UTILISATION OF STRAW AND SIMILAR AGRICULTURAL RESIDUES

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ABSTRACT

Considerable straw resources and the wish for a reduction of the CO₂ emission by substitution of fossil fuels with biomass are the basis for a still growing European interest in production of power based on straw or co-firing of straw and fossil fuels.

However, straw is an expensive fuel, and 15 years of experience have shown that straw is rather problematic as a fuel for heat and power production. To obtain reasonable power efficiencies, stable operational and environmental conditions, as well as an acceptable economy, it is important to know more about the characteristics of the straw and straw ash in relation to energy, to develop better firing and combustion technologies, and to optimise the logistics system for gathering and delivery of straw.

Compared with the coal firing technology, the extent of research and development within power production based on straw, is modest so far.

Political agreements on straw-based power production at big power plant units in Denmark and the UK will during the years to come contribute essentially to a higher degree of know-how on utilisation of straw for energy purposes.

KEYWORDS

Straw, agricultural residues, straw ashes

INTRODUCTION

The IEA-Activity

The IEA-Activity "Utilisation of Straw and Similar Agricultural Residues" under the IEA-Biomass Utilisation Agreement was initiated as an independent activity in 1989 with 5 participating countries.

During the three-year period from 1992 to 1995, 5 countries: Austria, Denmark, UK, the Netherlands, and Sweden, have participated in the activity. dk-TEKNIK, Denmark has been the activity leader since 1989.
The main purpose of the activity has since 1992 been to improve the utilisation of straw and similar agricultural residues and convert them into heat and electricity in an environmentally safe and energy-efficient way.

Contrary to most of the other activities under the IEA-biomass agreement, the activity is not limited to a specific process (combustion, gasification, fermentation etc.), but focuses on straw as a fuel in general. Therefore, the group has been free to deal with all processes connected to utilisation of straw for energy purposes. However, exceptions are gasification and pyrolysation of straw which are taken care of by other activity groups under the IEA-biomass agreement. So far the group has only been active on straw and only to a very limited extend to "Similar Agricultural Residues".

Straw Utilisation

From a European biomass point of view, straw has only a relatively limited interest in comparison with other bio-fuels, e.g. wood, with Denmark as an exception. Thus, straw is only utilised to a very limited extent for energy purposes in Austria, the UK, the Netherlands, and Sweden. Important barriers for a more widespread utilisation of straw are first and foremost:

- That straw in the 4 countries has to compete on commercial terms with other fuels, including fossil fuels and other biomass fuels such as wood which - especially in Sweden - make out a far bigger biomass resource.
- That experiences with utilisation of straw in these countries are limited, and as straw is a problematic fuel in comparison to wood and fossil fuels, there is, in light of a very limited (or totally lacking) economic incentive, a real scepticism towards straw (in comparison with e.g. chipwood) when choice of fuel has to be made.
- That the agricultural structure, especially in the Netherlands, Austria, and Sweden in comparison to the Danish agricultural structure, makes an efficient organisation of straw deliveries difficult, and that lack of a real, commercial market for straw for energy purposes make reliable evaluations of available resources difficult.

Denmark is in a very special position concerning utilisation of straw, partly because energy politics since the beginning of the eighties have put a strong effort in implementing biomass in the energy supply, (i.e. via compulsory control of choice of fuel and carrying through of superior, economic means, first and foremost exemption from taxes on biofuels) and partly because straw is a very essential biomass resource in Denmark.

Danish biomass energy politics has so far resulted in a yearly consumption of straw for heat and power production of approximately 1 million tonnes, distributed on approximately 13,000 farm plants, 69 district heating plants, and 5 combined heat and power production (CHP) plants. In the endeavours to realise a goal of reduction of the CO₂-emission of 20% before year 2000, it has furthermore become obligatory for the Danish power plants from the year 2000 to increase their consumption of straw by 1.2 million tonnes and their consumption of wood chip by 0.2 million tonnes per year.

In the UK, straw is traded to a limited extent on a commercial basis, but generally not for energy purposes. Private houses are heated with fossil fuels in individual furnaces, and a big number of farms use - like in Denmark - straw for heating the living quarters.
Over the last few years a number of very ambitious projects have been initiated, based on the NFFO-arrangement (Non Fossil Fuel Obligation). In these projects, straw is to a large extent going to become an essential part of the fuel consumption at a number of UK power plants. However, as straw has to compete with coal, being an essentially cheaper and more safe-operational fuel, and as the UK power plants are not forced to use straw (as in Denmark), only one or two projects (power production about 30-40 MW) appear realisable.

Project Plan

Based on the very different conditions for utilisation of straw and on the actual status for the real utilisation of straw for energy purposes in the 5 participating countries, the group has had certain difficulties in defining projects which all participants had a specific interest in and possibility for participating in.

The following topics had a both essential as well as common interest:

- Standardisation of straw- and straw ash analyses, sampling methods, sampling preparations, and new, alternative characterisation methods for straw fuel
- Handling and pretreatment of straw from harvest to delivery at the conversion plant
- Investigation of hindrances/means for rational use of straw
- Power production from straw
- Environmental impact

ACTIVITIES

Analysis of Straw and Straw Ashes

The continuously growing interest in straw and other kinds of biomass for energy utilisation has brought along a need for comparable characterisation methods. Consequently, investigations of straw and straw ashes are made in an increasing number in connection with the utilisation for energy purposes. For evaluation of combustion-related conditions, determination of e.g. the calorific value as well as content of water, ashes, and chlorine in the straw, is made. Concerning the ashes produced it is most frequently loss of ignition in connection with determination of the efficiency, and contents of salt and heavy metals for evaluation of the final applicability, which are determined.

In order to obtain better opportunities for evaluation and comparison of biomass data, initiatives have been taken in several countries to collect results from the investigations in databases. A database for biomass parameters is a natural basis for collection and spreading of biomass characteristics. However, the question is to which extent such databases are applicable. The problem is that no international, recognised testing methods exist for biofuels. The number of international directives is also very limited.

When different laboratories originally started making fuel analysis on straw, existing methods optimised for other purposes were therefore used, meaning that today a wide selection of methods is used for the same parameter, originally developed for e.g. coal, sewage sludge, and feedstuff, having the following, adverse consequences:
The results from different laboratories may deviate systematically. Determination of useless parameters is made. Methods for characterisation of handling, firing and combustion qualities made especially for straw, are lacking.

For determination of the ash content, coal standard methods are for example used, where the straw is ashed at 815 °C, and partly sludge standard methods, where the straw is ashed at 550 °C. As straw contains volatile, inorganic compounds (e.g. potassium compounds) a systematic difference will occur between the results found by the 2 methods.

A general problem in connection with comparison of the analysis results from laboratories with different backgrounds, is the procedure used for the preparation of an analysis sample. The analysis result obtained is to a high degree dependent on how the finely ground analysis sample (e.g. for determination of ashes) is prepared from the raw sample (e.g. a Hesston bale).

"Volatile matter" is an empirical parameter used for characterisation of coal. The younger and more reactive a coal is, the higher the content of "volatile matter" in the substance (water- and ash-free sample). By determination of "volatile matter" in straw and wood, a rather constant content around 80% on the water and ash-free sample is found. Therefore, this parameter has no essential value in connection with evaluation of the combustion qualities of straw and wood.

Thus, characterisation methods/analysis parameters are lacking, developed for straw fuel, which may e.g. describe differences in the behaviour of straw lots as to combustion, corrosion, and formation of slag deposits.

These problems were the background for the Straw Utilisation Group's initiation in 1990 of work concerning harmonisation of straw and straw ash analyses.

Since then, characterisation and harmonisation has been an essential part of the activity of the group. The objective has partly been to make recommendations concerning analysis principles for relevant, commonly used analysis parameters for straw fuel and ashes, and partly to describe status and need for both adaptation of already used methods and development of new, specialised methods.

The work started with a Round Robin among laboratories in the participating countries, reported in 1992. The Round Robin included ordinary parameters for an analysis sample of straw (content of moisture, ash, sulphur, chlorine, carbon, hydrogen, nitrogen, and heavy metals as well as calorific value) and composition (inclusive of unburnt matter) and fusibility conditions for an analysis sample of straw ash (fly ash).

The continued work in the group has resulted in the final report. The total report consists of 4 different, independent reports: Recommended Methods for Basic Parameters, Basic Parameters which Demand Further Investigation of Suitable Analytical Methods, Alternative Characterisation Methods, and Research and Development in the IEA Countries concerning Analysis and Characterisation of Biomass Fuels. State of the Art.

The recommendations given in part 1 are based on the results from the Round Robin combined with the existing experiences in the participating countries.

At the present state, the recommendations are given for suitable methods in principle, not as detailed recipes. In the long run, however, the intention is that the recommendations should result in international standards. In the meantime it is expected that comments on the
recommendations will be received, and hereby creating a wider basis for developing standard methods in detail.

It was recognised that methods used for some of the commonly analysed parameters need further investigation before it can be decided, whether the methods are suitable for the characterisation of biomass for energy utilisation.²

Furthermore, it was recognised that there is a need for other and more specialised methods for descriptions of problems related to the utilisation, such as reactivity, slagging/fouling and corrosion.

In part 3, there is a view over reported alternative methods for the characterisation of straw and straw ashes.²

In part 4 both finished and ongoing research and development concerning analysis and characterisation of biomass for energy utilisation in the participating countries are listed.²

Unfortunately, the contributions to parts 3 and 4 were few, and thus the group has only had a limited possibility for describing alternative methods for characterisation of specific, technical application conditions for straw.

Thus, a need for development and description of new methods still exists as well as co-ordination of such a work among the countries. It is the hope of the group that the reported work will stimulate the interest in documentation and development within analyses of biofuels.

Practical Knowledge on Straw Characteristics

In connection with a straw characterisation project running in parallel with the IEA-activity, (being a co-operation between Danish power plants, the research centre RISO, and dk-TEKNIK) a literature investigation was conducted and interviews made at straw fired district heating plants and CHP plants. The purpose of the investigation was to collect knowledge on the influence of different straw characteristics on the combustion and formation of slag deposits in the boilers. Often, differences have been found in the combustion qualities of straw, without clearly being able to say which fuel characteristics have caused the differences. The ideal would be to have a clear picture of the influence of the straw characteristics on the combustion process.

However, this is a very ambitious goal. Investigations have been made on coal for many years, and nevertheless the combustion qualities of coal are not always predictable. However, this fact does not exclude the indication of a number of seemingly important characteristics. From the investigation a few, important matters have been found. A difference is seen between the different straw lots when burnt in boiler plants. However, there is only very limited, reliable knowledge of the significance of the characteristics of straw on the combustion process. Calculations indicate that as to the complete burning out of straw coke, diffusion and thus the physical structure of the straw is of the greatest importance.

Formation of slag deposits in the boiler plant does always have to (and can normally) be held at an acceptable level with shot-rain cleaning and soot blowing. A strong presumption exists that big amounts of potassium in the straw strengthen the formation of slag deposits. Possibly, other elements in the straw may be of importance for the formation of slag deposits (Si, Cl, S). Rain washing of the straw may considerably reduce the potassium content of the straw.³
Handling of Straw

With the development of power production based on straw at big power plant units in Denmark and the UK, there is a need for more know-how on rational handling of straw from the field to delivery at the plant, and on handling at the plant.

The often long transportation distances, the demands from the plants on the quality of the straw, security for delivery on time, the dependence on agricultural cultivation, the weather, the wish for the cheapest possible delivery of straw, and the relatively large amounts required, demand an extremely well-functioning straw delivery and handling system.

Since the beginning of the eighties with the appearance of the first, straw-fired district heating plants in Denmark, most of the straw for district heating and CHP-plants has been delivered as Hesston bales (500 kg, 2.4 x 1.2 x 1.3 m).

Dependent on the firing technique the bales have been handled differently (shredded, cut, or fired as whole bales) at the plant. Only in very few cases are there examples of straw as a fuel being processed to briquettes, pellets, or dust.

With a view to lowering the costs in connection with handling, storage, and transport, and to increase the delivery and operational security at the plant, several theoretical and practical investigations of alternative possibilities for handling, storage, and transport have been carried out, especially during the latest 3-5 years.

The participants in the Straw Utilisation Group have been very active in connection with a number of these investigations. The group (UK, Denmark, and Sweden) investigated the logistics connected with a yearly delivery of approximately 500,000 tonnes of straw to 1 - 2 Danish power plants, through an exchange of literature and know-how on straw-handling.

The following conclusions were reached:

- Mostly due to consideration to the agricultural cultivation and the dependence on the precipitation conditions during harvest, the number of working days, where it is possible to gather in straw (to press and remove the straw from the field), is limited to approx. 15 - 30 days out of a normal harvest period of 2 months. Therefore, it is of great importance that a sufficient baling capacity is available during the period of harvest.
- Hesston balers, producing the traditional Hesston bales, dominate the market for delivery of straw to district heating and CHP-plants.
- Other kinds of balers (e.g. Claas and Welger and other kinds of Hesston balers) are available producing bales with a higher volume weight ratio and a shape that gives better transport capacity.
- Other baler manufacturers are developing integrated machines which in one pass produce bales of cut straw.
- With available technology, the power requirement to cut and press is higher, the yield lower, the dependence on the water content higher, and the harvesting capacity lower, than for pressing uncut straw.
- Bales of cut straw may be manufactured with a higher volume:weight ratio and shape giving transport advantages. Another, possible, important advantage is that the straw, provided that it has to be fired as cut straw, does not have to go through a cutting process at the plant.
- Harvesting straw as refined products (briquettes, pellets, dust or other kinds) is not realistic. The technology for mobile briquetting is at the development stage, and based on tests with
preliminary prototypes it has been found that the capacities are too low and the investments and energy consumption far too high.

- Decentralised refining with stationary equipment (stationary pelleting and briquetting machines are commercially available) might under special circumstances be interesting, provided of course that the facilities for reception and firing at the plant are made sufficiently flexible in order also to be able to handle this kind of fuel.
- As an alternative for storage in barns with a solid roof, straw bales may be stored in large, open, plastic or tarpaulin covered stacks in the field with low storage costs, but there are feedstock losses.
- A combination of open stacks and storage in closed barns on farms, together with a buffer store at the plant, give good possibilities for a flexible cost effective storage system.
- Storage of cut straw (not pressed) in open, uncovered stacks in the field is widely used in East European countries, but preliminary Danish investigations carried out under Danish conditions show that the different processes connected with such a storage method are not sufficiently well documented.
- In the UK very large stacks of Hesston bales are stored in the field without cover.
- The very large stacks making rational gathering and handling methods possible and the very low storage costs are important reasons why straw can be delivered at a lower price than in Denmark. The storage method used does, however, demand very big field units or central storage from several suppliers in straw-tight areas in order to reduce the waste.

The above investigation was followed with a more comprehensive study to compare the logistical advantages and disadvantages of different types of bales.4

Co-firing at Large Power Plants in Denmark

The political decision concerning increase of the Danish power plants consumption of straw by 1.2 million tonnes and 0.2 million tonnes of wood per year from the year 2000 has caused a long series of activities, i.e. with tests on co-firing of coal and straw at rather old, coal fired power plant boilers.

The many investigations and tests form the basis for evaluation of the most sensible plant concept:

- Two technically different development directions appear in the area: 1) Coal and straw co-firing in existing power plant boilers and 2) separate straw fired steam boilers.
- Co-firing at existing plants with high operation hours and high efficiency is estimated to give the best economy as well as reduction in CO₂ emission.
- The technical uncertainty of co-firing at coal fired plants is, however, considerable. The flue gas corrosion with straw firing is a problem at the typical temperature conditions in steam boilers, and the utilisation of residual products from combined coal/straw firing is problematic. Because of the content of alkali and chlorine in the straw ash, the utilisation of the mixed ash from coal/straw firing in the cement industry is problematic, and the mixed ash cannot - as neat straw ash - be spread out on farm land.
- Several tests have been carried out at existing plants with a view to identifying the main problems. The first tests showed that it is possible to add a large quantity of straw without essential combustion technical problems. In further tests, corrosion in the superheaters of the boiler, unburnt matter in the flyash, risk of fire in the air preheater, as a consequence of unburnt flyash, process problems in the gypsum process at desulphurisation plants as well as operational problems with the catalyser at plants with NOx-plants, were demonstrated.
Concerning the environment, there is a risk that the CO₂ advantage, intended to be the result of an increased utilisation of biomass in the electricity sector, can be lost because the power companies would prefer to establish the co-firing at the rather small, inefficient old plants, in order to minimise the technological risk. To achieve a great utilisation of straw, these plants have to run at maximum output implying increased coal consumption as some of the electricity production is moved from high-efficient modern plants to these older plants.

Efforts are made in order to establish large units where the biomass is separated from other fuels in separate steam boilers. Compared with the co-firing, possibilities are achieved in order to adapt steam data, minimising the corrosion as well as slagging problems and at the same time the straw ash is kept apart from the coal ash, giving opportunities for utilisation of both the coal and the straw ash.

OTHER ACTIVITIES

Straw Price

There are several, obvious reasons why especially utilisation of straw for energy purposes is far more widespread in Denmark than in the rest of the participating countries, or in Europe as such. The main reasons have already been mentioned, but it has been the aim of the group - through a detailed analysis of reasons and sensitivity analyses - to elucidate possible areas of action in the UK, the Netherlands, Sweden, and Austria with a view to initiating projects that might lead to utilisation of straw on a larger scale.

In order to at least get an impression of the extent to what the price of straw might be a decisive factor, the group has carried through a preliminary investigation of straw prices in the participating countries.

From this very preliminary investigation it is seen that:

- In the UK, the Netherlands, Sweden, and Austria there is no commercial market for straw for energy purposes as in Denmark. Therefore, it is very difficult to fix an average price for straw delivered to energy plants in these countries.
- Prices for straw delivered for several different purposes in the 4 countries vary from approximately 30 to approximately 135 US$ per tonne. Straw for energy purposes is traded in Denmark at about 75 US$ per tonne, but there are variations from the average.
- Cost of delivery are apparently lower in the Netherlands, Sweden, and Austria than in Denmark. However, the investigation was not carried out in a sufficiently specific way, making a direct comparison relevant.
- In the UK, the straw price is apparently lower than in Denmark (42-46 US$ per tonne).

As the investigation was carried through on a very low budget at a very preliminary, orienting level, the results cannot be used for evaluation of the influence of the straw price on differences in utilisation of straw in the 5 countries.

However, the investigation does give interesting information on essential differences in expenses in connection with delivery of straw for an energy plant.
Environmental Impact

Fluegas Emission

As a rule, the small plants are very simple and cheap with a relatively low efficiency and relatively big emissions of especially dust particles, because it is seldom economic to equip the plant with efficient flue gas cleaning equipment.

There are big differences in the European countries concerning the conditions from the authorities to emissions (dust, NOx, CO, etc.) from small, biomass fired plants.

In an attempt to obtain a harmonisation of fair emission limits to straw fired, small plants (below 1 MW output), the Straw Utilisation Group has started collecting emission data and background material. In order to achieve a better clarity and comparison, the permissible emission limits of the participating countries (so far only Sweden and Denmark) have been prepared in a schematic outline.

Ash Handling

Based on the straw characterisation activities of the group, an investigation of the composition, possible utilisation, and following consequences of straw ash has been carried out.

END OF TASK

With the end of this three-year period, the activity, Straw Utilisation, ceases to exist as an independent activity in the IEA-co-operation. The ongoing activities, including especially the endeavours to harmonise characterisation methods for straw as a fuel, will be carried out by other activity groups.

REFERENCES