ARCHIVES OF ENVIRONMENTAL PROTECTION

vol. 40 no. 3 pp. 101 - 113 2014

DE GRUYTER

PL ISSN 2083-4772
DOI: 10.2478/aep-2014-0027

CO-COMBUSTION OF MUNICIPAL SEWAGE SLUDGE AND HARD COAL ON FLUIDIZED BED BOILER WF-6

RAFAŁ RAJCZYK[1]*, JURAND BIEŃ[1], HENRYK PALKA[2], ANDRZEJ POGODZIŃSKI[2], HUBERT SMORĄG[2]

[1]Częstochowa University of Technology, Institute of Advanced Energy Technologies
J.H. Dąbrowskiego 73, 42-200 Częstochowa
[2]Boilers Factory SEFAKO S.A.
Przemysłowa 9, 28-340 Sędziszów
*Corresponding author's e-mail: rajczyk@fluid.is.pcz.pl

Keywords: Municipal sewage sludge, co-combustion, bubbling fluidized bed boiler.

Abstract: According to data of the Central Statistical Office, the amount of sludge produced in municipal wastewater treatment plants in 2010 amounted to 526000 Mg d.m. The forecast of municipal sewage sludge amount in 2015 according to KPGO2014 will reach 642400 Mg d.m. and is expected to increase in subsequent years. Significant amounts of sludge will create problems due to its utilization. In order to solve this problem the use of thermal methods for sludge utilization is expected. According to the National Waste Management Plan nearly 30% of sewage sludge mass should be thermally utilized by 2022. The article presents the results of co-combustion of coal and municipal sewage sludge in a bubbling fluidized bed boiler made by SEFAKO and located in the Municipal Heating Company in Morag. Four tests of hard coal and sewage sludge co-combustion have been conducted. Boiler performance, emissions and ash quality were investigated.

INTRODUCTION

SEFAKO S.A. is one of the biggest boiler manufacturers in Poland. The range of the boilers is covering large scale energy boilers, industrial boilers as well as the small units for e.g. production sector and food sector. Taking into account current trends in waste management the study aimed to assess the possibilities of a WF-6 boiler utilization for sewage sludge co-combustion process with respect to identification of an environmental issues (i.e. emissions and ash quality). As the result of the study a guideline for WF boiler series has been established in order to develop a boiler design making possible co-combustion of sewage sludge at high shares, fulfilling all of the environmental standards [4].

Stabilized municipal sewage sludge is classified in the waste stream as the group 19.08 – wastes from sewage treatment plants not otherwise specified and are assigned code 19.08.05 in accordance with the Regulation of the Minister of Environment of

27 September 2001 on waste catalog (Dz.U.01.112.1206). Thus, municipal sewage sludge, by the definition is considered as a waste and is subject of regulations included in the Law on Waste of 14 December 2012 (Dz.U. 2013 Nr 0 poz. 21). In accordance with the Waste Act, thermal processing of waste can be conducted in incineration plants or in co-combustion plants and entails additional requirements [1]. Installations for the incineration or co-combustion of waste are supposed to meet process requirements and fulfill emission standards. The process requirements are specifically addressed in the Regulation of the Minister of Economy on requirements for a waste incineration process (Dz.U.2002.37.339, Dz.U.2004.1.2, Dz.U.2010.61.380) and the Regulation of the Minister of the Environment of 4 November 2008 (Dz.U.2008.206.1291) on the requirements for emission measurements and used water measurements. The emission standards for waste incineration and co-combustion are specified in the Regulation of the Minister of the Environment on the emission standards of 22 April 2011 (Dz.U. 2011 No 95, item. 558). According to this Regulation, industrial installations where the co-firing of a sewage sludge is performed are required to fulfill emission standards, which are given in Annex 6 of the Regulation.

The paper presents the process data, emissions and ash sample analyses from co-combustion of hard coal and sewage sludge. The co-combustion process was performed on SEFAKO fluidized bed WF-6 boiler, located in a heating plant in Morąg, Poland. The main focus of the research was to determine maximum possible load of sewage sludge in a fuel mixture, taking into account operational parameters of the boiler, emissions and ash parameters.

EXPERIMENTAL

Fuels

Hard coal was used as a base fuel. Sewage sludge from treatment plant Dziarny near Iława was used (wastewater treatment plant is located approx. 60 km from Morąg). In the Dziarny plant sewage sludge is subject to an anaerobic digestion and mechanical dewatering, then the sewage sludge is dried in a solar dryer. Solar drying system was designed as a hybrid system using numerous drying heat sources such as solar energy, wastewater heat, ground energy and heat from cogenerators' cooling. At the moment only solar energy and heat from cogenerators' cooling are used for sewage sludge drying. At a present stage of the drying system sewage sludge moisture is subject to significant changes strongly dependent on weather conditions. The sewage sludge for the co-combustion process was collected from prism during February, thus resulting in high moisture content. In order to improve sewage sludge quality (*i.e.* to minimize moisture content and improve LHV), the storage of sewage sludge dried in a summer period should be considered under umbrella roof or in silos in order to prevent it from gaining additional moisture.

Fuel analysis was performed in accordance with PN-G standards for coal and PN-EN standard for sewage sludge. Fixed carbon was calculated from the balance. Elemental analysis of C, H, N and S was done using Leco TruSpec CHNS analyzer, elemental oxygen content was calculated from the balance. LHV was analyzed using Mikado KL-11 calorimeter. Proximate and ultimate analysis of hard coal and the sewage sludge is presented in Table 1.

Table 1. Proximate and ultimate analysis of the co-combustion fuels

Proximate analysis		Ultimate analysis	
Hard coal (as received)			
LHV (Q_j^r)	19695 kJ/kg	Coal content (c)	52,50%
Moisture (W^r)	12,87%	Hydrogen content (h)	3,90%
Ash (A^r)	18,90%	Nitrogen content (n)	1,09%
Volatile matter (V^r)	25,25%	Sulfur content (s)	1,46%
Fixed carbon (F_c^r)	42,98%	Oxygen content (o)	9,27%
Municipial sewage sludge (as received)			
LHV (Q_j^r)	5796 kJ/kg	Coal content (c)	17,16%
Moisture (W^r)	46,58%	Hydrogen content (h)	2,76%
Ash (A^r)	18,33%	Nitrogen content (n)	4,42%
Volatile matter (V^r)	28,72%	Sulfur content (s)	0,79%
Fixed carbon (F_c^r)	6,37%	Oxygen content (o)	9,96%

As already mentioned, the sewage sludge had a significant moisture content resulting in a poor LHV. During the experiment four tests were performed. In the first test only hard coal was burned. Then, the fuel mixtures were prepared and co-fired. The sewage sludge share in the fuel mixture was 15, 40 and 60% on a mass basis. The fuel mixture samples were taken during the tests from a fuel conveyor. The samples were then mixed and analyzed. Analysis of fuel samples is presented in Table 2.

Table 2. Fuel mixtures analysis (as received) vs. theoretical fuel mixture parameters

Contents kg/kg of fuel mixture	Sewage sludge in the fuel mixture						
	$0\%_{wt.}$ (*M0*)	$15\%_{wt.}$ (*M1*)		$40\%_{wt.}$ (*M2*)		$60\%_{wt.}$ (*M3*)	
	An.	*An.*	*Calc.*	*An.*	*Calc.*	*An.*	*Calc.*
Coal (c)	0.525	0.4772	0.4543	0.4053	0.3483	0.313	0.2882
Hydrogen (h)	0.039	0.0378	0.0318	0.0359	0.0209	0.0337	0.0147
Nitrogen (n)	0.0109	0.0148	0.0176	0.019	0.0276	0.0268	0.0332
Sulfur (s)	0.0146	0.0094	0.0133	0.0099	0.0113	0.0086	0.0101
Oxygen (o)	0.0927	0.0848	0.0941	0.0998	0.0962	0.1159	0.0973
Moisture (W^r)	0.1287	0.1584	0.1961	0.2046	0.2973	0.2757	0.3546
Ash (A^r)	0.189	0.2175	0.1879	0.2255	0.1862	0.2264	0.1852

An. – real fuel mixture taken from conveyor and analyzed in laboratory; *Calc.* – calculated on a basis of coal and sewage sludge properties.

Basing on the results of pure fuels analysis given in Table 1, the theoretical properties of fuel mixtures were calculated (assuming that a mixing process is perfect) and presented in Table 2 as well. The comparison between the theoretical parameters and parameters analyzed that good mixing has been achieved.

WF6 boiler, emission measurement, sampling

The experiment of the sewage sludge co-combustion with hard coal was performed on SEFAKO's bubbling fluidized bed boiler WF6, located in municipal heating plant (MPEC) Morąg, Poland. The capacity of WF6 is 6MW_{th},water pressure 1.43 MPa, water temperatures 150/70°C. Boiler's scheme is presented in Fig.1.

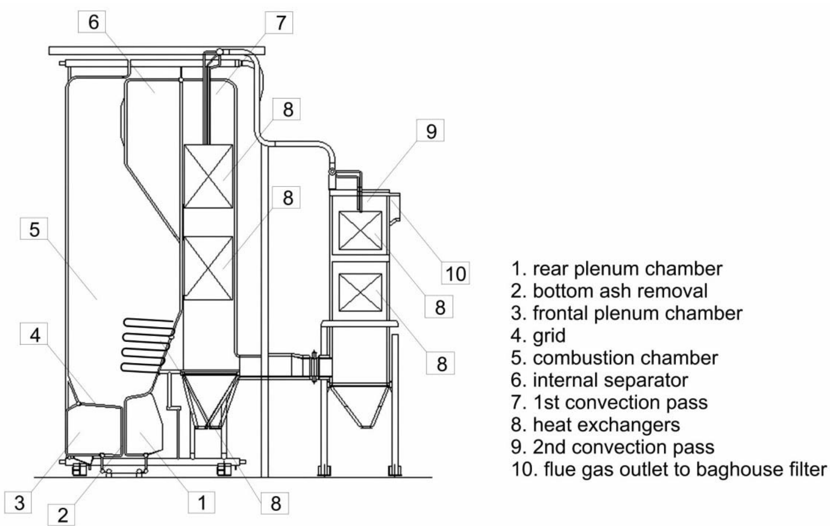

Fig. 1. Scheme of the WF 6 boiler

Temperatures were measured using the existing thermocouples in the fluidized bed. Flue gas components (CO_2, CO, SO_2, SO_3, NO_2, NO, N_2O, NH_3, HCN, H_2O, HCl, HF) were measured using Gasmet DX-4000. Fly ash and bottom ash sampling was done one per hour, later the daily (test) samples were prepared. Ash samples were analyzed using Leco TruSpec CHNS and PANalytical MiniPal 4. During the co-combustion experiments there was no limestone added. On the one hand it enhanced sulfur dioxide emissions significantly, but on the other hand, a potential of the sewage sludge ash for in-situ desulfurization was determined.

RESULTS

Boiler performance

Co-combustion of sewage sludge is a promising process combining a possibility of waste thermal utilization with a fossil fuel stabilizing the process. In order to achieve stable operation the fuel feeding system should be adjusted to the properties of a fuel mixture. However, the co-combustion tests were performed without any modification to the fuel feeding system and to the boiler. Research was focused on estimation of a maximum sewage sludge share in the fuel mixture, with respect to a stable operation of a boiler and the fuel feeding system, at its present shape. Key parameters of a fuel mixture that may affect the co-combustion process are as follows: moisture content, volatiles content, density of the fuels, and melting point of the ashes. It should be emphasized that a range of the mentioned parameters may vary in a sewage sludge, especially the moisture content.

Mean values of the temperatures in the fluidized bed and mean oxygen concentrations in the flue gas during co-combustion tests are presented in Figure 2. Changes of temporary temperatures and oxygen concentrations during the tests are shown as error bars in Figure 2.

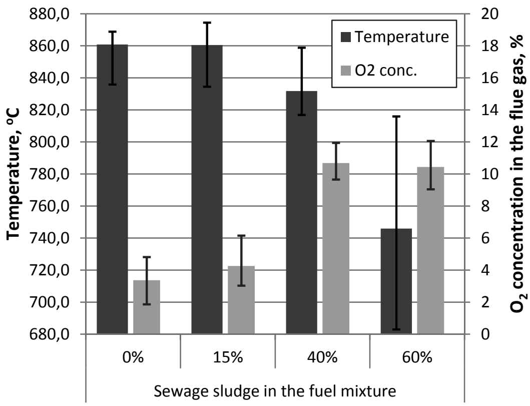

Fig. 2. Fluidized bed temperatures and O_2 concentrations in the flue gas during co-combustion tests

During the first test, when hard coal was the only fuel (*M0*), temperatures varied within a range of 835–870°C and the mean value was 860°C. Oxygen concentration in the flue gas was at a mean level of 3.37% (in wet gas). Co-firing of the sewage sludge at $15\%_{wt.}$ of the fuel mixture did not affect the mean temperature and temporary temperatures were almost within the same range (834–875°C). Oxygen concentration was slightly enhanced. The sewage sludge co-firing at 40% in the fuel mixture had only a minor influence on the fluidized bed mean temperature (836°C), comparing to *M0* and *M1* fuel mixtures combustion. The boiler operation was still stable. Nevertheless, the oxygen concentration increased significantly to 10.68% thus affecting other flue gas components emissions as they are normalized to 6% O_2 concentration. Enhanced oxygen concentration also indicates that the boiler performance and efficiency may go worse. The last test was performed for 60% sewage sludge share in a fuel mixture. The oxygen concentration was similar to the 40% test, but the temperature of the fluidized bed episodically dropped to an unacceptable level, below 700°C when the mean value for whole test was 746°C. The boiler operation was unstable (temporary temperatures were beyond the reasonable range i.e. 682–816°C). Problems with fuel feeding have been observed as well. It was concluded that due to the low LHV of the fuel mixture and fuel feeding performance a stable operation could not be achieved at that proportions.

From the design temperature point of view the operation of WF6 is possible up to 40% of the sewage sludge in a fuel mixture. However, the oxygen concentration during test with

40% of the sewage sludge as well as the operation of the fuel feeding system indicates that sewage sludge co-firing at that amount should be preceded by the boiler optimization.

Emissions

Composition and amount of pollutants from sewage sludge co-combustion is dependent on fuel properties and on combustion technology as well as the performance of gas cleaning processes. The composition of a flue gas is also related to the temperature in the combustion chamber.

According to the Ministry of Environment Regulation on emissions standards from installations, issued on April 22nd, 2011, standards for a waste co-combustion are established using "mixing" formula, as given in Appendix 6 of the Regulation [4]. On that basis, emission standards of NO_x (as NO_2) and SO_2 for installations of a different thermal power have been calculated and presented in Table 3, where C_{proc} is emission standard for fossil fuel combustion, C_{waste} is emission standard for pure waste combustion and C is emission standard for waste co-combustion. Table 3 does not include fly ash emission standards, because fly ash concentration was not investigated in the work.

Table 3. Emission standards of SO_2 and NO_x for waste combustion

Pollutant	Nominal thermal power of installation [MW]	Emission standard [mg/m^3_u]		
		C_{proc}	C_{waste}	C
Sulfur dioxide SO_2	50–100	850	50	730
	100–300	200	50	178
	>300	200	50	178
Nitrogen oxides as NO_2	50–100	400	200	370
	100–300	200	200	200
	>300	200	200	200

In Figure 3 nitrogen oxides – NO_X (i.e. NO+NO_2) and N_2O concentrations have been presented.

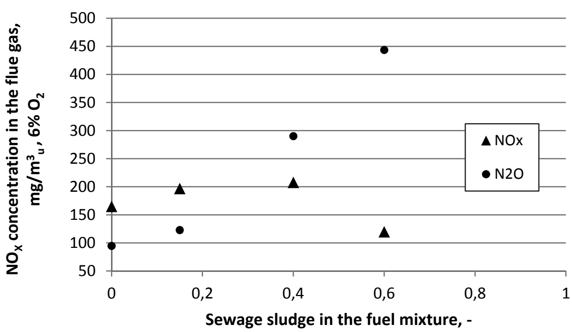

Fig. 3. NO_x and N_2O concentration during co-combustion of the hard coal and sewage sludge on WF6 boiler

NO_x concentrations are increasing slightly for 0%, 15% and 40% of the sewage sludge shares, than the drop of NO_x concentration is observed for the 60% share of the sewage sludge. Nitrous oxide concentrations are continuously increasing with increased sewage sludge shares in the fuel mixture. On the one hand, nitrogen oxides emission is closely related to elemental nitrogen content in fuel mixture, which is almost four times higher in the sewage sludge than in hard coal (see Tables 1 and 2). Also oxygen concentration plays an important role, as the concentrations of pollutants in the flue gas are normalized to 6% oxygen content. During tests with $40\%_{wt.}$ and $60\%_{wt.}$ of the sewage sludge, oxygen concentrations were enhanced (Fig. 2). On the other hand, nitrous oxide concentration was increasing with the higher shares of the sewage sludge in the fuel mixture, as a result of lower temperatures in the combustion chamber (see Fig. 2). Nevertheless, an individual nitrogen oxide concentration, total nitrogen oxides concentration ($NO_x + N_2O$) during the tests with $40\%_{wt.}$ and $60\%_{wt.}$ of the sewage sludge was at the similar level of 550 mg/m^3_u.

In Figure 4 sulfur dioxide concentrations are shown as a function of increasing sewage sludge shares in the fuel mixture.

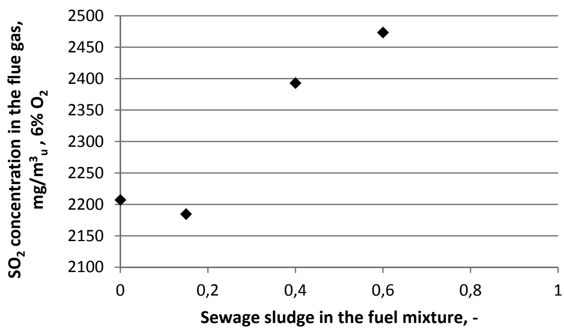

Fig. 4. SO_2 concentration during co-combustion of the hard coal and sewage sludge on WF6 boiler

The concentrations exceed the standards, however no limestone was used during the tests as it was explained previously. During the first test, when the hard coal was burned, SO_2 concentration amounted to 2200 mg/m^3_u.

Nevertheless, the sewage sludge contained almost a half of elementary sulfur less than the hard coal, the concentrations of sulfur dioxide were substantially higher when co-firing of blends with $40\%_{wt.}$ and $60\%_{wt.}$ of the sewage sludge. An increase of the SO_2 concentration was a result of several reasons. First of all, the oxygen concentration was higher during co-firing $40\%_{wt.}$ and $60\%_{wt.}$ of the sewage sludge, thus affecting the concentrations normalized to 6% oxygen content, similarly to the NO_x concentrations. However, it does not fully explain the increased SO_2 concentrations, because even in flue gas condition SO_2 content was higher for $40\%_{wt.}$ and $60\%_{wt.}$ of the sewage sludge co-combustion than for the coal combustion. It is most likely resulting from higher degree of the sewage sludge combustible sulfur conversion to sulfur dioxide than the conversion of the coal sulfur, as described in [2]. In the test with the $60\%_{wt.}$ of the sewage sludge the conversion of some sulfur to the hydrogen sulfide has been observed.

The concentration of sulfur trioxide was measured as well and SO_3 was present at a level of 25 mg/m^3_u during the hard coal combustion. During the tests with sewage sludge addition in the fuel mixture sulfur trioxide was not detected.

In Figures 5 and 6 the concentrations of HCl and HF has been presented respectively.

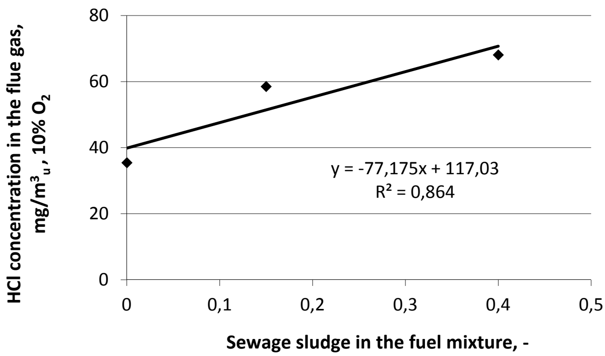

Fig. 5. HCl concentration during co-combustion of the hard coal and sewage sludge on WF6 boiler

Hydrogen chloride concentration in the flue gas is increasing when the amount of the sewage sludge in the fuel mixture is growing. A relatively high content of hydrogen chloride has been reported in the test with combustion of hard coal only. For the test with $15\%_{wt.}$ of the sewage sludge, hydrogen chloride concentration increased by more than 60% and for the test with $40\%_{wt.}$ of the sewage sludge – by almost 100% as compared to the concentrations obtained during the hard coal combustion. The hydrogen chloride emissions exceed the emission limits specified in the Regulation of the Minister of Environment of 22 April 2011 on emission standards from installation (Dz.U.2011.95.558) for incineration or co-incineration of waste [4]. A normative value for HCl is in fact 10 mg/m^3_u.

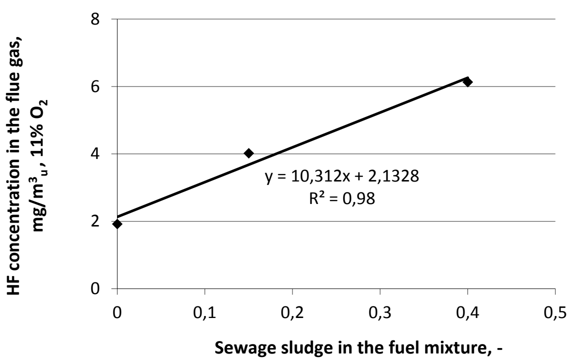

Fig. 6. HF concentration during co-combustion of the hard coal and sewage sludge on WF6 boiler

The content of hydrogen fluoride increases with an increase of the sewage sludge share in the fuel mixture, similarly to the case of hydrogen chloride. The 15%$_{wt.}$ share of the sewage sludge in the fuel mixture resulted in over of 100% increase in HF emission, while the 40%$_{wt.}$ share of the sewage sludge in the fuel mixture increased hydrogen fluoride emission by almost 200%, compared to the emission from the hard coal combustion. In all cases, the concentration of HF exceeds the limit values laid down in the Regulation of the Minister of Environment of 22 April 2011 on emission standards from installation (Dz.U.2011.95.558) – where the limit is defined on the level 1 mg/m^3_u of HF [4]. For both HCl and HF emission standards have been exceeded even for the test with hard coal combustion, thus a coal selection is an important issue in prevention of increased HCl and HF emissions.

Ash properties

Loss on ignition (LOI) for fly ash and bottom ash is presented in Table 4. High ignition loss in fly ash is considerable; it is resulting from unusual boiler design with combustion chamber height. Thus, ignition loss of the fly ash is higher than in other BFB type boilers and exceeds the limit for the combustible parts in slags and combustion ashes.

Table 4. Loss on ignition of ashes

Fuel mixture composition (on mass basis)	LOI, %$_{wt.}$	
	Fly ash FA	Bottom ash BA
hard coal 100% (*M0*)	18.06	0.56
hard coal 85%/sewage sludge 15% (*M1*)	16.06	1.37
hard coal 60%/sewage sludge 40% (*M2*)	15.56	0.66
hard coal 40%/sewage sludge 60% (*M3*)	18.53	0.27

LOI of the bottom ash is quite low taking into account boiler's type and size. High LOI in fly ash was observed during test with sole hard coal combustion as well as for the tests with sewage sludge co-combustion. An enhanced unburned carbon content in fly ash results from process parameters – boiler's height is 7 m and the time of a fuel particle residence in the combustion chamber is approx. 1.8 s (the boiler had to be fitted in an existing building of limited height). With increasing sewage sludge in the fuel mixture fly ash LOI is similar to LOI obtained for hard coal combustion. However, it should be noted that the addition of wet sewage sludge potentially may increase LOI of the fly ash. Moisture release from fuel particles could result in moving of a flame's core to the upper parts of the combustion chamber, thus shortening even more burning fuel particle's time of residence in the combustion chamber [6].

An oxide analysis of the fly ash is presented in Table 5. Analysis of trace elements content in the fly ash is presented in Table 6.

Table 5. Oxide contents in the fly ash

Fuel mixture	Al_2O_3	CaO	Fe_2O_3	MgO	P_2O_5	K_2O	SiO_2	MnO	TiO_2
	$\%_{wt.}$	$\%_{wt.}$	$\%_{wt.}$	$\%_{wt.}$	$\%_{wt.}$	$\%_{wt.}$	$\%_{wt.}$	$\%_{wt.}$	$\%_{wt.}$
(*M0*)	15.47	3.41	6.59	1.97	0.15	1.68	33.43	0.094	0.89
(*M1*)	16.20	4.90	6.95	2.25	1.23	1.73	33.49	0.1	0.79
(*M2*)	15.33	8.48	6.72	2.36	6.01	1.98	30.82	0.099	0.78
(*M3*)	14.21	10.45	6.43	2.35	8.01	1.96	29.09	0.092	0.82

Table 6. Trace elements contents in the fly ash

Fuel mixture	As	Cd	Co	Pb	Sb	V	Cr	Cu	Hg	Ni	Zn
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
(M0)	36.26	0.58	17.50	82.66	4.83	15.57	96.70	70.96	< 1	65.12	372.61
(M1)	34.16	0.49	19.44	88.92	3.09	16.61	106.88	122.30	< 1	59.06	376.07
(M2)	25.37	0.56	22.13	76.29	1.29	31.79	137.08	360.31	< 1	63.79	1123.39
(M3)	35.57	0.52	20.15	73.52	1.39	5.47	159.86	489.16	< 1	77.61	1478.74

An ash forming matter contained considerable amounts of SiO_2 with a tendency to decrease its content for fuel mixtures with higher sewage sludge shares. Ash forming matter consisted also of aluminum (III) oxide and the content of ($SiO_2 + Al_2O_3$) amounted to 45–50$\%_{wt.}$ of the ash forming matter during all the tests (Table 5). It indicates the presence of aluminoslicates which are usually main ash forming matters in Polish coals. The content of ash forming matter was quite similar to [5], where a sewage sludge was incinerated in a fluidized bed boiler and the composition of ashes was determined as: SiO_2 – 39.34, Al_2O_3 – 17.72, CaO – 15.20, Fe_2O_3 – 5.32, K_2O – 1.98.

In the ashes obtained during co-combustion of the higher shares of the sewage sludge an increase of calcium oxide and phosphorus (V) oxide was observed resulting from calcium and phosphorus compounds presence in the sewage sludge.

Trace elements content in sewage sludge is usually related to waste water quality in a certain region. The increase of Cu, Cr and Zn content has been observed when increasing the share of the sewage sludge in the fuel mixture. The increased content of Zn and Cu may result from those elements migration from pipes construction material and also from Zn content in cosmetics.

CONCLUSIONS

According to the UE Accession Treaty and the requirements of the Water Law Act of 18 July 2001, Poland was obliged to reduce biodegradable pollution loads and achieve 100% reduction of nitrogen and phosphorus inputs by 2015. Compliance with these requirements implies the need for an implementation of high effective methods of water treatment, thus enhancing a stream of a sewage sludge that must be disposed and managed properly. In terms of legislative restrictions including the prohibition of the municipal sewage sludge storage in landfills since 1 January, 2016, thermal methods, especially co-firing, seem to be one of the promising methods of sewage sludge utilization [7]. The co-combustion experiment of sewage sludge co-combustion on the SEFAKO's WF6 bubbling fluidized bed boiler was performed in order to assess the boiler's ability to co-fire sewage sludge at high shares in the fuel mixture. The study was carried out in the Municipal Heating Company in Morąg Poland. It should be emphasized that the boiler was designed for hard coal, the fuel which differs a lot from sewage sludge in terms of fuel parameters. Co-combustion tests were made without any previous changes to the boiler and its auxiliary systems, such as the fuel feeding system. Study was focused on establishing a maximum sewage sludge share in the fuel mixture while boiler's operation is still reliable with respect to combustion conditions as temperature, oxygen concentration in the flue gas as well as a performance of fuel feeding system. The mass share of the sewage sludge in the fuel mixture was 15%, 40% and 60%. A reference test with 100% of the design fuel was made as well. Despite the high moisture content in the sewage sludge during the test with 15% share of the sewage sludge operation of the boiler was stable and the efficiency was close to the reference one. Operational parameters were getting worse during the test with 40% share of the sewage sludge when oxygen concentration in the flue gas was increased and NO_X and SO_2 emissions increased as well. However, it was still possible to operate the boiler. Increasing the sewage sludge share up to 60% resulted in a significant temperature drop with all the consequences such as high emission of N_2O and drop of efficiency. Fuel feeding system problems forced the end of testing at that share of the sewage sludge in the fuel mixture.

The results are promising in terms of using bubbling fluidized bed boiler for waste based fuels co-firing such as sewage sludge. However, a number of improvements are essential in order to meet the waste fuel combustion process requirements including optimization of the temperature, gas residence in the combustion chamber and the limiting of organic carbon content in the ash. These requirements are specifically addressed in the Regulation of the Minister of Economy on requirements for waste incineration process (Dz.U.2002.37.339, Dz.U.2004.1.2, Dz.U.2010.61.380). The boiler height should be significantly increased in order to achieve 2s time of fuel residence in a zone of 850°C temperature above the highest point of air feeding. An additional gas or oil burner may be used as well to increase the temperature in the combustion chamber. Keeping the emission standards is also a crucial issue. The study revealed excess gaseous pollution emission. It should be noted that the aim of the study was not the optimization of emissions but providing the database for the future optimization. Basing on the study results and design experience in order to meet the emission standards the boiler should be supplied with a multi-stage gas cleaning system including precipitation system, desulfurization, nitrogen oxides reduction, acid gases reduction device.

ACKNOWLEDGEMENTS

The study was supported by Kielecka Staropolska Izba Przemysłowo-Handlowa under the frames of the project: „Świętokrzyski Transfer Wiedzy – wiedza i praktyka dla rozwoju gospodarki", co-financed by the European Union under the frames of European Social Fund.

ABBREVIATIONS

A^r – ash content in fuel, as received, $\%_{wt.}$
An. – analyzed, –
c – carbon content in fuel, $\%_{wt.}$
Calc. – calculated, –
C – emission standard for waste and hard coal co-combustion, $mg/m^3{}_u$
C_{proc} – emission standard for hard coal combustion, $mg/m^3{}_u$
C_{waste} – emission standard for waste combustion, $mg/m^3{}_u$
$F_c^{\,r}$ – fixed carbon in fuel, as received $\%_{wt.}$
h – hydrogen content in fuel, $\%_{wt.}$
LOI – loss on ignition, $\%_{wt.}$
M0 – fuel: 100$\%_{wt.}$ hard coal, –
M1 – fuel mixture: 15$\%_{wt.}$ sewage sludge and 85$\%_{wt.}$ hard coal, –
M2 – fuel mixture: 40$\%_{wt.}$ sewage sludge and 60$\%_{wt.}$ hard coal, –
M3 – fuel mixture: 60$\%_{wt.}$ sewage sludge and 40$\%_{wt.}$ hard coal, –
n – nitrogen content in fuel, $\%_{wt.}$
o – oxygen content in fuel, $\%_{wt.}$
s – sulfur content in fuel, $\%_{wt.}$
V^r – volatile matter content in fuel, as received, $\%_{wt.}$
W^r – moisture content in fuel, as received, $\%_{wt.}$

REFERENCES

[1] Bień, J.D., Szymanek, A. & Bień, B. (2011). Alternatywne dla spalania metody termicznej utylizacji komunalnych osadów ściekowych, Wydawnictwo Politechniki Częstochowskiej, Częstochowa 2011.
[2] Bień, J.D., Szymanek, A. & Bień, B. Emisja związków siarki ze współspalania osadów ściekowych i węgla w atmosferze O_2/CO_2, *Przemysł Chemiczny* (in print).
[3] Krajowy Program Gospodarki Odpadami KPGO2014, przyjęty uchwałą nr 217 Rady Ministrów z dn. 24.12.2010 (M.P. Nr 101, poz. 1183).
[4] Rozporządzenie Ministra Środowiska z dnia 22 kwietnia 2011 r. w sprawie standardów emisyjnych z instalacji (Dz.U.2011.95.558).
[5] Borowski, G. (2012). Suitability tests of fly ashes vitrification from sewage sludge incineration, *Archives of Environmental Protection*, 38, 81–87.
[6] Ściążko, M., Zuwała, J. & Pronobis, M. (2006). Zalety i wady współspalania biomasy w kotłach energetycznych na tle doświadczeń eksploatacyjnych pierwszego roku współspalania biomasy na skalę przemysłową. *Energetyka i Ekologia*, 3, 207–220.
[7] Rozporządzenie Ministra Gospodarki z dnia 8 stycznia 2013 r. w sprawie kryteriów oraz procedur dopuszczenia odpadów do składowania odpadów danego typu (Dz. U. 2013 poz. 38).

WSPÓŁSPALANIE KOMUNALNYCH OSADÓW ŚCIEKOWYCH Z WĘGLEM KAMIENNYM W KOTLE FLUIDALNYM WF-6

Według danych GUS w 2010 r. ilość osadów ściekowych wytworzonych w oczyszczalniach komunalnych wyniosła 526,1 tys. Mg s.m. Natomiast prognozowana wg KPGO2014 na 2015 r. ilość suchej masy komunalnych osadów ściekowych osiągnie poziom 642,4 tys. Mg i będzie dalej zwiększać się w kolejnych latach. Znaczne ilości osadów będą stwarzać problemy w ich zagospodarowaniu. W celu rozwiązania tego problemu stawia się na wykorzystanie termicznych metod unieszkodliwiania osadów. Zgodnie z zapisami Krajowego Planu Gospodarki Odpadami (KPGO2014) przewiduje się wręcz, że w perspektywie do 2022 r. ponad 30% osadów

będzie termicznie utylizowane. W artykule przedstawiono wyniki badań procesu współspalania czterech mieszanek na bazie węgla i komunalnych osadów ściekowych przeprowadzonych w kotle fluidalnym z warstwą pęcherzykową WF-6 produkcji SEFAKO zlokalizowanym w Miejskim Przedsiębiorstwie Energetyki Cieplnej w Morągu. Podczas badań określono towarzyszące temu procesowi emisje, skład powstających popiołów jak również wpływ współspalania na parametry ruchowe kotła.