Examples of Full scale tests on BFB Waste to Energy boilers (WtE) with direct impact on the future operation of the facility.

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Abstract
The growing problem with municipal solid waste has helped to accelerate de development of Waste to Energy plants (WtE). However, WtE-plants have problems with agglomeration, deposition and corrosion. And at the same time new waste streams are considered for combustion. Co-combustion has sometimes proven to have positive effects on the combustion environment. In this project full scale tests were performed on two twin 20 MW_{th} WtE Bubbling Fluidized Bed (BFB) boilers in Borås, Sweden. The aim of the research was to investigate if a lowered bed temperature by means of flue gas recirculation or addition of animal waste to the normal waste mix (NWM) could improve the boiler performance. The bed temperature was decreased from 870°C, the boiler design temperature, to around 750°C. The animal waste is a pumpable slurry consisting of crushed carcasses and slaughterhouse waste classified with risk of infection because of BSE (Bovine spongiforme encephalopathy or the mad cow disease). The result shoved both decreased deposit formation rate and decreased agglomeration tendency of the bed. And in the case with animal waste addition the NOx emission was reduced with 50% compared to ordinary performance. Furthermore the ammonia addition for NOx reduction was also cut by half in this case.
Keywords: WtE, BFB, RDF, waste, agglomeration, deposit, NOx

1 Introduction

As a result of increased amount of waste all over the world, controlled waste combustion for power and heat production is also increasing. This helps to accelerate the development of Waste to Energy (WtE) technology and promotes research in this area. But even sorted waste most often contains high concentration of alkali and chlorine compounds with both low melting and low vaporization temperatures, which causes deposition and corrosion on tubes and walls in the boiler [1, 2]. These problems could be eased by addition of various additives with the ability to capture alkali metals, e.g. kaolin and sulphur in different compounds [3-5]. In addition, fluidized bed (FB) boilers are known to be very fuel flexible, but as the combustion takes place in a sand bed, chemical reactions between sand-bed particles and inorganic compounds in the fuel may occur. These reactions often lead to the formation of eutectic melts causing bed agglomeration, and, in the worst case, total defluidisation. The bed temperature in FB boilers is typically 780°C to 900°C, controlled within a range of a few degrees [6].

The aim of this project was to investigate if a decreased bed temperature, by means of flue gas recirculation and water spraying on the fuel, by 100-150°C could decrease the deposit formation and bed agglomeration in a full scale WtE-boiler [7]. In addition, it was investigated if the flue gas recirculation and water spraying could be exchanged for addition of 15-20% of animal waste to the ordinary waste and what changes in chemistry this would give [8].

2 The Boilers

The two 20 MW_{th} BFB boilers at Borås Energy and Environment AB, Borås, Sweden, were used for the combustion tests. The boilers produce superheated steam with a temperature of 405°C and a pressure of 49 bars and are parallel but separate units sharing both fuel feed and ash transportation systems. Boiler no. 1 is equipped for research with measurement hatches in a number of locations in the walls in addition to sampling equipment for solid flows. However, boiler no. 2 is also equipped with some measurement holes. Because of their shared fuel and ash systems, both boilers were operated in the same way during the combustion tests.

3 The fuels

The used WtE BFB boiler is designed for a fuel mix of 80% sorted industrial waste (RDF) and 20% sorted household waste (MSW), which in this paper is referred to as Normal Waste Mix (NWM). Both these wastes consist mainly of paper, plastic and wood. The fuel quality has improved over the years since 2005 when the plant was opened, because of improved sorting, and today the heating value of the NWM is higher than the designed heating value.

The animal waste fuel, here referred to as AWF, consists of carcasses and slaughter house waste that are ground and pH-adjusted, in a separate plant, to a slurry. These animal wastes, classed by risk of infection, are regulated by the European Commission (EU) due to the BSE (bovine spongiform encephalopathy) outbreak in the European beef industry in the late 90s [9, 10]. The slurry is transported to a receiving tank at the WtE-plant, from which the slurry is pumped in a closed system directly into the combustion chamber.

In the animal waste combustion tests 20% of AWF was added to the NWM.

4 The tests

Three different tests were performed, and to prevent any memory effects, the boilers were operated with the selected fuel mix and temperature for three days before each sampling. In the reference test (Ref) the boiler was operated at the normal temperatures and with 100% NWM, Table 1. In the reduced bed temperature (RBT) case the boiler still was operated on 100% NWM fuel, but the bed temperature was decreased to 720°C by means of flue gas recirculation and water spraying of the fuel. And in the animal waste (AW) case the fuel mix consisted of 80% NWM and 20% AWF.

Table 1. Test matrix

Case	Bed temp	Fuel
Ref	850°C	100% NWM
RBT	720°C	100% NWM
AW	770°C	80% NWM+ 20% AWF

Continuous measurements and solid sampling of fuels, ashes and deposits were performed during each test day. The deposit probe was inserted just upstream of the first super heater package for three hours, carrying two collection rings [7].

4.1 Gas analysis

The flue gas was analyzed by FTIR down steam the flue gas cleaning system. And all flows of solids and gases in addition to temperatures were measured during the combustion tests. For detailed information see Pettersson et al. [7].

4.2 Analyses on solids

Elemental analyses of solid samples were made by ICP-AES, or ICP-MS. Additional analyses were made by means of SEM-EDX and Chemical fractionation (step by step leaching) [7].

5 Results

5.1 Fuel analysis

The fuel analysis showed that the NWM had a moisture content of around 38% and an ash fraction of around 12% on raw fuel, Table 2. The AWF had a moist content of 61% and half the ash fraction compared to the NWM. The concentration of N, Ca, P and Zn was higher in AWF compared to NWM. In addition the concentration of Al, Ti, Fe, Si, Cu and Pb was lower, Table 2. However, because of the mix of 80% NWM and 20% AWF the resulting fuel blend in the AW- case did not differ so much from the fuel in the Ref and RBT cases, see Table 2.

Case	**Ref**	**RBT**	**AW**	**AW**	**AW NWM+**
type	**NWM**	**NWM**	**NWM**	**AWF**	**AWF**
			[Wt-% raw]		
Moist	37.5	35.7	42.05	60.9	46.4
Ash	12.7	12.2	11.2	5.4	9.9
Ultimate analyse			**[Wt-% daf]**		
C	54	52	52	57	52
H	7.1	6.8	6.8	8.4	7.0
S	0.53	0.40	0.53	0.30	0.49
N	1.4	1.3	1.1	6.7	2.1
Cl	0.80	0.56	0.90	0.42	0.78
O	28	31	30	18	28
Heating value			**[MJ/kg]**		
LVH, raw	10.9	10.9	9.8	8.3	9.5
HHV, dry	18.8	18.8	18.7	25.0	19.8
Elemental analyse			**[mg/kg dry]**		
S	4 600	3 500	4650	2800	4300
Cl	6 600	4 900	7450	3500	6800
K	3 900	3 600	3100	2050	2900
Na	6 600	8 100	6300	4550	6000
Ca	27 400	26 900	31650	45100	33900
Al	11 600	11 500	11300	100	9400
Mg	2 700	3 100	3400	1000	3000
Ti	1 600	2 500	2900	100	2400
Mn	220	n. a.	200	100	180
Ba	240	n. a.	400	100	350
P	950	1 400	750	21900	4300
Fe	5 000	9 800	7150	400	6000
Si	38 400	45 500	42350	700	35500

NWM = normal waste mix, AW = animal waste
NWM+AW = 80 % normal waste mix +
20 % animal waste, n.a. = not analysed
daf = dry and ash free

Table 2 Fuel analysis

5.2 Flue gas analysis

The flue gas analysis showed that NOx was decreased with 50% in the AW case compared to the Ref and RBT case, see Fig. 1. In addition, the automatic ammoniac addition for NOx reduction decreased with 50% in the AW case. However, also in the RBT case the ammoniac supply was reduced by 50 %, but the NOx emissions were in the same level as in the Ref case. The NOx reduction in the AW case can be explained with that much of the nitrogen in the AWF is bound as amino acids, and during combustion this nitrogen is released as NH_3, thus replacing the ammoniac addition. The decreased ammoniac addition in the RBT case is related to the decreased bed temperature.

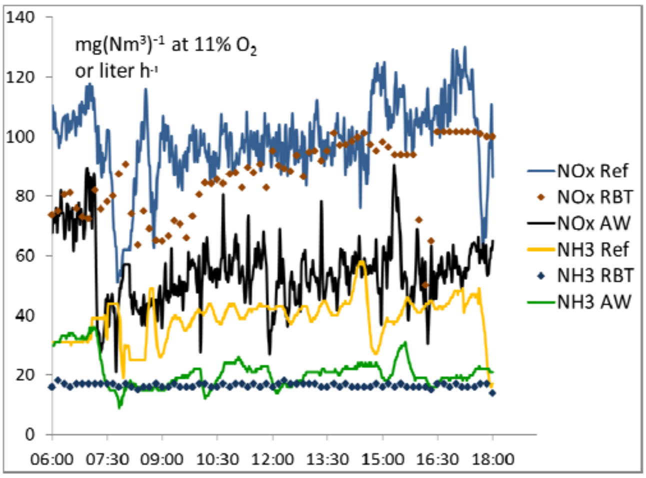

Fig. 1 NOx measured downstream of flue gas cleaning and ammoniac addition for NOx reduction.

No changes were seen in the emission of HCl in the three cases. However, the SO_2 emission was decreased in the AW case.

5.3 Ashes

By the ash analysis it was observed that most main elements had the same distribution in the ashes in all cases. However, S was found in high concentration in the bed and return sand in the RBT and AW cases, but in the Ref case most S was found in the fine fly ash.

The bed ash from the Ref case contained agglomerates up to a size of 70 mm, consisting of mostly bed sand, but also glass from the waste, stones and metals. All material in the bed ash and return sand fractions were covered with a coating with a glassy appearance. In the RBT and AW case there were no agglomerates at all, but also here all material had a coating layer. SEM-EDX analyses, see Fig. 2, and chemical fractionation showed that in the RBT and AW case the coating contained more S and Cl compared to the Ref case. In addition, the higher amount of P in with the fuel in the AW case was clearly reflected in the coatings. However, the concentration of Al and Si was higher in the Ref case compared to the RBT and AW cases. Combinations of Si and Al are known to increase the melt temperature of ashes, but in this case obviously not enough to prevent agglomeration.

The analyses of the fly ash fractions; boiler ash, cyclone ash and filter ash, showed that in the AW case there was an increase of Ca, P and S in the boiler ash and cyclone ash but in the cyclone ash S was decreased. The increases in Ca and P, as for S in the case where it also increased, were found in the acid soluble part of the ash. This could be explained by the fact that much of the P is bound in bone tissue as $Ca_{10}(PO_4)_6(OH)_2$ and β-$Ca_3(PO_4)_2$ [9, 10] which don't break at the investigated temperature but are soluble in acid.

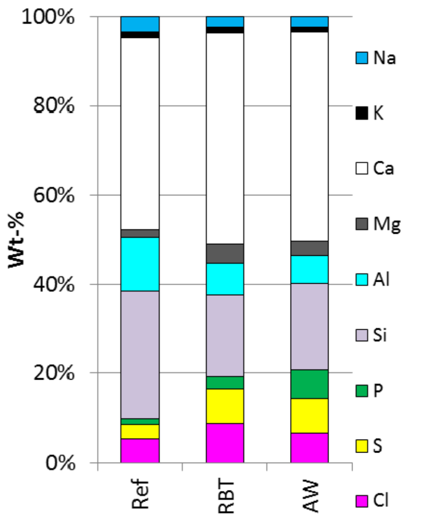

Fig. 2 SEM-EDX analysis of the coatings on return sand particles.

5.4 Deposit formation

The deposit formation decreased with the reduced bed temperature, but addition of AWF decreased the formation rate even more, Fig. 3. However, the elemental composition did not improve if considering Cl and alkali. No enrichment of Ca and P was found in the deposits despite the increased P and Ca concentrations in the AW case. This could be explained by the finding that much of the P is bound in bone tissue as discussed above. The rest of the P is bound in the soft

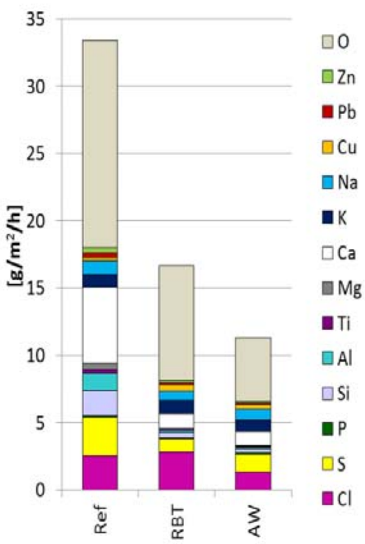

Fig. 3 Deposition grow rate and element composition on deposit rings.

tissue and is released during combustion. This P reacts with Ca if available in the NWM and forms calcium phosphates collected in the ash fractions [11, 12].

5.5 Discussion

The decreased NOx emission was even lover after a reconstruction of the AWF feeding system made after this project was ended. The measured emission was lower than ever, even though the ammonia addition connected to the anti-NOx system of the boiler was turned off. This means decreased costs, both regarding NOx emissions and ammonia, for boiler owners when adding AWF. Calculations on the current system with two twin boilers of 20 MWth each gives a total saved cost of 350 to 700 thousand Euro per year calculated on 2010 price on ammonia and emissions in Sweden.

Also the decreased bed agglomeration obtained both in the RBT and AW case, saves money for the boiler owners because of reduced need of fresh sand to the bed as a result of the increased availability of return sand.

Regarding the deposit formation no increase in corrosion rate could be found after running the boiler in the two different modes, RBT and AW for periods of 10 month. However, especially in the AW case it was reported that the cleaning of the heat transfer surfaces was easier to perform than after normal operation of the boilers.

6 Conclusions

Animal waste fuel (AWF) could be a good additive to waste combustion in FB-boilers

The high P concentration in AWF did not cause any problems regarding deposit formation or agglomeration. In fact, the deposit formation rate was decreased by more than 60 % compared with the Ref case and by 30 % compared with the RBT case.

At the investigated temperatures and conditions, addition of AWF reduced both the NOx emissions and the consumption of ammonia for the anti-NOx system by 50%.

6.1 Acronyms

AES	Atomic Emission Spectroscopy detector
AW	Animal waste combustion case
AWF	Animal waste fuel
BFB	Bubbling Fluidized Bed
BSE	Bovine Spongiforme Encephalopathy
EDX	Energy Dispersive X-ray detector
FB	Fluidized Bed
ICP	Inductive Coupled Plasma with
MS	Mass Spectrometer detector
NWM	Normal Waste Mix
RBT	Reduced Bed Temperature combustion case
RDF	Refuse Derived Fuels
SEM	Scanning Electron Microscopy
WtE	Waste to Energy

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