary condition to the CFD-calculation of the gaseous phase. The present bed-combustion models that easily can be implemented into CFD-calculations of grate furnaces are very simplified. When visually studying the combustion in a grate furnace it can be seen that there exists a range of effects in the fuel bed that need to be taken into account to create a reliable model. Such effects are e.g. channeling inside the fuel bed and at the bounding walls which are suspected to cause elevated emission levels of harmful substances and increased ware on the grate material. To some extent the disturbances can be explained by insufficient fuel mixing across the grate and air maldistribution through the fuel bed, but there are still a range of uncertainties that need to be further investigated. Therefore it is seen as important to develop models for the combustion in the fuel bed that not only are easy to implicate into CFD-models but also describe the real combustion situation in grate furnaces, i.e. that includes and investigate the combustion disturbances that occur in the fuel bed.

Objectives

1. Development of a fixed-bed model that includes multidimensional combustion disturbances, and implementation into commercial CFD-software.
2. Investigation of solid-fuel movement in fixed beds during conversion.
3. Evaluation of the model with experiments performed by the Swedish National Testing and Research Institute (SP).

Method

1. Computational fluid dynamics in combination with own developed models of thermal conversion of solid fuel.
2. Performing a project, in cooperation with research institute or consultant company, for measurements in the fuel bed and possibly in a grate of a grate furnace.

Publications and Presentations:

1. Hermansson, S.: 'Disturbances in Fixed-Bed Combustion', *Thesis for Degree of Licentiate of Engineering*, Chalmers University of Technology, Göteborg, Sweden, 2007.
2. Hermansson, S., Brink, A. and Thunman, H.: 'Inhomogeneous flow conditions and bed collapse in fixed-bed combustion', *Internal report*, Chalmers University of Technology, Göteborg, Sweden, 2007
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TOPIC	**Oxy-fuel combustion**

MAIN SUBJECT	**Combustion characteristics of oxy-fuel flames – Experiments and modelling**
SUPERVISORS	Professor Filip Johnsson, Associate Professor Henrik Thunman
M.Sc.	February 2005
DOCTORAL STUDIES	
Started	May 2005
To be completed	May 2010

Combustion characteristics of oxy-fuel flames

– Experiments and modelling

Stefan Hjärtstam

Background

Carbon dioxide is the dominant greenhouse gas in terms of amount of gas emitted, and global warming as a consequence of CO_2 emissions is undoubtedly one of the most challenging environmental problems of our time. Capture and storage of CO_2 produced by combustion of fossil fuels have a significant potential to contribute to CO_2 reduction, allowing for a continuous use of fossil fuels as a bridge towards more sustainable energy systems (ultimately being non-fossil). If the fossil fuel is co-fired with biomass the contribution of the reduction could be even greater. Oxy-fuel combustion (also known as O_2/CO_2 combustion) is emerging as a possible carbon-capture technology, due to its comparatively favourable economics, and since it is more or less based on known technology. In oxy-fuel combustion, N_2 is separated from the air, and the fuel is burnt in a mixture of O_2 and recycled flue gas. The resulting high concentration of CO_2 in the flue gas enables direct CO_2 recovery. If a mixture of fossil fuel and biofuel is co-fired in a future oxy-fuel power plant, a negative (or zero) contribution of CO_2 to the atmosphere is possible, if the emitted CO_2 is captured and stored. Resent research has shown that the combustion properties of oxy-fuel flames differ from those of conventional air-firing. Computational fluid dynamics (CFD) are commonly used as a tool for the prediction of the behaviour of various combustion units. Due to the different oxidant composition of oxy-fuel combustion compared to air-fired units, more detailed experimental data are of interest to further develop the present CFD-tools to better predict oxy-fuel combustion environments.

Objectives

4. Investigate the influence for different O_2 fractions (recycle rates) in the feed gas during oxy-fuel combustion and compare the results with a reference air-fired case.
5. Examine the effects on the flame structure and the emissions that follow from changing the recycle rate in oxy-fuel combustion. With the aim to gain sufficient data for future modelling of oxy-fuel flames.
6. Evaluate the existing CFD-models ability to handle oxy-fuel combustion and suggest possible improvements.

Method

Task 1. Perform measurements of temperature and gas composition in Chalmers 100 kW combustion unit for different oxy-fuel cases, in terms of O_2 concentration in the feed gas, and compare the results with a reference air-fired case.

Task 2. Use Computational Fluid Dynamics to model the Chalmers 100 kW unit. Based on the experimental data and the theoretical calculations, suggest suitable improvements for modelling of oxy-fuel flames.

International co-operation

This work is primarily sponsored by EU within the RFCS programme in the OxyMod project (Contract RFCR-CT-2005-00006) and from EU within the 6th framework programme in the ENCAP project (Contract SES6-CT-2004-502666).

Schedule

2006-2007: Task 1.

2007-2008: Task 2

Publications and Presentations

6. Hjärtstam, S., Andersson, K., Johnsson, F.: "Combustion characteristics of lignite-fired oxy-fuel flames", The Proceedings of the 32nd International Technical Conference on Coal Utilization & Fuel Systems, Clearwater, Florida, USA, June 10-15, 2007.
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TOPIC	**A laboratory method for studying high temperature corrosion caused by alkali salts**

MAIN SUBJECT	**Inorganic Chemistry**
SUPERVISORS	Doc. Bengt-Johan Skrifvars Prof. Mikko Hupa
M.Sc.	February 2002
LICENCIATE STUDIES	
Started	February 2005
To be completed	September 2007

A laboratory method for studying high temperature corrosion caused by alkali salts

Micaela Westén-Karlsson

Background

Combustion of biomass fuels is not considered to contribute to the greenhouse effect, due to the natural conversion of CO_2. Furthermore the conversion of biomass fuels appears to be a most promising way of producing electricity.

The goal today is to increase the steam temperature in the biomass boilers even further than today. It is well known that corrosive ashes may from in combustion of biomass. These ashes travel with the flue gases up to the heat exchanger, thus decreasing the life span of the heat exchanger.

There exist many different mechanisms of corrosion. For example high temperature oxidation, molten phase corrosion and active oxidation with chlorine as catalyzer cause all corrosion. Usually the corrosion is a combination of these and other mechanisms. The effect of ash deposit is an important issue.

Objectives

- To evaluate the corrosion test method, developed at Åbo Akademi University
- To make a descriptive analysis of the mechanisms of the oxide layer formation from the results gained with the method

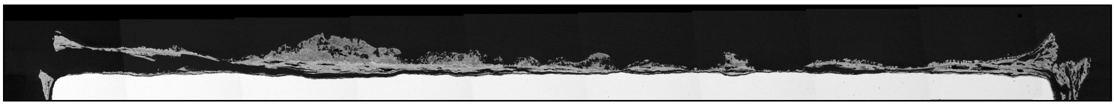
Method

The method used:

- Specific alloys are tested with synthetic ashes in a pipe oven in specific conditions (temperatures, atmospheres, times)

Here is one example how a sample looks after heat treatment for a week.

- The alloy is then cast in Epoxy, sawed (to get the cross section), polished and cleaned for SEM/EDXA.
- A panorama picture is taken during the SEM analyses. From the panorama one can get the amount of oxide layer formation.



Here is an example how a panorama picture looks like. The white is the metal and the gray layer on top on it is the oxide layer.

Progress:

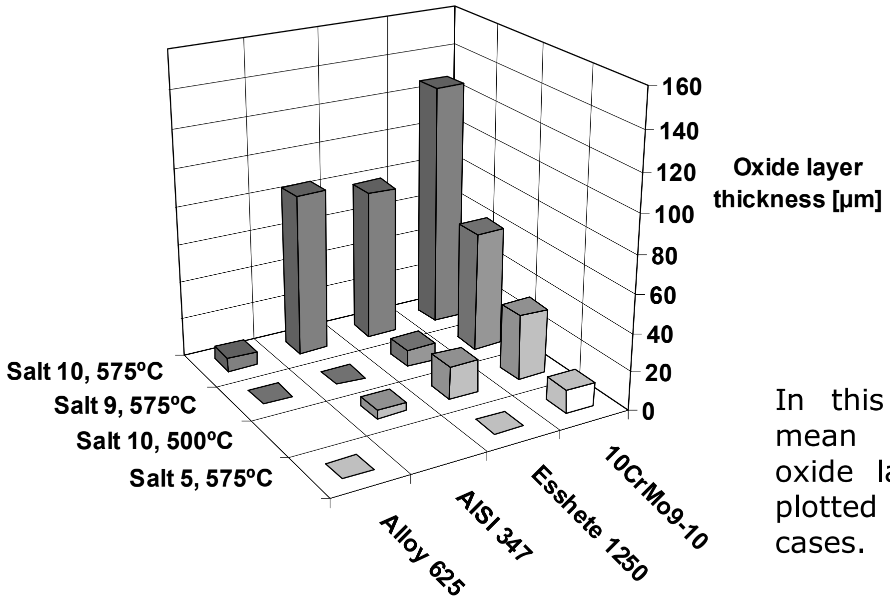
This method has shown to be very reproducible. The less porous the formed oxide layer is, the more accurate is the method.

12 Different cases have been examined. In the table below are the cases listed and in the figure below are the mean values of the oxide layer thicknesses plotted in the figure. As low alloyed steel is 10CrMo9-10 used, as austenitic steel are both Esshete 1250 and AISI 347 used, and as nickel based steel is Alloy 625 used. Salt 5, Na_2SO_4, is used as a reference salt, in salt 9 is some chlorine added to the Na_2SO_4. In salt 10 is some of the sodium in salt 9 replaced with potassium; therefore is the first melting temperature for the salt decreased.

In this comparison are we able to give a descriptive analysis of the mechanisms for chlorine induced oxide layer formation. By comparing salt 5 to salt 9 we are able to examine the effect of chlorine on the alloy. By comparing salt 9 to salt 10 in 575°C we are able to examine the role of potassium as well as the role of melt in the salt.

In this table are the different cases explained:

	Salt 5, 575°C Na_2SO_4	Salt 9, 575°C Na_2SO_4 + Cl	Salt 10, 500°C Na_2SO_4 + Cl + K	Salt 10, 575°C Melt Na_2SO_4 + Cl + K
Low alloyed steel	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Austenitic steel	**Case 5**	**Case 6**	**Case 7**	**Case 8**
Nickel based steel	**Case 9**	**Case 10**	**Case 11**	**Case 12**



In this figure are the mean values for the oxide layer thicknesses plotted for the different cases.

Publications and presentations:

- M. Westén-Karlsson, L. Silvander, B-J. Skrifvars and M. Hupa: "A laboratory method for studying high temperature corrosion", presented at the conference Impact of Fuel Quality on Power Production, Snowbird, Utah 2006.

The Licenciate Thesis have been submitted September 2007

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TOPIC	**CFD based modeling of black liquor char beds**

MAIN SUBJECT	**Inorganic Chemistry**
SUPERVISORS	Doc. Christian Mueller Prof. Mikko Hupa
M.Sc.	June 2005
DOCTORAL STUDIES	
Started	January 2006
To be completed	January 2010

CFD based modeling of black liquor recovery boiler char beds

Markus Engblom

Background

With the development of more sophisticated models, CFD is today considered a valuable research and engineering tool for studying industrial scale combustion processes.

The increase in the unit size of black liquor recovery boilers is largely contributed to better understanding of the furnace processes. CFD has played a central role in this development.

Black liquor combustion modeling requires sub-models for droplet conversion, gas phase combustion and char bed combustion. Although the char bed models have become more detailed and refined, the shape of the char bed has been presumed in these models. Observations from real furnaces show the char bed shape not to be constant. Instead, the shape is dynamic and needs to be monitored and controlled. The presumed bed shape has been sufficient for overall numerical studies of black liquor combustion, but for more detailed studies of the lower furnace processes, and especially the char bed processes, the bed shape should be determined by the combustion process.

Objective

To continue development of a char bed model to include shape predicting capability, by

- Developing a model for describing change in bed shape during simulation
- Identifying and including relevant physical and chemical bed shape influencing mechanisms in the model

- Validating model by comparing to observations from real furnaces

Method

- Utilizing commercial CFD software
- Developing necessary sub-models
- Comparison of simulation results against observations from real furnaces

Progress

- A model has been developed to calculate the bed shape as function of time.
- Bed shape is currently calculated based on carbon accumulation and a maximum allowed steepness of the bed.

The carbon accumulation in bed is calculated using a char bed model originally implemented for use in a CFD program by Bergroth et al[1]. Carbon accumulation is calculated as the difference between carbon arriving with the droplets to the bed and carbon converted by char bed burning.

Break down of a mound-like bed structure and consequent redistribution of bed material has been observed in video images. Based on this observation, a model has been developed describing maximum allowed steepness, i.e., angle of repose, of the bed. Bed material is redistributed such that the maximum allowed steepness is not exceeded.

A simulation result using the bed shape calculation model is shown in Figure 1.

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[1] BERGROTH, N., MUELLER, C., HUPA, M., "CFD Based Modeling of Recovery Boiler Char Beds", International Chemical Recovery Conference, 915-930 (2004)

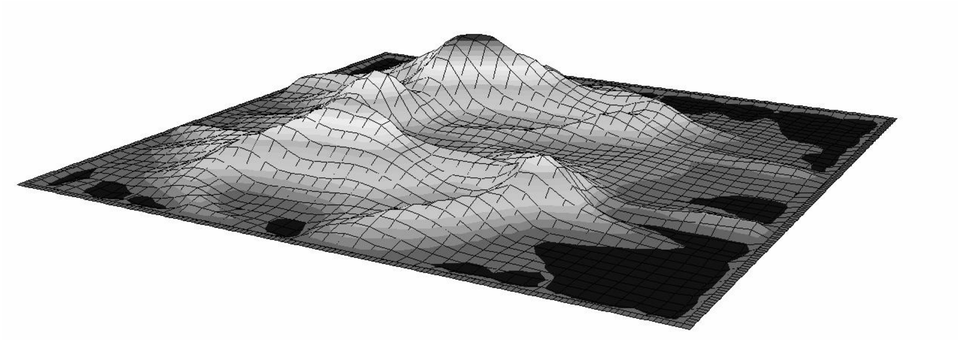

Figure 1. Example of calculated bed shape. Horizontal bed dimensions: 12 x 12 m^2. Maximum bed height 1.7 m.

International co-operation in addition to BiofuelsGS-2

- Andrew Jones, International Paper
- Industrial partners Andritz Oy, Foster Wheeler Energia Oy, International Paper, Metso Power Oy, Oy Metsä-Botnia Ab and Vattenfall Utveckling AB

Presentations

Markus Engblom*, Christian Mueller*, Anders Brink*, Mikko Hupa*, Andrew Jones** "Towards predicting the char bed shape in kraft recovery boilers", International Chemical Recovery Conference 2007

* Process Chemistry Centre
Åbo Akademi University
Combustion and Materials Chemistry

** Energy and Chemical Recovery Solutions
International Paper

List of associated graduate schools

Graduate School in Chemical Engineering (GSCE)

http://www.abo.fi/gsce

Graduate School of Materials Research (GSMR)

http://www.abo.fi/%7emhotokka/gsmr/gsmr.htm

Graduate School for Energy Science and Technology

http://www.tkk.fi/Units/Energy/suomi/tutkijakoulu.html

The Centre for Combustion Science and Technology

http://www.cecost.lth.se

Graduate School in Chemical Engineering, Molecular Product and Process Technology (MP_2T)

http://www.kt.dtu.dk/Forskning/MP2T