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LARGE-SCALE HANDLING AND USE OF SOLID BIOFUELS

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ABSTRACT
Utilising biomass in the CHP production is not without difficulties: the chemical and physical characteristics of the biofuels; corrosion, slagging and fouling; and working environment. An in-situ high-temperature corrosion monitoring test system was successfully developed. Furthermore, activities have been launched to develop a straw pre-processing method separating the aggressive substances from straw.

As a result of the gasification projects (straw, coal-straw, wood chips) it was concluded that it is possible to gasify straw - probably for 100% straw and definitely for 50/50 blends, although with some difficulties - and for wood chips deposit formation was a major obstacle. Further R&D is definitely needed, but with the limited international interest the gasification technology seems to have reached a dead end in Denmark.

Another focal point is the working environment, where care must be taken to limit any potential health hazards resulting from the handling of long-term stored biofuels.

Keywords: biofuels, corrosion, slagging, fouling, gasification, working environment

BACKGROUNO
The utilisation of biofuels in Denmark has been under significant political influence and in 1992 a 20% reduction of the CO_2-emission was agreed upon. As a result the Danish power pools are obliged to utilise 1.2 million tonnes straw and 0.2 million tonnes wood chips annually from year 2000, equalling approx. 19 PJ or 6% of the annual Danish energy consumption. However, utilising biomass in the combined heat and power production is not without difficulties and a number of factors must be considered.

An R&D plan adopting a coal/biofuel strategy based on fossil fuels and renewable energy sources was initiated to expand the knowledge of biofuels and to identify the immediate problems arising due to application of biofuels alone or mixed with coal.

The conversion technologies examined for the biofuel utilisation counted:

- Co-firing of straw and coal and further co-firing of wood powder and coal in pulverised coal fired (PF) boilers;
- Installation of new separate biomass-fired boilers, with the installation connected to the original pulverised coal-fired boiler system. A bio-boiler is a combined straw and wood chips-fired boiler type in which the steam is superheated in the wood-fired part before the steam turbine) (process diagram is outlined in figure 1);
- Installation of a circulating fluidized bed boiler fired with coal, wood chips and straw;
- Gasification of straw and coal and further gasification of wood chips mainly originating from short rotation forestry.

The R&D programme realised has been successful in respect to identification of problem areas and opportunities, and the complexity of the biofuels resulted in various concepts requiring further research and tests. Tests were carried out on test rigs as well as at full-scale plants. To understand how the envisaged annual amounts of biofuels can be handled and consumed in a secure and efficient way, it is necessary to look into the nature of biofuels. A large number of the issues normally considered as being problematic are identical and independent of the conversion technology in question.

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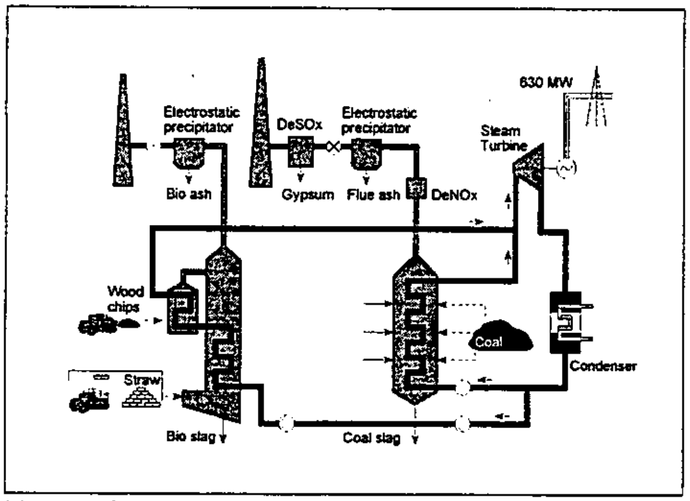

Figure 1. Process diagram for separate biomass-fired boiler. Annual capacity: 120,000 t straw/30,000 t wood chips.

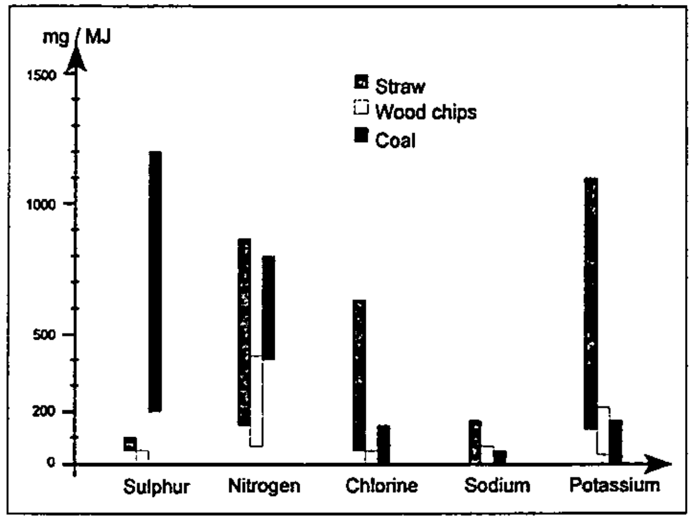

Figure 2. Range of content of some key components in straw, wood chips and coal on the basis of the lower heating value of the fuel.

CHEMICAL AND PHYSICAL CHARACTERISTICS OF BIOFUELS

When characterising a biofuel for conversion purposes, the data must be expressed both in terms of chemical compositions and physical properties. Figure 2 shows a comparison of the content of some of the key components in straw, wood chips and coal. Sulphur and nitrogen are important for SO_2 and NO_x emissions, and chlorine and alkalis are important in connection with corrosion, utilisation of fly ash and deactivation of high-dust SCR catalysts.

Coal has a higher heating value than straw and wood, and to allow for proper comparison, the contents have been calculated on a lower heating value basis. The figure shows that biofuels have a much lower sulphur content than coal and that the nitrogen content is comparable in straw and coal, but lower in wood. It is also seen that the content of chlorine and alkalis is comparable in wood and coal, but much higher in straw.

Table 1(in appendix 1) gives an overview of the chemical composition of Danish cereal straw and wood chips and shows a number of clear differences between the fuel data for straw and wood.

The lower heating value of the biofuels on a water and ash free basis is slightly higher in wood than in straw, but due to the higher water content in wood chips, the lower heating value as received is highest for straw. It is seen that the content of ash-forming and gaseous pollutant-forming elements is higher in straw than in wood. Most important is the fact that the content of potassium and chlorine in straw is of an order of magnitude higher than in wood chips. Sander, 1997

CORROSION, SLAGGING AND FOULING

Fuels with a high content of potassium and chlorine may cause technical problems such as corrosion of superheaters, increased slagging and fouling, increased deterioration rates of SCR catalysts for NO_x reduction, and in the co-firing concepts with coal, the utilisation of fly ash for cement and concrete production is impeded. Corrosion is not seen in boilers operating at temperatures below the critical level of approximately 450°C. However, in order to ensure high efficiency for a power plant, considerably higher steam temperatures are called for. In a conventional pulverised coal-fired (PF) power plant the steam temperature is 540°C today, where a new power plant will be operating at 580°C. At this temperature an electrical efficiency of 47% can be obtained in condensing mode.

Development of an **in-situ high-temperature corrosion monitoring test system** to further the understanding of the correlation between corrosion speed and deposit formation has therefore been given high priority. In order to achieve reliable corrosion data 2000 h test periods have been aimed for in all tests. Corrosion has been monitored by the use of temperature-regulated test probes. The temperature set point has been a material temperature corresponding to the steam temperature in a real-life superheater located in the boiler. Steam temperatures in the range of 450-580°C have been simulated and the test tube segments have been built into the superheaters and exposed at the same conditions as real superheaters of course. Corrosion results obtained have been found to be in accordance with built-in test pieces.

The development of the corrosion monitoring system has been an unquestionable success. The tests have demonstrated that corrosion rates start to increase at temperatures above 450°C, and very high corrosion rates are observed at the highest temperatures. Slagging and fouling are highly related to the corrosion problems. According to the results there is a close correlation between the content of potassium and chlorine in the straw and the degree of deposit formation. Henriksen 1997; Junker, 1997

PRODUCTION OF CORROSION-FREE STRAW-BASED FUELS BY UPGRADING AND GROWING

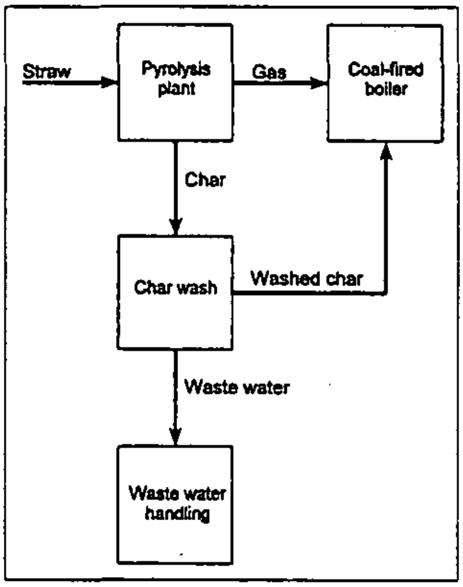

Figure 3. Pretreatment of straw by means of pyrolysis.

Activities have been initiated with a view to developing a pre-processing method for straw. The idea is to separate the aggressive substances (chlorine, potassium and sodium) from the straw before firing, but also full-scale trials utilising fertilizers devoid of chlorine have been conducted. Trials have demonstrated that by minimising the chlorine content in the fertilizers used by the farmers, the content of chlorine in the straw will be lowered proportionally.

In a project named "**Pretreatment of straw by pyrolysis and char wash**" it is investigated whether pyrolysis of straw with subsequent extraction of potassium and chlorine from the straw coke would be a practicable way of upgrading the fuel.

The fundamental principle of a pyrolysis/coke washing process for straw pretreatment is shown in figure 3. Straw is pyrolysed at a temperature which is sufficiently low to retain the content of potassium and chlorine in the coke. The pyrolysis gas is to be fired directly into the PF boiler. Potassium and chlorine are washed out of the coke and the coke is ready for firing. The sewage from the coke washout is discharged after being cleaning or possibly used as potassium raw material in the production of fertilizer.

The experimental investigations and the technical/economic evaluation of pyrolysis and coke washing as a means of pretreating straw have not been finalized at the time of writing, but based on the results of the project so far, it is estimated that the process can in principle be realised with a plant economy which is attractive compared with that of a separate straw-fired boiler. Degrees of treatment for potassium of at least 90% can be reached, thus making it possible to fire 25% straw on energy basis in a pulverised coal-fired boiler without causing the problems referred to above. However, a technology for straw pyrolysis at power plant scale remains to be found, and considerable development would be necessary to achieve this.

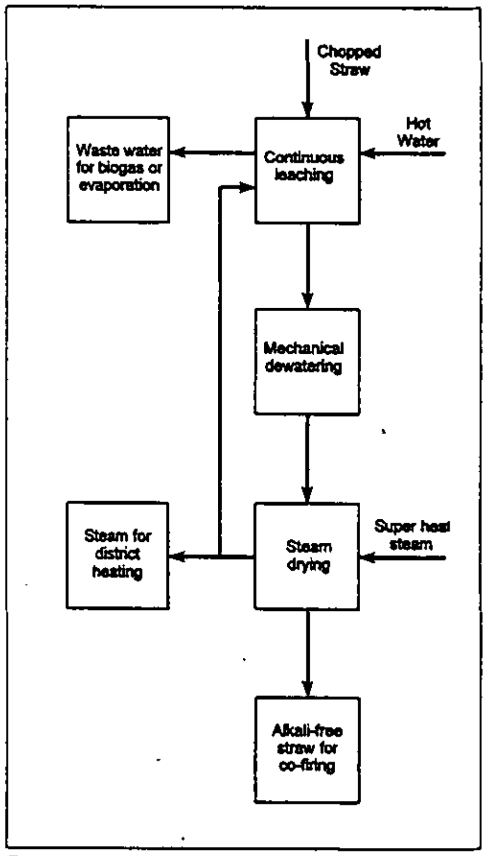

Figure 4. Flow chart illustrating the straw leaching process.

Pilot tests in a project named "**Pretreatment of straw by leaching**" (see figure 4) have shown that 90-95% of the content of potassium and chlorine in straw can be removed by simple washing at low temperatures and that the washed straw can be dehydrated before co-firing.

Calculations demonstrate that the loss of energy in the process is approx. 9% corresponding to the fact that straw can be co-fired at an arbitrary boiler plant (eg. 580°C steam temperature) with a power efficiency loss of approx. 4 %-points, ascribing the loss of efficiency to the straw alone.

The implementation of the process for co-firing of straw is primarily a question of plant design. A commercial full-scale plant is planned to become a reality in 3-4 years time. The costs of CO_2 reduction can be considered a fully competitive alternative to other CO_2 abatement methods.

The first phase of the project has been completed and reported. The second phase of the project is ongoing and will ao. deal with conditions in respect to mechanical dehydration of straw and sewage treatment. In addition to this, a detailed plant budget will be set up for a demonstration plant.

GASIFICATION

In Denmark in the 80s and early 90s environmentally dedicated politicians made the development of the gasification technology a political issue as they were convinced that gasification would give a 20% increase in efficiency compared to PF firing, and that the emission of hazardous compounds would be considerably lower. At first efforts focussed on coal gasification. However, the political interest in power plant utilisation of biofuels was linked with the interest in continuing the development of the gasification technology and the Danish Parliament ordered the power utilities to develop and construct a gasification plant.

A number of initiatives were launched to test the possibilities of gasification of coal and straw, and it was decided to investigate the concept of cofiring with coal because of the troublesome gasification properties envisaged for straw, the desire to have a reserve fuel, and to be able to determine the most economic size of a power plant.

ELSAMPROJEKT became engaged in the EU-supported APAS coal/straw gasification test programme with the overall objective of testing straw-only gasification, in a gasifier developed for coal only (oxygen-blown entrained flow) and in a gasifier developed for biomass, and test the coal-straw ratio for cofiring.

A series of tests were conducted in the entrained flow plant of NOELL near Dresden (a dedicated coal gasifier). The conclusion was that it is possible to gasify straw - probably for 100% straw feed and definitely for 50/50 blends. However, the energy consumed for drying and cutting the straw as well as the inert gas consumption for pressurization and pneumatic transport, renders the 100% straw solution prohibitive. Likewise a 50/50 coal-straw blend would call for extensive R&D efforts at international scale to develop suitable feeding equipment.

In the course of the project a gasifier tailor-made for biomass was tested at VTT's and later on also Enviropower's fluidized bed gasification plant. The conclusion of these tests was that gasification of straw only with a satisfactory result is not realistic. A 50/50 blend gave satisfactory results, but also the pressurized fluidized bed gasification technology will require specially developed feeding equipment. It should be remembered that the volume of straw is about ten times that of coal.

The international interest in straw is scarce and nothing seems to suggest a fast breakthrough for a straw gasification concept. In addition, the realisation of the construction of a demo plant would require immense resources; however, the APAS-project contributed with essential knowledge about the gasification technology. A good example of how this knowledge materialized into practical usage is the development of standardised calculation modules for the program SSYSIM (Steady State System SIMulation, a program developed by ELSAMPROJEKT) used for thermodynamic analysis.

The final report was submitted by mid 1995 (*Combined Gasification of Coal and Straw, Final Report, June 1995*). APAS 1994

Due to the somewhat cumbersome perspectives encountered for the straw gasification concept, it was agreed to turn to wood chips instead and as result the so-called *Biocycle Project* started end of 1992. This EU-supported project concentrated on gasification of wood chips, especially willow and from the forest industry. A series of significant test gasification rounds were realised in Enviropower's pilot plant in Tampere, whose gasifier is the same size as the one envisaged for the project. To the authors' knowledge, this was the first time ever to test gasification of willow chips at this scale, and the tests demonstrated that good carbon conversion up to 98% was obtained. During the tests it was found that there was a tendency for deposit formation in the gasifier. Subsequent analyses at VTT offered an answer to the cause for these deposits.

During the evaluation of the results it became clear that much R&D work still remains to be done in the field of the small gas turbines which can be applied for the low-calorific gas from a gasifier and that the gas turbine manufacturers exhibit only modest dedication to this issue.

Furthermore, on the basis of the findings of these projects it was concluded that cofiring straw and coal into an IGCC-plant was possible only to a modest degree. However, in view of the stage of this technology today, it was decided to go on with the ultra super critical (USC) plant technology (580°C/290 bar). One natural gas fired boiler has been commissioned and another one based on the same USC data is due for commissioning this year.

As a result the gasification technology in Denmark seems to have reached a dead end.

WORKING ENVIRONMENT

When it comes to wood chip storage, the working environment poses yet other problems to be taken into consideration. The growth of microflora in the form of fungi and bacteria may take place soon after the building of a pile of wood fuel chips. The number of fungi and bacteria as well as the growth rate depend on many and very complicated factors and combinations of these. A parallel situation will occur when straw with a moisture content higher than approx. 15% is baled. When handling biofuels, there is a risk of working environmental diseases which usually occurs when people get in direct contact with the microspores of fungi and bacteria. Spores are released as bacterial dust when the bacteria either die or divide, and from fungi when these multiply. These microorganisms represent the entire spectrum, from being totally harmless to being so hazardous so as to cause diseases that may neither be prevented nor cured.

Microspores

Fungi and moulds propagate by means of microspores and when detached they resemble a dust cloud. The microspores may have a diameter of less than 5 μm and are air-borne. Upon inhalation of large concentrations, the microspores may affect the respiratory system and cause allergic reactions in the persons in contact with the microspores. These reactions may be shortness of breath, fever and asthma-like symptoms. The diseases are known under names such as *farmer's lung disease, baker's lung disease, mushroom gatherer's disease* and *tobacco lungs*.

If a person is later exposed to the same microspores again, an even smaller amount may cause a reaction, and the immune system is so strongly activated that it will always react to the substance. Fungal spores may also cause inflammation of the small lung alveoli which also applies to endotoxins.

Endotoxin

Endotoxin is a chemical component placed in the outer membrane of the so-called Gram-negative bacteria, which is usually released when the bacteria multiply or die. When this takes place, a measurable amount is released. Continuous exposure to high levels of endotoxin may cause chronic bronchitis and impairment of the lungs. An acute onset may manifest itself in symptoms such as a dry cough, shortness of breath, chills and possibly headache, and usually the symptoms will appear a few hours after exposure. It is a toxic reaction to the alien substance in the lungs, and in the beginning the symptoms closely resemble those of influenza.

The disease is called *allergic alveolitis*, and it is an inflammation of the alveoli, in which the oxygen and carbon dioxide exchange with the blood takes place. In the alveoli there is direct access to the blood, and as the toxin can be carried in the blood stream to the neural centres in the brain, which controls the body temperature, the result is that the person runs a fever.

Emphasis on Storage Conditions and Handling

Based on the above it is paramount that storage conditions are given a high priority along with ways of handling which provide the lowest growth of microorganisms and hence release the lowest amount of spores likely to affect individuals who will later come into contact with the fuel. Jirjis, 1996

According to a recent study the amount of microspores differs significantly in willow fuels stored under different conditions. It may specifically be emphasized that the amount of fungi spores in anaerobically stored willow chips was found to be very low. At the same time, the test results document that there is a risk of heavy increase in spores if the piles are ventilated. After only a few days temperatures as high as 90°C have been measured in piles. Ventilation and high temperatures result in loss of dry matter and energy value, redistribution of the moisture content, partial freezing in the winter and notably also potential health hazards from airborne spores. Trials have demonstrated that this dry matter loss may reach as much as 30%. Kofman, 1997

Those responsible for avoiding health hazards are the plant designers, straw and wood chip procurement managers, maintenance managers and personnel engaged in the day-to-day activities at the plant facility.

CONCLUSION

A number of aspects when dealing with biofuels are identical for combustion as well as gasification technologies, and the R&D-programme carried out has been successful as regards identification of problem areas and opportunities, and the complexity of biofuels resulted in various concepts requiring research and tests. Tests were carried out on test rigs as well as at full-scale plants with fuel types such as straw, energy crops, wood chips from ordinary forestry, wood fuels from short rotation forestry, miscantus, fruit stones, cleansing process products, etc. for combustion as well as gasification technologies for the combined heat and power production.

Today both the separate bio-boiler, with an annual capacity of 120,000 tonnes straw and 30,000 tonnes wood chips, and the co-firing facility, with a capacity of 50,000 tonnes straw annually, have been commissioned.

When characterising a biofuel for conversion purposes, the data must be expressed both in terms of chemical compositions and physical properties. Corrosion, slagging and fouling problems have been explained and furthermore advice has been given as to the possibilities of upgrading straw to avoid corrosion.

On a laboratory scale the possibilities of pre-processiog straw by pyrolysis or hydrolysis have been examined with a view to identifying methods that can separate chlorine and alkali metals from straw.

A unique in-situ high-temperature corrosion monitoring test system has been developed and tested as a success

The work has generally coocentrated on issues to be considered for CHP plants producing steam by firing biomass only - or in a combination with coal. But also gasification trials of straw in mixtures with coal - and wood chips from willow plantations as the only fuel - have been carried out.

When the gasification programme was launched there was no international interest in straw as a fuel, but the prnjects conducted gave valuable insight into the gasification technology. A good example of how this knowledge materialized into practical usage is the development of standardised calculation modules for the program SSYSIM used for thermodynamic analysis.

The willow gasification tests demonstrated that it was possible to obtain satisfactory conversion of carbon (up to 98%), but deposit formation was found in the gasifier. This calls for further R&D efforts into this issue. However, the interest on the part of the gas turbine manufacturers is only modest. Consequently, the gasification technology from a Danish point of view seems to have reached a dead end.

The quality of the feedstock delivered to the plant depends on the methods applied in the process from the fields and forests until the biofuel is ready for firing. Another focal point is the question of working environment, where care must be taken to limit any potential health hazards resulting from the handling of long-term stored biofuels. Those responsible for avoiding health hazards are the plant designers, straw and the wood chip procurement managers, maintenance managers and the personnel daily working at the facility.

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APPENDIX 1

Water content and heating value		Straw		Wood chips	
	Unit	Typical	Variation	Typical	Variation
Water content	Weight-%	14	8-23	45	20-60
Lower heating value as received	MJ/kg	14.9	12.3-16.9	9.5	5.9-15.9
Lower heating value, water and ash free	MJ/kg	18.6	18.0-19.0	19.5	18.5-20.5

Chemical composition		Straw		Wood chips	
Unit: Weight-% on dry basis		Typical	Variation	Typical	Variation
Ash		4.5	2-7	1.0	0.3-6
Volatiles		78	75-81	81	70-85
Hydrogen	H	5.9	5.4-6.4	5.8	5.2-6.1
Carbon	C	47.5	47-48	50	49-52
Nitrogen	N	0.7	0.3-1.5	0.3	0.1-0.7
Sulphur	S	0.15	0.1-0.2	0.05	<0.1
Chlorine	Cl	0.4	0.1-1.1	0.02	<0.1
Silicon	Si	0.8	0.1-1.5	0.1	<1.1
Aluminium	Al	0.005	<0.03	0.015	<0.1
Iron	Fe	0.01	<0.03	0.015	<0.1
Calcium	Ca	0.4	0.2-0.5	0.2	0.1-0.9
Magnesium	Mg	0.07	0.04-0.13	0.04	<0.1
Sodium	Na	0.05	<0.3	0.015	<0.1
Potassium	K	1.0	0.2-1.9	0.1	0.05-0.4
Phosphorus	P	0.08	0.03-0.2	0.02	<0.1

Table 1. Fuel data for Danish cereal straw and wood chips.