

**EVALUATING THE POTENTIAL FOR COMBUSTION OF FUELS
FROM SEWAGE SLUDGE IN GRATE FURNACES**

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Abstract

This study aim was to evaluate the influence of combustion of fuels from sewage sludge on emission of pollutants.

Test results are presented combustion of three fuel types based on municipal sewage sludge with particle size 35 mm and 15 mm, i.e. fuel from sewage sludge and coal slime (*PBS fuel*), sewage sludge and meat and bone meal (*PBM fuel*) and fuel made of sewage sludge and sawdust (*PBT fuel*). The combustion tests were performed in a laboratory system enabling simulation of a combustion process present in stoker-fired boilers.

This paper describes and compares the combustion process of fuels from sewage sludge which differ as to grain size composition, and presents the results of changes in emission values of NO_x, SO₂ and CO₂. The emission results were compared with the corresponding results obtained during combustion of hard coal.

Note that the test results proved the potential of utilising sewage sludge fuels in co-combustion processes with coal in grate furnaces.

Keywords: sewage sludge, fuel from waste, combustion, grate furnace, emission.

Introduction

One of the key characteristics of Polish power generating system is a large number of boilers with grate furnaces fired with hard coal. Such boilers, operated in industrial boiler plants and local heating stations are units with relatively low power output, up to 25 MW.

They are the most commonly used equipment for incineration of waste in typical incineration plants. The grate boiler furnaces are increasingly used for co-combustion of hard coal with biomass and waste fuels (Beckmann et al. 2012, Hiltunen et al. 2008).

The literature on the subject presents information on co-combustion of coal and sewage sludge in grate furnaces (Fleck & Scholz 2011, Koziół 2010).

In Poland, the studies on the process of co-combustion of sewage sludge with coal in stoker-fired boilers in laboratory scale were performed by several research centres, and the studies performed both on steam and water boilers (Nadziakiewicz & Koziół 2003). At present, co-combustion of sewage sludge with coal in power plants in Poland is not employed, however preliminary trials are undertaken to enable a technical assessment of such a solution (Wasielowski et al. 2013).

The main issue in burning waste fuels and biomass in power boilers is a different, than that of coal, chemical and mineral composition of ash. The presence of components with low melting point in the ash from those fuels poses the risk of slag formation and problem of powdered material (pollutants) sedimentation of heated surfaces of heat exchangers.

Numerous studies have been devoted to the mechanism of ash formation and the behaviour of mineral matter in the processes of co-combustion of coal with other fuels with low caloric value, in particular biomass, among others (Pronobis 2008, Kupka et al. 2008).

Furthermore, an important issue, while utilising fuels from waste, is also sufficient mixing of the fuel on the grate, which is expected to prevent from such detrimental effects as local material overheating, leading to slag formation, furnace chamber damage and grate overburning.

An important parameter of the fuel combusted on a grate is its grain composition. Improper choice of the fuel grain size composition may lead to considerable loss of unburnt carbonisate in the slag and fly ash, since the content of combustibles in the slag may be even 25 – 30% of its weight, and in the fly ash 15 – 20% (Karcz et al. 2011).

In stoker-fired boilers, fuels with grain sizes 0 – 25 mm are usually burnt, with less than 25% 0 – 2 mm fractions.

Most of the stoker-fired boilers in use are not equipped in any flue gas treatment systems, except for the simplest dedusting equipment. The need to upgrade the flue gas treatment system, in order to comply with the emission standards and to adjust the flue system to the requirements of waste co-combustion process (conditions related to the minimum flue gas presence and minimum temperature in the furnace chamber) is the main subject of numerous discussions. The possibility of co-combustion of biomass and fuels from waste is often the only justification given to continue using some units with stoker-fired boilers (Kozioł 2010).

This paper evaluates the potential of burning fuels made of municipal sewage sludge in grate furnaces. The combustion tests were performed in a laboratory system enabling simulation of a process present in stoker-fired boilers.

Materials and methods

The combustion tests were performed on fuels made of municipal sewage sludge and other waste:

- fuel based on the municipal sewage sludge and coal sludge – **PBS fuel**;
- fuel based on the municipal sewage sludge and meat & bone meal – **PBM fuel**;
- fuel based on the municipal sewage sludge and saw dust – **PBT fuel**.

The fuels from sewage sludge contained also an addition of burnt lime. Energy properties of the fuels are listed in Table 1.

TABLE 1. Energy properties of fuels from sewage sludge vs. hard coal

Parameter	Unit	PBS fuel ^a	PBM fuel ^a	PBT fuel ^a	Hard coal ^b
Lower Heating Value, LHV	MJ kg ⁻¹	19.30	14.59	13.23	23.7 - 26.9
Higher Heating Value, HHV	MJ kg ⁻¹	21.71	15.97	15.54	26.0 - 28.3
Moisture	%	8.58	8.67	10.37	5.0 - 10.0
Voltaire matter	% DM	34.44	55.29	59.87	25.0 - 40.0
Ash	% DM	27.26	33.72	20.36	8.5 - 11.3
Elemental analysis					
Carbon		50.28	36.64	31.42	76.0 - 87.0
Hydrogen		3.91	4.12	4.43	3.5 - 5.0
Oxygen	% DM	15.01	17.95	40.50	2.6 - 12.8
Nitrogen		1.72	6.67	2.61	0.8 - 1.5
Sulphur		1.16	0.68	0.65	0.5 - 3.1
Chlorine		0.06	0.02	0.03	<0.10

^a - Source: Wzorek (2012)

^b - Source: Rybak (2006)

DM - dry mass

Fuels with grain sizes 35 mm and 15 mm were tested in order to evaluate the effect of grain size on the combustion process and emission of pollutants.

The combustion tests were performed on a laboratory scale at the Silesian University of Technology, Department of Technologies and Installations for Waste Management. This system is used for testing combustion of various types of waste and waste fuels.

The main component of the test stand is a boiler with special construction that enables simulation combustion processes present in water boilers with a stationary and mechanical grate. The boiler comprises two main parts: the bottom one with adjustable heating temperature (up to 1200 °C), and the top one with water jacket.

The test stand is schematically shown in Fig. 1.

In the tests, the type of fuel fired was adopted as the input value (variable), and based on a series of initial tests and literature data, the following constant values were adopted as the system operating parameters:

- thickness of the bed of fuel being burnt – ca. 75 mm (each time 2.5 kg sample was burnt);
- process duration – 3600 s from starting fuel feeding to the combustion chamber;
- air excess ratio in the furnace chamber $\lambda=1.8$;
- secondary air stream – $5 \text{ Nm}^3 \text{ h}^{-1}$;
- initial temperature in the combustion chamber – $900^\circ\text{C} \pm 10\text{K}$;
- minimum temperature during the combustion process – 800°C .

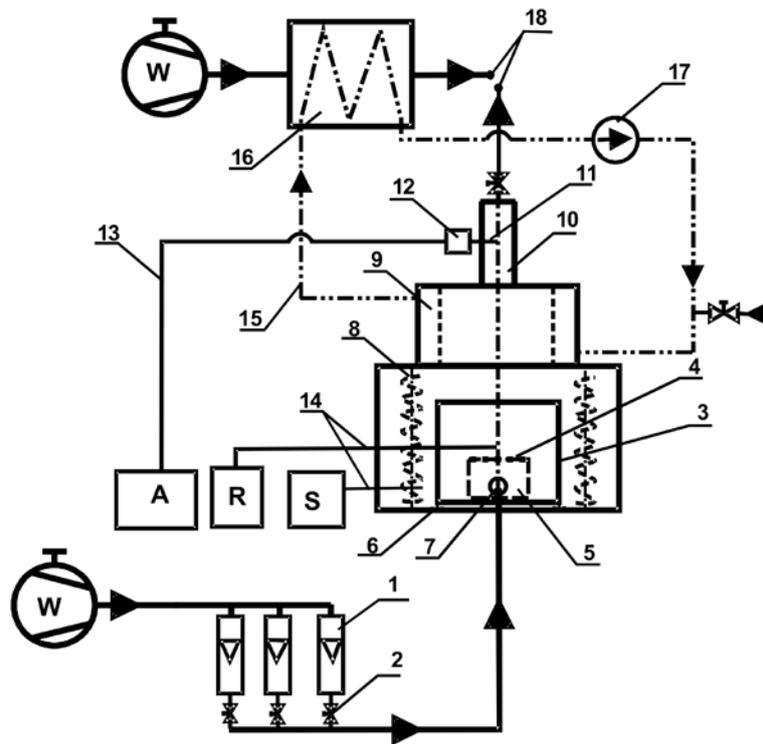


Figure 1. Test stand diagram (Wzorek et.al., 2010):

A – flue gas analyser, S – furnace control system, R – recorder, W – ventilator, 1– rotameter, 2 – valve, 3 – reciprocal bed with a grate, 4 – grate, 5 – plenum system (ash pit), 6 – rail, 7 – air nozzle, 8 – heating element (electrical), 9 – water jacket, 10 – stack, 11 – measuring probe, 12 – probe head, 13 – heated hose, 14 – thermo elements with compensating cables, 15 – cooling water circuit, 16 – water/air heat exchanger (cooler), 17 – circulation pump, 18 – ambience

During the tests, MGA 5 MRU flue gas analyser was used, with a heated probe and internal flue gas conditioner. The analyser allows measuring of flue gas composition with reference methods (measuring CO₂, CO, NO, NO₂, SO₂ – NDIR sensor; O₂ – electrochemical sensor). During the tests, the concentration of measured gases in the flue gas was continuously measured. The results were averaged in 10 s intervals, read and recorded.

Since the systems with fixed grates operate mainly in quasi-steady state at the most, to determine fuel behaviour on the grate, gaseous pollutants were measured from feeding the fuel to the combustion chamber to the process end. Presentation of results for the entire combustion time enables forecasting of system operation in steady conditions (average value), and is a source of knowledge allowing forecasting the degree of emission variations in unstable operating conditions.

Results and discussions

Combustion process of fuels from sewage sludge

The combustion process of fuels from sewage sludge, along with the variations of CO₂, CO, NO, SO₂ emissions, is graphically shown in Figs 2–6.

As the '0' moment, the start of air feeding to the combustion process was assumed. The earlier time is marked with negative values. Emissions measured while burning fuels from sewage sludge were compared to the average values for hard coal combustion (particle diameter 15 to 30 mm) (Wzorek et al. 2009).

Changes of CO₂ emissions shown in Fig. 2 best reflect the variations of combustion intensity.

Analysing the variations of CO₂ emission while combustion of fuels with the same composition, but different particle size, great similarity can be noted. The most intense burning process was observed between 250 and 1800 s; after that the CO₂ decreased slowly. Maximum values of CO₂ emission were observed while burning the PBM fuel with both particle sizes. It contains meat and bone meal, and animal derived waste, as proved by the research of Karcz et al. (2009), burn faster than other fuels e.g. lignite. This can explain different behaviour of PBM fuel while combustion, as compared to other sludge fuels. The PBS fuel firing appears to be the closest to burning hard coal, particularly with particle size 15 mm.

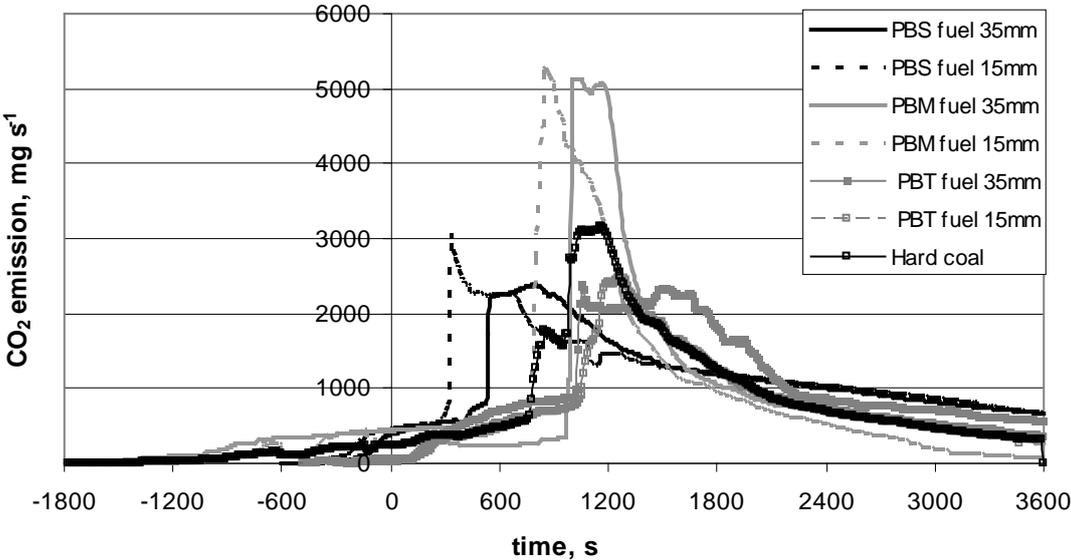


Figure 2. Variations of CO₂ emissions during combustion of fuels

Analysing Fig. 2, it can be noted that for sewage sludge fuels, the fuels with lower particle sizes were ignited faster. The shortest ignition time is achieved for the PBS fuel with particle

size 15 mm. Since the ignition time of a fuel depends mainly on the moisture content and the time of thermal decomposition of the organic matter, it can be concluded that the cause for a faster ignition of PBS fuel is the lower moisture content than in other sludge fuels.

Fig. 3 presents CO emissions achieved while combustion of the sewage sludge fuels.

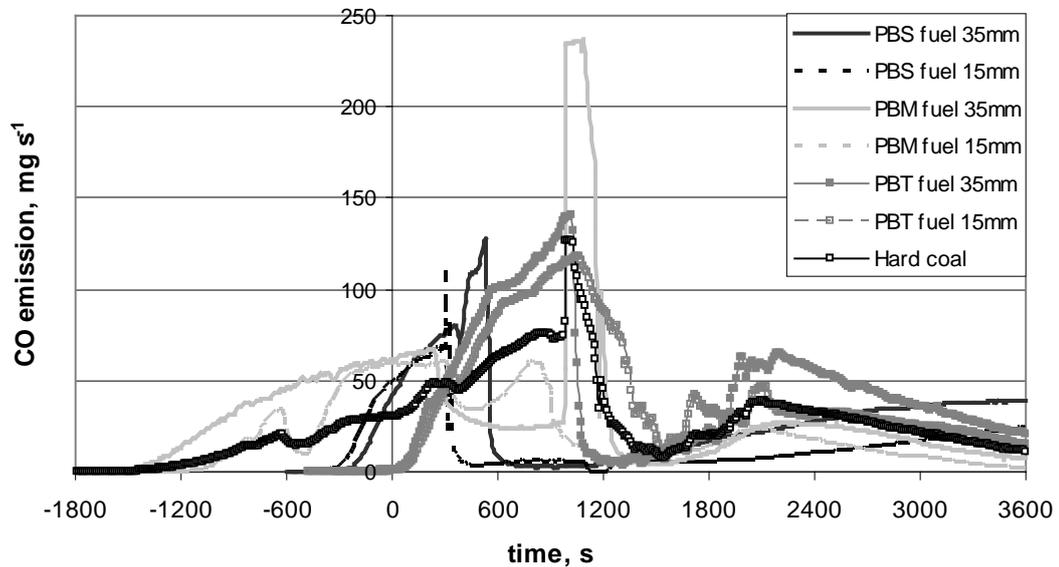


Figure 3. Variations of CO emissions during combustion of fuels

The CO emission changes for PBS and PBT fuels are similar. In case of the PBM fuel with particle size 35 mm max CO emission was noted at 1090 s (above 240 mg/s).

Between 500 and 1500 s, after reaching the maximum values for individual fuels, CO emissions to values dropped close to 0, which was the result of the way the test was performed – feeding secondary air. After that, the CO emission values increased, not exceeding 60 mg s⁻¹. According to Koziol (2010), such emission drops and increments are typical for burning fuels in grate furnaces.

While measuring the NO₂ concentration, in neither of the tests performed was it found in the flue gas. It may be due to the stabilisation of temperature in the combustion chamber during the tests at the temperature level 900 °C. NO₂ is formed mainly as a result of reactions in temperatures lower than 750°C (Wilk 2000).

The NO emission changes during combustion are shown in Fig. 4.

For all sludge fuels, very rapid increase of NO emission was observed in a the time interval between 350 and 1500 s.

For particle size 15 mm, this value at 530 s was almost 9 mg s⁻¹, and for 35 mm, in the interval (790 – 830 s) – 7.8 mg s⁻¹.

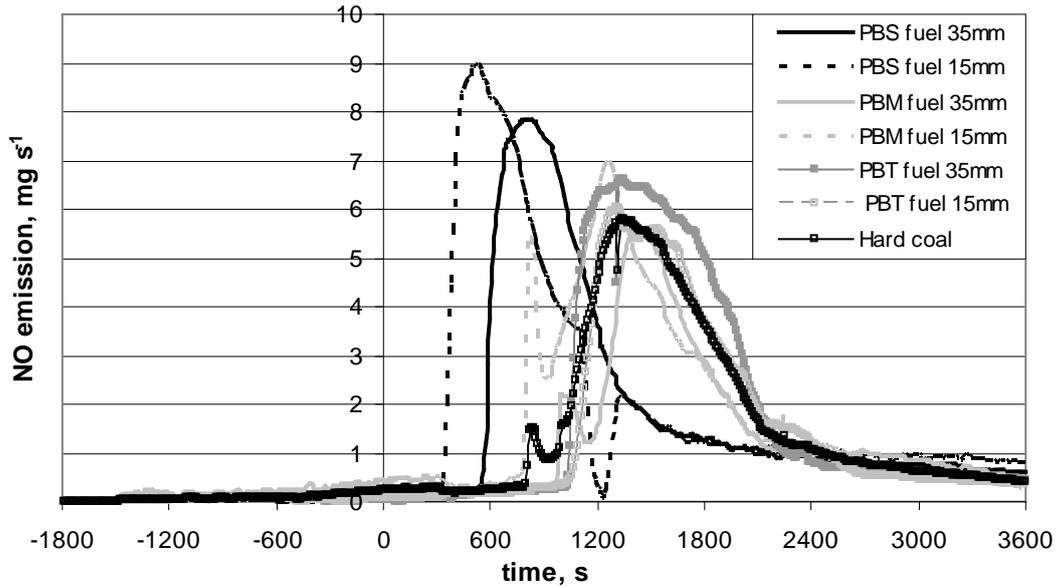


Fig. 4. Variations of NO emissions during combustion of fuels

A probable cause of higher NO values, achieved while combustion of sludge fuels than for coal is the higher content of elementary nitrogen in the sludge fuels, which – by the subject literature including Boardman & Smooth (1993), Habi et al. (2008) and Williams et al. (1997) – is referred to as the fuel mechanism, one of three major causes for NO_x formation.

In relation to SO_2 momentary emissions (Fig. 5), it can be noted that the highest values were noted while combustion of the PBS fuel (grain size 35 mm), reaching 10 mg s^{-1} at 510 s, and for the PBM fuel (grain size 35 mm), for which the maximum was almost 9.90 mg s^{-1} at the 1020 – 1050 s interval.

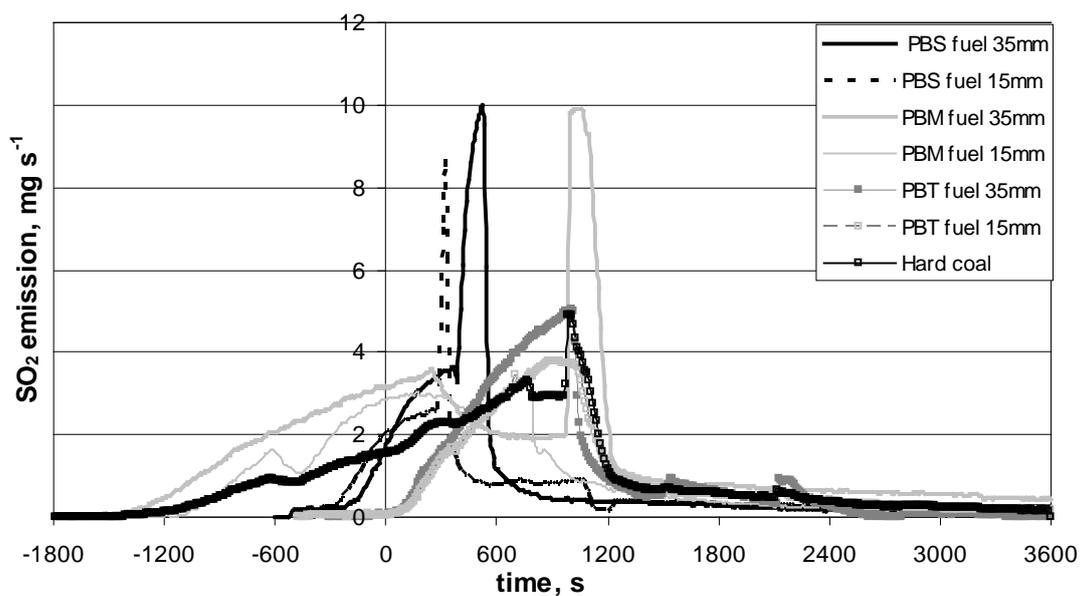


Figure 5. Variations of SO_2 emissions during combustion of fuels

All curves, up to 1200 s, are characterised by rapid fluctuations. The exception is the emission of the PBT fuel (grain size 35 mm), for which the stabilisation of SO₂ emission changes occurs only at 2200 s.

The results of measurements carried out on an industrial system of the stoker-fired boiler type ORS-16, in which hard coal was co-combusted with sewage sludge (mass content in the mixture being burnt 11-12.9%) presented in publications (Stelmach & Wasilewski 2008 and Wandrasz 2003) prove that during combustion an increase of NO_x emission by 12 – 62%, and SO₂ by 10 to 40% (compared to combustion of coal alone) was observed, depending on the amount of sludge added to coal. Increased emission of those compounds was accompanied by an increased share of sewage sludge in the mixture being burnt.

Similar relationship is also described by Werther & Ogada (1999) for fluidised bed boilers, based, among others, on the tests performed by van Doorn et al. (1992), in which the co-combustion of the sewage sludge was tested both with hard coal and lignite. In both cases, as the mass content of sludge in the burnt mixture was increased, also the NO_x emission was increasing.

However, Morgan & van de Kamp (1995), based on their own research, concluded that for mass content of sludge above 50%, the NO_x emission reached its maximum, and after that, reduced with the increased share of sludge in the mixture being burnt.

As the practice shows, co-combustion of dried sludge with coal (with 1% share) does not increase the NO_x concentrations, and the SO₂ concentrations noted are even lower by 12% (Wandrasz 2003).

Analysis of slag and ash from combustion of sewage sludge fuels

The residues after combustion process were analysed for the presence of combustible matter in the slag and ash. Results of the analysis according to PN-90-G-04512 are shown in Table 2. In the slag and ash after combustion process of sludge fuels less than 5 % of combustible matter content was determined.

The problem of storage of the residue after burning the sewage sludge fuels was also analysed. One of the criteria determining the possibility to refer the waste to landfill, other than for hazardous waste, are the acceptable values of leaching the pollutants, as defined by the Ordinance of the Minister of Economy and Labour of 7 September 2005 on the criteria and procedures for the acceptance of waste for land filling (OJ. Laws No. 186, item. 1553). requirement of the Regulation of the Minister of Economy dated March 21, 2002 on the

requirements as to the process of thermal conversion of waste for slag and ash from co-combustion of waste), which acknowledges the correct choice of the combustion process parameters and its proper performance.

TABLE 2 Combustible matter content in slag and ash from sewage sludge fuels

Fuel type		Combustible matter content, %
PBS fuel	35 mm	2.61
	15 mm	1.60
PBM fuel	35 mm	2.80
	15 mm	1.30
PBT fuel	35 mm	1.43
	15 mm	1.49

Therefore, the residue after combustion sewage sludge fuels was tested for leaching hazardous compounds. For that reason, water extracts were created according to PN-EN 12457-4:2006, and in the water eluates, among others, chlorides (according to PN-ISO 9297), sulphides (PN-74/C-04566) and the heavy metal ions were determined with Perkin-Elmer Plasma 400 ICP Emission Spectrometer.

The results of analyzes were compared with the criteria for approving waste for deposition on a neutral waste landfill, according to the above Regulation, and are listed in Table 3.

TABLE 3. Analysis of water extracts from the residues after combustion of sewage sludge fuels

Parameter	Unit	PBM fuel	PBM fuel	PBT fuel	Limit value ^a
pH	-	9.60	9.80	9.00	-
Phosphates	mg PO ₄ dm ⁻³	<0.03	<0.03	<0.03	-
Chlorides	mg Cl dm ⁻³	699.5	216	585	800
Sulphides	mg SO ₄ dm ⁻³	960	553	994	1000
As		0.10	0.10	0.10	0.5
Cr		0.43	0.28	0.32	0.5
Zn		0.10	0.10	0.10	4.0
Cd		0.01	0.01	0.01	0.04
Cu		0.10	0.10	0.10	2.0
Pb	mg dm ⁻³	0.10	0.10	0.10	0.5
Hg		0.01	0.01	0.01	0.01
Se		0.30	0.30	0.30	0.1
Fe		0.01	0.14	0.47	-
Mn		0.10	0.10	0.10	-
Ba		0.33	10.0	14.0	20
B		0.30	0.30	0.30	-

^a – limit values for substance leaching according to Annex 3 of the Regulation of the Minister of Economy and Labour on the criteria and procedures for referring waste deposition on neutral waste landfill

The data in Table 3 prove that the leaching of pollutants, in the extracts from sludge fuels residues after their combustion was, in each case, lower or equal (for mercury) the level determined by the Regulation, so the ash and slag can be deposited on neutral waste landfill.

Conclusions

To sum up, it can be concluded that the tests performed showed some difference of the process of burning sewage sludge fuels as compared to hard coal. Momentary emission of CO₂, NO and SO₂ while combustion of fuels with the same composition, differing as to the grain size is similar. A noticeable difference between both particle sizes was the reduced ignition time and reduced emission of CO for fuels with smaller particles (15 mm).

Unfortunately, as in the case of co-combustion of dried sludge, the problem of NO_x emission still remains. However, while burning sludge fuels with coal, reducing the emission of nitrogen compounds can be expected, and the NO_x emission (due to the fuel origin of nitrogen in the process discussed) will limit the share of sewage sludge fuels in the mixture being burnt.

While combustion of the sewage sludge transformed into granulated fuel, typical problems of co-combustion of dried sludge with coal can be avoided.

Grain size composition of the sludge fuels is close to that of pea coal and adjusted to the grate firing process.

It can be concluded that the test performed proved the potential of utilising sewage sludge fuels in co-combustion processes with coal in grate furnaces.

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