BiofuelsGS-2

norden

Nordic Energy Research

Annual Report 2007-2008

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

Edited by Anne-Leena Gröning

Inquiries:

Anne-Leena Gröning
Phone: +358 2 215 4989
E-mail: anne-leena.groning@abo.fi

Cover design and layout: Anne-Leena Gröning
ISSN 1459-6407
Karhukopio Oy

Table of Contents

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. Maria Zevenhoven (ÅAU). The coordination office is located at Åbo Akademi University in Turku, Finland and the coordinating assistant is MSc 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 2007-2008 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 end of 2007 and in 2008. These students report only their plans in this annual book. Furthermore, the annual report provides general information about the BiofuelsGS-2 as well as of the participating universities.

We wish 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 2007-2008

The Biofuels GS-2 was initiated the 1st of January 2007. During the second half of 2007 and the beginning of 2008 7 more students were appointed in or connected to the school. At the moment of writing the school counts 15 participating students.

The website was updated and can now be found on: http://web.abo.fi/instut/biofuelsGS-2/New%20web/index.html.
Through this site information about the program such as courses, meetings and seminars is delivered. The site also provides a description of the school and a list of contact addresses of all participants.
Also two newsletters were sent to participants and their supervisors.

Two courses were held during the fall of 2007. The first was held in Turku, Finland at Åbo Akademi University the 22nd-26th of October; "Chemistry in combustion processes part II".
The second was held in Gothenburg at Chalmers University of Technology the 19th-23rd of November, "Thermal conversion of solid biomass and wastes".

We are also pleased to tell that students from the earlier BiofuelsGS and from this present school have achieved their academic goals.
From CTH, David Pallarès, has defended his doctoral thesis within the subject;
Fluidized bed combustion - modeling and mixing

From ÅAU, Daniel Lindberg, has defended his doctoral thesis within the subject;
Thermochemistry and melting properties of inorganic alkali compounds in black liquor conversion processes

From DTU, Niels Bech, has defended his doctoral thesis within the subject;
In situ flash pyrolysis of straw

From NTNU, Michaël Becidan, has defended his doctoral thesis within the subject;
MSW/ Biomass devolatilisation/pyrolysis with emphasis on NOx precursors, product distribution, gas composition and weight loss

During 2008 the following students from Åbo Akademi finalized their licentiate theses with the following topics;
Tor Laurén:
Methods and Instruments for Characterizing Deposit Buildup on Heat Exchangers in Combustion Plants

Micaela Westén-Karlsson;
Assessment of a Laboratory Method for Studying High Temperature Corrosion Caused by Alkali Salts

In the autumn of 2008 the following students will defend their doctoral thesis;
From
NTNU, Daniel Stanghelle
CTH, Robert Johansson
DTU, Kim Hougaard Pedersen

One student took the opportunity to visit a partner laboratory. Sven Hermansson (CTH) spent three months in Åbo Akademi in the autumn of 2007.

An important part of the activities in the school is the annual seminar. In 2007 this seminar was held in Kimito in Finland with ÅAU as host, the 26th-28th September. Almost all students and supervisors attending the school were present.

Visit to the Viking village during the seminar in Kimito.

In the autumn of 2008 CTH will be host of the annual seminar that will be held 14th-16th September in Visby, Sweden.

In the spring of 2008 preparations started for the course in "Analytical techniques in combustion". All participating universities will take part in teaching. The first part will take place in Gothenburg, 20th-24th October.

The coordination of the graduate school was led by Doc. Bengt-Johan Skrifvars until October 2007 when Dr. Tech. Maria Zevenhoven took over.

3. 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.

Address: Åbo Akademi University

Process Chemistry Centre

Biskopsgatan 8

FI-20500 Åbo

Finland

Phone: +358 (0) 2 215 31

Telefax: +358 (0) 2 215 4962

WWW: http://www.abo.fi/instut/pcc

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.

Address: Chalmers University of Technology

Department of Energy Conversion

Hörsalsvägen 7 (visiting address)
SE-412 96 Göteborg
Sweden

Phone: +46 (0) 31 772 1000 (Switchboard)

Telefax: +46 (0) 31 772 3592

WWW: http://www.entek.chalmers.se

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.

Address: Technical University of Denmark

Combustion and Harmful Emission Control

(CHEC) Research Centre,

Department of Chemical Engineering

Building 229, Søltofts Plads
DK-2800 Kgs. Lyngby

Denmark

Phone: +45 (0) 45 25 28 00

+45 (0) 45 25 29 57 (direct)

Telefax: +45 (0) 45 88 22 58

Email: chec@kt.dtu.dk

WWW: http://www.chec.kt.dtu.dk

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

Address: Norwegian University of Science and Technology
Department of Energy and Process Engineering
Kolbjørn Hejes vei 1B
NO - 7491 Trondheim
Norway

Phone: +47 (0) 73 59 38 60

Telefax: +47 (0) 73 59 38 59

WWW: http://www.ept.ntnu.no/

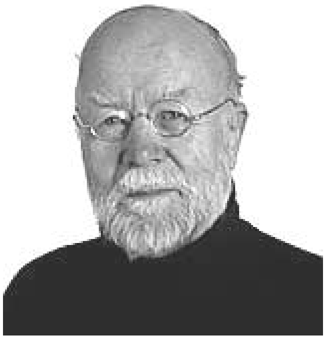
4. Organization of BiofuelsGS-2

4.1 Board

Professor Mikko Hupa
Åbo Akademi
Process Chemistry Centre
Biskopsgatan 8
FI-20500 Åbo
Finland

PHONE	**+358 (0) 2 215 4454**
FAX	**+358 (0) 2 215 4962**
E-MAIL	**mikko.hupa@abo.fi**

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

Department of Energy Conversion

Chalmers University of Technology

SE-412 96 Göteborg

Sweden

PHONE	**+46 (0) 31-772 1431**
FAX	**+46 (0) 31-772 3592**
E-MAIL	**ble@entek.chalmers.se**

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
Combustion and Harmful Emission Control
(CHEC) Research Centre
Technical University of Denmark
Department of Chemical Engineering
Building 229, Søltofts Plads
DK-2800 Kgs. Lyngby
Denmark

PHONE	**+45 (0) 4525 2845**
FAX	**+45 (0) 4588 2258**
E-MAIL	**kdj@kt.dtu.dk**

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
Department of Energy and Process Engineering
Norwegian University of Science and Technology
Kolbjørn Hejes vei 1B
NO-7491 Trondheim
Norway

PHONE	**+ 47 (0) 735 92513**
FAX	**+ 47 (0) 735 98390**
E-MAIL	**johan.e.hustad@ntnu.no**

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

Dr. Tech. (Chem. Eng.) Maria Zevenhoven

Åbo Akademi University
Process Chemistry Centre
Biskopsgatan 8
Fi-20500 Åbo, Finland

PHONE	**+358 2 215 4718**
FAX	**+358 2 215 4962**
E-MAIL	**maria.zevenhoven@abo.fi**

Besides acting as coordinator for the Nordic Graduate School of Biofuel Science and Technology, Biofuels 2, I am senior researcher in ash forming matter at the Åbo Akademi Process Chemistry Centre.

I wrote my PhD thesis on ash forming matter in biomass fuels in 2001 and since then I have been involved in different projects where ash forming matter, ash or heavy metals played an important role.

I am also involved in teaching at the university and coordinate the course Chemistry in Combustion processes-2

MSc Anne-Leena Gröning

Åbo Akademi University
Process Chemistry Centre
Biskopsgatan 8
FI-20500 Åbo
Finland

PHONE	**+358(0)2-2154989**
FAX	**+358(0)2-2154962**
E-MAIL	**anne-leena.groning@abo.fi**

Parallel to my studies in analytical chemistry at the Åbo Akademi University I worked in several projects connected to environmental analysis. 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
(CHEC) Research Centre
Technical University of Denmark
Department of Chemical Engineering
Building 229
Søltofts Plads
DK-2800 Kgs. Lyngby
Denmark

PHONE	**+45(0) 4525 2883**
FAX	**+45(0) 4588 2258**
E-MAIL	**ff@kt.dtu.dk**

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. Has 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. He is 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
Department of Energy Conversion
Chalmers University of Technology
SE-412 96 Göteborg
Sweden

PHONE **+46 (0) 31-7721451**
FAX **+46 (0) 31-7723592**
E-MAIL **heth@entek.chalmers.se**

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.

Dr. Øyvind Skreiberg

Department of Energy and Process Engineering

Norwegian University of Science and Technology

Kolbjørn Hejes vei 1B

NO-7491 Trondheim

Norway

PHONE	**+ 47 (0) 6926 1831**
FAX	**+ 47 (0) 9913 7857**
E-MAIL	**Oyvind.Skreiberg@ntnu.no**

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 students

Sven Hermansson

Chalmers University of Technology
Division of Energy Conversion
S-412 96 Göteborg, Sweden

PHONE	**+46 (0) 31 772 14 55**
FAX	**+46 (0) 31 772 35 92**
E-MAIL	**sven.hermansson@chalmers.se**

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. Analysis of fixed-bed combustion at different flow and porosity conditions.
3. Introducing theories of non-linear bed shrinkage and fuel flow due to conversion.

Method

Computational fluid dynamics in combination with existing models of thermal conversion of solid fuel and own theories of bed shrinkage and movements.

Publications and Presentations:

1. Hermansson, Sven; Brink, Anders; Thunman, Henrik: Structural collapses and inhomogeneous flow conditions in

fixed-bed combustion. Proceedings of the American-Japanese Flame Research Committees International Symposium.

2. Frigerio, Simone; Thunman, Henrik; Leckner, Bo; Hermansson, Sven: Estimation of gas phase mixing in packed beds. Combustion and Flame, 153 pp. 137-148.
3. Hermansson, S.: ‘Disturbances in Fixed-Bed Combustion’, *Thesis for Degree of Licentiate of Engineering*, Chalmers University of Technology, Göteborg, Sweden, 2007.
4. Hermansson, S., Olausson, C., Thunman, H., Rönnbäck, M., Leckner, B.: ‘Combustion Disturbances in the Fuel Bed of Grate Furnaces´, *Proceedings of the 7th European Conference on Industrial Furnaces and Boilers*, Porto, Portugal, 18-20 April 2006.
5. Ghirelli, L., Hermansson, S., Thunman, H., Leckner, B.: ‘Reactor residence time analysis with CFD’, *Progress In Computational Dynamics*, Vol. v 6, n 4-5, 2006, p 241-247.

Stefan Hjärtstam

Chalmers University of Technology
Department of Energy and Environment
S-412 96 Göteborg, Sweden

PHONE	**+46 (0) 31 772 14 42**
FAX	**+46 (0) 31 772 35 92**
E-MAIL	**stefan.hjartstam@chalmers.se**

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

2007-2008: Task 2.

2008-2009: 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.
7. Andersson, K., Johansson, R., Hjärtstam, S., Johnsson, F.: ”Radiation intensity of lignite-fired oxy-fuel flames”, Submitted for publication, 2007.

Fredrik Lind

Chalmers University of Technology
Division of Energy Conversion
S-412 96 Göteborg, Sweden

PHONE	**+46 (0) 31 772 52 43**
FAX	**+46 (0) 31 772 35 92**
E-MAIL	**fredrik.lind@chalmers.se**

TOPIC	**Gasification**

MAIN SUBJECT	Biomass gasification
SUPERVISORS	Associate Professor Henrik Thunman, Professor Filip Johnsson
M.Sc.	Finished during 2008
DOCTORAL STUDIES	
Started	To be started during 2008
To be completed	2013

Biomass gasification coupled to a boiler for district heat production

Fredrik Lind

Background

The use of biomass as a heat source is not a new concept; it has more likely been used as long as man has been able to tame fire. During the 19th and 20th century biomass was out of competition as a heat source in comparison to coal and oil. Today, when reduction of fossil carbon dioxide is of great importance, biomass has gained a new position as a carbon dioxide neutral fuel for heat and power production. Biomass can also be converted to a fuel for vehicles which enables the diffuse emissions of carbon dioxide from transport sectors to be reduced. One process that can be used is thermal gasification with fuel production. In the gasification operation 70 – 95 % of the dry biomass is devolatilised by heat to a synthesis gas.

In the fuel process the synthesis gas can be used either for production of synthetic natural gas or for the production of a liquid fuel such as methanol, dimethyl ether or Fischer-Tropsch diesel. The devolatilisation operation is endothermic and heat has to be transferred to the biomass. After the devolatilisation the char is remaining, which in turn can be used for heat production. This concept is used in the 2 – 4 MW_{fuel} gasifier at Chalmers University of Technology.

In December of 2007 the gasification unit was taken in operation. The gasification unit is coupled to a circulating fluidized bed boiler for district heat production. The gasifier has high flexibility to different types of biomass. A great advantage of this gasifier, in comparison with units for industrial purposes, is the possibility to supervise the processes with a lot of different parameters. At present the raw gas from the gasifier is transferred to the boiler where the gas is burned. The raw gas line is equipped with installations for gas removal from which gas samples can be taken out for analysis. The knowledge of the gas composition is of great importance for optimization of fuel production.

Objectives

Literature studies and development of an analysis system for the raw gas from the gasifier.

Method

1. Building up a gas analysis system by using chemical- and mechanical engineering. The system should include gas cooling and cleaning as well as the analysing equipment, for example gas chromatography.

Frida Claesson

University College of Borås
Allégatan 1
SE-501 90 Borås, Sweden

SP Technical Research Institute of Sweden
Box 857
SE-501 15 Borås, Sweden

PHONE	**+46 (0) 10 516 57 67**
FAX	**+46 (0) 33 13 19 79**
E-MAIL	**Frida.claesson@sp.se**

TOPIC	**Waste combustion**

MAIN SUBJECT	**Inorganic reactions in waste combustion**
SUPERVISORS	Docent Bengt-Johan Skrifvars, Docent Bengt-Åke Andersson Doktor AnnaLena Elled
M.Sc.	June 2007
DOCTORAL STUDIES	
Started	September 2007
To be completed	August 2012

Inorganic reactions in waste combustion

Frida Claesson

Background

Modern Energy-from-Waste (EfW) plants often combust several different waste fractions, including household waste and various fractions of industrial waste. Even though household waste is heterogeneous, it constitutes similar amounts and types of paper, plastics, metals etc. Industrial fractions originating from specific sources can, on the other hand, be rather homogenous although; there is a great variety of sources and the reciprocal variation is vast. Identifying the composition of the major fractions combusted in a plant can, together with an enhanced knowledge of the impact of joint fraction, facilitate proactive selection of fractions to be co-combusted and a raised possibility of limiting fouling, corrosion and agglomeration.

This project considers two cases; the fluidized-bed waste combustors in Borås and the grate furnaces burning waste at Renova in Göteborg. It concerns the characterization of the composition of the major waste fractions (in terms of yearly basis average values as well as seasonal fluctuations) and the impacts from selected components such as K and Na. Based on this information, thermodynamic equilibrium calculations will be performed to simulate the levels of certain inorganic combination. The specific inorganic combination that will be focused on depends on the fuel characteristics and the requirements of the involved companies. In-situ measurement of gases, deposits and particles in the gas suspension will thereafter be performed, together with chemical analysis of fuels, deposits, ashes and flue gases. This constitutes the verification data for the thermodynamic equilibrium calculations. The verification of the calculations indicates the degree of reliability of the simulations and is a key parameter. The simulations aim to evaluate the potential of adding different waste fractions or chemical elements in order to reduce the impact of certain challenging components, such as Na, K and Cl (parameter study). This will be compared to full-scale experiments in both the grate furnace and the fluidized bed furnace.

In brief: the project focuses on mapping of current waste compositions and generic understanding of the reactions of inorganic components occurring when firing different waste fuels in a power boiler. An underlying aim is to be able to follow and understand the pathway of the inorganic element through the boiler, *i.e.* from fuel composition, through evaporation and creation of aerosol to deposits and ash contents. Apart from thermodynamic equilibrium calculations, mass balances need to be formulated from the fuel characteristics as well as from the composition of the deposits and the ashes. Data generated from experiments in the waste combustors in Borås and Göteborg will be used as input to the mass balances. Such data includes information on operating conditions, fuel, deposits and ash composition as well as characterization of vaporized elements in the suspension and emissions. The scientific challenge of this project is to understand and predict the governing phenomena of fouling, corrosion and agglomeration. The industrial benefits are raised awareness of the fuel composition, which facilitates an active selection of co-combusted fractions and fault detection of sources to unwanted chemical elements. The effect targets are increased boiler availability, boiler efficiency and power production.

Objectives

7. Give enhanced cognizance on the composition and seasonal variation of waste fuels.
8. Give enhanced knowledge on inorganic reactions and inorganic element behaviour in waste combustion.
9. Knowledge on how to give less boiler shut downs and increase the boiler life time.
10. Reduce the annual maintenance cost.
11. Possibility to increase the steam temperature (50-100ºC).
12. Give raised possibilities of locating sources of unwanted waste fractions.

Method

1. Mapping of current waste composition for the fluidized bed in Borås and the grate furnace in Göteborg.
2. Thermodynamic equilibrium calculations of fuel components will be compared with In-situ measurements from the boilers.

Publications and Presentations:

Markus Engblom

Åbo Akademi
Biskopsgatan 8
20500-Åbo-Finland

PHONE	**+358 2 215 4036**
FAX	**+358 2 215 4962**
E-MAIL	**markus.engblom@abo.fi**

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, computational fluid dynamics (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 had 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. The presumed bed shape has been sufficient for overall numerical studies of black liquor combustion, but for more detailed studies of the char bed processes, the bed shape should be determined by the combustion process. Description of relevant physical and chemical bed processes is a requirement for a model to predict correctly the behavior of a char bed, including burning rates and shape.

Objective

To continue development of a char bed model by

- Developing a model for describing change in bed shape during simulation
- Identifying and including description of relevant physical and chemical char bed processes
- Validating model by comparing to observations from real furnaces
- Use of model to gain insight into char bed processes

Method

- Use of commercial CFD software
- Development of sub-models
- Comparison of simulation results against observations from real furnaces

Activities 2007-2008

- Studying the role of boundary layer processes in "gas-to-char bed" mass transfer

During kraft char bed burning, reaction with oxygen, carbon dioxide, water vapour and sulphate are generally considered the main char carbon conversion pathways.
Black liquor char bed burning was studied by Brown et al.[1]. The results showed that oxygen was consumed by char bed conversion products carbon monoxide and hydrogen in the boundary layer above the bed.
The observation from the experiments by Brown et al. can have implications for kraft char bed modeling. In order to gain more insight into the processes occurring in the boundary layer above the bed, the experiments have been simulated using CFD. Selected results are presented below. The simulation results are qualitatively in-line with the experimental ones and it is believed that the developed model can shed light on the importance of boundary layer reactions in modeling of industrial scale char bed burning.

[1] Brown, C.A., Grace, T.M., Lien, S.J., Clay, D.T., "Char bed burning rates – experimental results" International Chemical Recovery Conference 1989 proceedings, p. 65-74, 1989.

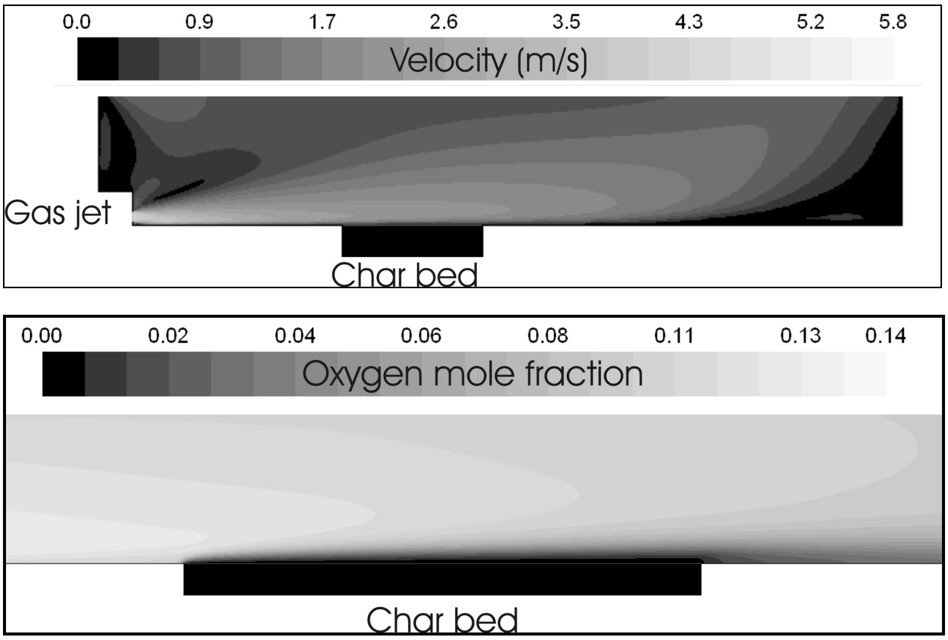


Figure 1. Simulated gas jet velocity (upper) and oxygen mole fraction (lower) over a char bed. The length of the char bed is 10 cm.

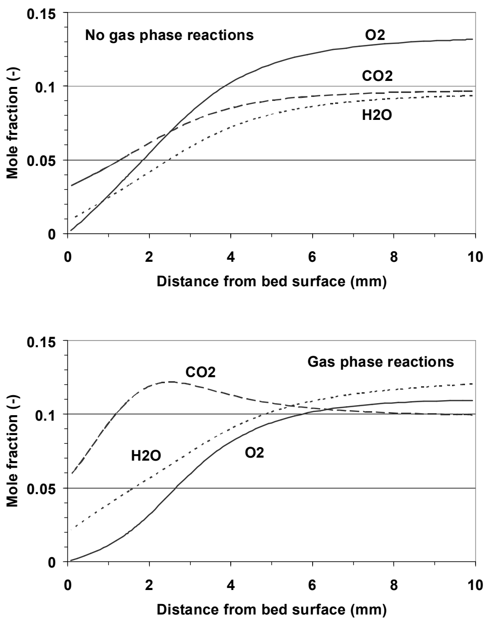


Figure 3. Influence of gas phase reactions on mole fraction profiles in the boundary layer above the bed.

International co-operation in addition to BiofuelsGS-2

- Andrew Jones, International Paper Inc.

Presentations and publications

1 Li, B., Brink, A., Engblom, M., Mueller, C., Hupa, M., Kankkunen, A., Miikkulainen, P., Fogelholm, C-J., "Spray models for CFD of black liquor recovery furnaces", 15th IFRF Members Conference, Pisa, Italy, 2007.

2 Engblom, M., Brink, A., "Influence of Stefan flow and boundary layer reactions on surface reaction rate", Nordic Section of the Combustion Institute - Biennial Meeting, Åbo, 2007.

3 Brink, A., Engblom, M., Hupa, M.,"Investigation of nitrogen oxide formation in a black liquor boiler using CFD combined with a detailed reaction mechanism", accepted for publication in TAPPI JOURNAL, 2008.

4 Engblom, M., Mueller, C., Brink, A., Hupa, M., Jones, A.,"Towards predicting the char bed shape in kraft recovery boilers", accepted for publication in TAPPI JOURNAL, 2008.

Oskar Karlström

Åbo Akademi University

Technical Faculty

20500 Turku, Finland

PHONE	**+358 (2) 215 4035**
FAX	**+358 (2) 215 4962**
E-MAIL	**oskar.karlstrom@abo.fi**

TOPIC	**Modeling biomass conversion**

MAIN SUBJECT	**Inorganic Chemistry**
SUPERVISORS	Dr. Anders Brink, Professor Mikko Hupa
M.Sc.	March 2008
DOCTORAL STUDIES	
Started	June 2008
To be completed	May 2012

Modeling Thermal Conversion of Biomass Particles – Determining Fuel Specific Parameters

Oskar Karlström

Background

Nowadays, thermal conversion of solid biomass for energy production is becoming more and more important. In e.g. Finland, 30 % of the total energy consumption is represented by biomass conversion. In EU, the energy production from solid biomass is expected to increase by 25 % between 2006 and 2010.

Optimizing and designing thermal conversion processes of solid biomass require understandings and descriptions of the conversion of single particles. The conversion steps of biomass are drying, pyrolysis and char conversion. The conversion steps occur in sequences for thermally small particles and models describing the conversion are generally fast and CFD-applicable. For thermally large particles the conversion steps somewhat overlap each other because of intra particle temperature gradients. The temperature distribution in thermally large particles needs to be significantly simplified to make single particle models CFD-applicable. Several CFD-applicable single particle models, both for thermally small and thermally large particles, have been reported and evaluated in literature.

Using single particle models for certain biomass materials require parameters describing the pyrolysis and the char conversion. In this field, a lot of works have been done for pulverized biomass fuels. Determining parameters for thermally large particles have mostly been done based on thermally small particles. In fact, very little work has been done on determining parameters based on thermally large biomass particles.

Objectives

Develop a simple and fast method that finds necessary information for modelling the thermal conversion of biomass.

Tasks

- Develop a routine for determining fuel specific parameters for modeling the conversion of a thermally large particle, with a CFD-applicable single particle model.
- Model the conversion of several different kinds of biomass materials in comparisons with experiments. Parameters will be determined with the developed routine (task 1.).
- Extract fuel specific parameters from existing data sets in cooperation with IFRF (International Flame Research Foundation). The database contains information of more than 50 different pulverized fuels that have been combusted in a drop-tube reactor. This work will also threat the possibility to use the data-base parameters for modeling thermally large particles.
- Model a real combustion case, based on the determined parameters, in CFD.

Johan Lindholm

Åbo Akademi University
Laboratory of Inorganic Chemistry
Biskopsgatan 8
FI-20500 Åbo, Finland

PHONE	**+358 (0) 2 215 4140**
FAX	**+358 (0) 2 215 4962**
E-MAIL	**johan.g.lindholm@abo.fi**

TOPIC	**Experimental testing of new flame retardants in polymers**

MAIN SUBJECT	**Inorganic chemistry**
SUPERVISORS	Dr Anders Brink, Professor Mikko Hupa
M.Sc.	March 2004
LICENTIATE STUDIES	
Started	January 2007
To be completed	December 2008

Experimental testing of new flame retardants in polymers

Johan Lindholm

Background

Flame retardants are additives in products to reduce the risk of fire. These additives inhibit and prevent fires in different ways. For our safety, the use of flame retardants has increased during the last decades to finally be present almost everywhere, from electronic equipment to furniture, and the need is growing. Halogenated flame retardants have been widely used because of their high efficiency and low cost. Recently it has been proven that several of the halogenated flame retardants are carcinogenic bio-accumulative substances, and have then been banned by the EU.

In Finland 40 900 tons of electronic waste were produced in 2006. One third of this was hazardous waste. This waste cannot be incinerated as municipal solid waste. It has to be handled with special treatment in order to recover the harmful chemicals. The decisions by the EU and these problems have forced the polymer industry to find new alternatives and develop environmentally friendly non-hazardous flame retardants. Regulations and laws on flame retardancy and allowed flame retardants can differ from one country to the other. The new EU legislation for Registration, Evaluation, and Authorization of Chemicals (REACH) requires industry to provide data to establish the safety of new and existing chemicals.

When developing efficient new environmentally friendly flame retardants testing is needed. Many countries have different testing standards. One of the aims of this work is to develop a useful toolbox for testing new flame retardants in polymers using different techniques. To do this existing equipment will be used and new equipment will be installed, tested and used.

Objectives

- To develop test methods for evaluating the flammability of polymers.
- To apply the methods to support the development of new fire retardants.
- To study the physico-chemical mechanisms responsible for the effects of fire retardants.

Methods

- UL 94 standard testing
- Cone Calorimeter
- Video combustion
- Pyro-GCMS
- DSC-TGA
- Hot stage microscope

Progress

A UL 94 testing device has been installed, tested and used successfully. Video combustion and thermogravimetric methods have also been used to test new flame retardants.

Publications and Presentations:

Johan Lindholm[1], Anders Brink[1], Mikko Hupa[1] and Mélanie Aubert[2], Carl-Eric Wilén[2]: "Reproducibility of the UL 94 flammability test of flame retarded polypropylene samples", The Scandinavian-Nordic Section of the Combustion Institute, Åbo 2007.

[1]Åbo Akademi Process Chemistry Centre, Biskopsgatan 8, FI-20500 Åbo, FINLAND
[2]Åbo Akademi University, Laboratory of Polymer Technology, Biskopsgatan 8, FI-20500 Åbo, FINLAND

Norazana binti Ibrahim

Technical University of Denmark
Department of Chemical and Biochemical Engineering
2800 Kgs.Lyngby, Denmark

PHONE	**+45 (0) 4525 2839**
FAX	**+46 (0) 4588 2258**
E-MAIL	**nbi@kt.dtu.dk**

TOPIC	**Flash Pyrolysis of Agricultural Residues for Bio-oil Production and Utilisation**

MAIN SUBJECT	**Flash Pyrolysis of Agricultural Residues for Bio-oil Production and Utilisation**
SUPERVISORS	Professor Kim Dam-Johansen Associate Professor Peter Arendt Jensen
DOCTORAL STUDIES	
Started	July 2007
To be completed	June 2010

Flash Pyrolysis of Agricultural Residues for Bio-oil Production and Utilisation

Norazana Ibrahim*, Peter Arendt Jensen, Kim Dam-Johansen

Combustion and Harmful Emission Control (CHEC), Department of Chemical and Biochemical Engineering,
Technical University of Denmark, DK-2800, Kgs. Lyngby, Denmark

Background

Renewable energy is of growing importance in satisfying environmental concerns over fossil fuel usage. Wood and other forms of biomass including agricultural wastes and energy crops are some of the main renewable energy resources available. Biomass is unique in providing the only renewable source of fixed carbon, which is a crucial ingredient in meeting many of our fuel and consumer goods requirements.

Bio-energy could provide a large part of the projected renewable energy provisions of the future. There are many ways of utilizing biomass, including thermal and biological conversion, of which pyrolysis, and particularly flash pyrolysis, forms the focus of this study.

Pyrolysis is a thermal conversion routes without oxidizing agent to recover energy from biomass whereby a liquid oil with a high energy density is provided. During pyrolysis, biomass is thermally decomposed to solid charcoal, liquid oil and gases. Lower process temperatures and longer vapour residence times favour the production of charcoal. High temperatures and longer residence times increase biomass conversion to gas, and moderate temperatures, high heating rates and short vapour residence times are optimal for producing liquids. The yields of the end products of pyrolysis are dependent on several parameters including temperature, biomass species, particle size, reactor condition, operating pressure and reactor configuration, as well as the possible extraneous addition of catalysts [1].

In flash pyrolysis, biomass decomposes to generate vapors, aerosols and some charcoal-like char. After rapid cooling and condensation of the vapors and aerosols, a dark red liquid is formed known as pyrolysis liquid or bio-oil that has a heating value of about half that of conventional fuel oil [2]. The process produce 50-75 wt % of liquid bio-oil, 15-25 wt % of solid char and 10-20 wt % of noncondensable gases, depending on the feedstock/biomass used [3 , 4].

Objectives

The main objective of this study is to optimize the flash pyrolysis process in order to produce bio-oil from different agricultural residues, waste water sludge and to investigate the storage, handling and combustion properties of bio-oils. A model to elucidate the connection between biomass structure and the bio-oil produced also will be developed.

Project Description

- Initially, a literature review covering the current status of the research in fields related to the project will be done. The major areas of the review will be: flash pyrolysis technology, operating conditions, structure and composition of the biomasses used, properties of pyrolysis oil, combustion behaviour of pyrolysis oil, pyrolysis oil stability and mathematical modelling of flash pyrolysis processes.
- The influence of pyrolysis conditions such as particle size of biomass, moisture content and operating temperature on pyrolysis products yields mainly bio-oil and its composition will be experimentally investigated. The agricultural residues such as wheat straw, rice husk, lignin residue and sludge will be used as feedstock. Parallel to the experimental work, a model will be developed to improve an understanding of the process.
- Storage stability: Pyrolysis liquids (bio-oils) exhibit considerable changes in their physical and chemical composition with time and

temperature. Since pyrolysis oils contain a large amount of functional group, polymerization and other reactions will take place during storage. These reactions will affect the viscosity, water content and molecular weight of bio-oils. Therefore, in this stage the effect of storage conditions on pyrolysis oil properties will be thoroughly investigated. In order to achieve this task, the pyrolysis oil will be stored systematically under different conditions and its physical-chemical properties will be monitored during storage.

- Combustion properties of pyrolysis oil: Testing the combustion of bio-oils taking account of the effect of atomization, ignition, coking tendency and exhaust emissions.

Method

In this work, a new reactor as shown in Figure 1 developed by Bech and co-workers [5] will be used. The biomass will be introduced by a screw feeder into a horizontal heated tube. Here, a three-blade rotor with close clearance to the reactor wall provides rotation of the gas phase and the biomass particles.

The residence time in the reactor for the evolved gasses is controlled by means of a recirculation compressor. Liquids are condensed by passing the gasses through a cooler tar/water condensation after the char particles have been removed in a catch pot and a cyclone. Aerosols are collected in a coalescer and removed by gravity. Before the gas is metered, it is cooled to ambient temperature in order to remove water. Gas for recirculation is preheated in order to avoid condensation of liquid products within the reactor.

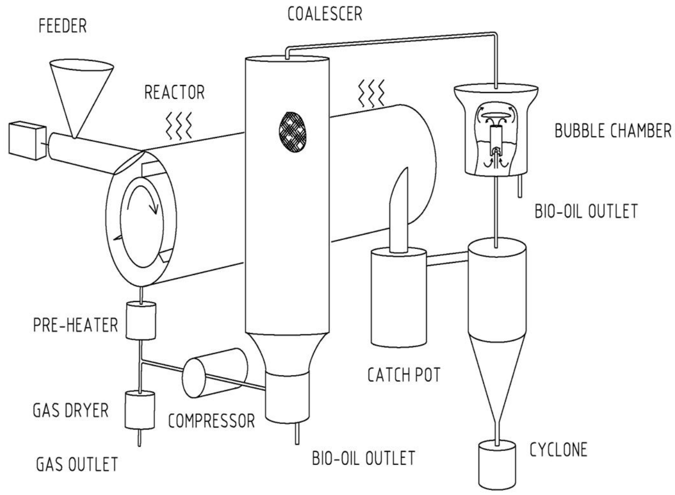


Figure 1: Schematic diagram of the developed ablative pyrolysis bench reactor system [5].

References

[1] Bridgwater, A.V. (1994). Catalysis in thermal biomass conversion. Applied Catalysis. A, General 116, 5–47.

[2] Bridgwater, A.V., and Peacocke, G.V.C. (2000). Fast pyrolysis process for biomass. Renewable & Sustainable Energy Reviews, 4, 1–73.

[3] Mohan, D., Charles, U., Pittman, J., and Philip, H.S. (2006). Pyrolysis of wood/biomass for bio-oil: Critical Review. Energy & Fuels, 20, 848–889.

[4] IEA - International Energy Agency (2006), www.ieabioenergy.com.

[5] Bech N, Jensen PA, 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).

Niels Bech

Technical University of Denmark
Department of Chemical Engineering
Building 228, Technical University of Denmark
2800 kgs. Lyngby
Denmark

PHONE	**+45 45252837**
FAX	**+45 45882258**
E-MAIL	**nsb@kt.dtu.dk**

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).

Bech, N., Dam-Johansen, K. A Method and a Mobile Unit for Collecting Biomass. PCT Patent application, submitted May 3, 2006.

Bech, N., Dam-Johansen, K, Jensen, P.A. Pyrolysis Method and Apparatus. PCT Patent application, submitted May 3, 2006.

Kim Hougaard Pedersen

CHEC Research Centre
Building 229/Office 122
Department of Chemical Engineering
Technical University of Denmark
DK-2800 Kgs. Lyngby, Denmark

PHONE	**+45 45252890**
FAX	**+45 45882258**
E-MAIL	**kvp@kt.dtu.dk**

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

MAIN SUBJECT	
SUPERVISORS	Professor Anker Jensen Professor Kim Dam-Johansen
M.Sc.	July 2004
DOCTORAL STUDIES	Ph.D.
Started	09/2004
To be completed	06/2008

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

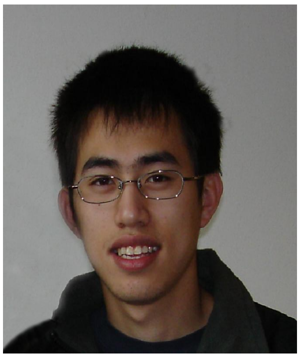
Task 2: Conduct combustion experiments with pulverized fuel on different kinds of experimental setups such as a swirl burner and an entrained flow reactor. Characterize the ashes with emphasis on parameters which are important for their performance in concrete. Evaluate the relationship between the combustion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

Publications

1. Pedersen, K.H., Andersen, S.I., Jensen, A.D. and Dam-Johansen, K.: Replacement of the foam index test with surface tension measurements, Cement and Concrete Research, Vol. 32 (2007), 996-1004.
2. Pedersen, K.H., Jensen, A.D., Skjøth-Rasmussen, M.S. and Dam-Johansen, K.: A review of the interference of carbon containing fly ash with air entrainment in concrete, Progress in Energy and Combustion Science, vol. 34 (2008), 135-154.



Hao Wu

Technical University of Denmark
Department of Chemical and Biochemical Engineering
2800 Kgs.Lyngby, Denmark

PHONE	**+45 (0) 4525 2927**
FAX	**+46 (0) 4588 2258**
E-MAIL	**haw@kt.dtu.dk**

TOPIC	**Co-combustion of fossil fuels and waste**

MAIN SUBJECT	**Co-combustion of coal and waste in pulverized coal-fired plant**
SUPERVISORS	Associate Professor Peter Glarborg Professor Kim Dam-Johansen Associate Professor Flemming J. Frandsen
M.Sc.	August 2007
DOCTORAL STUDIES	
Started	November 2007
To be completed	October 2010

Co-combustion of coal and waste in pulverized coal-fired plant

Hao Wu

Background

Co-combustion of coal and waste offers a short-term and low-cost opportunity to reduce the net CO_2-emissions from dedicated coal combustion, and at the same time to get rid of a certain amount of waste produced from industry, agriculture and household. In comparison with a conventional waste incineration plant, co-combustion of coal and waste in a pulverized coal-fired plant offers advantages such as improved electrical efficiency, increased waste disposal capability, and higher value of usable ash products. In Denmark, the Danish government launched in February 2008 a new long term energy plan in which co-combustion of coal and waste is pointed out to give an important contribution to reduce fossil fuel consumption.

In order to promote co-combustion of coal and waste in Denmark, there is a need to investigate and understand the impacts of the co-combustion process and related parameters (such as coal quality, waste type and quality, waste energy fraction, particle size and injection mode) to the fuel burnout, flame stability, deposit formation and corrosion, fly ash quality, gaseous emissions (such as NOx and SO2), and trace element partitions in industrial pulverized coal-fired plant. The results from the investigation will show whether co-combustion of coal and waste can be successfully performed in industrial pulverized coal-fired plants. In addition, the choice of waste materials and operational parameters will be optimized for the industrial co-combustion process, based on this project.

Objectives

- Identification of suitable waste types, energy fraction and particle size that can be co-combusted in pulverized coal-fired power stations
- Investigation of the influences of co-combustion on deposit formation, fly ash qualities, gaseous emissions, and trace element partitions
- Evaluation of the co-firing process through kinetic/equilibrium modelling

Method

- Performing co-firing experiment in laboratory-, pilot- and full-scale facilities
- Using global equilibrium model/reaction model to analyze the transformation of major inorganic elements and the partition of trace elements during co-combustion

Daniel Stanghelle

NTNU
Kolbjørn Hejes vei 1B
7491 Trondheim

PHONE	**+47 73592799**
FAX	**+47 73593859**
E-MAIL	**Daniel.Stanghelle@ntnu.no**

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	October 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

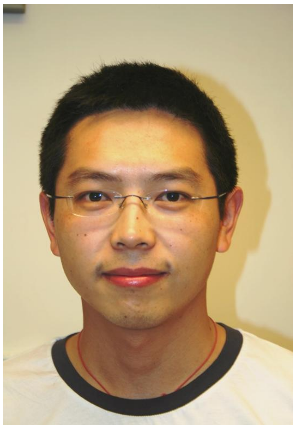
- Filtration with a complete PBF system in Hadeland.
- Laboratory tests with new louver design.
- Contributing to the complete system tests of the BioSOFC system in Austria

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

	**Liang Wang** **Norwegian University of Science and Technology** **Department of Energy and Process Technology** NO-7491 Trondheim, Norway
PHONE	**+47 73 59 31 61**
FAX	**+47 73 59 83 90**
E-MAIL	**liang.wang@ntnu.no**

TOPIC	**Ash related problems in biomass combustion and gasification**

MAIN SUBJECT	**Effect of additives in reducing fouling and corrosion in biomass combustion and gasification applications**
SUPERVISORS	Professor Johan E. Hustad
M.Sc.	August 2005
DOCTORAL STUDIES	
Started	September 2006
To be completed	December 2009

Effect of additives in reducing fouling and corrosion in biomass combustion and gasification applications

Liang Wang

Background

Biomass is a potentially CO2-neutral and renewable energy resource. As an alternative fuel, it has attracted much attention worldwide in the recent years. At present, biomass is converted into heat, electricity and liquid fuel most often by combustion and gasification. The most relevant issues of the biomass thermal utilization are problems related to the behavior of ash during biomass combustion and gasification, which include agglomeration, slagging, fouling and corrosion. As biomass fuels are ash rich in comparison to oil and natural gas, ash related problems have a strong impact on the lifetime, availability and operation of biomass combustion and gasification systems and consequently are of great economic and ecological relevance. Chlorine and alkali metals compounds present in biomass are very problematic, especially for the some herbaceous and agricultural waste fuels. The combination of alkali metals like potassium and sodium under combustion and gasification conditions leads to the production of gaseous and condensing potassium and sodium chloride that are troublesome for boiler operators. The ash originating from biomass has a lower melting temperature than of other fuels resulting in serious slagging and fouling of the installations. Moreover, the alkali metals compounds being extremely corrosives and deposit forming at combustion and gasification conditions create a great risk of failure, unexpected shut downs and costly repairs.

The existing uncertainties in the chemistry of reaction between the alkali metals (K and Na), S, Cl during the combustion process are main barriers for widespread introduction of high alkali like straw on the energy production market. Concerning the ash-related problems such slagging of furnace walls, fouling and increased corrosion of superheater tubes due to the chlorine rich deposit, addition of chemical material (additives) has been tested as the practical and cheap treatments to reduce the ash-related problem. Some different groups of additives such as the Kaolin, dolomite, have been identified are promising additives and used in full-scale investigation. A number of laboratory and full-scale investigations have revealed that alkali getter additives can be used to react with gaseous KCl, whereby the chlorine is released as HCl and the potassium incorporated into higher-melting temperature compounds. Thus, it is a possible method to use the alkali getter to reduce the extent of ash-related problems in the biomass-fired boilers. The use of commercially available additives products such as Kaolin, bentonite is often not financially attractive because of their relatively high costs. For this reason, it is interesting for power generators to search for alternatives to the commercial and effective products. On the other hand, there are few publications about the method for the estimation of the necessary amount of such additives, which can be used for the combustion of biomass fuels with greatly varying amount and composition of inorganic compounds, especially for the alkali metals contained in the biomass.

Finding the new attractive additives and clear quantitative information about the role of additives in the combustion and gasification process is first issue of the research. Furthermore, extensive research on alkali sequestering and alkali capture by additives will be carried out for some problematic biomass fuel with high fouling and corrosive tendency in terms of reaction mechanism and efficiency. For the pellets, the effects of organic binder and inorganic additives to the combustion and ash properties are also attractive issues to reduce the operation and maintenance costs and gain the overall availability of pellet combustion plants. The pellets with low fouling and corrosive tendency will be made based on the former research results by adding additives.

Objectives

- Investigation the effect of co-added additives on devolatilization, ignition and char reactivity properties of biomass particles with aim of characterizing the chemical and physical transformation during the combustion and gasification process.

- Characterization the ash behaviour of the biomass ash with addition of additives by analysis the chemical composition, mineralogical formation and morphological transformation.

- Studying the co-effect of organic binders and inorganic additives on the biomass pellet combustion.

Method

- Investigation the pyrolysis, gasification and combustion behavior of biomass samples with addition of inorganic materials by Simultaneous Thermogravimetric Analysis (TGA-SDTA) and Mass spectrometry (MS). Thermal events, products distribution and reactivity during the biomass heating process will be studied. The alkali chlorides and HCl in gas phase will be tested to evaluate the interaction between the additives and ash forming compounds in biomass.

- Char form the biomass and mixtures with additives will be investigated separately in terms of reactivity, chemical and physical transformation.

- Characterization the ash properties of the biomass ash with addition of additives. Ash fusion behavior will be tested by ash fusion analyzer to study the effect of additives on the biomass ash fusibility. The crystalline phase, chemical composition and morphology of the ashes that come from combustion and gasification of biomass with addition of additives will be analysised by different kinds of techniques: XRD, ICP-MS and SEM-EDX. The mechanism of the reaction between the additives and ash forming compounds will be studied and presented.

- Investigation the coactions of organic binders and inorganic materials on the biomass pellets by TGA, and ash analysis techniques.

Geir Skjevrak

NTNU / Statoil
Kolbjørn Hejes vei 1B
7491 TRONDHEIM

PHONE: **+ 47 957 44 766**
FAX: **+ 47 947 73 334**

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 used in new areas, are as follows:

- A relatively homogeneous fuel
- Easy fuel to trade
- Quality standards are established
- Very high energy content regarded to volume
- Transportation and handling is done in closed systems with pressure air.

- Wood-pellets are dry, and problems with fungus, air quality in storage-rooms and frozen material is non-existing.
- An easy fuel should increase the possibilities to increase both environmental and economic prestations regarding all conversion 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 personnel is not used to both boilers and these heating systems. In addition, many installations are using wood-pellets, but the boilers are designed for wet wood-chips with weak running prestations as a result.

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

Objectives

- Investigate the system fuel-heating central-personnel 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
- Due to lack of traditional raw materials for pellets productions, investigate new interesting ones like pine pulpwood with bark and lignin residues from 2G-ethanol

Method

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

Task 2. Production of wood-pellets from pine pulpwood with bark; fresh and 6 month aged. Fuel quality and combustion behaviour

Task 3. Production of wood-pellets from pine pulpwood with added pure lignin. Fuel quality and combustion behaviour.

Publications and presentations

Articles from task 1 and 2 are to be published in Biomass & Bioenergy journal.