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SEWAGE SLUDGE AS A BIOMASS ENERGY SOURCE

Pavel Kolat, Zdeněk Kadlec

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Abstract

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The major part of the dry matter content of sewage sludge consists of nontoxic organic compounds, in general a combination of primary sludge and secondary microbiological sludge. The sludge also contains a substantive amount of inorganic material and a small amount of toxic components. There are many sludge-management options in which production of energy is one of the key treatment steps. The most important options are anaerobic digestion, co-digestion, incineration in combination with energy recovery and co-incineration in coal-fired power plants. The goal of our applied research is to verify, if the sludge from waste water treatment plants may be used as a biomass energy source in respect of the EU legislation, which would comply with emission limits or the proposal of energy process optimizing the preparation of coal/sludge mixture for combustion in the existing fluid bed boilers in the Czech Republic. The paper discusses the questions of thermal usage of mechanically drained stabilized sewage sludge from the waste water treatment plants in the boiler with circulated fluid layer. The paper describes methods of thermal analysis of coal, sewage sludge and its mixtures, mud transport to the circulating fluidised bed boiler, effects on efficiency, operational reliability of the combustion equipment, emissions and solid combustion residues.

sewage sludge, energy, combustion, coal, emission, fluid, boiler

The goal of our research is to verify, if the sewage sludge from waste water treatment plants WWTP may be used as a biomass energy source in respect of the EU legislation, and/or its other modifications (with additives, decontamination technologies) for suitable fuel, which would comply with emission limits or the proposal of energy process optimizing the preparation of coal/sludge mixture for combustion in the existing circulating fluidised bed boiler in the Czech Republic.

Though the aim of sewage treatment is to produce clean water, it is never to produce "clean" sludge. Indeed, the "dirtier" the sludge-the more complete its concentration of the noxious wastes-the more the treatment has done its job. If there are industrial chemicals, pharmaceuticals, hormones, nano particles, prions, hospital wastes including antibiotic-resistant bacteria-and there will be all of these-you want them to end up in the sludge. Municipal waste water treatment can be considered as a continuous activity also in the future. It is organizationally, technically, and economically hardly possible to prevent or strongly reduce the amount of municipal wastewater. Also, the presence of toxic pollutants in municipal wastewater can not be avoided because a large part of these toxics originates from diffuse sources.

Incineration of sewage sludge is aimed at a complete oxidation at high temperature of the organic sludge compounds also including the toxic organic compounds. The process can either be applied to mechanically dewatered sludge or dried sludge. Potential environmental problems related to sludge incineration are the gaseous emissions of pollutants and quality of the ashes (LOO *et al.*, 2008).

Co-combustion, of sewage sludge, with coal can be the most cost-effective possibility, as existing installations can be used with minor adaptations and preservation of the regular high efficiencies of modern coal-fired power stations (ČECH *et al.*, 2006).

MATERIALS AND METHODS

Diagnostic co-combustion methods basically cover:

- Measurement of fluidized bed temperatures, furnace temperatures, flue gases temperatures at ancillary heating surfaces up to the boiler.
- Measurement of flue gas velocity in the furnace chamber and exits of cyclones, in cyclones, at the cyclone exit to second pass as well as in the area of additional boiler surfaces, sampling of flue gas in the boiler.
- Sampling of characteristic solid ash particles including isokinetic sampling to determine solid particle concentrations.

To monitor the fluidized bed boiler operation process O_2, CO, CO_2, NO_X, and SO_2 measurements can be taken. Other elements are usually monitored up to the exit from the separator of solid particles in front of the chimney. Sampling of flue gases from the second pass of the boiler occurs at temperatures safely below 800 °C. Thanks to that temperature a larger part of the gaseous sample is not able to oxidize quickly and thus it is possible to use a sampling tube made of stainless steel or sintered corundum, Al_2O_3. To set concentration (e.g., SO_2), sampling channels must be heated up during the sampling operation so that no reaction with water occurs. A grid method of measuring concentration was used. Measurements were taken using instrumentation openings in the middle of the side walls of the combustion chamber. To determine the solid particle concentration in air flow, the Czech standard ČSN ISO 9096 needs to be observed. It is gravimetric determination of concentrations based on isokinetic sampling of solid particles from air flow. In the case of fluidized bed chambers the aim is to determine the solid particle concentration in the lower part of the fluidized bed layer and in the boiler furnace. All combustion regimes were sampled according ISO 9096 standard from storage tanks of fuel and all sections of the electrostatic precipitator. To determine the concentration at the measuring points, a disposable sampling probe is used. Analysis of major, minor and trace elements was performed by X-ray fluorescence spectrometry (SPECTRO XEPOS) and mineral analysis was carried out using X-ray diffraction analysis (BRUKER D8 ADVANCE). Ash content of the samples was determined at 815 °C. The distribution of macro pores was determined by means of mercury porozimetry (Micromeritics – AUTOPORE IV); SORPTOMATIC 1990 (Thermo Finnigan) equipment was used for the determination of specific surface area and mezopore-size distribution. Scanning electron microscope micrographs were taken by SEM PHILIPS XL – 30. The X-ray diffraction patterns were obtained for the samples of unburned carbon, bottom ash and fly ash. With the aid of elemental analyses of unburned carbon and ash samples the major mineral phases were established in the diffraction patterns. The morphology of coal, sludge, unburned carbon and bottom ash grains was studied using scanning electron microscopy with the secondary-electron beam method. The combustion tests with the mechanically drained digested sewage sludge (the water ratio in the sludge ca. 63%) was done at the boiler with the circulating fluidised bed boiler of its output 130 MW_t. The mixture of hard coal and the coal shed of average lower heating value Q_i^r = 19 MJ.kg^{-1}, water ratio W^r = 7.5% a ash content A^r = 30% is generally combusted at the boiler. During the combustion tests the fuel was distributed to the boiler having the ratio: 11% weight sewage sludge from the waste-water treatment plant of Ostrava, 28% weight coal and 61% weight coal shed. During the additional combustion of the sludge the mixture characteristics changed this way: heating value Q_i^r = 17 MJ.kg^{-1}, water ratio W^r = 14.5% a ash content A^r = 28%. Based on the fact that the total lower heating value of the fuel mixture thus dropped by ca. 2 MJ.kg^{-1} during the additional combustion the volume of the mixture must be increased ca. by 0.65 kg.s^{-1} to maintain the constant boiler output. However, the total coal consumption does not raise and this fact is important. The emission measurements of the CO, NO_x, SO_2 and relative oxygen were done by the "Accredited centre for operation and diagnostics of heat generation equipment" in VŠB – Technical University of Ostrava. From 2010 received accreditation as 1588 testing laboratory. Measuring combustion modes are performed in order of tens of hours. Statistical evaluation therefore does not add any substantial refinement of measured values. Measurement error is individual for each measured variable at temperatures of 1%, and gas analyzes 2–5%. Measurements of the emissions of cadmium, mercury, lead, arsen and their compounds, polychlorinated dibenzodioxines PCDD, polychlorinated dibenzofurans PCDF, polychlorinated bifenyls PCB, polycyclic aromatic hydrocarbons PAU, gaseous anorganic chlorine and fluor compounds, hard pollutants TZL were done by the company TESO Ostrava. (www.teso-ostrava.cz).

RESULTS

The sewage sludge is a heterogeneous mixture of organic elements (both live and lifeless microorganism cells) and anorganic elements. The organic part of the sewage sludge is mainly represented by the proteins, sugars and lipids. The anorganic part sustains mainly of the compounds of silicon, ferrum, calcium and phosphorus. Moreover the sludge consist of a wide range of harmful substances as well – heavy metals, persistent organic elements PCB, PCDD/F, PAU etc. and other organic harmful elements (Bartoňová *et al.*, 2010). Tab. I, illustrates the summary of the organic pollutants in the sewage sludge dry residues taken from the Central Sewage Plant of Ostrava (CSPO) and it is evident that almost all limits of the monitored

I: *Organic pollutants in sewage sludge*

Indicator – sample from the CSPO		Limit value	Rated value
Benzene	[mg.kg^{-1}] dry residue	0.1	0.135
BTEX	[mg.kg^{-1}] dry residue	10	5.46
EOX (Cl)	[mg.kg^{-1}] dry residue	10	11.7
NES	[mg.kg^{-1}] dry residue	200	4840
ΣPAU (15)	[mg.kg^{-1}] dry residue	10	103
PCB (summary of 6 congeners,)	[mg.kg^{-1}] dry residue	0.2	0.3
TOC	[%]	20	25.3
Tetrachlorethen	[mg.kg^{-1}] dry residue	0.5	< 0.030
Trichlorethen	[mg.kg^{-1}] dry residue	1	0.233

II: *The fuel composition*

Fuel	samples		Coal	Sludge	Coal shed
Water ratio	w^r	[%]	10.23	62.36	6.22
Ash content	A^r	[%]	24.77	19.52	31.78
Lower heating value	Q_i^r	[kJ·kg^{-1}]	18854	1476	18962

III: *The fuel characteristics in crude/ waterless form*

	[%]	Coal	Sludge	Coal shed
Carbon	C^d	59.88/82.7	22.50/46.72	56.34/85.21
Hydrogen	H^d	3.92/5.42	3.48/7.22	3.36/5.08
Sulphur	S^d	0.35/0,48	0.63/1.31	0.22/0.33
Nitrogen	N^d	1.30/1.79	2.40/4.99	1.21/1.84
Oxygen	O^d	6.96/9.61	19.14/39.75	4.99/7.55
Ash	A^d	27.59	51.85	33.88

IV: *The silicate analysis of the coal, sludge and coal shed by RTG-fluorescence method*

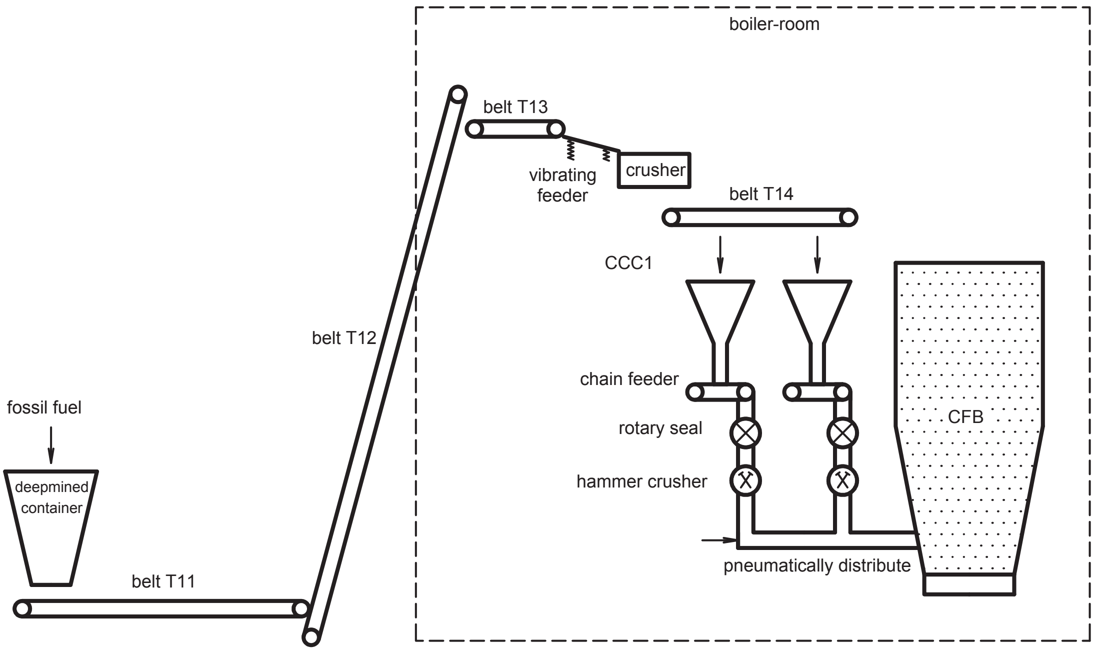
Sample	SiO_2 [%]	TiO_2 [%]	Al_2O_3 [%]	Fe_2O_3 [%]	MnO [%]	MgO [%]	CaO [%]	Na_2O [%]	K_2O [%]	SO_3 [%]	P_2O_5 [%]
Coal	16.02	0.28	7.2	1.96	0.04	< 0.8	0.92	< 2.02	0.86	1.6	0.22
Sludge	13.78	0.25	2.49	10.24	0.11	< 0.8	13.73	< 2.02	0.38	3.35	6.44
Coal shed	22.46	0.35	9.48	3.26	0.05	< 0.8	1.07	< 2.02	1.28	1.87	0.24

pollutants are exceeded. The description of the combusted fuel is illustrated at the Tab. II, III.

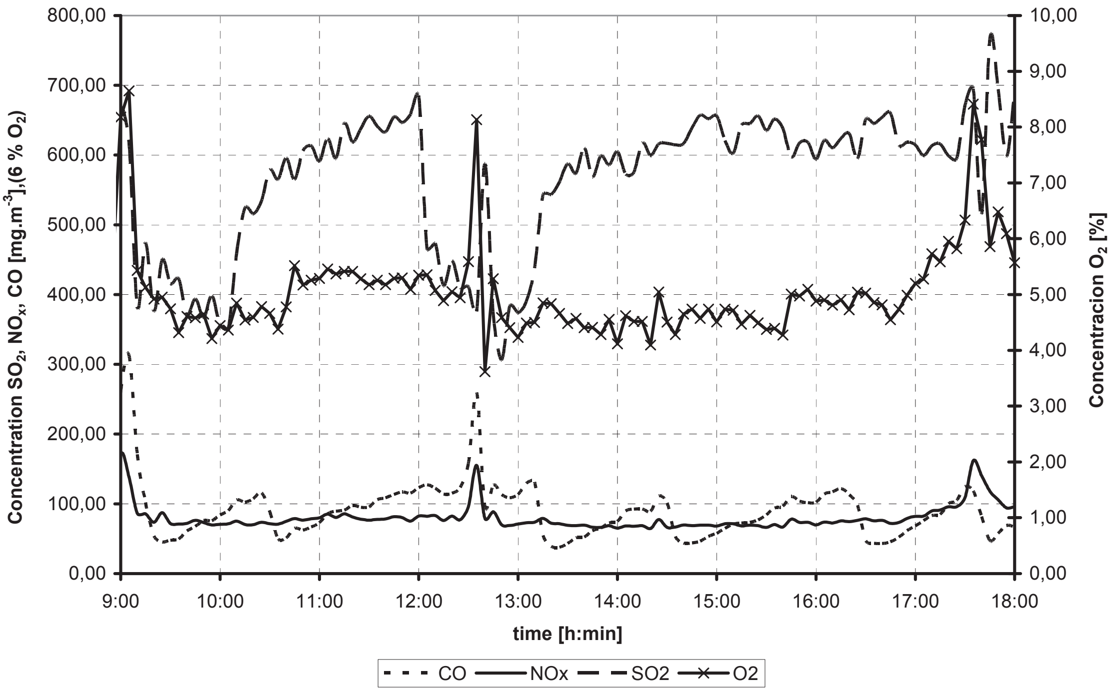
The fuel is distributed from the deep mined container by the belt conveyer to the containers of the crude coal (CCC) – Fig. 1. Then it is lifted from here by the chain feeder through the rotary seal to the swing-hammer crusher and pneumatically distributed to the boiler.

The combustion tests showed the fact that 15% of content of the sludge in the mixture is the cut-off amount that is able to pass through the swing-hammer crasher. The moisture is of a fundamental importance concerning the allowable amount of the sludge in the mixture. During the combustion tests the sludge moisture was ca. 65% compared to the hard coal moisture 7.5%. The higher moisture makes the temperature drop behind the crasher and it results in sealing the crasher with the mixture of the wet mud.

Based on the combusted coal and the sewage sludge of given ratio the ca. 0.3% drop in the boiler efficiency was monitored. For mixture I. – coal and coal shed was 89–90.5% and for mixture II. – coal, coal shed and sewage sludge 88.8–90.2%. The content of the combustible carbon in the products of the combustion corresponds with the fine hard coal combustion. The combustible matter content in the bed ash was 0.25–0.3% and in the fly ash 5.8–6.5%. If we focus on the operational efficiency of the boiler under the condition of the additional combustion of the sludge it means monitoring possible unwanted states given by the high and low-temperature rust, silting the heat transfer surfaces and abrasion. Concerning the boilers with the fluid furnace and the additive desulphurisation the marks of the chlorine rust pop up even if the chlorine content in the fuel is low. The ratio Cl/SO_2 has an impact on the high



1: *The scheme of the distribution and the fuel ratio to the boiler*



2: *The NO_x, CO, SO_2 emissions and O_2 concentration*

temperature chlorine rust intensity. The chlorine content in the sewage sludge does not exceed the volume that was found out concerning the energy coal. (chlorine concentration of energy coal was 0.15%, sewage sludge 0.13% and coal sludge 0.17%). The HCl concentration in waste gases influences the low-temperature rust intensity. In our case the rust is to be taken into consideration considering the recuperative air heater. Another characteristic of the operational efficiency is the silting the heat transfer surfaces. These characteristics are demonstrated by the temperatures: t_A – softening point, t_B – melting point a t_C – pour point. The results of experiments shows the fact that the lowest temperature for the mixture of the sludge and the coal is ca. 1 220 °C for the half-reductive atmosphere. During the combustion of the sludge in the mixture with the coal no raise in silting the heat transfer surfaces of

V: *The RTG diffraction analysis of the hard residues of the combustion process*

		Bed ash (T_4)	Fly ash (T_5)
Amorphous		49.3 ± 6.00 %	58.3 ± 5.10 %
Anhydrite	$CaSO_4$	1.84 ± 0.48 %	4.26 ± 1.08 %
CaO Lime	CaO	0.58 ± 0.30 %	1.38 ± 0.42 %
Hematite	Fe_2O_3	1.84 ± 0.51 %	4.70 ± 0.63 %
Muscovite 1Md	$KAl_2(Si_3Al)O_{10}$	14.7 ± 4.20 %	12.2 ± 4.20 %
Orthoclase	$KAlSi_3O_8$	1.09 ± 0.60 %	0.97 ± 0.60 %
Periclase	MgO	0.58 ± 0.42 %	1.48 ± 0.45 %
Plagioclase Albite	$NaAlSi_3O_8$	2.3 ± 0.93 %	1.85 ± 0.90%
Quartz	SiO_2	27.79 ± 2.19 %	14.8 ± 1.05 %

VI: *The silicate analysis of the hard residues of the combustion process by method RTG-fluorescence*

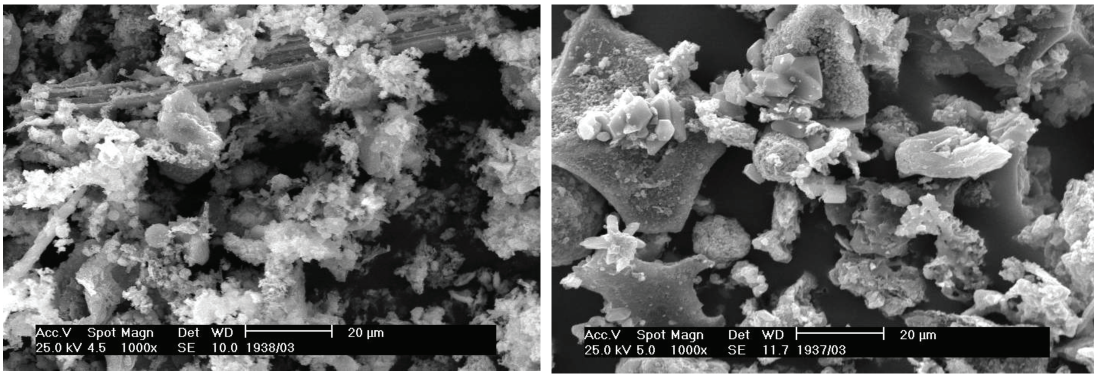
Sample	SiO_2 [%]	TiO_2 [%]	Al_2O_3 [%]	Fe_2O_3 [%]	MnO [%]	MgO [%]	CaO [%]	Na_2O [%]	K_2O [%]	SO_3 [%]	P_2O_5 [%]
Bed ash (T_4)	63.96	0.73	19.84	5.45	0.07	1.19	2.66	<2.02	2.81	1.43	0.17
Fly ash (T_5)	48.13	0.82	21.16	7.88	0.13	1.58	6.49	<2.02	2.49	2.97	1.29

the boiler was monitored. The abrasion of the heat transfer surfaces is mainly dependent on the ash ratio in the waste gases velocity. The ash content for the given ratio of the sludge in the mixture with coal will be almost identical as a if it happened during the combustion of the fine coal. However due to the enlarge volume of the transported amount of the fuel the velocity of the waste gases will raise. The loss in the pipe wall thickness is proportional to the 3rd power of the waste gases velocity and thus when thinking of the additional combustion of the sludge the bigger influence of the abrasion must be taken into consideration and it is wise to protect the heat transfer surfaces. Time flow of the emissions and O_2 is illustrated in Fig. 2. The taken values of the pollutants were re-counted to 6 % O_2. (NO_x – 80 mg.Nm^{-3} SO_2 – 560 mg.Nm^{-3}, TZL – 11 mg.Nm^{-3}, HCl – 17 mg.Nm^{-3}, HF – 0.2 mg.Nm^{-3}, PCDD/F – 0.006 ng(TEQ).Nm^{-3}, Hg – 0.0013 mg.Nm^{-3}). The components CO, NO_x, TZL, PCDD/F, HF, Hg meet the requirements of the public notice No. 352/2002, 354/2002 of the Code of Law but the emissions SO_2 and HCl does not. This fact can be interpreted the way that the sorbent dosing to the boiler was put out of action during the test and thus the process of the conversion both SO_2 to $CaSO_4$ and HCl to $CaCl_2$ could not happen.

The monitored hard residues Fig. 3 of the combustion (T_4 – bed ash, T_5 – fly ash) are characterized by the stable composition with the high content of the amorphous substances (ca. 50–60% weight). Except the flint and the micaceous mineral (white mica 1Md) the other found phases are present in the accessory amount. Tab. V, VI.

DISCUSSION

The limiting factor for sludge utilization from WWTP in agriculture is the increased content of risk elements and also the occurrence of organic pollutants – primarily polyaromatic hydrocarbons, PCB and AOX. The limiting factor for sludge combustion at incineration plants is water content. With regard to the fact that from 2005 the EU Directives EU expects to ban waste disposal sites with any material with content of organic substances



3: *Configuration of hard residues – bed and filter ash*
Enlargement 1 000x

above 10%, it is apparent that the priority condition is sludge decontamination or power engineering utilization (LOO *at al*., 2008). One of goals is also the utilization of uncontaminated sludge from WWTP in the process of hygienic procedures and subsequent production of pellets, which includes the fermentation process.

Such high values unable using the sewage sludge for agricultural purposes and land reclamation – meaning the usage of both the underground and exterior storage. The biggest problem is in this case the high content of the polyaromatic hydrocarbons that is ten times higher than the limit is. It is probably because of the industrial waste-water disposal. The value TOC (total organic carbon) that does not fit can be considered rather useful than limiting factor (BARTOŇOVÁ *et al*., 2008, 2009). The energy content of the sewage sludge is based on the chemical energy of the organic components that are able of oxidation. The important criterion of keeping the combustion process balanced is the water ratio in the sludge. Thus a problem arrives because water ratio of the mechanically drained sludge is high (60–80%) for the relatively low heating value and there wise the sludge cannot be combusted singly (SZELIGA *et al*., 2008). The most important energy characteristic of each single fuel is its lower heating value. The dry residue lower heating value of the anaerobic stabilized sewage sludge is in range 7–10 $MJ.kg^{-1}$. Two groups of energy recovery processes can be distinguished: chemical/thermal processes and biological processes. If the temperature is high enough, the chemical/thermal processes result in a complete oxidation of the organics and also the toxic organics (Bartoňová *et al.*, 2010). Heavy metals are often immobilized in the inorganic matrix. Experience and knowledge obtained in the research into production of energy from biomass can be beneficial for the further development of energy carriers and electricity from bio-wastes, such as sludge from waste water treatment plants. (WINTER *et al*., 1997). However, for a successful breakthrough, it will always be necessary to find a definitive solution for the toxics in the sludge. Also, the increasing focus on the direct recovery of phosphorous from wastewater or sewage sludge is an issue of increasing interest. This aspect may negatively interfere with energy production from sewage sludge.

CONCLUSION

The combustion tests the circulating fluidised bed boiler 130 MWt proved the possibilities of the opportunities of the combined combustion of coal, sewage sludge and coal shed in the fluid bed boilers. The advantages of such method are mainly in reliable decomposition and the oxidation of the organic harmful elements and significant sludge volume reduction. Another possibility of using the sludge is to lower its humidity and thus to improve the lower heating value, transportation and manipulation. The disadvantage of the thermal usage of the sewage sludge is higher concentration of the heavy metals and the microelements entering the combustion process.

SUMMARY

The goal of present research is to verify if the sludge from waste water treatment plants WWTP may be used as a biomass energy source in respect of the EU legislation.

The combustion test with the mechanically drained digested sewage sludge was done at the boiler with the circulating fluid layer of its output 130 MW_t. The mixture of hard coal and the coal shed has of average lower heating value $Q_i^r = 19$ $MJ.kg^{-1}$, water ratio $w^r = 7.5\%$ a ash content $A^r = 30\%$. During the combustion tests the fuel was distributed to the boiler having the ratio: 11% weight sewage sludge from the waste-water treatment plant of Ostrava, 28% weight coal and 61% weight coal shed. Based on the combusted coal and the sewage sludge of given ratio the ca. 0.3% drop in efficiency of the boiler was monitored. The content of the combustible carbon in the products of the combustion corresponds with the fine hard coal combustion. The combustible matter content in the bed ash was 0.25–0.3% and in the fly ash 5.8–6.5%. During the combustion of the sludge in the mixture with the coal no raise in silting the heat transfer surfaces of the boiler was monitored. The ash content for the given ratio of the sludge in the mixture with coal will be almost identical as a if it happened during the combustion of the fine coal. The taken values of the pollutants were re-counted to 6% O_2 (NO_x – 80 $mg.Nm^{-3}$ SO_2 – 560 $mg.Nm^{-3}$, TZL – 11 $mg.Nm^{-3}$, HCl – 17 $mg.Nm^{-3}$, HF – 0.2 $mg.Nm^{-3}$, PCDD/F – 0,006 ng(TEQ).Nm^{-3}, Hg – 0.0013 $mg.Nm^{-3}$). The concentration of the CO, NO_x, TZL, PCDD/F, HF, Hg meet the requirements of the public notice No. 352/2002, 354/2002 of the Code of Law but the emissions SO_2 and HCl does not. The monitored hard residues of the combustion (T_4 – bed ash, T_5 – fly ash) are characterized by the stable composition with the high content of the amorphous substances (ca. 50–60% weight). Except the flint and the micaceous mineral the other found phases are present in the accessory amount. The combustion test proved the possibilities of the opportunities of the additional fuel combustion in the fluid bed boilers. The advantages of such usage of the sewage sludge are mainly the reliable decomposition and the oxidation of the organic harmful elements and significant sludge volume reduction.

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Address

prof. Ing. Pavel Kolat, DrSc., doc. Ing. Zdeněk Kadlec, Ph.D., Department of Energy, VSB – Technical University of Ostrava, 17. listopadu 15, 708 33 Ostrava, Czech Republic, e-mail: pavel.kolat@vsb.cz, zdenek.kadlec@vsb.cz