TWO YEARS' OPERATIONAL EXPERIENCE AND FURTHER DEVELOPMENT OF FULL-SCALE CO-FIRING OF STRAW

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ABSTRACT: By use of large-scale co-combustion of straw in coal-fired power plants, significant amounts of biomass can be utilised for power production with high electrical efficiency, low emissions and low investment costs. Based on the results from 10 years of biomass R&D work in Denmark, the 350 MWe coal-fired Studstrup Power Plant, Unit 4, was converted to commercial operation with co-combustion of straw in the beginning of 2002. Use of straw implies technical challenges due to difficult mechanical handling properties and a high content of potassium and chlorine in the fuel. The paper presents an overview of the operational experience from the first two years of operation with focus on availability of straw handling equipment, burner operation, influence on NO_x emissions, deposit formation and ash properties. Furthermore results from the ongoing development of the knowledge of co-combustion technology are described. This includes corrosion tests, compliance tests for use of fly ash in concrete, impactor measurements for characterisation of the formation of submicron particles and slip stream reactors for investigation of SCR catalyst deactivation in high dust position. The efforts on modelling co-fired furnaces will also be discussed. The results from these activities have further improved the co-combustion technology as a feasible concept for large-scale use of biomass.
Keywords: Co-combustion, Straw, Operating experience

1 INTRODUCTION

Elsam Engineering is a part of the Elsam Group. The mission of Elsam Engineering is to provide consulting engineering services for energy and power to its owner and to domestic and international clients world-wide.

Elsam Engineering has been involved in development of the co-firing technology for more than 10 years and is currently acting as engineer on the first US large-scale switchgrass co-firing project in Iowa as well as co-firing projects in Australia. Further Elsam Engineering has been retrofitting a 350 MWe unit at Studstrup Power Station, Denmark into co-firing of coal and straw [1]. The plant has been in commercial operation for two years now.

Co-firing is here defined as firing a minor share (<20%) of biomass into a large-scale fossil-fuelled (mainly coal) power plant. The actual co-firing technology depends on the type of biomass to be fired. Possible resources are: wood and bark, herbaceous matter (straw, switchgrass, miscanthus, etc.), sewage sludge, etc.

2 BACKGROUND

Back in 1995 the 150 MWe pulverised coal-fired Studstrup Power Station, Unit 1 - now demolished - was converted into co-firing of coal and straw for technology demonstration purposes. The conversion consisted of establishing a fully commercial straw pre-processing plant with a capacity of 20 tonnes per hour, corresponding to 20% of the total energy input at full load, and modifying the burner system. After plant commissioning in January 1996, a 2-year demonstration programme was initiated. The objective of the programme was to evaluate the influence of co-firing upon boiler plant performance, combustion chemistry, heat surface deposits and corrosion, ash residue quality, and emissions. In general the results were very encouraging for a further use of straw co-firing. However in 1998 it was not possible to utilise the fly ash from co-firing for cement or concrete production and commercial use of the co-firing technology was not possible. This obstacle was partly removed some years later where the requirements for use of fly ash for cement producion were revised and a 350 MWe unit was converted to straw co-firing in the beginning of 2002.

3 THE STUDSTRUP CO-FIRING CONCEPT

3.1 Plant description

Studstrup Power Station, unit 4 (SSV4) consists of a 350 MWe pulverized coal-fired unit commissioned in 1985. The boiler is a once-through single reheat type fitted with 24 low NO_x burners in two levels arranged as opposed wall firing. The steam temperature is 540°C at 250 bar. Four Deutsche Babcock MPS coal mills are used for pulverization of the fuel. SSV4 is equipped with a semi-dry desulphurisation plant. The upper burner level on the rear furnace wall was converted into combi-burners. The modifications of the burners involved only a few changes, see figure 1. The oil lance and the flame scanner were relocated in order to clear the core of the burner for pneumatic straw feeding.

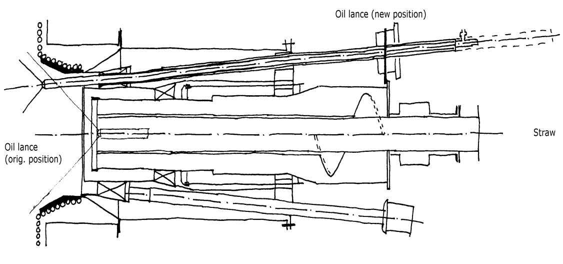

Figure 1: Burner modifications.

3.2 Straw handling

The straw handling equipment consists of a storage facility and a processing building erected at the south-west corner of the coal ya sections with a capacity of 560 Hesston bales each. The bales with a standard dimension of 1.2 × 1.3 × 2.4 m and a typical weight range of 450-600 kg are delivered to the Studstrup Power Station by trucks.

The trucks are unloaded by an overhead crane. The crane unloads 12 bales - one batch - in the same procedure. During unloading the bales are weighed, the moisture content is measured - using microwave techniques - and the data are stored on a central logistics computer.

The processing plant consists of 4 parallel lines each with a processing capacity of 5 tonnes straw per hour, see figure 2. In total the maximum straw capacity is 20 tonnes/h corresponding to a straw share of 10% on energy basis at full boiler load. The straw flow to the boiler is controlled by tier conveyors situated before the shredder. After the cords – holding the bales together – are cut, the straw is shredded be means of heavy-duty garbage disposal machinery. The straw is then sucked trough a stone trap – removing the heaviest particles – into the hammermill. In the hammermill the straw is cut into lengths of no more than 50 mm. From the hammermill the grinded straw is passing through an airlock from where it is pneumatically transported in four parallel lines the final 300 meters before it enters the furnace.

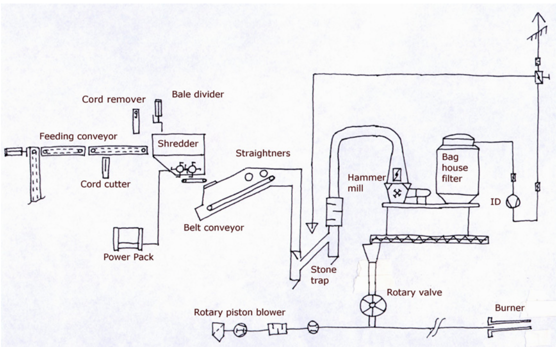

Figure 2: Straw processing at Studstrup.

4 EXPERIENCES FROM STUDSTRUP

4.1 Fuel

Imported coal from South Africa and Colombia are the main coal types used at SSV4. Most of the combusted straw are wheat straw, but also barley, oats, hay and rape straw are received. Analysis of coal and straw are shown in table 1.

Table 1: Fuel analysis of South African (SA) and Colombian (CO) coal and Danish straw

	SA coal	CO coal	Straw	
			Typical	Variation
Moisture (%)	8.4	12.2	14	8-23
Ash (%), dry	14.5	11.3	4.5	2-8
Q eff. (MJ/kg)	24.8	24.7	14.9	12.2-16.7
S (%), dry	0.6	0.9	0.15	0.1-0.2
Cl (%), dry	0.01	0.02	0.4	0.1-1.1
N (%), dry	1.7	1.5	0.7	0.3-1.5
K (%), dry	0.08	0.22	1.0	0.2-2.6
Na (%), dry	0.02	0.06	0.05	<0.3
C (%), dry	71.4	69.9	47.5	45-49
H (%), dry	3.8	4.7	5.9	5.4-6.4

Due to wet weather condition in the 2002 harvest season the content of potassium and chlorine in the straw was lower than typical (0.8% K and 0.2% Cl). The 2003 harvest season was dry and the content of potassium and chlorine was higher than typical (1.5% K and 0.5% Cl).

4.2 The straw pre-processing

In connection with the transfer of co-firing from Studstrup unit 1 to unit 4 the operation pattern changed fom 5 x 24 hours to 7 x 24 hours and the straw pre-processing facilities were upgraded. When the straw pre-processing facilities were established back in 1994 the idea was to use very sturdy components rather than using the agricultural machinery that were previously used. In spite of this approach the availability was not sufficient. Major upgrades were made on the straw shredders where the hydraulic system was completely renewed and on the hammermills where larger electrical motors were installed. The upgrade has been successful and servicelife, availability and working environment have been significantly improved.

4.3 Combustion

Four of the six upper level rear wall burners were converted into combined coal/straw burners. Experience from especially unit 1 have shown that LOI in the bottom ash may be high due to unburned straw nodes causing problems in the subsequent handling and reuse of the bottom ash. At SSV4 we have succeeded in optimising combustion by coal/straw burner regulation and straw feeding velocity which together with the opposed wall firing is giving a LOI at almost the same level as for firing coal alone. There are no handling problems with the bottom ash and it is sold for brick production.

On several occasions LOI in fly ash has been measured for co-firing of straw and for comparison also when firing coal alone. The results in table 2 show that co-firing of straw generally improves the carbon burn out. In some cases char particulates from straw can be observed visually in the fly ash, but this do not contribute significantly to the LOI.

Table 2: LOI in fly ash for firing coal alone and co-firing of straw

Trial date	13-05-2003	06-08-2003	03-09-2003	10-09-2003	20-09-2003
LOI, co-firing [%]	2.5	2.2	1.8	1.3	3.1
LOI, 100% coal firing [%]	2.8	3.7	2.2	1.4	3.5
Oxygen percent in boiler [%]	2.8	2.3	5.2	4.1	-
Load [%]	100	100	50	75	-
Straw share, energy basis [%]	6.6	9.7	9.9	10.9	7

Based on the data from table 2 and the fact that unburned carbon in the bottom ash is only slightly increased compared to 100% coal-firing, and based on the fact that more than 90% of the in-fed amount of ash become fly ash, it may be concluded that straw co-firing actually improves the boiler efficiency compared to firing coal alone.

4.4 Fly ash properties and utilization

Sale of fly ash from co-firing for industrial utilization must be secured for a successful implementation of co-firing technology. As shown above co-firing of straw do not increase LOI and content of unburned carbon in the fly ash, but the content of K_2O, CaO, P_2O_5, SO_3 and Cl in the fly ash may be increased dependent on the coal composition, combustion conditions and straw share. The content of water soluble potassium and chloride is increased as shown in figure 3, but the level is very low. Impactor measurements in the flue gas have shown that 7% straw co-firing on energy basis do not increase the formation of submicron particles, but may increase the content of potassium in the submicron particles due to formation of potassium sulphate. The reason for the limited effect of co-firing on water soluble potassium and chlorine in the fly ash is that KCl from straw reacts with coal ash at the high combustion temperatures in a PF boiler. Hereby potassium is captured as potassium-alumina-silicate and chloride is released as gaseous HCl. Typically 5-10% of the potassium from straw is found as water soluble potassium in the fly ash.

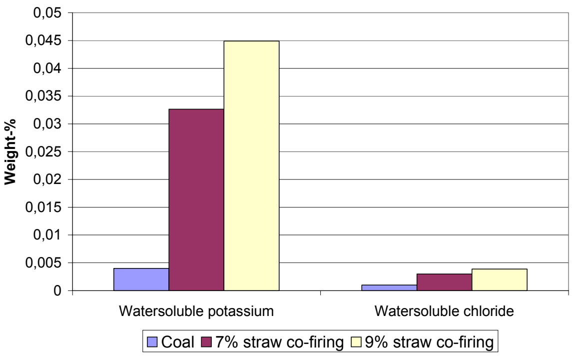

Figure 3: Water soluble potassium and chloride in fly ash from coal firing and straw co-firing.

In Denmark coal fly ash is mainly used in cement production and in concrete mixtures. The limits for content of alkali in fly ash for cement production can be met by use of low-alkali coal and presently this is the main use of ash from SSV4. Use of ash from co-firing in concrete is presently not allowed by the European standard EN450, but a revision of EN450 that allow co-firing of specific fuels, including straw, is expected soon. Fly ash from SSV4 comply with all requirements in the revised EN450 and an extensive compliance test programme has been initiated in cooperation with the Danish concrete industry. By an amendment of national rules use of fly ash from co-firing in concrete is expected to be possible in Denmark by the end of 2004.

4.5 Deposit formation and corrosion

Deposit formation was investigated during the demonstration programme at Studstrup unit 1 in 1996-98. At 10% straw share on energy basis an increased deposit formation was observed, but this was handled without problems by increased soot blowing. Coal types with high content of sulphur and alkali may however cause fouling problems due to increased formation of K_2SO_4. At 20% straw share some slagging problems were seen.

At SSV4 deposit formation has not yet been studied in details, but within the first two years of operation no fouling problems have been observed and there has been no need for increased soot blowing.

Superheater corrosion was investigated at Studstrup unit 1 by exposure of metal rings on cooled probes and of a range of materials build into the superheater [2]. The exposure time was approximately 3000 hours at 10% and 20% straw share on energy basis. It was found that no chloride corrosion occurs and no chloride was detected in the corrosion samples. By co-firing of 10% straw the corrosion rates were at the same low level as for coal firing alone. By 20% straw co-firing the corrosion rates did increase by a factor 2 to 3 due to higher content of potassium sulphate in the deposits.

At Studstrup unit 4 corrosion tests were initiated in September 2002. Test tubes of different materials were build into the super heater and will be exposed up to three years in order to examine the long term corrosion rates. The first results will be available by the end of 2004.

4.6 NO_x emissions

In general, the NO_x formation process strongly depends on the residence time, temperature profile and air-to-fuel stoichiometry profile of the combustion process. It is by co-firing of pulverized wood - at comparable firing principles - shown that a low NO_x effect can be obtained. The explanation may be that the higher volatile matter of the biomass results in larger releases of volatiles and fuel-N in the flame. The result is a lower stoichiometry, which suppresses NO formation from fuel-N in staged combustion. Compared to the used straw grinding it is questionable how much the relative large particle size of the straw will restrain the release and volatiles and fuel-N and by that the low NO_x effect.

In figure 4 examples of NO_x emission measurements at SSV4 at 100%, 75% and 50% load are shown. The NO_x emissions by 10% co-firing of straw is maintained at the same level as coal-firing alone or marginally reduced.

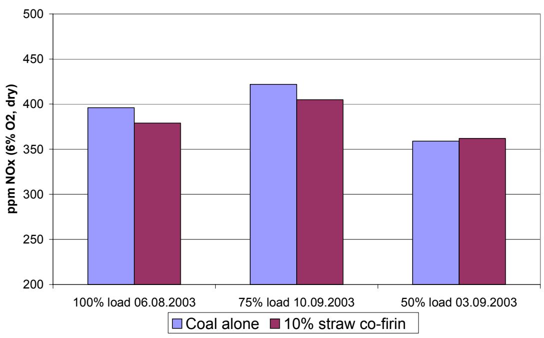

Figure 4: NO_x emission measurements at SSV4.

The content of nitrogen in straw varies depending on the fertilizer dose and climatic conditions. In the above shown tests the average concentration of N was 0.40g/MJ for straw compared to 0.64g/MJ for coal. From figure 4 it can be calculated that the reduction in NO_x is comparable to what could be attributed from the reduced fuel-N input.

4.7 SCR catalyst deactivation

Deactivation of high-dust (HD) SCR catalysts is one of the critical issues of straw co-firing. In order to investigate this problem slip stream SCR reactors have been installed at SSV4 and SSV3. SSV3 is a coal-fired sister unit to SSV4, that can be used as a coal-reference for deactivation tests. The reactors are exposed with flue gas extracted between the economizer and the air preheater, where the flue gas temperature is 300-380°C depending on boiler load. The reactors are equipped with soot blower system supplied with pressurized air. Nine SCR elements with dimension 150 x 150 x 500 mm are installed in each reactor.

The exposure was initiated in November 2002 and finalized in July 2003. An exposure time of 5000 hours was achieved. The mean straw share in this period was 7% on energy basis (11 weight-%).

Three different types of HD catalysts were investigated. Figure 5 show the relative catalyst activity as a function of exposure time for coal-firing in SSV3 and straw co-firing in SSV4 for the catalyst type delivered by Topsoe.

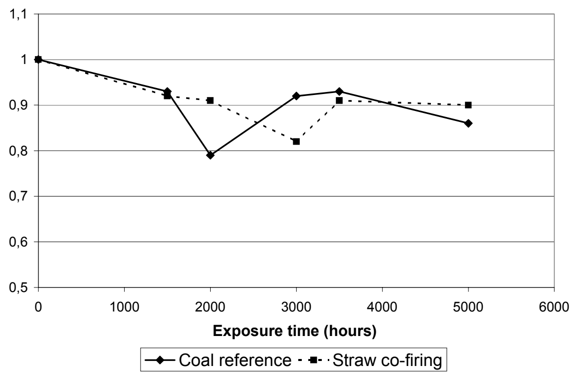

Figure 5: Relative catalyst activity vs. exposure time.

There is no distinguishable difference between the deactivation of HD catalyst by exposure of flue gas from coal alone and from 7% straw co-firing. Similar results were obtained for the two other HD catalyst types. The observed deactivation is caused by As-poisoning and formation of ash surface layers. In order to confirm these encouraging results long time deactivation tests (20,000 hours exposure) are in planning.

5 MODELLING COFIRED FURNACES

In 2002, a R&D project titled: "Modelling of bio-boilers– 2nd generation co-firing" was started. The project is a continuation and extension of an ongoing project: "Biomass Co-firing in Suspension-Fired Power Plants". The funds for these two projects alone are 4 million Euro.

The overall objective of the R&D project is to develop a CFD based model that can contribute as a decision tool for co-firing of future units. At first the project will aim to model co-firing of biofuels and later focus on a wider fuel spectrum, including waste fractions.

The model will to a large extent be verified and compared with test data from pilot plants and full-scale plants. The model will incorporate the knowledge gained from other projects – both already completed and ongoing projects.

6 CONCLUSIONS AND FUTURE PERSPECTIVES

The main conclusions from the first two years' operational experiences of full-scale commercial co-firing of 10% straw on energy basis at Studstrup unit 4 are that

- Acceptable availability of the straw pre-processing unit can be achieved
- LOI in fly ash is reduced by co-firing
- NO_x emissions by co-firing are maintained at the same level as for firing coal alone or marginally reduced
- No increase in boiler deposit formation is seen
- Fly ash can be used for cement production and in near future presumably also for concrete
- No increase in deactivation of high dust SCR catalyst by 7% co-firing has been observed

In order to further verify the feasibility of the straw co-firing concept long term tests of super heater corrosion are in progress and long term tests of SCR catalyst deactivation are planned. Also the alkali-chloride-sulphur chemistry of straw co-firing will be studied in more detail in order to improve the understanding of the mechanisms of corrosion, catalyst deactivation, fly ash properties etc. Furthermore the development of a CFD based model for co-firing will assist in optimisation of future co-firing plants.

We consider co-firing to be a feasible concept both from a technical and a financial perspective. We consider the co-firing technology to have a very interesting future with many new plants to be installed in the years to come. Co-firing will not be limited to biomass but will also be used with a number of other fuels. The need to burn all-combustible wastes as directed by the EU is likely to fuel this development.

ACKNOWLEDGEMENTS

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