

SIMULTANEOUS REDUCTION OF NO AND KCl DURING INJECTION OF AMMONIUM SULPHATE IN A BIOMASS FIRED BFB BOILER

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Abstract - Sulphate containing additives, such as ammonium sulphate (AS), are used for sulphation of KCl during biomass combustion. Another aspect with injection of AS is that a significant NO_x reduction is achieved but it may also have an impact on other flue gas components. Operating parameters such as the air excess ratio and the presence of combustibles could also have an effect on the flue gas chemistry involving NO and KCl. This paper is based on results obtained from a measurement campaign during combustion of demolition wood in a 63 MW_{th} Bubbling Fluidised Bed (BFB) boiler. Ammonium sulphate was injected for simultaneous reduction of NO and KCl at two positions in the boiler i.e. in the upper part of the combustion chamber and in the empty pass. The impact of AS on the flue gas chemistry was investigated at different operating conditions. Several measurement tools including, IACM (on-line measurements of gaseous alkali chlorides) and gas analysis were applied. The position for injection of AS as well as the operating parameters had an impact on the flue gas chemistry for reduction of both NO and KCl.

INTRODUCTION

High levels of potassium chloride (KCl) in flue gas during combustion of a biomass fuel can enhance deposit formation and a high content of KCl in the deposits may accelerate superheater corrosion. These operational problems can be reduced by sulphur/sulphate containing additives which converts KCl to a less corrosive alkali sulphate as shown in Kassman et al. 2001, Kassman et al. 2008, Kassman et al. 2010, Kassman et al. 2013b, Wu et al. 2014, Viklund et al. 2009, Aho et al, Kassman et al. 2013a, Viklund et al. 2015 and Kassman and Åmand 2015. In Kassman et al. 2011, Kassman et al. 2008, Kassman et al. 2010, Kassman et al. 2013a Kassman et al 2013b and Kassman and Åmand 2015 results are presented from experiments when using elemental sulphur (S) and/or ammonium sulphate (AS, (NH₄)₂SO₄). AS lowered the concentration of gaseous KCl and simultaneously reduced the chlorine content in the deposits significantly better than sulphur (Kassman et al. 2010). AS can, in parallel to the sulphation of KCl be used as an alternative additive to ammonia (NH₃) and urea (CO(NH₂)₂) for SNCR (selective non-catalytic reduction) of NO.

The influence of oxygen and combustibles on the sulphation of gaseous KCl and reduction of NO during injection of AS has previously been investigated in a 12 MW Circulating Fluidised Bed (CFB) boiler at Chalmers University of Technology (Kassman et al. 2013a, Kassman and Åmand 2015). The results revealed both the air excess ratio and the selected position had an impact on the reduction of NO as well as KCl (Kassman and Åmand 2015). The efficiency of AS for reduction of NO and KCl were in general affected in similar ways but the reduction of NO was significantly better in certain positions. The sulphation of KCl was somewhat more sensitive for the presence of volatile combustibles and interactions from the O/H radical pool than NO reduction (Kassman and Åmand 2015).

The scope of the present paper is to further investigate sulphation of gaseous KCl and reduction of NO during injection of AS in a full-scale 63 MW_{th} Bubbling Fluidised Bed (BFB) boiler. The experimental strategy applied was similar as in Kassman and Åmand 2015 and it focused on aspects of the flue gas chemistry of especially KCl and NO during injection of AS at various excess air ratios.

THEORY

Interactions occur between the CH oxidation and the chemistry of K, S, N and Cl during combustion (Glarborg 2007). Many of these interactions are concerning the so-called “chain carrying radicals”, which include the radical pool of hydroxyl (OH), oxygen (O) and hydrogen (H) radicals. The chain branching reaction (R8) in Table 1 is the most important reaction for radical production. Light volatile hydrocarbons are oxidised in a series of steps by the chain carrying radicals and finally CO is formed in the last step. CO is further oxidised to CO₂ mainly by a hydroxyl radical (R9). The reaction between hydrocarbon radicals and

chain carrying radicals is normally faster than R9 (Hindiyarti et al. 2006). This leads to an accumulation of CO, which starts to oxidise when the hydrocarbon oxidation is completed. Thus, the presence of combustibles has a large influence over the O/H radical pool.

Reactions of particular interest are shown in Table 1 and they involve the reduction of NO by SNCR, sulphation of gaseous KCl, and the O/H radical pool. NO reduction by NH₃ is initiated by an OH radical (R1) and the formation of OH radicals can be promoted or inhibited by additives (Tayyeb et al. 2007). AS is in Kassman et al. 2010 proposed to decompose into NH₃ and SO₃ according to (R2) when injected into a hot zone in a boiler. The overall sulphation reaction of KCl by SO₃ may be described as in (R3). Sulphation of gaseous KCl is more efficient in the presence of SO₃ rather than SO₂ (Kassman et al. 2010). The oxidation of SO₂ to SO₃ (global reaction R4) involves recombination of SO₂ with O or OH radicals and it may involve HOSO₂ as an intermediate (R5, R6), and SO₃ may be reduced by H radicals (R7). R7 is a fast reaction and the presence of H radicals can thus have a great influence on the efficiency of the sulphation of KCl (Kassman et al. 2013a and Hindiyarti et al. 2007) Furthermore, the presence of KCl may consume OH radicals and inhibit oxidation of CO by (R10) Hindiyarti et al. 2006.

Table 1 Reactions of interest

Description of reaction	Number and reaction
Reduction of NO by NH ₃	(R1a) NH ₃ + OH → NH ₂ + H ₂ O (R1b) NH ₂ + NO → N ₂ + H ₂ O
Decomposition of ammonium sulphate Sulphation of KCl by SO ₃	(R2) (NH ₄) ₂ SO ₄ → 2NH ₃ + SO ₃ + H ₂ O (R3) 2KCl + SO ₃ + H ₂ O → K ₂ SO ₄ + 2HCl
Oxidation of SO ₂ to SO ₃ Recombination of SO ₂ by O radicals Recombination of SO ₂ by OH radicals with HOSO ₂ as an intermediate Reduction of SO ₃ by H radicals	(R4) SO ₂ + ½O ₂ ⇌ SO ₃ (R5) SO ₂ + O ⇌ SO ₃ (R6a) SO ₂ + OH ⇌ HOSO ₂ (R6b) HOSO ₂ + O ₂ ⇌ SO ₃ + HO ₂ (R7) SO ₃ + H ⇌ SO ₂ + OH
Chain branching reaction Oxidation of CO by a hydroxyl radical Interference of alkali on CO oxidation	(R8) H + O ₂ ⇌ OH + O (R9) CO + OH ⇌ CO ₂ + H (R10) K + OH + M ⇌ KOH + M

METHODOLOGY

Operating conditions and experimental procedures

The experimental work was performed in a Combined Heat and Power (CHP) boiler located in Jordbro, south of Stockholm. The boiler is owned and operated by Vattenfall AB and it is a BFB of Valmet design and commissioned in 2010. It produces a total of 63 MW_{th}, of which 20 MW_{el} in a turbine. The boiler in Fig. 1 is designed for wood fuels such as demolition wood and forestry residues, with a moisture content ranging from 20% to 45%, with steam data of 80 bar and 470°C for 100% demolition waste wood and 495°C for 100% of forest residues. The fuel was demolition waste wood (DWW) and Table 2 shows the fuel properties of DWW together and for straw pellets obtained from Kassman et al. 2013a and Kassman and Åmand 2015. Important differences between them are the content of ash, nitrogen (N), alkali (Na, K) and certain trace metals i.e. lead (Pb) and zinc (Zn). The greater amount of N and Na originates from composite board and paint (Enestam 2011). Pb and Zn mainly originates from painted wood (Enestam 2011).

The boiler was initially operated without any additives to prevent superheater corrosion. Superheater SH2 has the highest out-going steam temperature (470°C) and is made of a low alloyed material (10CrMo9-10). Parts of SH2 was replaced 2014 after four years of operation. The ChlorOut concept (Andersson 2006a and 2006b) was installed in 2014 to extend the life-time of the superheaters during combustion of demolition waste wood. Tube analysis revealed that the superheater corrosion was significantly reduced after installation, Kassman et al. 2017. This concept consists of IACM, a measurement device for gaseous alkali chlorides, and a sulphate-containing additive that converts alkali chlorides to less corrosive alkali sulphates. The sulphate-containing additive is often ammonium sulphate, although several other sulphates are also included in the concept. The installation consisted of a dosage system for injection of aqueous ammonium sulphate (40% wt) including an external storage tank (outdoors), an intermediate storage tank, pumping and control units as well as lances and nozzles (Fig. 2).

Table 2. Fuel properties

Fuel analysis	DWW	Straw pellets	Ash analysis (g/kg dry ash)	DWW	Straw pellets	Trace elements (mg/kg dry fuel)	DWW
Proximate analysis			K	26	139	Cd	1.5
Water (wt-%, raw)	20.7	6.3	Na	29	3.9	Pb	73.6
Ash (wt-%, dry)	2.9	5.1	Al	28	1.9	Cr	48.2
Combustibles (wt-%, dry)	97.1	94.9	Si	154	250	Cu	36.2
Ultimate analysis			Fe	43	1.8	Ni	5.0
C, (wt-%, daf)	50.1	49.4	Ca	117	65	Mn	81.8
H, (wt-%, daf)	6.2	6.2	Mg	18	14	Zn	76.8
O, (wt-%, daf)	41.5	43.5	P	3.1	11		
S, (wt-%, daf)	0.06	0.10	Ti	45	0.1		
N, (wt-%, daf)	2.1	0.58					
Cl, (wt-%, daf)	0.12	0.29					
Lower heating value							
H, daf, (MJ/kg)	18.4	18.4					
H, raw, (MJ/kg)	16.2	16.2					

DWW = Demolition waste wood, daf = dry and ash free, raw = as received

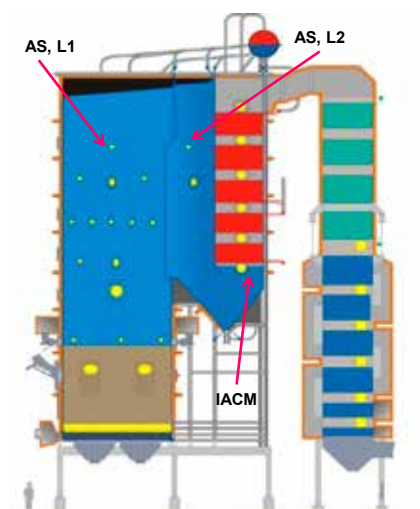


Fig. 1. The BFB boiler in Jordbro with IACM and injection points L1 and L2 for AS indicated.



Fig 2. Rear end of lance and tip of a nozzle for injection of ammonium sulphate (AS) in Level L2.

Fig. 1 shows a sketch of the boiler with injection levels for AS (L1 and L2), and the location for on-line measurements of gaseous alkali chlorides (IACM) indicated. Openings are located at the same position on the left and right side of the boiler. The injection positions for AS were in the upper part of the combustion chamber (Level L1) and in the upper part of the empty pass (Level L2). The boiler is also equipped with a separate SNCR system for ammonia (NH_3) which were not in operation during the project. The positions for injection of AS and NH_3 were horizontal.

Table 3. Operating parameters

Parameter/Case	Normal	Low	High	Parameter	Normal	Low	High
Excess air ratio (λ)	1.20	1.17	1.28	Flue gas flow ($\text{m}^3_n \text{ dg/s}$)	23.6	22.7	25.0
Load (MW)	65.8	65.9	65.7	Primary air flow (m^3_n/s)	6.6	6.9	5.8
O_2 control, (% wg)	3.0	2.5	4.0	Flue gas recirc. (m^3_n/s)	6.0	5.8	6.8
Temperature, $T_{\text{Level L1}}$ ($^\circ\text{C}$)	880	900	860	Sec. air, front-back (m^3_n/s)	7.1	6.2	8.4
Temperature, $T_{\text{Level L2}}$ ($^\circ\text{C}$)	840	860	820	Tert air, left-right (m^3_n/s)	6.0	5.8	6.3
Temperature, $T_{\text{Before Eco}}$ ($^\circ\text{C}$)	468	480	468	Total air (m^3_n/s)	19.7	18.8	20.5
Temperature, $T_{\text{After Eco}}$ ($^\circ\text{C}$)	223	224	225	Sec. air/total air flow (%)	66	64	71
Temperature, $T_{\text{After Filter}}$ ($^\circ\text{C}$)	149	148	146	Tert air, left-right (m^3_n/s)	6.0	5.8	6.3
Steam flow (kg/s)	25.7	25.6	25.6	Total air (m^3_n/s)	19.7	18.8	20.5
Steam temp, $T_{\text{After SH2}}$ ($^\circ\text{C}$)	471	471	470	Sec. air/total air flow (%)	66	64	71

The performance of ammonium sulphate (AS) for reduction of NO and KCl was investigated. The strategy was to inject AS by so-called transient tests (TT). These transient tests were performed during three different excess air ratios (λ). These test cases are referred to as *Normal*, *Low* and *High* which corresponded to an O_2 for combustion control of 3.0% ($\lambda=1.20$), 2.5% ($\lambda=1.17$) and 4.0% ($\lambda=1.28$) respectively. Three O_2 analysers were located at the boiler roof after the superheater region. Operating parameters are shown in Table 3.

Increasing amounts of AS were injected in a sequence in the upper part of the combustion chamber (L1 in Fig. 1) and in the upper part of the empty pass (L2). Each sequence consisted of a reference without any injection of AS (Ref), and injection of increasing amounts of AS. Full load was 65MW and the flow of AS was based on so-called load factors. Injection of 65 litres/h of AS corresponded to a load factor of 1.0 litres/MWh. The load factors for injection of AS during the transient tests were Ref (0); 0.5; 1.0; 1.5; 2.0. The load factors were recalculated to molar ratios S/Cl and NH_3/NO during evaluation. The strategy was to perform all measurements in a sequence for each test case. The time required to reach steady state are fast for most gas phase reactions of interest such as KCl, NO, N_2O , CO, and O_2 and each measurement was typically carried out during 20 minutes of stable operation. However, only the last 10 minutes were evaluated. The time required to obtain accurate values for SO_2 , HCl and NH_3 -slip from stack measurements after the fabric filter in Jordbro are often longer than 20 minutes. This means results obtained for these components within transient tests to a certain extent are trends rather than exact values. Data was evaluated from the recording system of the plant concerning a large amount of parameters which were considered relevant in order to characterize the different operating conditions and their impact on the emissions. Operating parameters are shown in Table 3. The data evaluation was based on 1-minute values for these parameters.

The corresponding molar flows and molar ratios of certain experimental parameters during the transient test at $\lambda = 1.2$ are shown in Table 4. The molar ratio S/Cl is a measure to which degree a fuel mix is corrosive and it is presented as both added sulphur from AS (S^{AS}) and for the total amount of sulphur (S^{tot}) from the fuel and AS. The risk of corrosion is often considered great at a molar ratio S/Cl less than 2.0 and the chlorine content in deposits is also a measure of the risk of corrosion. No chlorine was found in the deposits when sulphur was available in the form of SO_3 instead of SO_2 at a total molar ratio S/Cl of 1.0 (Kassman et al. 2013b) and 2.1 (Kassman et al 2010). Thus the form of oxidised sulphur (i.e. SO_2 or SO_3) has a great impact on the risk of corrosion. According to R3, a molar ratio of 0.5 is sufficient to produce K_2SO_4 if K prefers S over Cl. In practice, however, S and Cl compete with each other and an excess of S is needed. The molar ratio Cl/(K+Na) was 0.59 and it is a measure of the amount of Cl available in relation to the alkali content of the fuel. The alkali (Na+K) and chlorine input load in Table 4 remained constant since no additional alkali or Cl were supplied. The input load of S varied significantly, since sulphur originated both from the fuel and injected ammonium sulphate.

Table 4. Experimental parameters for AS at 65.0 MW during the transient tests at $\lambda = 1.20$.

Test case	AS (l/MWh)	NH_3/NO molar ratio	S^{AS}/Cl molar ratio	S^{tot}/Cl molar ratio	Sulphur ^{tot} mol/MWh	Chlorine mol/MWh	Alkali (Na+K) mol/MWh
Ref	0.0	0	0	0.51	4.02	7.9	13.1
AS-0.5	0.50	0.56	0.24	0.74	5.90	7.9	13.1
AS-1.0	0.99	1.12	0.47	0.97	7.72	7.9	13.1
AS-1.5	1.50	1.69	0.71	1.21	9.62	7.9	13.1
AS-2.0	1.99	2.24	0.94	1.44	11.4	7.9	13.1

S^{AS}/Cl = Molar ratio based on added sulphur from AS. S^{tot}/Cl = Molar ratio based on added sulphur from fuel and AS.

An IACM (In-situ Alkali Chloride Monitor) instrument located prior to the superheaters in Fig. 1 measured the alkali chlorides (KCl and NaCl) in the gas phase. IACM is a measurement device which consist of a transmitter (lamp) and a receiver (spectrometer). The lamp sends UV-light over the flue gas channel (measurement path) to a spectrometer on the opposite side of the boiler wall. The light is absorbed at characteristic wave lengths depending on the concentration of certain gaseous species such as KCl and SO_2 . The measuring principle is Differential Optical Absorption Spectrometry (DOAS). The result is expressed as the concentration of KCl and SO_2 respectively in ppm although a certain part of the alkali chlorides are present as NaCl during combustion of DWW. The result is obtained after data evaluation of a spectrum by the IACM computer. IACM has been used in several previous projects related to alkali chloride issues in which it is described in more detail in Kassman et al. 2008, Kassman et al. 2010, Kassman et al. 2013b, Leffler et al. 2016, and Kassman 2012.

RESULTS AND DISCUSSION

Table 5 shows selected gas concentrations at Ref and at load factor 1.0 for L1 and L2 respectively. The results regarding reduction of NO_x and sulphation of KCl for the three different excess air ratios ($\lambda=1.17$, $\lambda=1.20$ or $\lambda=1.28$) and positions L1 and L2 for addition of AS are summarised in Figs. 4-6.

Table 5. Gas concentrations at Ref and at load factor 1.0 for injection of AS in L1 and L2 for the excess air ratios.

Test case	λ	O ₂ ^a % dg	NO ^a mg/MJ	KCl ^b ppm wg	SO ₂ ^b ppm wg	CO ^a mg/m ³ _n	NH ₃ slip ^a mg/m ³ _n	HCl ^a mg/m ³ _n	N ₂ O ^a mg/m ³ _n
Ref	1.20	3.5	69	30	31	45	7	6	7
L1 AS-1.0	1.20	3.7	56	23	48	49	5	8	9
L2 AS-1.0	1.20	3.4	49	14	40	56	4	6	9
Ref	1.17	3.0	66	34	31	54	4	7	8
L1 AS-1.0	1.17	2.9	45	29	55	59	3	8	10
L2 AS-1.0	1.17	3.1	43	20	35	67	3	8	10
Ref	1.28	4.5	92	31	30	57	3	8	7
L1 AS-1.0	1.28	4.4	59	16	44	59	3	7	9
L2 AS-1.0	1.28	4.3	64	16	35	72	3	11	9

a = stack measurement, b = measured by IACM prior to SH2

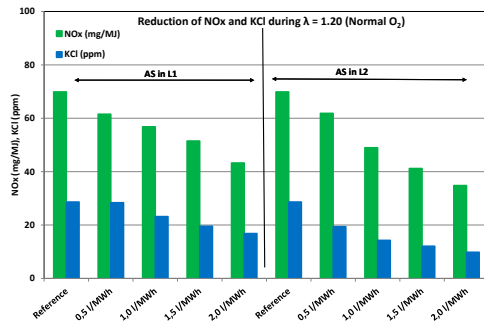


Fig. 4a. NO_x emission and KCl concentration for Normal O₂ ($\lambda=1.20$). AS injection in L1 (upper part of combustion chamber) and L2 (upper part of the empty pass).

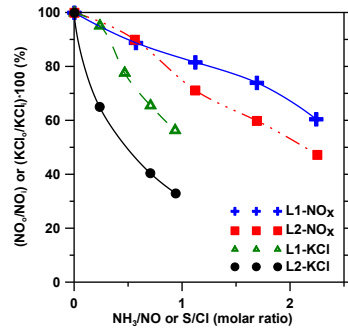


Fig. 4b. Reduction of NO or KCl versus molar ratio NH₃/NO or S/Cl at $\lambda=1.20$. Injection of AS in L1 and in L2.

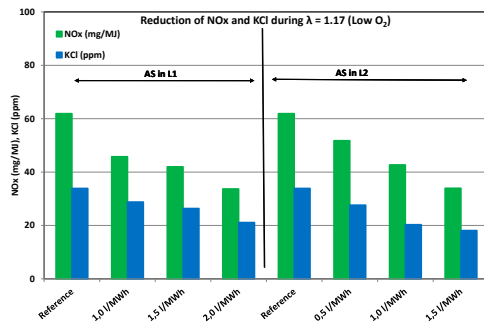


Fig. 5a. NO_x emission and KCl concentration for Low O₂ ($\lambda=1.17$). AS injection in L1 (upper part of combustion chamber) and L2 (upper part of the empty pass).

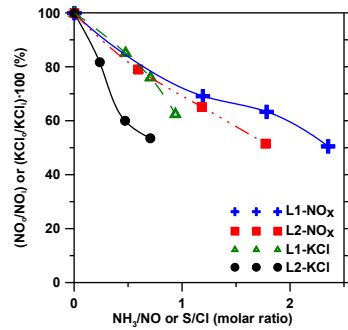


Fig. 5b. Reduction of NO or KCl versus molar ratio NH₃/NO or S/Cl at $\lambda=1.17$. Injection of AS in L1 and in L2

The optimal performance of AS for reduction of NO_x to the lowest level was achieved in L2, (upper part of the empty pass in Fig.1) at a molar ratio NH₃/NO of 1.8 during $\lambda=1.17$ (Load factor AS=1.5 in Fig. 5a). A similar result was achieved when the excess air ratio was raised from 1.17 to 1.20, with optimal NO_x

reduction when adding AS to L2. The picture was somewhat altered at $\lambda = 1.28$ and there was similar reduction of NOx regardless if AS was injected in the upper part of the combustion chamber, (L1) or in the empty pass, (L2). The optimal performance of AS for reduction of KCl was achieved at $\lambda = 1.20$ in L2. The reduction of KCl was almost identical regardless of injection point, L1 or L2 at the greatest excess air ratio ($\lambda = 1.28$). The optimal performance during the lowest excess air ratio ($\lambda = 1.17$) was achieved during injection of AS into L2 in the empty pass. The performance of AS for NOx reduction was improved during the lower O₂ level ($\lambda=1.17$ compared to $\lambda=1.20$) but the reduction of KCl was less efficient.

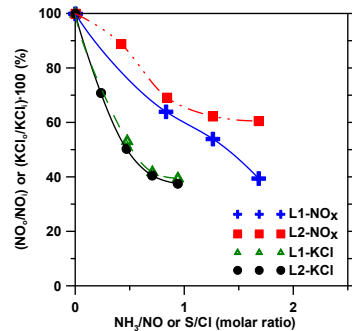
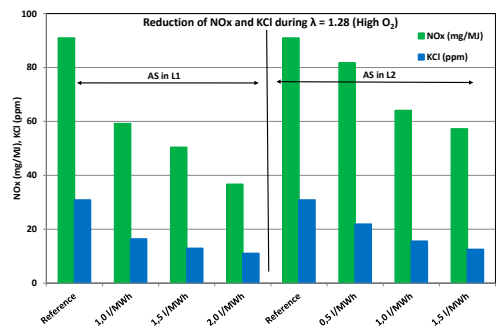


Fig. 6a. NO_x emission and KCl concentration for High O₂ ($\lambda=1.28$). AS injection in L1 (upper part of combustion chamber) and L2 (upper part of the empty pass).

Fig. 6b. Reduction of NO or KCl versus molar ratio NH₃/NO or S/Cl at $\lambda=1.28$. Injection of AS in L1 and in L2

The investigation concerning influence of oxygen and combustibles on the flue gas chemistry of KCl and NO during injection of AS was quite informative. A few observations are highlighted in Fig. 7 and Fig. 8 for NO and KCl respectively. The reduction of KCl (the rate of sulphation, R3) is always better than the reduction of NO, (the rate of reaction R1b in Table 1) when comparing the same excess air ratio and injection point. The reduction of KCl was impressively good at $\lambda=1.28$, regardless in which position AS was injected and it was also similar to what was achieved at $\lambda=1.20$. Here it was only required a molar ratio S/Cl of 0.7 to reach more than 50% reduction. It required a molar ratio NH₃/NO of 1.7, more than twice the amount of ammonia on molar basis, to achieve a similar reduction of NO at $\lambda=1.28$ during injection in position L1. This result was achieved despite the fact that the reference levels of NO were greater than the corresponding level for KCl in Fig. 6a.

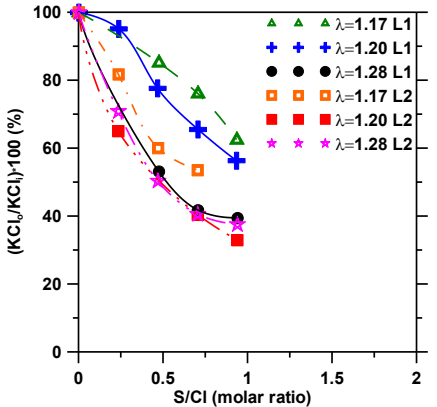
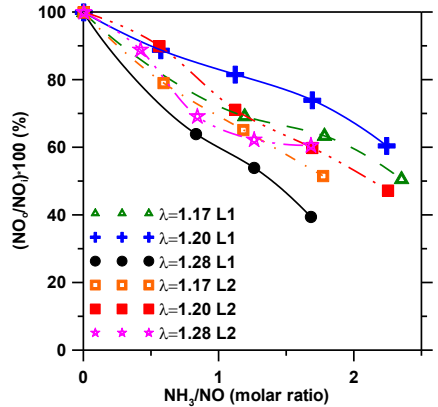


Fig. 7. Reduction of NO versus molar ratio NH₃/NO during injection of AS in L1 (upper part of combustion chamber) and L2 (empty flue gas pass) for $\lambda=1.17$; $\lambda=1.20$ and $\lambda=1.28$.

Fig. 8. Reduction of KCl versus molar ratio S/Cl during injection of AS in L1 (upper part of combustion chamber) and L2 (empty flue gas pass) for $\lambda=1.17$; $\lambda=1.20$ and $\lambda=1.28$.

A comparison can also be made between the results in the BFB boiler and the ones obtained from the CFB boiler in the previous investigation, Kassman and Åmand 2015. Fig. 9 and Fig. 10 shows comparative plots for NO and KCl at the similar conditions with an excess air ratio λ of 1.20. AS was injected into the cyclone of the CFB boiler and in the empty pass (L2) for the BFB boiler. The NO reduction was better in the CFB boiler in comparison but the performance of AS for sulphation of KCl (reduction of KCl) was the opposite with a better reduction of KCl in the BFB boiler.

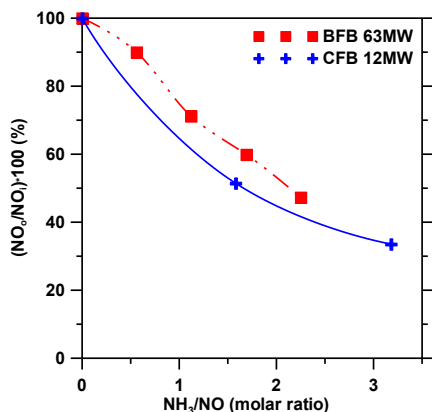


Fig. 9. Comparison of the reduction of NO between the 12 MW CFB boiler at Chalmers and the 63 MW BFB boiler in Jordbro. Injection of AS at $\lambda=1.20$ into the cyclone in the CFB boiler and into the empty pass in the BFB boiler.

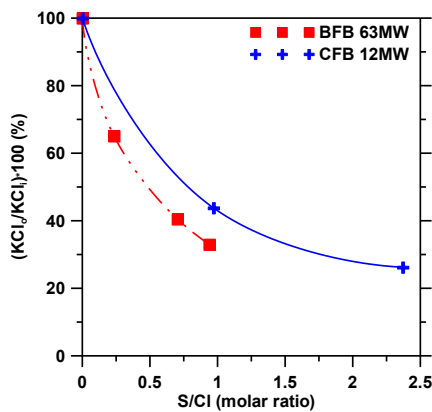


Fig. 10. Comparison of the reduction of KCl between the 12 MW CFB boiler at Chalmers and the 63 MW BFB boiler in Jordbro. Injection of AS $\lambda=1.20$ into the cyclone in the CFB boiler and into the empty pass in the BFB boiler.

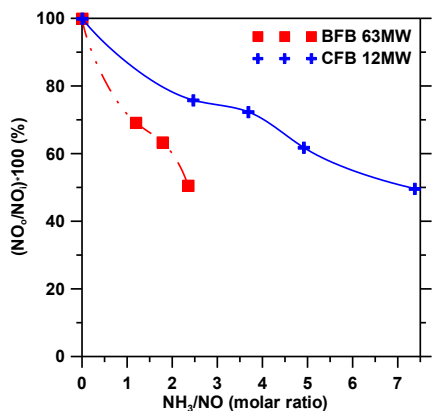


Fig. 11. Comparison of the reduction of NO between the 12 MW CFB boiler at Chalmers and the 63 MW BFB boiler in Jordbro. Low O_2 . Injection of AS to the upper part of the combustion chamber (L1 and H11).

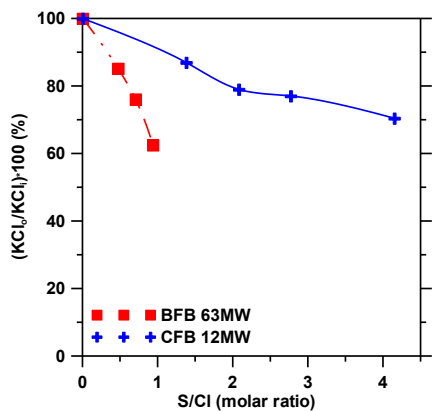


Fig. 12. Comparison of the reduction of KCl between the 12 MW CFB boiler at Chalmers and the 63 MW BFB boiler in Jordbro. Low O_2 . Injection of AS to the upper part of the combustion chamber (L1 and H11).

The results revealed that both the air excess ratio (i.e. content of O_2) and the selected position had an impact on the reduction of NO as well as KCl during injection of ammonium sulphate. The impression was that the efficiency of AS for reduction of NO and KCl in general were affected in similar ways. A less efficient reduction was achieved in earlier positions although the residence time was longer in comparison with other positions with the same air excess ratio. The proposed explanation is that a more complete burn-out of the combustibles gave fewer interactions with the O/H radical pool, R1a, R5, R6a and R7 in Table 1. There

were, however, examples of positions in which the NO reduction was significantly better. It is suggested that sulphation of KCl is somewhat more sensitive for interactions with the O/H radical pool. The reduction of both KCl and NO is influenced by the competition for OH radicals (R1a, R6a) but the sulphation of KCl is also influenced by H-radicals, R7 in Table 1.

The interactions with the O/H radical pool becomes even more evident when comparing the injection of AS into the upper part of the combustion chamber at Low O₂ conditions in both the CFB and BFB boiler in Figs 11 and 12. The final oxidation of hydrogen (H₂), carbon monoxide (CO) and light hydrocarbons (C1-C3), important species for consumption of OH radicals, is less efficient in the upper part of the combustion chamber in the CFB boiler due to the presence of recirculating bed material. A BFB boiler is operated with lower fluidisation velocities than a CFB boiler. The bed material is coarser and the solid density (kg particles/m³ reactor) become much lower at the same position in the BFB, which could explain the different behaviour when it comes to gas phase chemistry and final burnout of combustibles between the boiler types.

The development of the NO_x reduction in boilers has a long history which goes back to the time when the high emissions of NO_x from coal-fired utility boilers were no longer accepted. The SNCR technology was introduced by Exxon Research and Engineering (Lyon 1975). Ammonia was the first reagent but it was followed by urea (Muzio et al. 1976) and cyanuric acid (Perry and Siebers 1986) and also ammonium sulphate was tested as a reagent and carrier for amines (Chen et al. 1988) at that time. Extensive review articles are available, Tayyeb et al. 2007, Coda Zabetta et al. 2005. The most severe problems experienced with the SNCR technology is: the narrow temperature window, poor performance (i.e. a reduction of NO less than 50%), ammonia or hydrogen cyanide (HCN) emissions at low temperatures or to high additions during low reduction ratios, poor final oxidation of CO, and finally an unwanted formation of nitrous oxide (N₂O) that is a greenhouse gas.

The SNCR technology with NH₃ from AS as reagent works well for the BFB boiler although some of the possible drawbacks can be found in Table 5. No problems occurred concerning ammonia emissions, CO-oxidation or the temperature in the reaction zone for ammonia. The project, nevertheless, reveals that during injection too early in the presence of combustibles and when the O₂-level is low, poor performance for NO_x reduction was achieved in the BFB as well as in the CFB boiler in a previous investigation by Kassman and Åmand 2015.

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