Corrosion and deposit investigations during large-scale co-combustion of switchgrass at a coal-fired power plant

Jacob Nygaard Knudsen*, Jens Juel Christiansen, Lars Lærkedahl, Ole Hede Larsen and Bo Sander, Elsam Engineering A/S[1], Kraftværksvej 53, 7000 Fredericia, Denmark
Melanie Montgomery, IPL, Technical University of Denmark, Kemitorvet, 2800 Lyngby, Denmark
Jon Bickford, Alliant Energy, 20775 Power Plant Road, Ottumwa, Iowa – USA
Thomas R. Miles, T R Miles Technical Consultants, Inc.,1470 SW Woodward Way, Portland, OR 97225 - USA
Kevin Comer, Antares Group Inc., 4351 Garden City Drive, Suite 301, Landover, MD 20785 – USA

*Corresponding author. Phone: + 45 30 94 99 51, e-mail: jackn@dongenergy.dk

Abstract

Since year 2000 tests have been conducted with co-firing of switchgrass at the 725 MWe coal-fired power plant, Ottumwa Generation Station, in Iowa as part of the Chariton Valley Biomass Project. In this paper, corrosion and deposit investigations during a 2000-hour continuous co-firing test with an average input of 12.5 t/h switchgrass are presented. The deposition behavior was characterized by short-time exposure of cooled deposit probes at three different locations in the boiler. Analysis of the deposits indicated that the deposition behavior and the deposit chemistry were not influenced by switchgrass co-firing to a significant extent. Comparison of fly ash samples collected during co-firing tests and coal reference tests also indicated that the influence of co-firing was minor. Test tubes for quantification of corrosion rates were installed in the most critical parts of the superheaters and were exposed to co-firing of switchgrass for 1675 hours. SEM analyses of the test specimens revealed no signs of accelerated or chlorine-induced corrosion because of co-firing of switchgrass.

Keywords: Co-combustion, biomass, full-scale tests, deposition, corrosion

Introduction

Substitution of fossil fuels by biomass remains an attractive option to reduce the net CO_2 emissions from power generation in the short and middle term. The large quantities of biomass required in order to provide significant substitution of fossil fuels, urges the power generators to explore other biomass resources than the traditional woody fuels. Herbaceous biomass such as straw and grasses is in many parts of the world available in substantial quantities. However, “standalone combustion” of herbaceous biomass in heat and power-producing boilers has been known to cause severe problems with fouling, slagging, and chlorine-induced corrosion because of the relatively high contents of chlorine and potassium in these types of biomass (Baxter, 1998, Michelsen et al., 1998, Sander et al., 2000). On the contrary, co-combustion of coals and biomass fuels has been shown to decrease the adverse impacts of biomass, because the mineral constituents of coals may incorporate the potassium of the biomass into high-melting, less-corrosive compounds. Among others, co-firing with up to 20 %-wt. high-alkali straw has been successfully demonstrated in full scale (Sander and Wieck-Hansen, 2005, Hansen et al., 1999).

In certain parts of the USA, switchgrass (Panicum virgatum) has been considered a promising co-fuel. Switchgrass (SWG) is a native Iowa grass that grows well on marginal ground. The most important elements with respect to deposit formation and corrosion introduced by co-firing SWG are potassium and chlorine. The content of these elements varies much in SWG, but especially in the early harvest SWG has a significantly higher content of K and Cl than the Powder River Basin coal used at the plant.

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[1] Elsam Engineering A/S is now a part of Dong Energy

The goal for the Chariton Valley Conservation Reserve and Development Inc. (CVRCD) is to grow up to 200,000 tons of SWG annually, and by co-firing the biomass at the Alliant Energy's coal-fired power plant Ottumwa Generating Station (OGS) up to 5% of the annual coal consumption could be replaced.

As part of the Chariton Valley Biomass Project (a federally cost-share funded project coordinated by CVRCD) several co-firing tests have been conducted, and the goal is a commercial system with a full design capacity of 25 tph (22.7 tonnes/h), generating ~35 MW_e of power from renewable energy sources.

The first test campaign was performed from November 2000 through January 2001 with non-commercial SWG handling equipment. The aim of the first test was to observe the effects on the boiler operation and emissions and to study the handling of the SWG. It was shown that co-firing of up to 16.8 tons/h (15.2 tonnes/h) - corresponding to a heat input of about 3% - is feasible without adverse operational problems.
From November through December 2003, the project's Interim Co-firing Test was completed. The purpose was to test and improve the processing equipment, to verify the emissions and performance information obtained during the first test campaign and to collect and characterize coal, SWG and ash samples.

This paper describes the findings with respect to corrosion and deposition during the project's third and final test burn, a 2,000 consecutive hour continuous test burn of SWG co-fired with coal in the OGS boiler. The test burn was conducted from February through May 2006, and 1675 hours of operation were achieved burning around 15,650 tons of SWG. In addition, a coal only reference test was carried out in July 2006. The third test burn was intended primarily to assess long-term impacts of burning SWG in the OGS boiler.

Experimental

Site description and fuels

Ottumwa Generating Station, operated by Alliant Energy, is pursuing co-firing of SWG as a supplementary fuel in its 726 MW_e (675 MW_e, net plant output) tangentially-fired pulverized coal boiler. This boiler, which went into commercial operation in May 1981, is fired with low-sulfur Powder River Basin (PRB) coal. The characteristics of the coals fired during the test campaign are shown in Table 1.

The boiler is a twin furnace design without division walls. It has eight firing corners. The boiler is equipped with a hot-side electrostatic precipitator, but no desulphurization unit.

The current capacity of the SWG processing facility is 12.5 t/h. The SWG is transported pneumatically about 1000 feet from the processing building into two burners placed in the corners opposite of each other in the eastern part of the twin furnace. The characteristics of the SWG fired during the co-firing tests are shown in Table 1.

Table 1. Coal and SWG characteristics (average of all tests)

	Moisture (% a.r.)	*Ash (%-wt.,dry)*	*LHV (MJ/kg, dry)*
Coal	24.7	6.2	27.6
SWG	7.7	5.9	18.3

	Si	*Al*	*Ti*	*Fe*	*Ca*	*Mg*	*Na*	*K*	*P*	*N*	*S*	*Cl*
						(%-wt., dry)						
Coal	0.91	0.52	0.05	0.23	1.13	0.21	0.10	0.02	0.02	0.85	0.38	0.002
SWG	1.79	0.07	0.00	0.05	0.51	0.14	0.01	0.39	0.12	0.69	0.07	0.07

Test plan and procedure

In order to quantify the effect of co-firing on deposition and superheater corrosion, short-term test campaigns and long-term exposure of test tubes have been performed.

The short-term tests are performed as five-hour measuring campaigns with stable and well-defined operational conditions. This will ensure that complete and consistent data sets can be established. In each measuring campaign, the deposit probes were exposed for three hours and samples of coal, SWG, and ash were taken.

Originally, it was planned to conduct tests with SWG with respectively a high and low content of alkali and chlorine, i.e., early and late harvest, however as the bales collected for the long-term test burn have been accumulated over 3 years it was not practically possible to differentiate them in the available stock.

Therefore, the general idea of the test plan was to perform short-term tests at 100% boiler load and at 50% boiler load with the SWG capacity as close to 12.5 t/h during the entire period. Following this approach, the boiler load is used to change the SWG share. Both tests were repeated once. Furthermore, a 24-hour test was made under “normal load conditions”. The schedule shown in Table 2 was followed.

The maximum capacity of the SWG processing facility is 12.5 t/h corresponding to a SWG share of approximately 3 %-wt. (dry basis) at full boiler load.

Table 2. Test plan - deposit probe measurements

Test #	*Date*	*Time*	*Boiler load*	*Exposure time (h)*
Co-firing				
1	22 March 2006	9.00-14.00	100%	3
2	22-23 March 2006	23.00-04.00	50%	3
3	23 March 2006	09.00-14.00	100%	3
4	23-24 March 2006	23.00-04.00	50%	3
5	24-25 March 2006	07.00-09.00	“normal load”	24
Coal reference				
1	3 July 2006	8.00-12.00	100%	3
2	3 July 2006	12.00-16.00	100%	3
3	5 July 2006	20.00-00.00	50%	3
4	6 July 2006	00.00-04.00	50%	3
5	6-7 July 2006	06.00-06.00	“normal load”	24

For the long-term corrosion test, the corrosion probes were installed for a total of 4 months.

In Figure 1, an illustration of the boiler top with the locations of the different measurement probes is shown.

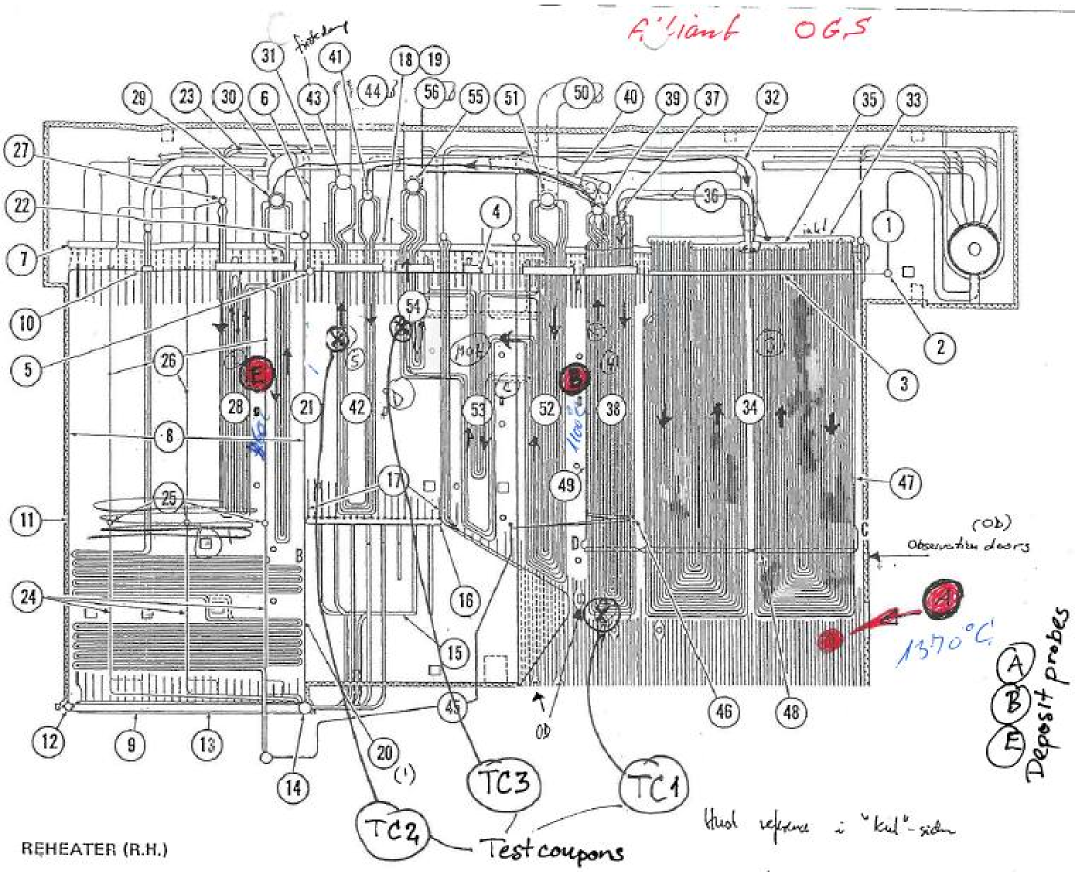


Figure 1. Illustration of boiler top and locations of deposit probes and test coupons

Deposit probe measurements

The effect of co-firing on the initial deposition rate and initial deposit chemistry was evaluated by the use of cooled deposit probes. A schematic illustration of the applied deposit probe is shown in Figure 2. The probes were equipped with two exchangeable test rings for deposit collection and a thermocouple ring for metal temperature measurement in three circumferential positions. The surface temperature of the probe was in all tests maintained at a predefined value (540°C) by automatic control of the flow of cooling air. Test rings made of 10CrMo910 steel, i.e., common superheater material, were utilized in all tests.

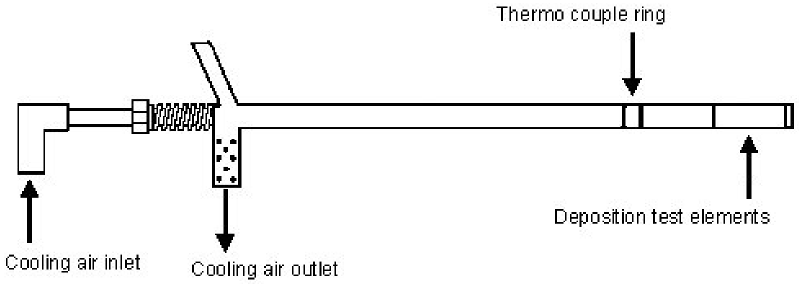


Figure 2: Schematic outline of air-cooled deposit probe

The positions of the deposit probe measurements have been chosen to be able to evaluate the effect of co-firing on both high-temperature and low-temperature fouling. High-temperature fouling is important, as the increase in potassium from SWG may soften the silicates in this zone. Low-temperature fouling is important, as the Powder River Basin coals have a high tendency towards this type of fouling, mainly due to the high content of Ca and the potassium from the SWG, which may affect this type of fouling. The probe measurements are made in three positions in the eastern part of the boiler as shown in Figure 1; position A – before the Division Panel section, position B after the Pendant Platen Section, and position E before the Low-temperature Pendant Section.

As indicated in Table 2, the deposit probes were exposed for three hours of the five-hour test. Two supplementary long-term tests were conducted for a period of 24 hours at normal load for the coal-only reference and for the co-firing period. Each test included simultaneous measurement in all positions, i.e. three probes.

After exposure, the test rings were dismantled with great care to ensure that no deposit was removed. In the laboratory, by use of a preformed shape, deposits were carefully removed on the upstream and downstream side respectively. The weights of upstream and downstream deposits were measured. The composition of the upstream and downstream deposits was analyzed for the elements S, Cl, P, Si, Al, Fe, Ca, Mg, K, Na, Ti, and water-soluble Na and K. In selected tests, the cross-sections of test rings were analyzed in a scanning electron microscope with analysis facilities (SEM-EDS) after metallographic preparation without the use of water as a lubricant, i.e., to avoid leaching/redistribution of soluble elements.

Corrosion tests

The corrosion tests included both analysis of the deposit probes and the installed corrosion test tubes.

The deposit probes were exposed in positions A, B, and E indicated in Figure 1. The probes are made of 10CrMo910 with 2.0-2.5 %Cr and 0.90-1.10 Mo. They have had 540 °C metal temperature and varying flue gas temperatures where A≈1370 °C, B≈1100 °C and E≈750 °C. The exposure time was 3 hours.

Test tubes for quantification of corrosion rates were installed in the most critical parts of the superheaters (position TC1, TC2, and TC3) as shown in Figure 1. The corrosion probes were installed for a total of four months (2880 hours), however, co-firing of SWG only occurred during the last 1675 hours. After exposure, the test tubes were removed, mounted in epoxy resin and metallographically prepared for SEM investigation. The steam temperature was 540 °C, and the gas temperature was approximately 1350 °C in position TC1.

All of the specimens analyzed in this work were positioned in the TC1 location. The alloys investigated were 10CrMo910, 13CrMo44, 347H, and 304H. The specifications for the specimens investigated are given in Table 3.

Table 3. Composition of the four steels applied in the corrosion tests

Material	*C*	*Fe*	*Cr*	*Ni*	*Mn*	*Mo*	*Nb*	*Si*
10CrMo910	0.07-0.15	rest	2.0-2.5		0.40-0.70	0.90-1.0		0.20-0.50
13CrMo44	0.08-0.18	rest	0.70-1.10		0.40-1.00	0.40-0.60		0.10-0.35
347H	0.04-0.10	rest	17.0-20.0	9.0-13.0	<2.0		0.8-1.0	<1.00
304H	0.04-0.01	rest	18.0-20.0	8.0-10.5	2.00			0.75

The specimens were investigated using a JEOL JSM 590 scanning electron microscope with EDS facilities and a backscattered detector. For the deposit specimens, a sample of deposit was removed from the ring, and in addition the ring specimen was cross-sectioned. All specimens were prepared without the use of water as a lubricant.

Results and Discussion

Fuel composition

By co-firing SWG, the deposition behavior may be affected because of the higher content of water-soluble alkali elements, mainly potassium, in SWG compared to that of coal. Potassium associated in water-soluble compounds, i.e., salts, is easily volatilized in the burner zone and may subsequently form low-melting deposits on heat transfer surfaces (Baxter, 1998, Michelsen et al, 1998). However, during co-firing with coal the potassium that has been volatilized from SWG may to a high extent be transformed into high-melting Al-silicates by interaction with the mineral constituents of coal (Sander, 2005). For this reason, the stoichiometry between the Al, Si, and alkali elements is important in determining the impact of SWG co-firing on deposition.

On the basis of fuel analyses (Table 1), the changes in the molar ratios of the key ash-forming elements have been estimated as shown in Table 4. It is seen in Table 4 that the SWG share during the co-firing tests has been in the range of 3-5 %-wt. (dry matter) of the total fuel input. This has resulted in an increase of the total alkali input of 5-13% compared to coal firing alone. Additionally, it appears that the increase in alkali input has not affected the Al/(K+Na) and Si/(K+Na) ratios significantly compared to coal-firing alone. For all of the conducted tests, there is a vast excess of Al and Si to facilitate complete incorporation of the alkali constituents into alumina-silicates. Table 4 further indicates that in all of the co-firing tests, the Cl/(K+Na) and 2S/(K+Na) molar ratios are significantly below and above unity, respectively. This indicates that in the case that the alkali contents of SWG is not completely incorporated into Al-silicates, the remnants will most likely be present as sulfates instead of the more corrosive chlorides.

Thus, based on the change in bulk ash composition no significant change in the deposition behavior or fouling tendency is expected during SWG co-firing by up to 5 %-wt.

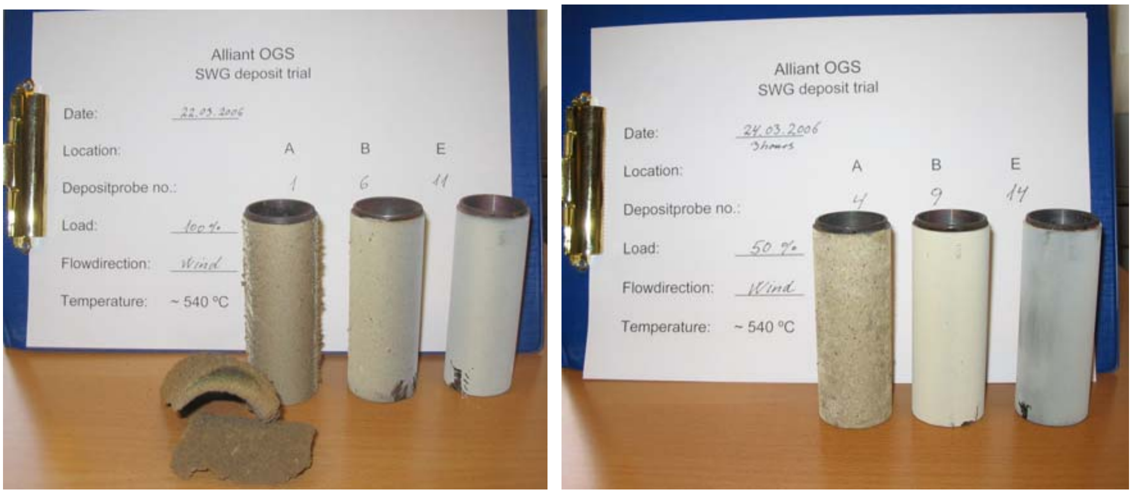
Table 4. Influence of SWG co-firing on bulk ash composition.

Test	*SWG share (%-wt., dry)*	*Increase in K+Na (%)*	*Al/(K+Na)*	*Si/(K+Na)*	*Cl/(K+Na)*	*2S/(K+Na)*
Pure coal (average)	0	-	3.9	6.0	0.01	3.6
Pure SWG (average)	100	-	0.26	6.1	0.18	0.26
Co-firing:						
Test 1	3.1	6.3	4.3	8.0	0.038	4.6
Test 2	5.1	13.3	3.2	5.8	0.038	3.3
Test 3	3.0	6.2	3.9	6.8	0.013	3.3
Test 4	4.6	12	3.3	5.5	0.022	3.1
Test 5	3.3	5.0	3.7	5.0	0.018	2.7

Deposit probe tests

In general, the deposit probe measurements confirm that the deposit composition and the deposition behavior are only marginally influenced by SWG co-firing. On the other hand, the change of boiler load from 100 to 50% has a great impact on the deposition behavior.

In Figure 3, pictures of deposits obtained during SWG co-firing at 100 and 50% boiler load, respectively, are shown. The big deposit pieces, which are seen in front of test ring A (left picture) are recovered from the outer deposit layer (upstream side). These pieces detached during probe retraction. It is evident from Figure 3 that most material is deposited in position A followed by B and E. It is also clear that more material is deposited during the test at 100% load despite the fact that the SWG share is lower during this test.



Alliant OGS
SWG deposit trial
Date: 22.03.2006
Location: A B E
Depositprobe no.: 1 6 11
Load: 100 %
Flowdirection: Wind
Temperature: ~ 540 °C

Alliant OGS
SWG deposit trial
Date: 24.03.2006 3 hours
Location: A B E
Depositprobe no.: 4 9 14
Load: 50 %
Flowdirection: Wind
Temperature: ~ 540 °C

Figure 3. Deposit test rings after 3 hours' exposure. Left: Co-firing Test 1 - 100% load. Right: Co-firing Test 2 – 50% load.

Estimates of the deposition fluxes (upstream side) at positions A, B, and E can be derived from the deposit probe measurements, which are shown in Figure 4. As some of the deposited material was lost from the probe during retraction in most of the tests, the estimated values only provide an order of magnitude estimate. At position A, the deposition flux is very high (1-10 kg/m^2/h) during full load but decreases substantially (10-20 g/m^2/h), as the load is reduced. In position B, the deposition flux is much lower than at A at full load, but at 50% load the difference is less pronounced. In position E, the deposition flux is lower (0.5-6 g/m^2/h) than at the other two positions. It is expected that locations further downstream are experiencing lower deposition fluxes, because the flue gas temperature is lower (≈750 °C at pos. C contra ≈1370 °C at pos. A) and thereby the fly ashes have lower tendency to stick. Figure 4 furthermore reveals that SWG co-firing has no detectable influence on the deposition fluxes.

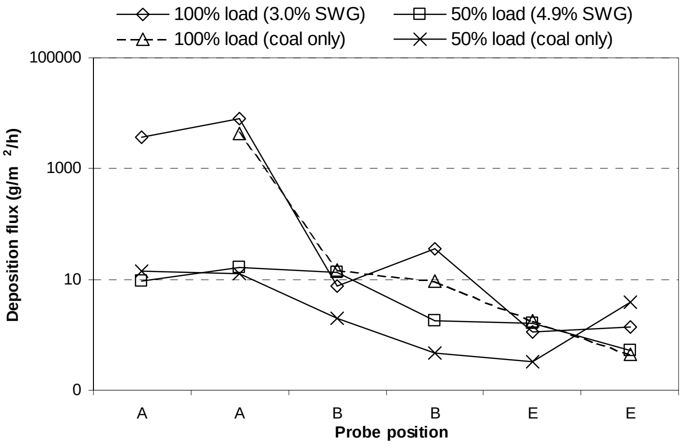


Figure 4. Measured deposition flux (upstream side) as a function of probe position.

The deposition flux at the downstream side of the deposit probe has been estimated to be in the range of 0.5-20 g/m^2/h. The influence of probe location and boiler load is less distinct. Again, no noticeable effect of the SWG share is observed. The deposition flux at the downstream side is expected to be much lower because it is shielded from impacting particles.

Chemical analyses have been performed on the deposit samples. In most of the tests, the material collected at position E was too low to allow full chemical analysis. In Figure 5, the elemental composition of the deposits collected at positions A and B during co-firing and 100% coal-firing is shown. The chlorine content is not shown in the diagrams, as it was very low (<0.1 %-wt.) and typically below the detection limit at all probe locations (A, B, and E) and for all SWG shares. The low chlorine content of the deposits indicates that the risk of chlorine-induced corrosion at the SWG share applied in these tests is low. Likewise, the concentration of low-melting alkali chlorides in the deposits is too low to affect the general melting behavior of the deposits.

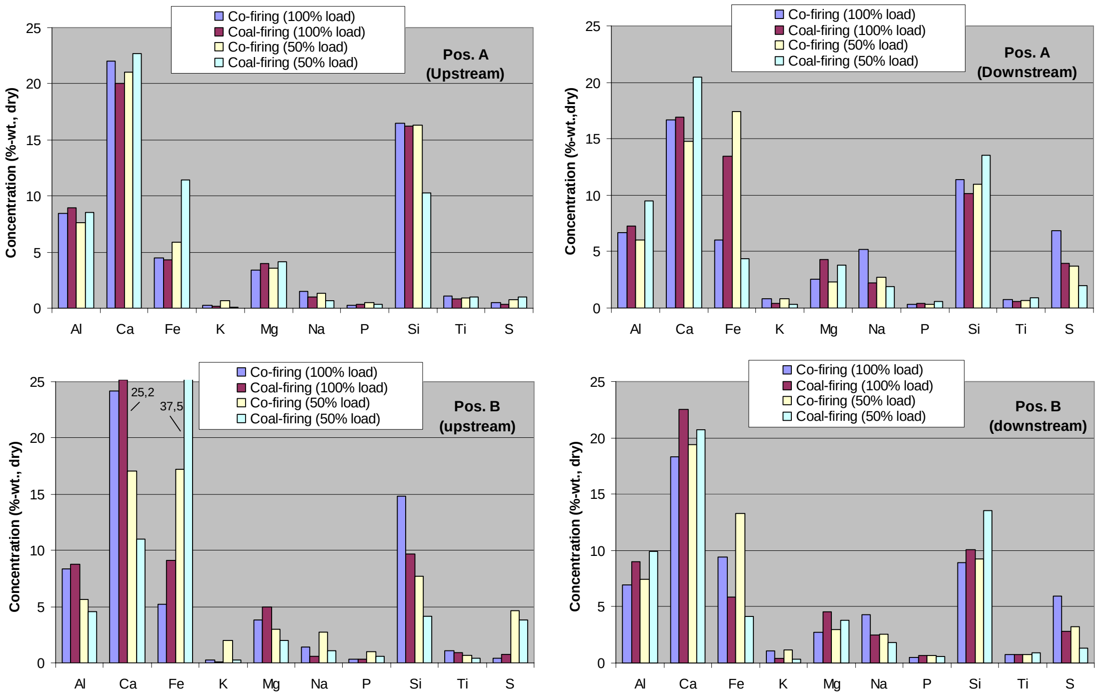


Figure 5. Elemental composition of deposit samples obtained during SWG co-firing and coal reference tests.

Generally, Figure 5 shows that the deposits collected during co-firing and 100% coal-firing as well as at 100 and 50% load (corresponding to 3.0 and 4.9 %-wt. SWG share, respectively) have very similar composition. The increase in potassium content caused by the increased SWG share is insignificant. Comparison of the upstream and downstream side of the deposits reveals that the downstream side contains higher levels of sodium and sulfur, i.e., sodium sulfate. This is as expected as the leeward side will be richer in flame-volatilized species and leaner in elements contained in entrained ash particles (non-volatile elements). The high iron content observed in some of the samples is most likely related to contamination of the deposit sample with iron from the metal test ring. This may artificially lower the concentration of the other elements.

The concentration of water-soluble alkali (K+Na) in the deposits is varying between 0.1 and 6.7 %-wt. In Figure 6, left and right, the concentration of water-soluble K+Na in the deposits collected on the upstream and downstream side, respectively, is shown as a function of the applied SWG share. 0 %-wt. share SWG represents the coal reference tests.

It appears from Figure 6 that there is no clear correlation between the SWG share and the concentration of water-soluble alkali in the deposits. This is probably related to the fact that even small variations in the alkali concentration of the coals causes greater change in the K and Na inputs than co-firing of up to 5 %-wt. SWG. In addition, as the SWG share was increased by decreasing the boiler load, the flue gas temperature will decrease at each probe position as well. This suggests that flame-volatilized species may condense further upstream at reduced boiler load, which is in agreement with the results in Figure 6.

On the upstream side, it is seen that the concentration of water-soluble alkali is very low for all tests at probe position A. For probe positions B and C, the concentration of soluble alkali is in most cases significantly higher. At probe position E, the concentration of soluble alkali appears to be higher for the co-firing tests than the coal reference tests.

For the downstream side, Figure 6 (right) indicates that there are small amounts of water-soluble alkali present in the deposits collected at all locations. This is probably related to the fact that the downstream side, to a higher extent, is composed of flame-volatilized material. The concentration of soluble alkali on the downstream side does not appear to increase with increasing SWG share.

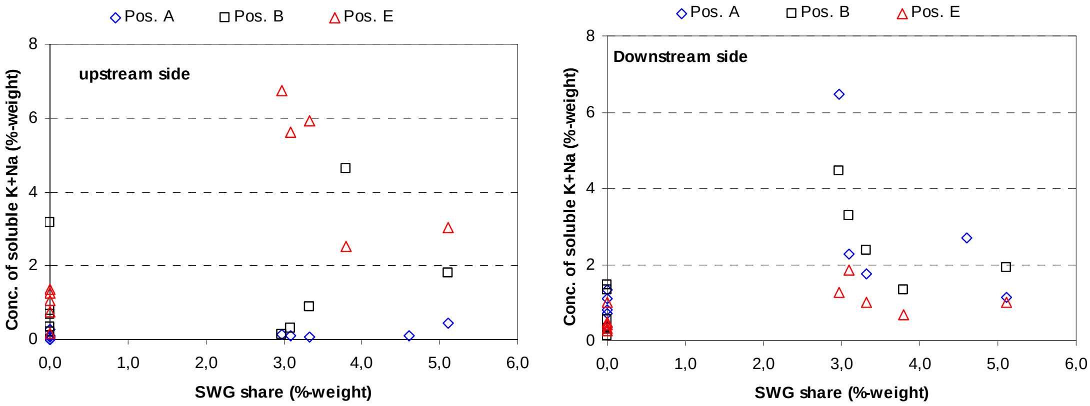


Figure 6. Concentration of soluble K+Na (%-wt.) in deposit from the upstream and downstream sides.

Altogether, the deposit probe measurements revealed that neither the deposit chemistry nor the deposition behavior was significantly affected by co-firing of up to 5 %-wt. SWG.

Corrosion tests

Deposit probes: For all test rings investigated, chlorine was not present within the deposit or oxide layers. The major elements identified in the deposits were Ca, Fe, Si, Al, and S. This is in good agreement with the results obtained from the chemical analysis of the deposits.

An example of an SEM image of a test ring (co-firing Test #4, position A) is shown in Figure 7. There are large and small silicon, aluminum, and calcium rich particles (spot #5 & 4). Sodium and sulfur are present between these particles. There is also an enrichment of sulfur within the inner chromium rich oxide (spot #2). No chlorine is present.

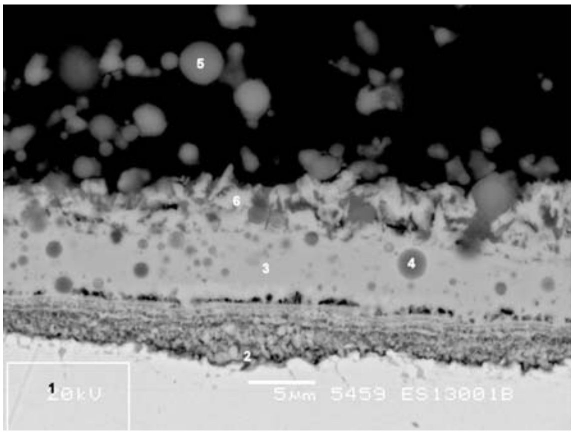


Figure 7: Cross section of deposit at position A, co-firing Test #4.

Corrosion test tubes:

In Figure 8, SEM images of test specimens #121-124 (cross sectional view) are shown. The specimens #121-124 are fabricated from 307H, 10CrMo910, 13CrMo44, and 304H, respectively. The numbers appearing in the images refer to the spots where the composition was determined by EDS analysis.

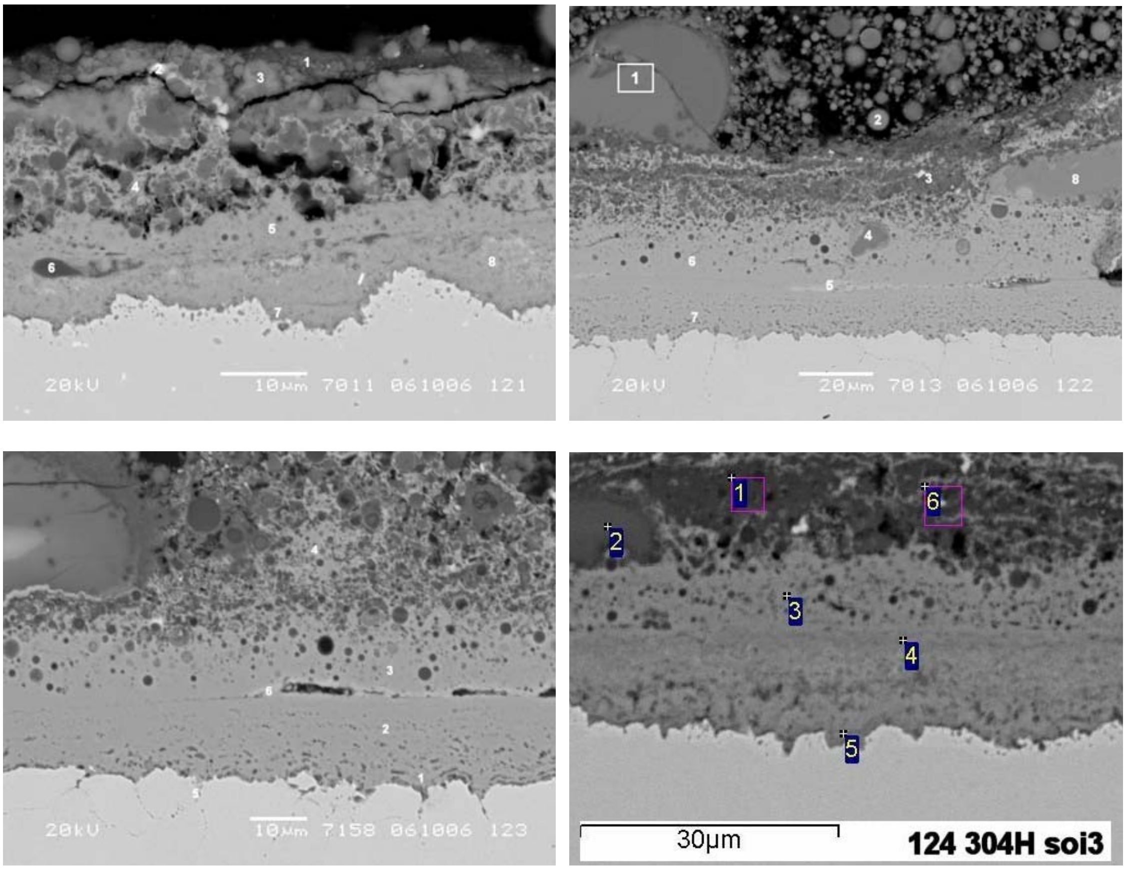


Figure 8. SEM EDS analysis of test specimens exposed for 1675 h at position TC1. Sample #121 is 347H, sample #122 is 10CrMo910, sample #123 is 13CrMo44, and sample #124 is 304H.

a) 347H
For the specimen #121, the deposit adjacent to the oxide predominantly consists of calcium, oxygen and sulfur, presumably calcium sulfate (spot #1 and 3). In the deposit, aluminum and silicon are also present presumably as particles; barium was also detected. The oxide consisted of an outer oxide of iron oxide (spot #4 and 5) and an inner oxide of iron-chromium-nickel oxide (spot #7 and 8). Sulfur was also enriched within this oxide. Iron oxide particles are also present within the deposit as threads of oxide.

b) 10CrMo910
For the specimen #122, the outer deposit was rich in titanium. The inner deposit was more calcium and sulfur rich with particles of calcium, silicon, and aluminum, presumably calcium silicate/aluminates. In addition there are many fine particles consisting of silicon and aluminum. Sulfur and oxygen are present throughout the whole of the deposit.

Analysis of the corrosion products adjacent to the oxide layer (spot #3) reveals the presence of deposits rich in calcium and potassium and iron together with calcium and potassium and iron - perhaps an iron alkali (Ca, K) sulfate. In addition, there is presence of iron calcium oxide (spot# 1, 2, and 4), which indicates that the calcium and potassium sulfates attack the outer iron oxide. The temperature of the surface of the alloy is unknown; however, the flue gas temperature is approximately 1350 °C, which indicates high heat flux. $CaSO_4$-K_2SO_4 forms a eutectic melt at 867 °C, which can lead to hot corrosion. In addition an iron sulfate-alkali sulfate mixture forms a eutectic melt around 620 °C. The presence of sodium will further reduce this melting point. The inner part of the oxide also contains metal sulfides/sulfates (spot #5-8).

c) 13CrMo44
Specimen #123 has an outer calcium, silicon, and aluminum rich deposit. The corrosion products are predominantly iron oxide. However, both calcium and sulfur are detected within the outer oxide.

d) 304H
The outer deposit of specimen #124 is calcium sulfate (spots #1 and 6) and alumina silicate (spot #2). The outer oxide is iron oxide (spots #3 and 4), and the inner oxide is iron-chromium oxide (spot #3). The inner oxide close to the oxide-metal interface is also rich in sulfur.

Implications of corrosion tests
On the basis of the analyses undertaken, it must be concluded that generally there is no chlorine present in the deposits and corrosion products. Instead the deposit contains calcium sulfate and alumina silicates; however, there are also small amounts of both potassium and sodium present. Thus, there is no evidence to suggest that co-firing of up to 5%-wt. SWG influences the corrosion mechanism and corrosion rate. It is suggested that both hot corrosion and sulfidation has occurred. In general, the test specimens contain higher levels of sulfur in the oxide layer than seen in earlier co-firing investigations (Sander and Wieck-Hansen, 2005), considering the relatively short exposure time (1675 hours). This is presumably related to the relatively high calcium content of the coals, which provides good sulfur capture capability of the deposits.

Impact on fly ash composition
In Table 5, the elemental composition of fly ash samples obtained during co-firing and coal-reference tests are shown. In general, there is very little difference in the ash characteristics between the reference and co-firing tests. Similarly no significant influence of boiler load (and SWG share) is observed. The potassium content is slightly higher in the fly ashes obtained during SWG co-firing due to the increased potassium input with SWG. However, the concentration of soluble potassium remains low although it increases marginally. The chlorine concentration is very low in all the fly ash samples. The concentrations of sulfur, sodium and water-soluble sodium are somewhat higher in the fly ash generated during co-firing. As the sodium and sulfur contents of SWG are relatively low, these differences are presumably related to variations in the sodium and sulfur contents of the coals fired in the two testing periods.

It also appears from Table 5 that the fly ash composition resembles the composition of the deposits collected from the upstream side in positions A and B (Figure 5).

Table 5. Influence of SWG co-firing on fly ash composition (%-wt., dry).

Test	*Na(aq)*	*K(aq)*	*Si*	*Al*	*Fe*	*Ca*	*Mg*	*Na*	*K*	*S*	*Cl*
Co-firing:											
Test 1 – 100% load	0.97	0.09	15.4	8.7	4.3	20.5	3.6	3.0	0.44	1.37	0.002
Test 2 – 50% load	0.93	0.12	15.2	8.4	4.0	21.2	3.6	2.9	0.44	1.43	0.002
Coal reference:											
Tests 1,2 – 100% load	0.35	0.04	15.8	8.9	3.7	19.7	3.9	1.9	0.32	0.86	0.001
Test 3 – 50% load	0.30	0.03	15.6	9.1	3.6	20.0	3.8	1.8	0.30	0.90	0.001

In conclusion, the elemental composition of fly ash is not affected considerably by co-firing of SWG in the applied amounts.

Conclusions

As part of the Chariton Valley Biomass Project, measurements have been conducted at a 725 MW_e coal-fired power plant in order to assess the long-term influence of switchgrass co-firing on deposition and superheater corrosion. Altogether, the investigation revealed that co-firing with up to 5 %-wt. switchgrass only influenced the deposition behavior and the corrosion mechanisms marginally.

Tests with deposit probes indicated that the deposition fluxes and the deposit chemistry in the superheater region were virtually unchanged by switchgrass co-firing. No indications of increased contents of alkali chlorides in the deposits were found. Samples of fly ash collected during co-firing tests also showed no increase in the chlorine content compared to coal reference ash. However, a minor increase in the potassium content was observed.

Analysis of corrosion test tubes exposed for 1675 hours of switchgrass co-firing further revealed that the corrosion behavior was largely unaffected by the increased chlorine and potassium inputs. No chloride was present in the inner deposit or the corrosion products. On the contrary, sulfur was found to play a dominant role in the corrosion mechanism. The input of sulfur with the switchgrass compared to that of the coals is negligible.

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