

Ammonium Sulphate and Co-Combustion with Peat – Two Strategies to Reduce Gaseous KCl and Chlorine in Deposits during Biomass Combustion

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ABSTRACT

Combustion of a biomass with an enhanced content of chlorine (Cl) can result in operational problems including deposit formation and superheater corrosion. The strategies to reduce such problems include co-combustion and the use of additives. The positive effects of such measures are mainly due to sulphation of the alkali chlorides (KCl for biomass) to less corrosive alkali sulphates or capture of released alkali (K) in components such as potassium aluminium silicates. A mixture of wood pellets and straw pellets was fired in a 12 MW circulation fluidised bed (CFB) boiler. PVC was added to the fuel in order to achieve a further enhanced reference level of gaseous KCl during certain tests. Two strategies were applied to decrease the risk for superheater corrosion by reducing gaseous KCl and content of chlorine in deposits. The strategies were sulphation of KCl by injection of ammonium sulphate and co-combustion with peat. During co-combustion of biomass with peat both sulphation of KCl and capture of released K in ash components can be of importance. The results were evaluated by means of several advanced measurement tools including IACM (on-line measurements of gaseous KCl), deposit measurements (chemical composition in collected deposits, initial corrosion), ash analysis (chemical composition in fly ashes). The overall performance was better for ammonium sulphate, which significantly reduced gaseous KCl. Meanwhile almost no chlorine was found in the deposits. Only a minor reduction of gaseous KCl was obtained during co-combustion of biomass with peat although the chlorine content in the deposits was greatly reduced.

Keywords: *Sulphation, Alkali Chlorides, Combustion of biomass, Peat*

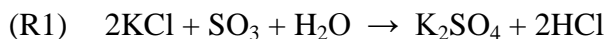
1. INTRODUCTION

Certain biomass fuels, such as straw, contain high amounts of alkali (mainly potassium, K) and of chlorine (Cl), and low of sulphur (S). Chlorine is during combustion released to

the gas phase mainly as HCl and KCl. High levels of KCl in the flue gas can cause enhanced deposit formation and high content of chlorine in deposits causes accelerated superheater corrosion. Combustion of such biomass fuels in a fluidised bed boiler can result in various operational problems including bed agglomeration, deposit formation and superheater corrosion [1, 2]. These operational problems can be mitigated by either co-combustion or the use of additives. Peat, coal and municipal sewage sludge are among the fuels suitable for co-combustion with biomass [3-5]. Another possibility to extend the lifetime of superheater tubes in a boiler is to replace low alloyed steels with more corrosion resistant materials. Chromia forming austenitic stainless steels, high alloyed FeCr steels and Ni based superalloys are among the alternative materials when firing biomass and waste fuels [6].

During co-combustion with peat both sulphation of KCl due to its sulphur content and capture of released K in ash components can be of importance. Various peat fuels representing a wide range of ash forming elements have been investigated [3, 7]. The major ash forming elements were Si, Al, Ca, Fe and S in these investigations. It was proposed [7] that the positive effects on deposits during co-combustion with peat were capture of alkali in the gas phase via reactive peat ash. The composition of the reactive components in the peat ash was not identified since only small amounts of crystalline phases were detected by XRD. Despite these efforts, the positive effects on deposit formation and superheater corrosion from peat are not yet fully understood. Al and Si in peat ashes can capture alkali from KCl by means of formation of alkali aluminosilicates. This formation is also an important during co-combustion with coal, since its ash contains clay minerals [4], and during addition of clay minerals such as kaolin [8, 9]. The main constituent of kaolin is kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$). Reactions between kaolinite and KCl to form leucite (KAlSi_2O_6) and kalsilite (KAlSiO_4) were presented in [9].

Elemental sulphur or other sulphur/sulphate containing additives can be used for sulphation of alkali chlorides. The additive reacts with KCl during biomass combustion and converts it to a less corrosive alkali sulphate. Both homogeneous (gas phase) and heterogeneous (liquid or solid phase) mechanisms have been proposed for formation of alkali sulphates from alkali chlorides found in deposits or in ash particles [10]. In Kassman et al. [11], two sulphur containing additives were evaluated for sulphation of gaseous KCl: elemental sulphur (S) and ammonium sulphate ($(\text{NH}_4)_2\text{SO}_4$). Ammonium sulphate lowered gaseous KCl and also reduced the chlorine content in the deposits significantly better than sulphur. Thus the presence of gaseous SO_3 was of greater importance than that of SO_2 for sulphation of gaseous KCl [11]. This supported that sulphation of gaseous KCl takes place according to the reaction formula (R1):



The scope of this paper is to demonstrate two strategies to decrease the risk for superheater corrosion by reducing gaseous KCl and content of chlorine in deposits. Additionally, results concerning the initial corrosion are presented. The selected strategies were co-combustion with peat and injection of ammonium sulphate. This investigation was included in a larger project carried out in a circulating fluidised bed (CFB) boiler. Results obtained in the same project focusing on co-combustion with sewage sludge are presented in [5].

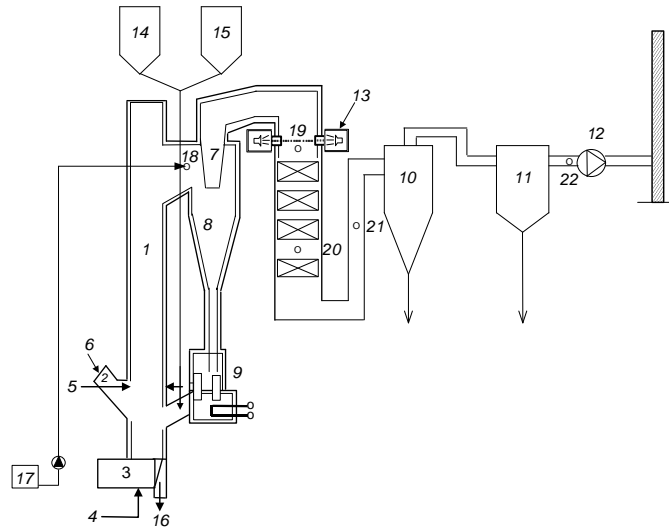


Figure 1: The 12 MW CFB boiler. 1. furnace; 2. fuel chute; 3. air plenum; 4. primary air; 5. secondary air; 6. fuel feed and sand; 7. cyclone outlet; 8. primary cyclone; 9. particle seal; 10. secondary cyclone; 11. bag house filter; 12. flue gas fan; 13. IACM; 14. PVC; 15. kaolin; 16. bed material; 17. ammonium sulphate (AS); 18. Injection of AS; 19-22. measurement positions; 19. before the convection pass; 20. in the convection pass, 21. after the convection pass; 22. before the stack.

2. MATERIALS AND METHODS

2.1 The boiler and the operating conditions

The 12 MW CFB boiler at Chalmers University of Technology (CTH) shown in Figure 1 was used for the experimental runs. An advantage with it is the possibility to perform measurement campaigns in a real boiler, while maintaining control over important operation parameters such as load, air supply and composition of the fuel mix. Alkali related issues have previously been investigated in the Chalmers boiler in [5, 11-14]. The combustion chamber has a square cross-section of about 2.25 m² and a height of 13.6 m. Fuel is fed from a fuel chute (located at the front of the boiler) to the lower part of the combustion chamber. The bed

Tabl 1. Operating parameters

Parameter	Average	Standard deviation
Load (MW)	6.2	0.2
Fraction of straw pellets, % of load	24	1.0
Bed temperature (°C)	851	0.2
Temperature, top of furnace (°C)	869	4
Temperature, cyclone outlet (°C)	822	5
Temperature, after bag filter (°C)	153	4
Pressure drop in furnace (kPa)	7.4	0.2
Excess air ratio	1.23	0.0
Primary air/total air flow (%)	56	1.0
Fluidisation velocity (m/s)	4.8	0.1

material is recirculated through the cyclone back to the combustion chamber, whereas the combustion gases enter the convection pass where the gases are cooled down to 150 °C before cleaning in a secondary cyclone and a bag house filter. Operating conditions typical for a CFB boiler were selected (Table 1). Silica sand ($d_p=0.3$ mm) was used as bed material.

Table 2. Fuel properties

	Wood pellets	Straw pellets	Peat
Proximate analysis			
Water (wt-%, raw)	8.5	9.5	42
Ash (wt-%, dry)	0.6	5.3	4.1
Combustibles (wt-%, dry)	99.4	94.7	95.9
Volatiles (wt-%, daf)	82	81	70
Ultimate analysis (wt-%, daf)			
C	50.5	49.3	56.9
H	6.0	6.1	6.1
O	43.4	43.8	34.0
S	0.01	0.08	0.30
N	0.06	0.46	2.71
Cl	0.02	0.27	0.04
Ash analysis (g/kg dry ash)			
K	138	157	3.6
Na	7.5	6.3	1.3
Al	6.7	4.0	77
Si	116	230	150
Fe	8.8	3.4	159
Ca	152	72	93
Mg	30	12	13
P	13	12	12
Ti	0.4	0.3	1.5
Ba	2.2	0.7	1.6
Lower heating value (MJ/kg)			
H, daf	19.1	18.4	21.9
H, raw	17.1	15.5	11.2

daf = dry and ash free, raw = as received

The base fuel was wood pellets (made from saw-dust of stem wood of pine and spruce from the saw mill industry in Sweden). Straw pellets (made from wheat straw and manufactured in Denmark) were used as additional fuel to increase the level of gaseous KCl with a constant ratio of about 25% of the energy input to the boiler. Co-combustion was carried out with a mixture of straw pellets and peat and also with wood pellets and peat. The peat selected had low calcium content. The different fuel properties are given in Table 2. The test cases in the test plan are described below. The reference case (**Ref**) was wood pellets with straw pellets at a constant ratio of about 25% of the energy input. During co-combustion of peat (**Peat**), a mixture of straw pellets and peat was used to obtain similar molar flows of alkali as in

Ref. A flue gas with a further enhanced level of KCl (**RefCl**) was achieved by adding polyvinyl chloride (PVC) to (14). Ammonium sulphate (AS, $(\text{NH}_4)_2\text{SO}_4$) was added in the SNCR zone before the primary cyclone (18) under similar conditions as in Ref and RefCl respectively. These test cases were named **AS** and **ASCl**. Hydrated lime was added before the bag house filter (11) to reduce the emissions of HCl and SO_2 during RefCl and ASCl. Kaolin was added to (14) (molar ratio Al/alkali = 1) to study its effect on bed agglomeration during AS. Ammonium sulphate is a part of the ChlorOut concept. It consists of IACM [15], an instrument for on-line measurements of gaseous alkali chlorides, and a sulphate-containing additive that converts alkali chlorides to less corrosive alkali sulphates [16]. The additive is often $(\text{NH}_4)_2\text{SO}_4$, and, therefore, a significant NO_x reduction is also achieved parallel to the sulphation of alkali chlorides [13]. Five tests were carried out altogether: Ref, Peat, AS, RefCl, ASCl.

Table 4 presents different experimental parameters for the test cases. These experimental parameters were discussed in [11]. The molar ratio S/Cl indicates the degree to which a fuel mix is corrosive and is here given for the total amount of sulphur in fuel and additive. The risk for corrosion was considered high at a molar ratio S/Cl less than 2.0, whereas it was low at an S/Cl above 4.0 according to [17]. Peat and AS had the highest values for S/Cl and Ref and RefCl the lowest ones. Calcium (Ca) in the fuel ash from biomass is reactive and it also competes with potassium in reacting with sulphur and chlorine. It was found that the chlorine content in the deposits increased at molar ratios of

$S/(Ca+K_2+Na_2)$ lower than 0.2 in the fuel [18]. Sulphur is from fuel and additive in the molar ratios $S/(Ca+K_2+Na_2)$ and Ca/S in Table 4. The molar ratio $Cl/(K+Na)$ is a measure of the amount of Cl available in relation to the alkali content of the fuel. It varied between 0.33 and 0.86 for the present test cases. This implies a lack of Cl to form KCl even during RefCl. The alkali (Na+K) input load in ranged from 12 to 16 mol/MWh supplied energy. The sulphur input load varied significantly, which was expected since most of the sulphur came from the additives. The aluminium (Al) input load is high for Peat and AS (due to added kaolin) and it is important since Al is involved in alkali capture reactions.

Table 4. Experimental parameters

Test case	Alkali ^a mol/MWh	Sulphur mol/MWh	Al mol/MWh	S/Cl ^b	$S/(Ca+2K+2Na)^b$	$Cl/(Na+K)^b$	Ca/S^b
Ref	13.9	2.0	0.5	0.38	0.06	0.38	3.3
Peat	13.4	10.2	12.3	1.89	0.24	0.40	1.5
AS	15.8	8.5	16.2	1.65	0.21	0.33	1.0
RefCl	12.4	1.8	0.5	0.17	0.06	0.86	3.6
ASCl	15.9	10.9	0.7	1.05	0.27	0.65	0.8

a = (Na + K), Expressed as mol/MWh, b = molar ratio

2.2 Measurement techniques

A so-called IACM (*In-situ* Alkali Chloride Monitor) located at (13) was used to measure the alkali chlorides in the gas phase [15, 19]. It measures the sum of the KCl and NaCl concentrations on-line but can not distinguish between these two species. The result is expressed as KCl during biomass combustion. IACM also measures SO₂ simultaneously. Light from a xenon lamp is sent across the furnace or flue gas channel. The light, which arrives at the receiver, is analysed by a spectrometer. The measurements are made by the principle of optical absorption. IACM has been used in the present boiler in several previous projects related to alkali chloride issues [5, 11-14].

Flue gas was also extracted through a heated probe and heated sampling lines to a FTIR (Fourier Transform Infra-Red) analyser for the determination of HCl, SO₂, N₂O, NO, NO₂ and NH₃ on hot wet flue gases and further to on-line IR-VIS instruments measuring CO, SO₂ and N₂O and a paramagnetic analyser for O₂ on cold dry gases. A chemiluminescence analyser was used (in connection to the cold system) for the measurement of NO. Gas concentrations were measured in a location prior to the convection pass (19), after the convection pass (21) and before the stack (22).

The deposit measurements were carried out in (19) using temperature controlled deposit probes. Steel rings were exposed during 4 hours at 500°C and 600°C ring temperature, respectively. The ring materials in this paper were made of 304L and Sanicro 28, and the focus during evaluation was on composition of collected deposits and initial corrosion. The chemical composition of 304L and Sanicro 28 is described in [6]. 304L is an austenitic stainless steel alloyed with chromium (Cr) and nickel (Ni). Sanicro 28 is a high-alloyed Fe-based stainless steel with more chromium and nickel compared to 304L. An important parameter concerning the ability to resist corrosion is the Cr/Fe weight ratio and it is 0.28 for 304L and 0.77 for Sanicro 28. After exposure, the deposits on the Sanicro 28 ring (500°C) were analysed by wet chemistry (Inductive Coupled Plasma with

Optical Emission Spectroscopy ICP-OES and Ion Chromatography IC), whereas deposits on the 304L ring exposed at 600°C were analysed by means of SEM-EDX (Scanning Electron Microscopy – Energy Dispersive X-ray) and XRD (X-Ray Diffraction). The SEM-EDX and XRD analysis were performed on the windward side of the samples whereas the ICP-OES and IC analysis were made on all of the deposit on the ring.

3. RESULTS

3.1 Concentration in the gas phase

Figure 2 shows transient tests from the starting procedure for the test cases with co-combustion of peat (Peat) and injection of ammonium sulphate (AS). KCl was measured by IACM before the convection pass at (19), SO₂ and HCl were measured by FTIR before the stack (22). The transient test for Peat is shown in Figure 2a. KCl was less than 5 ppm during combustion of pure wood pellets (I). Straw pellets were introduced as additional fuel at t = 20 minutes and as result KCl rose to 40 ppm (II). Co-combustion of peat started at t = 45 minutes and gaseous KCl decreased to 30 ppm. It was also observed that SO₂ increased to more than 100 ppm and HCl rose to 70 ppm. The increase in HCl was greater than the decrease in gaseous KCl (III). This indicated that sulphation of KCl and/or reactions capturing K during the release of HCl had taken place.

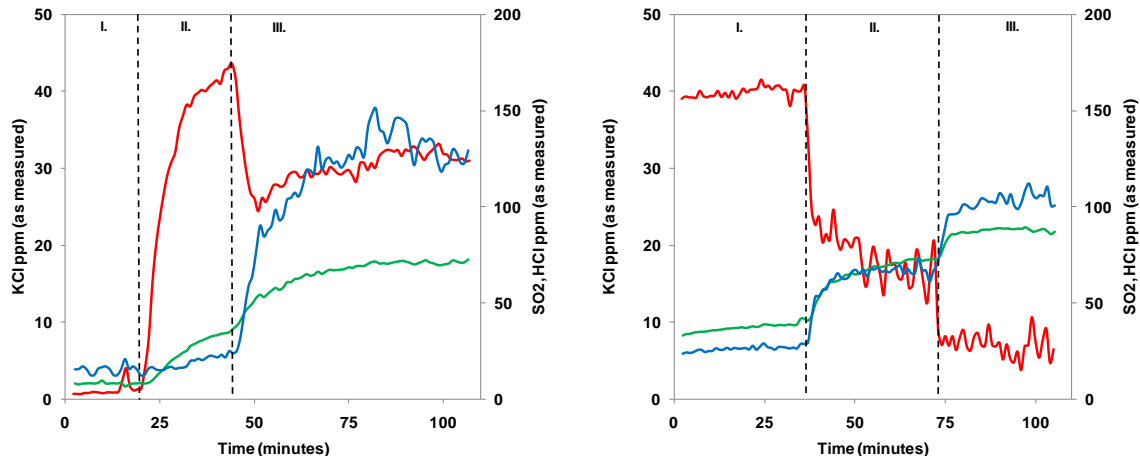


Figure 2: KCl, SO₂ and HCl in transient tests for test cases Peat (a) and AS (b). — KCl IACM, — SO₂ FTIR, — HCl FTIR. Peat (a) I. Wood pellets only, II. Supply of straw pellets, III. Peat replaced the wood pellets. AS (b) I. Wood pellets and straw pellets, II. Injection of 5 l/h ammonium sulphate (S/Cl=1.0), III. Injection of 10 l/h ammonium sulphate (S/Cl=1.5).

The transient test for AS is shown in Figure 2b. The level of gaseous KCl was 40 ppm during combustion of wood pellets with 25% straw pellets and addition of kaolin (I). Ammonium sulphate was injected (S/Cl=1.0) at t = 35 minutes and KCl, SO₂, HCl responded directly (II). The flow of ammonium sulphate was increased to an S/Cl of 1.5 at t = 75 minutes and once more an immediate change in the gas phase concentrations of KCl, SO₂, HCl were observed. Sulphation of KCl in the gas phase according to (R1) is a fast reaction and the immediate decrease of KCl during injection of ammonium sulphate

proved a gas phase reaction had occurred. A comparison between the transient tests for test cases Peat and AS reveals significant differences. Although the concentration of gaseous SO₂ is higher during Peat, the reduction of gaseous KCl is less efficient. This proves that the sulphur in AS (i.e. SO₃) is more efficient for reduction of gaseous KCl than the sulphur in peat (i.e. SO₂). Reactions with ash components capturing released gas phase KCl would also have decreased KCl during Peat.

Table 4. Gas concentrations (recalculated to ppm dry gas @ 6 % O₂)

Test case	KCl ^a , ppm	SO ₂ ^a , ppm	HCl ^b , ppm	NO ^c , ppm	CO ^c , ppm
Ref	44	9	35	86	0
Peat	29	84	83	78	4
AS	7	90	90	23	10
RefCl	109	2	73	73	5
ASCl	15	91	155	12	19

a = measured at (19), b = measured at (21), c = measured at (22).

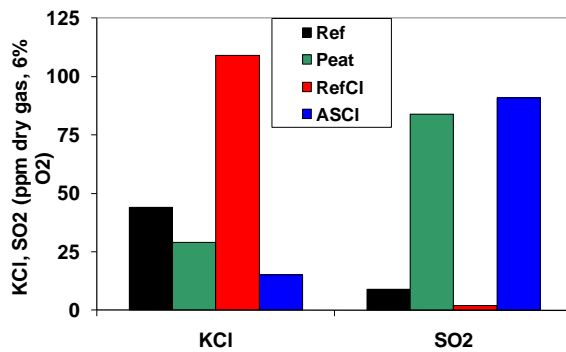


Figure 3: Concentration of KCl and SO₂ for test cases Ref, Peat, RefCl and ASCl.

Results from IACM and gas analysis are shown in Table 4. The concentration of HCl increased during Peat compared to Ref, and during ASCl compared to RefCl. CO increased somewhat during test cases AS and ASCl, and a similar effect has previously been observed [11, 13]. A great reduction of NO was achieved during injection of ammonium sulphate. Figure 3 shows the concentration of KCl and SO₂ for test cases Ref, Peat, RefCl and ASCl. The measurements were performed before the convection section (19) where the

temperature of the gas was approximately 800 °C. The level of KCl was 44 ppm during Ref and KCl decreased to 29 ppm during test case Peat. Compared to Ref, only a minor reduction of gaseous KCl was observed during Peat. The addition of PVC increased KCl to 109 ppm (RefCl) whereas it dropped to 15 ppm during test case ASCl. The injection of ammonium sulphate significantly lowered the level of gaseous KCl in the flue gas.

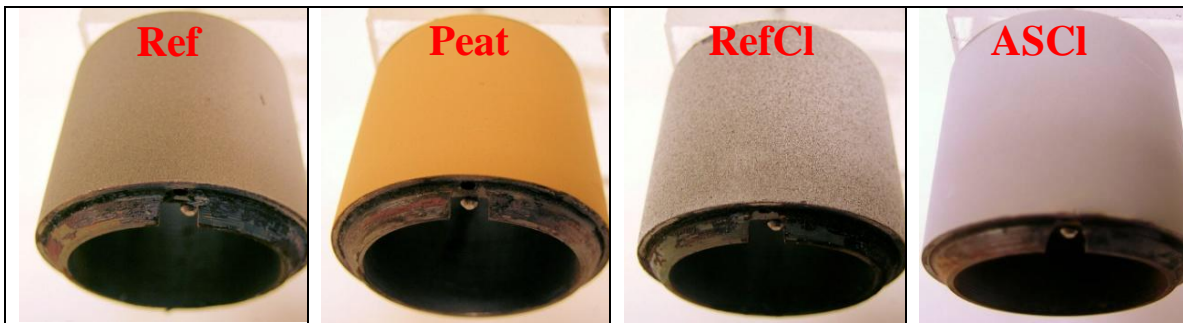


Figure 4: Deposits collected on rings made of 304L at 600°C for test cases Ref, Peat, RefCl and ASCl.

3.2 Concentration in deposits and fly ash

Figure 4 shows the deposits collected on rings made of 304L at 600°C for test cases Ref, Peat, RefCl and ASCl. The colour of the deposits collected during Peat differed from the other ones, and probably due the presence of ash components originating from Peat.

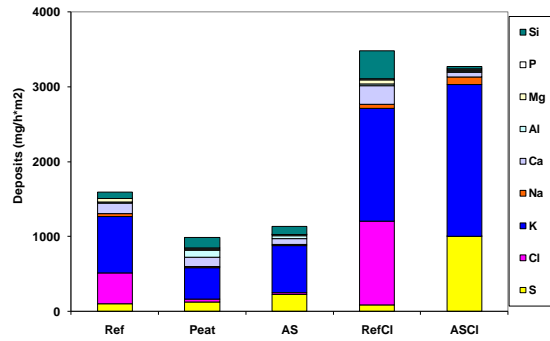


Figure 5: Composition of deposits given as elements.

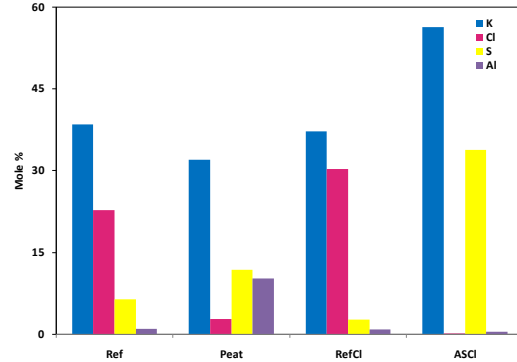


Figure 6: Mole % of potassium (K), chlorine (Cl), sulphur (S) and aluminium (Al) in the deposits

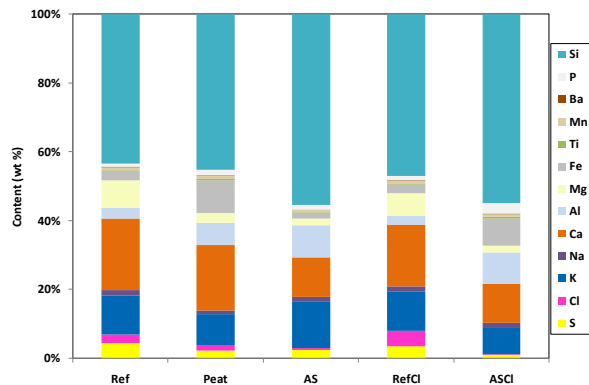


Figure 7: Chemical composition in weight % for fly ash (sec. cyclone)

Figure 5 shows the composition in deposits collected from the whole ring analysed by ICP-OES and IC. During Ref the deposits consisted mainly of K and Cl. The chlorine content was much lower during Peat compared to Ref. The reduction of Cl was achieved although the content of sulphur was still low. This indicated that the chlorine was reduced by capture of K during the release of Cl as HCl rather than sulphation. The highest chlorine content was present during RefCl. Nevertheless no chlorine was found in the deposits during ASCl, when ammonium sulphate was injected

at a molar ratio S/Cl of 1. Figure 6 shows the mole % of K, Cl, S and Al for test cases Ref, Peat, RefCl and ASCl. The deposit consisted mainly of KCl during RefCl, which was fully sulphated during ASCl. It was observed that the deposit contained more aluminium during Peat, which could possibly be explained by capture of K in a potassium aluminium silicate. Figure 7 shows the chemical composition in fly ashes from the secondary cyclone. There was no chlorine present in the ashes from AS and ASCl. The ash from Peat had an enhanced content of Fe and Al compared to Ref and both of these elements can have an impact on the deposit chemistry for Peat. Evaluation of XRD analysis of the fly ash from Peat is complicated due to the interference from amorphous components. There is, nevertheless, an indication of the presence of iron oxides and silicates.

3.3 Gaseous KCl and chlorine in deposits

Injection of ammonium sulphate significantly lowered gaseous KCl and almost no chlorine was found in the deposits. It was possible to reduce completely reduce chlorine at a molar ratio S/Cl of 1. Sulphation of gaseous KCl was less important during the co-combustion with peat, but the chlorine content in the deposits was, nevertheless, greatly reduced (S/Cl = 1.9). This could possibly be explained by sulphation or capture of K on reactive ash components followed by the release of HCl when using peat. It is indicated that chlorine was reduced in the deposits by capture of K rather than sulphation.

3.3 Initial corrosion

The corrosion front during test cases Ref, Peat and ASCI was investigated by means of SEM-EDX analysis. The deposit layer was mechanically removed from rings made 304L exposed at 600°C for 4 hours.

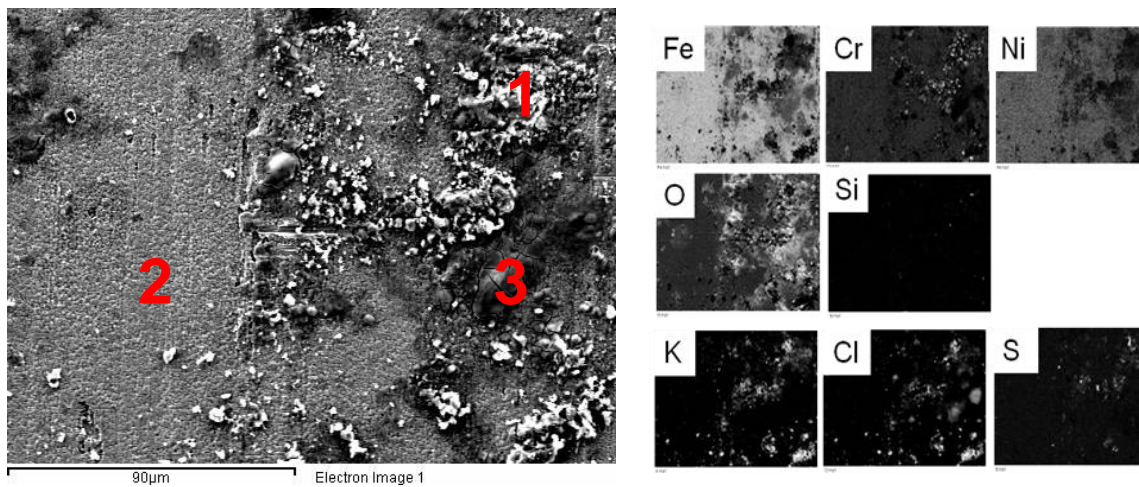


Figure 8: EDX maps of the area beneath the deposit layer on 304L at 600°C during Ref.

Table 5. EDX quantifying of element composition in the points shown in Figure 8.

(a%)	O	K	Na	Mg	Ca	Al	P	S	Cl	Si	Fe	Cr	Ni
1	55	14	1	0	1	0	0	9	2	1	8	9	0
2	17	1	1	0	0	0	0	1	1	0	60	8	11
3	60	1	0	0	0	0	0	0	13	0	22	1	3

Figure 8 shows that although most of the deposit layer was removed, some areas are still covered by deposit particles. According to the EDX analysis, these areas are rich in K and Cl indicating the presence of KCl (which also was detected by XRD). In addition, areas containing K, S and O (probably K_2SO_4) are detected. However, there are some areas enriched in Cl indicating the presence of deposit particles. Near point analysis #3, the chlorine content is around 13% whereas the potassium content is low. Instead, the EDX quantification indicates the presence of transition metal chloride, probably $FeCl_2$. There are a number of spots enriched in chromium, in the vicinity to point analysis #1. These areas correlate with potassium, indicating the presence of potassium chromate (K_2CrO_4).

The EDX quantification in point #2 shows an area covered with an oxide. This oxide is depleted in chromium and is instead dominated by iron.

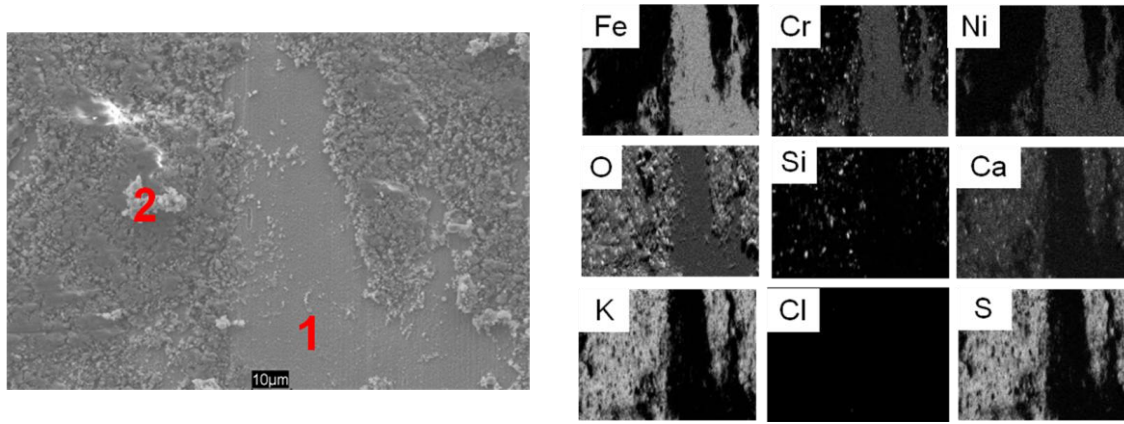


Figure 9: EDX maps of the area beneath the deposit layer on 304L exposed at 600°C during Peat.

Table 6. EDX quantifying of element composition in the points shown in Figure 9.

(a%)	O	K	Na	Mg	Ca	Al	P	S	Cl	Si	Fe	Cr	Ni
1	0	1	0	0	0	0	0	0	0	2	72	15	10
2	37	21	2	2	4	6	1	11	0	2	13	2	0

The EDX analysis of the ring from the exposure during test case Peat is shown in Figure 9 and Table 6. The SEM image reveals an area where the deposit layer is partly removed. In the middle of the image, the underlying steel can be seen as Fe, Cr and Ni can be correlated whereas the occurrence of elements emanating from deposit particles is low. The deposit layer is dominated by K, S and O. However, Al, Ca and Si appears sporadically within this layer. According to the EDX quantification, the Al content is 6% (point #2). The chlorine content is below the detection limit of EDX analysis, all over the surface. Spots enriched in chromium can be found within the deposit layer. These spots also contain manganese (not showed), indicating the presence of a Cr-Mn spinel oxide.

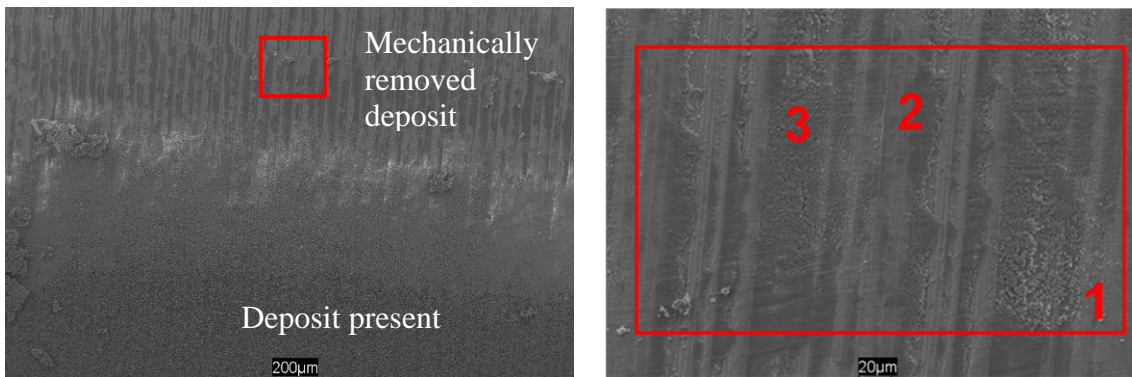


Figure 10: SEM images of the 304L sample exposed for 4 hours at 600°C in test case ASCI.

The 304L sample exposed at 600°C for 4 hours in the exposure for ASCI is shown in Figure 10. An overview image of the surface after mechanically removed deposit layer is

shown to the left. The red square marks the analysed area in the right image. SEM image to the right has a higher magnification of the area marked by a square in the left image. The EDX quantification of the area where the deposit layer was removed is shown in Table 7. According to the EDX analysis, the presence of chlorine is low in all point and area analyses performed. In point 1 (sum spectrum) and point 3, a 2:1 correlation between K and S, which is in agreement with XRD results showing the presence of K₂SO₄. Point #2 is performed on an area where no deposit particles were present. Instead, the EDX quantification reveals a FeCrNi oxide. The low oxygen content (37%) indicates that the oxide thickness is below 0.5 µm (The analysis depth is roughly 0.5µm). This oxide is enriched in chromium compared to the original content of 304L.

Table 7. EDX quantifying of element composition in the points shown in Figure 10.

(a%)	O	K	Na	Mg	Ca	Al	P	S	Cl	Si	Fe	Cr	Ni
1 (sum)	36	17	2	1	1	0	0	10	0	1	19	10	3
2	31	1	0	1	0	0	0	0	0	1	41	20	5
3	0	28	2	0	1	0	1	15	0	1	33	13	4

4. CONCLUSIONS

Two strategies to decrease the risk for superheater corrosion by reducing gaseous KCl and content of chlorine in deposits were evaluated. The selected strategies were co-combustion with peat and injection of ammonium sulphate. The overall performance was somewhat better for ammonium sulphate, which significantly reduced gaseous KCl and no chlorine was found in the deposits. The sulphation of gaseous KCl was less efficient during co-combustion with peat. The chlorine content in the deposits was, nevertheless, greatly reduced.

5. ACKNOWLEDGEMENTS

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