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EVALUATION OF ASH RELATED PROBLEMS DURING SEWAGE SLUDGE COMBUSTION

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Abstract

A good function of waste-to-energy installation requires knowledge of the combustion characteristics of the fuel and fusion characteristics of the ash produced in the combustion process. Sewage sludge could be considered as renewable fuel due the high quantity of organics of sufficiently high calorific value. The combustion of sewage sludge can cause operating problems due to high ash content containing mineral compounds.

This paper presents the oxide composition of three kinds of sewage sludge ashes and the influence on the slagging and fouling process in combustion. For comparation, two coal samples were selected, a low and a high rank coal. The mineral matter were investigated by the X-ray fluorescence analytical technique using the Rigaku CG X-ray Spectrofluorimeter. The evaluation of slagging and fouling process was performed on the basis of some indices: the basic oxides, the base-to-acid ratio, the slagging index and the fouling index.

The conclusion based on experimental studies is that depending on mineral content the sewage sludge ash can cause high to moderate slagging and fouling hazard.

Keywords: *ash, fouling, sewage sludge, slagging index*

Introduction

The use of sewage sludge as a source of renewable energy is an option, both in the EU and in the Romanian sludge management strategy (PNGD 2017). In dehydrated form sewage sludge could be considered as renewable fuel due to its calorific value (Serbanescu et al 2017). The combustion of sewage sludge is becoming more attractive, due to the destroying of hazardous constituents and considerable volume reduction. Thermal processes involve removing the organic part of the sludge, leaving only the ash component for final disposal.

Sewage sludge can be directly incinerated in different types of incinerators or co-incinerated with other fuels. Compared to other solid fuels, such as coal, the sewage sludge has a greater ash content, between 20-50% wt % on dry basis, which involves ash handling systems and flue gas cleaning systems.

The complex characterization of sewage sludge plays an important role both in the design and exploitation of combustion installations. For the good function of the sewage sludge combustion or incineration installations is important to know the energy and fusion characteristics of the ashes. Sewage sludge combustion can lead to exploitation problems, by slag formation in the combustion chamber and refractory material, producing heat transfer efficiency decreasing, boiler flow rate decreasing refractory material degradation and deposits formation on pipes.

A scheme of the ash formation and transformation mechanism in the combustion processes is shown in fig. 1 (Yanqing Niu et al 2016).

Similar to pulverized coal combustion during the combustion of sludge particles and the formation of char particles, volatile organometallic compounds are first released followed by devolatilization; then, partial alkali and alkali-earth elements (e.g. K, Na, and Ca) and volatile trace elements (e.g., Hg, As and Se) diffused out of the char. As the gas temperature decreases, the volatile components nucleate and condense to form submicron sized particle. Also, some volatile material condenses on residual fly ash (Yanqing Niu et al 2016). Important issues related to ash in the combustion processes are the slagging (ash fusion) and the agglomerations.

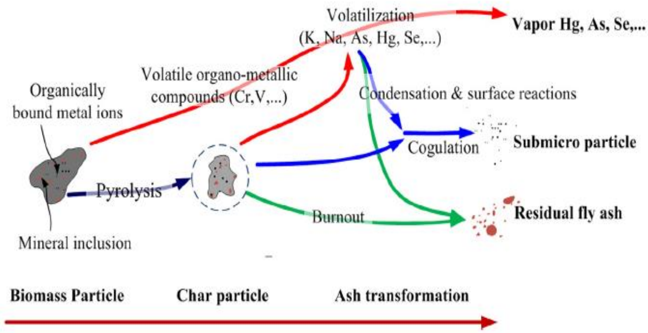

Figure 1. Scheme of the ash formation and transformation mechanism in the combustion processes (Yanqing Niu et al 2016)

During the combustion, there are a number of physical changes of the ashes in the furnace. As the temperature rises, the ash particles soften until they are completely fused. Fuels with low fusion temperatures of ash, lead to increase the slag formation risk on grates. The fusion temperature varies depending on several factors, most important of which is the nature of the waste fuel used.

The major ash formers elements (Al, Ca, Fe, Mg, P, K, Si, Na, and Ti) are responsible for the ash fusion, the deposits formation and corrosion processes. In addition, volatile elements, such as Na and K, are the main components of aerosols, in the form of solid particles, dispersed in the gases removed from the combustion. Volatile minor elements (As, Cd, Hg, Pb, Zn) play a major role in gas emissions (Kim et al 2017).

The article presents the influence of ash oxide composition for three sewage sludge samples and two coal samples on slagging and fouling tendency in combustion processes.

Materials and Methods

The experimental study was carried out on three dehydrated sewage sludge samples from different wastewater treatment plants. Samples were noted: NA, NB, NF. For comparison, 2 samples of coal were selected, a high rank coal (pit coal-H) and a low rank coal (lignite-L).
For characterization, the samples were prepared in the laboratory by air drying at ambient temperature and milled using the Retsch Vibratory Disc Mill RS 200 in order to obtain a laboratory sample with a grain size less than 200 μm. The higher calorific value was determined by calorimetric method (ASRO 2009) using PARR 6200 calorimetric bomb. The elemental analysis, carbon, nitogen and hydrogen content was determined by a chromatographic method using the Thermo Scientific FlashEA 1112 Elemental Analyser (ASRO 2011). The sulphur content was determined spectrophotometric (ASRO 2017).
The sewage and coal samples ash composition was determined by the X-ray fluorescence technical analysis according to method (ASRO 2007) using the Rigaku CG X-ray fluorescence spectrometer. For the sewage sludge samples, the oxide composition was determined from the ash obtained at three temperatures: 550^0C, 815^0C and 915^0C.

Results and Discussion

The technical and elemental characteristics of the studied coal and sludge samples are presented in table 1. The three sludge samples had a lower calorific value between 2108 kcal/kg and 2677 kcal / kg at dry bases (8.8-11.2MJ/kg at dry bases) and a high ash content higher than 47% at dry bases, which indicates that combustion can be used for energy recovering.

Table 1. Main physical-chemical characteristics of analysed samples

Sample	Ash (wt.% d.b.)	Ultimate analysis (wt.% d.b.)				HHV (kcal/kg d.b.)	LHV (kcal/kg d.b.)
		C	H	N	S		
H	7.36	75.37	3.83	2.53	0.80	7296	7108
L	32.01	41.79	3.04	1.10	2.58	3907	3758
NA	54.12	23.54	2.85	3.28	1.13	2248	2108
NB	56.33	23.58	2.77	3.36	1.08	2393	2257
NF	47.35	27.62	3.31	4.76	0.77	2840	2677

d.b.-dry basis; HHV-high heating value; LHV-low heating value

The ash composition expressed as oxides for the studied coal and sewage sludge samples are presented in table 2.
The main components of the studied ashes are SiO_2, CaO, Al_2O_3, Fe_2O_3, P_2O_5. The oxide composition of the studied samples are relatively different. The NA sample had a lower content of acid oxides (SiO_2, Al_2O_3) than the NB and NF samples but a CaO content much higher than the NB and NF samples. The results for the oxide composition are not different for the three temperatures used for calcination.

Table 2. Ash composition expressed as oxides, wt. %

Sample/ oxides	SiO_2	CaO	Al_2O_3	Fe_2O_3	P_2O_5	MgO	Na_2O	K_2O	TiO_2	MnO	SO_3
H	47.59	4.80	24.75	9.53	0.71	1.62	2.65	1.52	1.23	0.09	4.35
L	40.97	9.70	22.69	7.31	0.17	1.86	3.10	1.38	0.87	0.06	10.79
NA1	27.77	30.76	9.14	8.46	5.68	2.20	4.67	1.39	0.69	0.11	7.62
NA2	30.22	30.29	9.99	8.31	5.91	2.46	3.77	1.53	0.72	0.11	5.14
NA3	28.50	31.33	9.52	8.56	5.94	2.35	3.92	1.29	0.72	0.11	6.28
NB1	50.06	7.46	12.83	9.49	3.62	2.13	2.67	1.81	0.70	0.26	4.88
NB2	50.15	8.23	13.71	10.33	4.34	2.15	2.20	2.07	0.83	0.29	4.33
NB3	51.12	8.49	13.08	10.58	3.96	2.11	1.66	2.06	0.83	0.29	2.36
NF1	43.33	13.87	10.55	4.95	10.2	4.43	3.34	2.27	0.81	0.19	4.65
NF2	44.06	13.98	10.71	5.04	10.39	4.65	3.00	2.32	0.83	0.19	3.47
NF3	46.28	14.38	10.57	5.21	9.70	4.56	2.62	2.43	0.83	0.20	1.85

There are four characteristic temperatures for the ash flow: the shrinking temperature (ST), the deformation temperature (DT), the hemisphere temperature (HT) and the flow temperature (FT).

For the ash behaviour estimation in combustion processes some slagging and fouling indices are used (Pronobis 2005). This index was established based on the effects of the temperature on the ash. The following indices have been used:

- Basic oxides: ($R_b = Fe_2O_3 + CaO + MgO + Na_2O + K_2O + P_2O_5$), which lower the melting temperature. The minimum ash softening temperature occurs by R_b = 35-55%;

- Acid oxide: ($R_a = SiO_2 + Al_2O_3 + TiO_2$), which increase the melting temperature;

-The base-to-acid ratio ($R_{b/a(+P)} = (Fe_2O_3 + CaO + MgO + Na_2O + K_2O + P_2O_5)/ (SiO_2 + Al_2O_3 + TiO_2)$). For $R_{b/a}$ <0,15 both hemisphere temperature (HT) and the flow temperature (FT) exceed 1600^0C. The smaller the $R_{b/a}$, the higher the HT and the FT, the slagging tendency decrease. For $R_{b/a}$ ~ 0.75, HT and FT are below 1200^0C, resulting in a very high slagging tendency.

-The slagging (Babcock) index: $R_S = (B/A) * S^d$, S^d represents the sulphur content in dry sample. For R_S < 0,6 the slagging tendency is small; R_S = 0,6 – 2,0 the slagging tendency is medium; For R_S = 2,0 – 2,6 the slagging tendency is high; R_S > 2,6 the slagging tendency is extremely high.

- The fouling index $F_u = R_S * (Na_2O + K_2O) / S^d = (B/A) *(Na_2O + K_2O)$. For $F_u \leq 0.6$ the fouling tendency is low; $0.6 < F_u \leq 40$ the fouling tendency is high; F_u > 40 the fouling tendency is extremely high, there are a tendency for sintering of deposits.

For the calculation of the slagging and fouling indices during the combustion process, the oxide composition of the ash was normalized to 100% for a base without SO_3.

The indices for slagging and fouling tendency calculated for the analysed samples are presented in table 4. In fig. 2 and 3 are presented the variation of basic and acidic oxides.

Table 4. Indices for slagging and fouling tendency evaluation

Sample/Indices	R_A	R_B	$R_{B/A}$	R_S	F_u
H	73.57	20.12	0.27	0.22	1.14
L	64.53	23.35	0.36	0.62	1.62
NA1	37.60	47.48	1.26	1.43	7.65
NA2	40.93	46.36	1.13	1.28	6.00
NA3	38.74	47.45	1.22	1.38	6.38
NB1	63.59	23.56	0.37	0.40	1.66
NB2	64.69	24.98	0.39	0.42	1.65
NB3	65.03	24.90	0.38	0.41	1.42
NF1	54.69	28.86	0.53	0.41	2.96
NF2	55.60	28.99	0.52	0.40	2.77
NF3	57.68	29.20	0.51	0.39	2.56

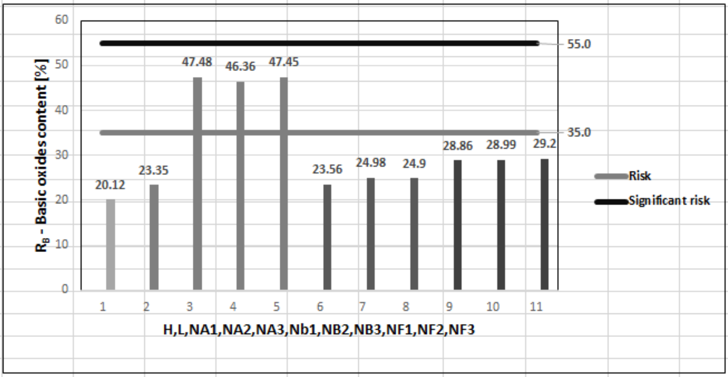

Figure 2. The content of basic oxides in the analysed ash samples

The pit coal sample (H) has the lowest content of basic oxides, and the highest content of acid oxides. The basic oxides for the lignite sample (L) is comparable to that of the NB sludge sample. The basic oxides for NA is between 35 and 55%, which places it in the area with the minimum softening temperature for the ash. The NB and NF sludge samples, as well as the coal samples, are located outside for this area of risk.
The base-to-acid ratio (**$R_{b/a}$**) for the analysed samples is presented in fig. 4.
The hemisphere temperature (HT) and the flow temperature (FT) both for coal and NB and NF sludge samples are below 1600^0 C. For the NA sludge sample, base-to-acid ratio exceeds the limit of 0.75, resulting in a very high slagging tendency.

The slagging (Babcock) index R_S for the analysed samples is presented in fig. 5. Analysing the tendency of slagging according to this index, only NA sludge sample shows a medium slagging tendency.

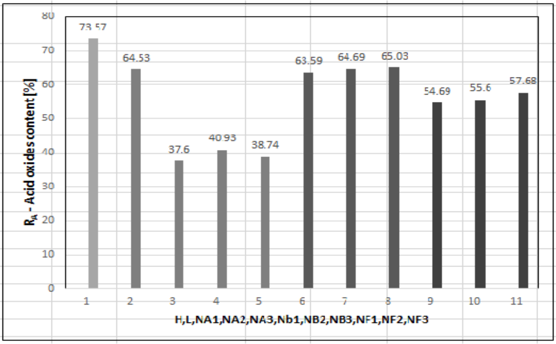

Figure 3. The content of acidic oxides in the analysed ash samples

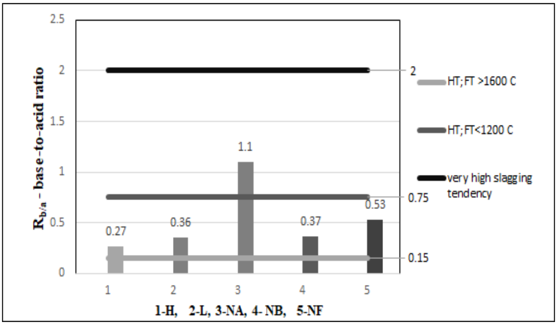

Figure 4. The base-to-acid ratio (**$R_{b/a}$**) for the analysed ash samples

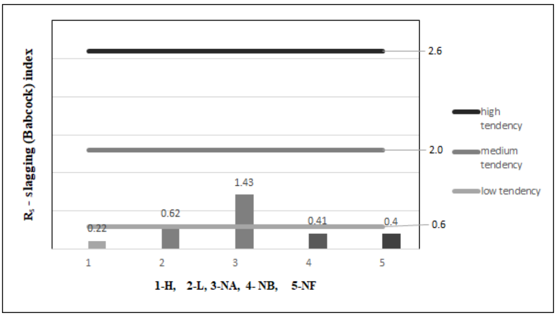

Figure 5. The slagging (Babcock) index (RS) for the analysed ash samples

The **fouling index F_u** for the analysed samples is presented in fig. no. 6. The fouling index Fu is based on the base-to-acid ratio ($R_{b/a}$), but also considering the sum of Na and K oxides. Alkali metals are known to form eutectic in combination with SiO_2. Consequently, as the values of the Fu index are higher, the tendency of the deposits formation is higher.

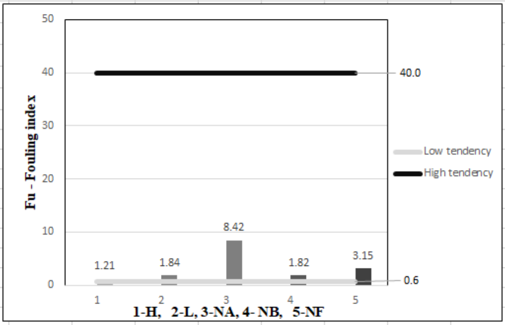

Figure 6. Fouling index (F_u) for analysed ashes

For a value of $F_u \leq 0.6$, the deposits tendency of ash is low, for $0.6 < Fu \leq 40$ the deposits tendency of ash is high, and for $Fu > 40$ the tendency of agglomeration (sintering) of deposits is high. All the studied ashes present a high tendency of deposits formation ($0.6 < Fu \leq 40$).
Analysing the slagging and fouling indices for the analysed sludge and coal samples, the high rank coal sample (H) presents the lowest slagging and fouling tendency, followed by the sludge sample (NB), due to the high acidic oxide (SiO_2, Al_2O_3) content of the ash 73,57% and 64,53%. The low rank coal sample (L) and the sludge sample (NF) present a medium slagging tendency. The sludge sample (NA), due to the basic oxide content of the ash (~47%), presents a high slagging tendency.

Conclusions

The paper presents an analysis of slagging and fouling tendency in combustion process for three sewage sludge and two coal samples, using some indices (basic oxides, acid oxides, base-to-acid oxides, slagging and fouling indices)
The full characterisation of the sludge samples, including the ash composition and ash slagging and fouling tendency, has an important role in the design and exploatation of combustion installations, where sewage sludge is used for incineration or co-incineration.

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