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FiB
Bioenergy research



The CHEC Research Centre

At the CHEC Research Centre, which is located at the Department of Chemical Engineering at the Technical University of Denmark, more than 40 researches and students of ten different nationalities are working determinedly to improve the exploitation of biomass for energy purposes.

During the past 20 years, the researchers of the CHEC centre have been part of the international elite as regards more efficient and environmentally friendly exploitation of biofuels for energy production.

CHEC stands for Combustion and Harmful Emission Control, and the team of researchers represent a great asset for the part of Danish business working with industrial high temperature processes, reduction of harmful emissions, particle technology and product design.

Cooperation with the best international research communities and Danish business life is a matter of course, and the research centre has strong relations with Elsam, Energi E2, F.L. Smidth, B&W Energi, Babcock & Wilcox Vølund, Haldor Topsøe and Hempel among others. Furthermore, CHEC is an active partner of the Graduate School of Chemical Engineering, which is a cooperation between universities and business life. Internationally, the research centre is one of the initiators behind the Nordic Graduate School BiofuelsGS.

The systematic and determined process to establish the CHEC centre began in the mid-eighties. A vast amount of experiments and measurements have been carried out at laboratory, pilot and full scale. The experiments and measurements have taken place in close cooperation with a permanent group of engineers, who help ensure continuity and quality.

Over the past few years, considerable efforts have been made within research in thermal conversion of biomass for electricity and heat production. On the following pages, we focus on a series of research projects of the CHEC group.

Flue gas cleaning at biomass-fired power plants

Photo: Torben Skøtt/BioPress

Studies at the Studstrup plant have shown that flue gas cleaning with catalysts is just as effective when firing with straw and coal as when firing with coal alone.

Coal-fired power plants have good experience of using catalysts to clean flue gas of NO. This technique, however, cannot be transferred to plants that combust biomass alone, as the catalysts rapidly deactivate. At the CHEC centre, researchers are studying how the catalysts can be regenerated and how alternative flue gas cleaning methods can be applied.

Power plant boilers emit large amounts of nitrogen oxides. Since the mid-eighties, the authorities have continuously increased the requirements for power plant emissions of these substances, which has led to the development of new and efficient flue gas cleaning installations.

Coal-fired power plants use so-called SCR catalysts to clean the flue gas of nitrogen oxide. In essence, ammonia is added to the flue gas, whereby nitrogen oxide is converted into pure nitrogen, which is harmless and already present in large amounts in the air.

The power plants would like to use the same process to clean the flue gas from biomass-fired plants, but the catalyst rapidly becomes ineffective. This has been proved by a series of studies in Sweden and Denmark and may limit the use of biomass as fuel if the problem is not solved.

The CHEC Research Centre is involved in a series of projects to identify why the catalysts become ineffective, how they can be regenerated and how alternative catalysts can be developed. The projects are carried out in cooperation with companies such as Energi E2, Elsam and Haldor Topsøe and are co-funded by the EU and the PSO scheme.

The results of the projects are extensive and some of them will be briefly mentioned here. Laboratory testing has shown that potassium chloride and potassium sulphate from straw ash poison the SCR catalyst. In practice, these substances are present in the flue gas as small solid particles, the so-called aerosols.

To perform more realistic tests, pilot reactors have been built and commercial catalysts are subjected to different types of aerosols. When a catalyst is exposed to aerosols containing potassium, a rapid deactivation is seen, where the catalyst loses more than 70 per cent of its activity in only 2,000 hours. That is 10-20 times faster than in the case of coal-firing. It is possible to regenerate the catalyst by washing it with a mild acid, but the rapid deactivation means that in practice this solution can prove to be problematic.

In a parallel project, deactivation of catalysts in connection with coal-firing and combined coal- and straw-firing has been studied at the Studstrup plant for up to 5,000 hours. The results are promising, as no increase in deactivation in connection with coal/straw-firing has been noted compared to coal-firing. The reason is probably that potassium is bound in coal ash as alumino-silicates, which are not poisonous to the catalyst.

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The articles on page 1-5 have been written by the core of the CHEC research group, which consists of:

- Junior teacher Martin Skov Skjøth-Rasmussen
- Senior lecturer Peter Glarborg
- Senior lecturer Anker Jensen
- Senior lecturer Peter Arendt Jensen
- Senior lecturer Flemming Frandsen
- Senior lecturer Søren Kiil
- Engineering lecturer Jan E. Johnsson
- Professor Kim Dam-Johansen.

For further information about the group's work, see www.chec.kt.dtu.dk.

Potassium, sulphur and chlorine in straw-fired

Detailed studies of how potassium, chorine and sulphur react in a power plant boiler have improved the possibility to create a fuel that minimises the emission of sulphur from straw-fired power plants.

In comparison with coal, straw has a high content of potassium and chlorine. This is the reason for a series of the problems that can occur when straw is used for electricity and heat production.

Ash deriving from combustion of straw has a high content of potassium and chlorine, which may cause problems such as slagging, ash deposits, corrosion and particle emission of HCl and SO2. In comparison with coal-firing, however, the latter is a lesser problem, as the sulphur content of straw is lower than that of coal.

Via a PhD project, an EU-financed European cooperation and a close cooperation with Elsam, a detailed study of how potassium, chlorine and sulphur react during combustion of straw in a grate-fired power plant boiler has been carried out.

Photo: The CHEC Research Centre

CHEC engineers preparing measurements of the Avedøre plant's straw-fired boiler.

The project has provided basic knowledge of the liberation of different substances from the primary combustion zone. On the basis of this knowledge and a certain knowledge of the processes in the combustion chamber, it has become easier to create a fuel that minimises the emission of sulphur from straw-fired plants. Furthermore, the project has provided better possibilities to model when and where deposits will occur in straw-fired boilers.

The results of the project are based on detailed laboratory testing, which was succeeded by a series of tests at the Ensted plant near Aabenraa in September 2004. In the long term, the results will become part of a larger project (see the article below) which will establish a model of the combustion end deposit formation in biomass-fired boilers. ■

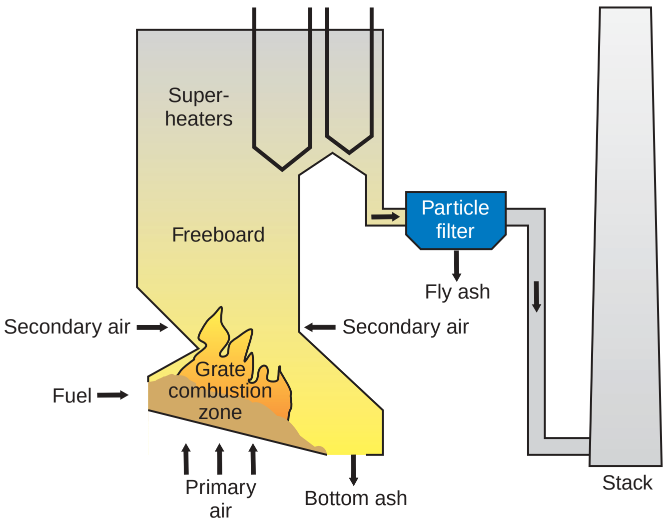
Joint project on grate-fired boilers

A joint project between universities and the industry will make it possible to establish a Danish model for design and optimisation of biomass-fired power plant boilers.

In Denmark, the most widespread technology for biomass-fired power plants is combustion on a grate. To better understand the chemical and physical processes of grate-firing, since 2000 the researchers of the CHEC centre have participated in the joint project; a large cooperation with participants from e.g. Aalborg University, the power plants and Babcock Wilcox Vølund A/S.

Through close cooperation between universities and the industry, the project aims at establishing Danish model competence for design and optimisation of grate-fired plants. One of the results is a so-called Computational Fluid Dynamics model, which describes the combustion on a grate and in the freeboard between the grate and the superheater tubes.

The project will lead to a better understanding of the processes that cause corrosion and deposits in power plant boilers and emissions of harmful substances such as nitrogen oxides, SO2 and HCl. In a current project, model calculations are compared to pilot and full-scale measurements carried out at the plants at Ensted and Avedøre. The projects have received considerable resources from the PSO scheme. ■



Outline of a grate-fired boiler, which is the most widespread technology for electricity production based on straw.

Computer tool for description of bioprocesses

Advanced computer programmes provide researchers with insight into the complicated flow conditions in power plant boilers, but the programmes can also be used to study gasification plants and processes for biodiesel production.

Photo: The CHEC Research Centre

The students' final projects often form part of the research projects.

Computational Fluid Dynamics, colloquially called CFD, is a complex computer tool to calculate the gas flows in a combustion chamber.

The researchers of the CHEC centre have not developed CFD programmes themselves, but for several years they have used commercial software to study processes - primarily concerning emissions. During the past few years, the work has been focused primarily on incorporating more chemistry in the models. This provides a better and more precise description of the primary combustion as well as the emissions from the boiler.

The computer tool still has great development potential, so that apart from giving an insight into the complicated flow conditions it will also become capable of contributing more detailed information about the combustion processes. Furthermore, the use of CFD is expected to become more widespread in future, so that the tool will also be used to study gasification plants, processes for biodiesel production and similar projects. In principle, all processes involving complex flow patterns can be described by means of the CFD tool.

Advanced measurements of power plant boilers

Advanced measuring equipment will supplement laboratory results with data from full-scale plants.

Photo: The CHEC Research Centre

Deposit measurements in a power plant boiler.

The researchers of the CHEC centre have always found it important to supplement laboratory and pilot scale testing with data from power plants operating at full scale. Measuring parameters such as temperature, gas composition and deposit formation in large boilers with limited access can be quite challenging though, and it has often been necessary to invent special probes for particular purposes.

An example of such equipment is probes used to study how deposits are formed in a biofuel-fired power plant boiler. The probes consist of a steel tube, in which a constant surface temperature of e.g. 500 °C is sustained by means of compressed air and water. This simulates a traditional superheater boiler tube cooled by means of steam. After the deposits have been taken out of the combustion chamber, they are weighed, and the chemical compositions of the different layers are analysed. This contributes to a good understanding of how the deposits are formed and developed over a period of time.

Another important question is how the deposits are released. At some plants, the deposits are actively removed by means of soot blowing, while at other plants they attain a relatively stable level - i.e. a balance between formation and release.

In order to throw light on this balance, the researchers of the CHEC centre have developed an advanced release probe. The new probe consists of a tube in which the temperature is also kept constant by means of compressed air and water. The energy absorption is registered continuously, and a load cell registers the weight of the deposits. Furthermore, it is possible to observe changes in the deposits by means of two video cameras.

In all, these measurements improve our understanding of how deposits are formed and released. The advanced probe has been used for measurements at the straw-fired boiler at the Avedøre plant, and in future it will be used for measurements in other biomass-fired boilers in order to form the basis of model development.

Testing different additives

Additives like kaolin or coal ash can reduce the risk of corrosion in biomass-fired power plants.

The power plants' use of straw and wood has increased considerably during the past few years. In the beginning, biomass was primarily used at grate-fired plants, but the demand for increased efficiency and profitability means that development activities are now increasingly directed towards large powder-fired power plant boilers.

Because of the boiler technology and the high superheater temperatures, serious deposit and corrosion problems may occur. A possible solution is to fire the biomass together with coal, as is the case at the Studstrup plant, while another is to add additives to the biomass.

Additives can increase the melting temperature of the ash, which reduces the risk of deposits in the boiler. Furthermore, a suitable additive can convert the chlorine content of the fuel into gaseous chlorine, thus reducing the risk of corrosion.

Photo: The CHEC Research Centre

The CHEC centre has one of the world's best-equipped testing halls with high-temperature pilot plants.

In cooperation with Elsam and Energi E2, researchers at the CHEC centre have carried out experiments with various additives. The substances have been tested in a so-called entrained flow reactor, where the conditions in powder-fired boilers can be simulated. All parameters can be controlled in the reactor, which makes it far easier to study the combustion here than in a power plant boiler.

Possible additives such as kaolin, coal ash, lime, calcium phosphate and ammonium sulphate have been studied in the project. Generally speaking, additives with a high content of silicon and aluminium can be used. In practice, this could be minerals such as kaolin or coal ash, which have high contents of both silicon and aluminium.

Choosing the right additive can be complicated, because in each case fuel properties, boiler technology, flue gas cleaning and the properties of the residual products must be taken into consideration.

Various tests are now performed with selected additives in the biomass-fired boilers of the power plants. ■

Improved electricity production from waste

Samples of bottom and fly ash from 22 waste-fired power plants have given researchers a better understanding of the formation of ash and deposits in boilers.

Highly corrosive deposits with a relatively high content of chlorine, sulphur, sodium and zinc are often seen in waste-fired boilers. To reduce corrosion a low superheater temperature is applied, but that also reduces the electricity efficiency.

In cooperation with Elsam and a series of waste-fired power plants, samples of bottom and fly ash, respectively, have been collected from a total of 22 boilers. Subsequently the samples were chemically and physically analysed, and researchers have thus obtained a better understanding of the formation of ash and deposits in the boilers. The activities were financed by Denmark's Energy Research Programme.

When waste is combusted on a grate, ash is formed from the non-combustible parts. Part of this ash is carried up through the combustion chamber by the air that is added under the grate.

Apart from the fly ash that consists of calcium and aluminium silicates, a series of volatile elements are released including sodium, potassium, zinc, lead, chlorine and sulphur. These substances react in the gaseous phase to form gaseous chlorides and sulphates, which condense on the fly ash and heating surfaces when the flue gas is cooled between the combustion chamber and the stack.

Deposits in the boiler are probably formed when a thin layer of chloride and/or sulphate compounds creates a sticky surface on which the fly ash is deposited. In the beginning, the ash particles are slightly sintered and the deposit is relatively porous. This entails reduced heat transfer, and the surface temperature of the deposit is increased, which in turn entails new deposits. ■

The future

It is the CHEC centre's ambition to continue to play a key role in education and research concerning biomass for energy purposes in close cooperation with Danish companies. New activities will include increased focus on production of fluid biofuels and increased use of CFD tools in the description of chemical processes. ■

Erik Steen Jensen, head of a new programme on biomass for energy and materials at RISØ. In the background, a row of wind turbines used by the Test Station for Wind Turbines at RISØ.

Photo: Torben Skøtt/BioPress

From nuclear power to bioenergy

Since its establishment in 1958, RISØ has played a central role in energy research. In the 1960s, focus was on nuclear power. Later on wind power became important, and lately RISØ has focused on bioenergy.

By Torben Skøtt

Denmark has been the world's largest wind turbine producer for years, and today wind power covers 16 per cent of our total electricity consumption. This is a success story, which has only become reality because we got started in time and because politicians, the industry and researchers agreed to dedicate resources to wind.

RISØ National Laboratory, which has played an important part in researching wind power, now thinks that bioenergy is next. Bioenergy is at least as valuable a resource as wind power, and if we make an effort now, Denmark will be able to play an important part in developing the necessary technology to exploit the total potential of the resource.

There is nothing new to using biomass for energy purposes. Today, bioenergy covers 11-14 per cent of the world's total energy consumption, and in many developing countries it is the most important energy source.

– But the technology that we use to exploit the energy is not always optimal. In many cases, strengthened research would enable us to optimise the energy output, reduce the environmental load and improve profitability, explains Erik Steen Jensen, who is the head of a new programme on biomass for energy and materials at RISØ.

Intelligent exploitation

- Research can enable us to exploit biomass more intelligently, says Erik Steen Jensen. As an example he mentions the production of bioethanol, where at present a simple process to convert sugary crops into ethanol is used.

– The problem with this technology is that farmers are forced to grow certain crops which do not always have high energy outputs. Therefore, RISØ is working on developing a new technology to convert cellulosic products such as straw, grass and wood into ethanol. This would give access to a far broader range of raw materials at lower prices, i.a. because some of the raw materials are considered waste or residual products with no particular use-value.

In particular, RISØ has concentrated on pre-treatment of the biomass in a so-called wet oxidation process, which so to speak opens up the straw. After this treatment, the biomass can be converted into ethanol and other products for energy purposes by means of enzymes and bacteria.

"Triple helix"

Erik Sten Jensen explains that RISØ finds it important to involve the "triple helix" principle in the research. This means that researchers, politicians and the industry must agree that this is an area that needs to be promoted as much as possible.

– Of course we also need to develop new areas, of which we are not immediately sure of the purpose but that is not the primary task. What is most important is to study something that can be used in practice - something which is important for Denmark. We always keep in mind how society can benefit from our research - maybe not tomorrow, but in the foreseeable future, says Erik Sten Jensen.

In connection with ethanol, to which RISØ devotes a lot of resources, however, Erik Sten Jensen has to admit that the politicians are not all that supportive.

– The researchers, the industry, the agricultural sector and many others have a clear interest in this area, but we lack the acceptance of the politicians in the form of lower taxes. If the politicians are not in, bioenergy will never break through. We will have a hard time exporting our knowledge if we do not believe in it ourselves, and we cannot perfect the technology if we do not have production plants in Denmark.

The IBUS project

RISØ has established a close cooperation with Elsam on the so-called IBUS project, where straw is converted into ethanol, animal feed and fuel for the power plants. The project, which among other things comprises test and pilot plants at the Funen plant (Fynsværket), will result in a full scale plant which can process 40 tonnes of straw an hour.

– It is surprising that politicians do not realise that this is a growth area with enormous potential, says Erik Steen Jensen. The IBUS project is known worldwide, and we have already made a cooperation agreement with the north Chinese province of Jilin that houses the world's largest factory for bioethanol production on the basis of corn. Today, only the grains are used, but by using the technology from the IBUS project the Chinese will be able to use the entire crop. At the same time, Danish researchers gain better knowledge of corn waste, which is one of the most important biomass resources globally.

Sustainable crops

Erik Sten Jensen warns of rejecting certain types of bioenergy, because at the moment there seem to be problematic elements.

Photo: Torben Skøtt/BioPress

RISØ's laboratory reactor for wet oxidation of biomass.

As an example he mentions that many people are reluctant to promote the use of biodiesel, because as it is today the production is based on rape, which requires relatively large amounts of fertilizers and pesticides.

– It is far to early to conclude that rape is not a sustainable crop, says Erik Sten Jensen. The rape plant has been improved over the years in order to obtain the best possible properties for food production, but in the process a series of the substances that give the plant its natural resistance have been lost.

– If bioenergy is to replace a substantial part of our oil consumption, we must of course optimise the plants to produce energy instead of foodstuffs. There is great potential in developing crops with a high energy output, but which do not require fertilisers or pesticides, says Erik Sten Jensen. He also imagines that it will become possible to develop new cereals where the entire plant can be converted into ethanol without adding enzymes or other types of chemistry.

Be far-sighted

According to Erik Sten Jensen, modern bioenergy can present the agricultural sector with a series of new possibilities. The competition on traditional agricultural products will be sharpened considerably in the years to come because of the cheap labour in the new EU countries. Therefore Danish agriculture will have to focus on areas which require more knowledge. It is necessary to develop new multifunctional systems, where the agricultural sector forms a synthesis of food production, energy production, groundwater protection and preservation of rural amenities.

Finally, Erik Steen Jensen points out that the technology for exploiting bioenergy is an important part of the efforts to develop a hydrogen society, where biomass can be used to produce hydrogen. If we turn down the host of opportunities of a more advanced exploitation of bioenergy, we also turn down some of the opportunities in its wake.

Environmental award for eco-car

The students behind the “Spirit of Copenhagen“ eco-car have been awarded an environmental award of DKK 250,000 from Aase and Ejnar Danielsen's Foundation.

“Spirit of Copenhagen” was designed by 20 students and teachers at the Department of Mechanical Engineering at the Technical University of Denmark last spring. What is special about the car is that it runs on the practically non-polluting fuel dimethylether, which can be made from e.g. biomass.

On the Circuit Paul Armagnac race track in France in competition with more than 100 other projects, the car drove 583 kilometres on an amount of dimethylether which corresponds to one litre of petrol.

The team behind “Spirit of Copenhagen” will construct two cars for next year's Shell Eco-Marathon in France. One of them will run on dimethylether and the other one on hydrogen.

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Editor responsible:
Torben Skøtt

Production:
BioPress
Vestre Skovvej 8
DK-8240 Risskov
Telephone +45 8617 3407
Telefax +45 8617 8507
E-mail: biopress@biopress.dk
Homepage: www.biopress.dk

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Photo: Technical University of Denmark

New research centre for biofuels

On Wednesday 1 December, a new research centre opened which will unite the expertise within liquid biofuels.

The head of the new research centre, professor Birgitte Kiær Ahring, on her way to the inauguration in an ethanol car.

The originators of the new centre, which is called Danish Center for Biofuels, are Technical University of Denmark, RISØ National Laboratory and the Royal Veterinary and Agricultural University, Denmark. The centre will be the spearhead of the efforts of Danish research and business to develop sustainable and CO_2-neutral biofuels. Apart from research and educational purposes the centre will work on strengthening the cooperation between the research communities and the industry.

The day-to-day head is professor Birgitte Kiær Ahring, who is well-known as a spokeswoman for environmentally friendly refineries, which can convert various types of biomass into ethanol, hydrogen and biogas. She has an extensive international network and is known as an expert of converting the more difficult types of biomass such as straw into ethanol and biogas.

- We have so many opportunities in this area in Denmark, and our research is already in the world elite. I see the centre as an opportunity for us to stay in the world elite as regards research in biotechnological processes. Furthermore, we have a system for gathering straw from the fields, which is worthy of serving as a model, so we already have the raw materials ready to produce enough bioethanol to replace five to six per cent of the oil-based fuels, says Birgitte Kiær Ahring.

The industry welcomes the new centre.

- Denmark has all it takes to make biofuels a value creating activity. Bioethanol from plant starch was the first generation, and biofuels from biomass are the next. It is both difficult and technically demanding, but we will create a technological platform which can develop replacements for the petrochemical production, says research manager Lene Lange from Novozymes, which is at the forefront of the development of cheap and efficient enzymes that can be used in the production of ethanol.

So far, the centre is financed by grants of a total of DKK six million from the Danish Energy Authority, the EU and the Danish Technical Research Council. In future the centre expects to receive grants from the new High-Technology Foundation under the Ministry of Science, Technology and Innovation.