Archives of Waste Management and Environmental Protection

Archiwum Gospodarki Odpadami i Ochrony Środowiska
ISSN 1733-4381, vol. 16, issue 4 (2014), p. 93-102

http://awmep.org

Specificity combustion of sewage sludge

Agnieszka KIJO-KLECZKOWSKA[1], Henryk OTWINOWSKI[1], Katarzyna ŚRODA [1]*

[1] *Czestochowa University of Technology, Institute of Thermal Machinery, Armii Krajowej 21, 42-201 Czestochowa, Poland; e-mail: kijo@imc.pcz.czest.pl*

Abstract

The paper takes the issue of how the disposal of sewage sludge with particular regard to their combustion, as a priority method of disposal. The development of civilization leads to more and more waste. In Poland, in the years 1999-2012, the amount of sewage sludge from municipal sewage treatment plants, rose almost one and a half. There is the problem of the use of this waste, even associated with increasingly restrictive legal provisions on the storage of sewage sludge since 2016. Given that it is currently working in Poland until 11 installations using sewage sludge as a fuel is to anticipate the further development of these technologies. Combustion of sewage sludge is an attractive solution their utilization, mostly because of the minimization of odor, a significant reduction in the volume of the starting material, the possibility of further use of the ash, and the thermal destruction of the organic and toxic components of the waste. A similar calorific value of sewage sludge to lignite, justifies the need to use the waste as fuel energy. The paper presents the results of the combustion of sewage sludge and hard coal, brown coal and biomass in a stream of air.

Keywords: sewage sludge, kinetics of fuels combustion

Streszczenie

Specyfika spalania osadów ściekowych

Praca podejmuje tematykę związaną z unieszkodliwianiem osadów ściekowych, ze szczególnym uwzględnieniem procesu spalania, jako priorytetowej metody ich utylizacji. Rozwój cywilizacji prowadzi do powstawania coraz większej ilości odpadów. W Polsce, w latach 1999-2012, ilość osadów ściekowych z komunalnych oczyszczalni ścieków wzrosła prawie półtorakrotnie. Problem związany z tymi odpadami nabiera coraz większego znaczenia. Wynika to z restrykcyjnych przepisów dotyczących składowania osadów ściekowych od 2016 roku. Biorąc pod uwagę, że obecnie w Polsce istnieje aż 11 obiektów wykorzystujących osady ściekowe jako paliwo można przewidzieć dalszy rozwój tych technologii. Spalanie osadów ściekowych jest atrakcyjnym rozwiązaniem ich wykorzystania, przede wszystkim ze względu na minimalizację odoru, znaczne zmniejszenie ilości materiału wyjściowego oraz możliwość dalszego wykorzystania popiołu. Ponadto możliwa jest destrukcja termiczna organicznych i toksycznych składników tych odpadów. Poza tym zbliżona wartość opałowa osadów ściekowych do węgla brunatnego, uzasadnia konieczność wykorzystania tych odpadów jako paliwa energetycznego. W pracy przedstawiono wyniki spalania osadów ściekowych, węgla kamiennego, węgla brunatnego i biomasy w strumieniu powietrza.

Słowa kluczowe: osady ściekowe, kinetyka spalania paliw

1. Introduction

Sewage sludge are organic and mineral matters separated from wastewater during their purification. Due to the physico-chemical and biological properties that may pose to human health and the environment, the settlement must be subjected to appropriate processing and then properly disposed of. Characteristics of sewage sludge are discussed in the papers [1,2,3,4].

Over the last few years, utilization of sewage sludge in Poland was implemented by:

- agricultural use,

- remediation of industrial sites and landfills,
- development of land wastewater treatment plants and storage of sludge in the wastewater, including lagoons and ponds,
- production of compost,
- landfilling of municipal waste,
- thermal utilization [5].

According to the National Waste Management Plan [6] predicted that in the perspective of 2020, more than 30% of sewage will be managed in heat.

2. Utilization of sewage sludge

Figure 2.1 and 2.2 show the change in the use of sewage sludge in Poland in the years 1999-2012. We can observe the growing interest of thermal methods of this waste.

Increasing the amount of sediment begins to cause huge problems in their rational land use, the more that landfilling of untreated sewage sludge, which so far has been a popular method of managing them will be more and more limited, and since January 1, 2016 impossible [7]. Methods for thermal treatment of sewage sludge include combustion, co-combustion, alternative methods, gasification and pyrolysis. An important argument in favor of combustion and co-combustion is complete mastery of the basics of processes, including purification techniques resulting products. Regarding the suitability of sewage sludge for thermal disposal, we should pay attention to the chemical composition of the burning material and mineral matter, volatile matter content, moisture, ash and its composition. These parameters determine the choice of method of thermal process allows the behavior of the minimum emissions and avoid the risks of use. During the thermal utilization of change in the nature of the end product from waste which is converted into an alternative fuel. It saves the resources of hydrocarbons (coal and gas) and produces heat and electricity. During the drying process at 130^0C obtained granulate with a dry content of 90 %, the energy value of which is close to lignite. And this is just an alternative fuel, which is well suited for use in industrial processes, eg. in cement kilns for clinker burning, whether in conventional coal-fired power plants [8].

Figure 2.3 shows the thermal treatment of sewage sludge. Particularly noteworthy co-combustion of the waste from the fuel basic, which is very important from the point of view of environmental protection. Co-firing of sewage sludge with coal in existing power plants has significant advantages: low investment and operating costs of the process, safety and environmental technology, use knowledge of personnel experienced in the use of boilers and the use of existing exhaust after treatment system.
The sewage sludge co-firing technologies can be divided into:

- the direct co-firing by mixing sewage sludge with coal in a landfill or mixing in the boiler,
- the indirect co-firing by gasification of sewage sludge.

In Polish conditions of particular interest appears to be sewage sludge co-combustion in the pulverized boilers, in the clinker burning technology and sewage sludge co-combustion with municipal waste. This solution is primarily aimed at reducing the costs of waste disposal and sludge [10].
Recent years have seen dynamic growth in the use of thermal methods of sewage sludge management methods, in particular in the field of drying and mono-combustion, mainly in large cities. Figure 2.4 illustrates location plants in Poland, where there is the thermal utilization of sewage sludge. Should be highlighted here: 11 mono-incineration be distinguished sewage sludge, 20 thermal sewage sludge drying, 12 solar sewage sludge drying, 9 cement plants with lines of alternative fuels.

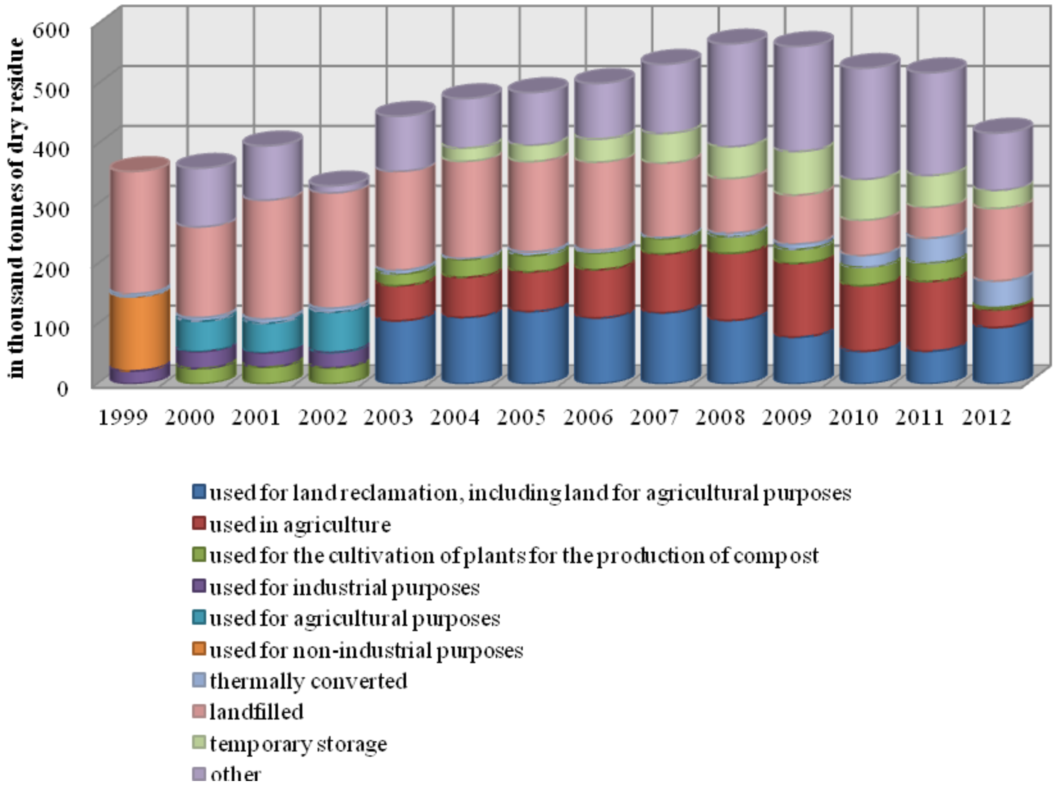


Fig. 2.1. Proceeding with sludge from municipal sewage treatment plants in the years 1999-2012 [9]

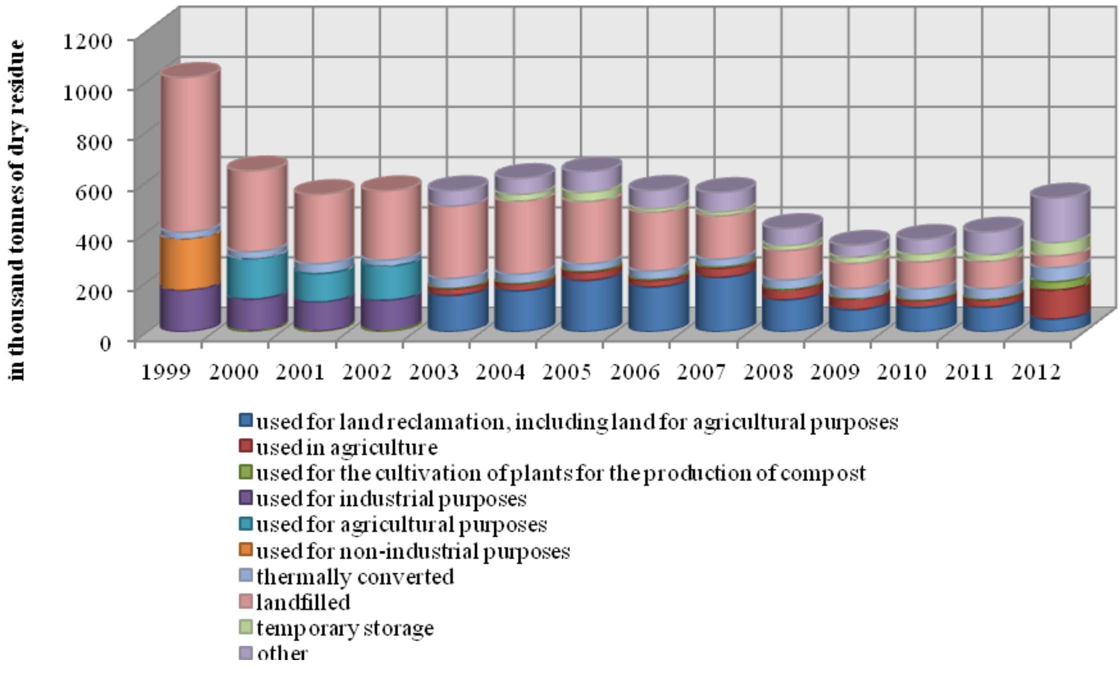


Fig.2.2. Proceeding with sludge from industrial sewage treatment plants in the years 1999-2012 [9]

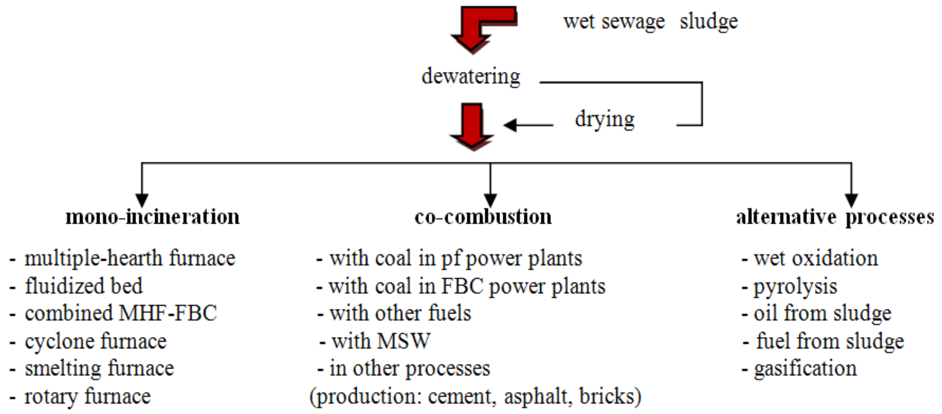


Fig.2.3. Methods for thermal treatment of sewage sludge [11]

Fig.2.4. Thermal utilization of sewage sludge in Poland [12]

Combustion is a fundamental process of thermal utilization. The combustion process is not indifferent to the environment, and is associated with the emissions of dust, sulfur and nitrogen compounds, and dioxins and furans. For this reason, combustion installations must be equipped with a range of devices for purifying exhaust gases. Combustion of sludge is accomplished mostly in the fluidised bed (bubbling or circulating). The Polish example of the sewage sludge thermal utilisation can be a WWTP in Gdynia-Debogorze. The process of sludge utilisation takes place in the system, which includes, in addition to the fluidized bed boiler, tumble dryer, heat exchanger assembly and after-treatment devices. Incinerator capacity is approximately 80 Mg of sludge/day [10].

Sewage sludge exist in three states:

- wet: 85-90% water,
- pasty: 65% water,
- granular: 10-25% water.

Sewage sludge incineration mechanism different from the mechanism of coal combustion, mainly due to:

- substantial hydration: 65-75%,
- a large share of the mineral substance: 50% dry matter,
- high content of volatile matter: 90% combustible substances.

Thermal decomposition of sewage sludge starts from $150^{0}C$ and it occurs almost simultaneously with the drying phase, and the dynamics of the volatiles evolution is higher than in the case of brown coal. Incineration of sewage sludge char is much faster than that of coal, mainly due to high reactivity, high porosity and a low content of carbon in the fuel.

Combustion and co-combustion of sewage sludge with other fuels, as well as the effect of these processes on the environment is at the present time very important and widely described in the literature, both the national and the international, including: [13,14,15,16,17,18,19,20].

3. Experimental studies

Table 3.1 shows the analysis of selected chemical properties of sewage sludge used in the study. Table 3.2 presents the elementary and technical analysis of sewage sludge in reference to coal and biomass. It should be noted the content of volatile matter and carbon in fuels and their calorific value significantly affect the combustion process.

The experimental nature of the study conducted in a wide scope required preparation of a test stand and development of appropriate measurement methods. The combustion chamber (Fig.3.1) was made of a ceramic block, inside which there were heating elements of the total power of 4,4 kW mounted in special grooves; they were necessary to obtain the desired temperature in the vicinity of fuel. The chamber was thermally insulated and covered with stainless steel sheet. As a temperature sensor in the measurement stand a NiCr-Ni thermocouple co-operating with a temperature controller was used. At 1/3 height of the combustion chamber there was a visualization glass of dimensions of 70x80 mm, allowing observation of the fuel combustion process. In the side wall of the combustion chamber there was a test entrance through which a fuel sample was fed on a chassis. Gases formed as a result of the fuel combustion process were taken into the stack through the expansion chamber and flue gas exhaust.

Table 3.1. Analysis of selected chemical properties of sewage sludge used in the study

Rate	Unit	Result research granules A	Result research granules B	Result research granules C	Permissible content heavy metals in municipal sewage sludge, according to Regulation Minister of the Environment of 13 July 2010 (for use in agriculture and land reclamation for agricultural purposes)
Reaction	unit pH	7,4	7,0	7,8	
Water content	%	4,60	7,00	14,7	
Loss on ignition	%	55,6	64,2	56,4	
Ammonium	$\%_{d.w.r.}^{*}$	0,17	0,27	0,38	
Kjeldahl nitrogen	$\%_{d.w.r.}^{*}$	3,9	5,1	4,1	
Phosphorus	$\%_{d.w.r.}^{*}$	3,0	3,2	3,3	
Calcium	$\%_{d.w.r.}^{*}$	4,7	3,1	4,9	
Magnesium	$\%_{d.w.r.}^{*}$	0,53	0,67	0,73	
Cadmium	$mg/kg_{d.w.r.}^{*}$	5,9	2,3	< 1	to 20
Chromium org.	$mg/kg_{d.w.r.}^{*}$	340	160	80	to 500
Copper	$mg/kg_{d.w.r.}^{*}$	360	470	210	to 1000
Nickel	$mg/kg_{d.w.r.}^{*}$	190	97	19	to 300
Lead	$mg/kg_{d.w.r.}^{*}$	160	62	12	to 750
Mercury	$mg/kg_{d.w.r.}^{*}$	0,61	0,50	0,48	to 16
Zinc	$mg/kg_{d.w.r.}^{*}$	2400	950	1000	to 2500
$^{*}{}_{d.w.r.}$ - dry waste residue					

Table 3.2. Technical and elementary analysis of fuels used in studies

Fuel type	***Technical analysis***				***Elementary analysis***				
	Humidity content	Content of volatile elements	Ash content	Heat of combustion	Content of coal element	Content of hydrogen element	Content of nitrogen element	Content of oxygen element	Content of total sulphur
	W^a	V^a	A^a	Q_i^a	C_t^a	H_t^a	N^a	O_d^a	S_t^a
	%	%	%	kJ/kg	%	%	%	%	%
Brown coal	14,46	37,11	18,42	16165	43,16	3,08	0,55	19,81	0,52
Hard coal	2,66	30,90	2,36	31198	79,33	4,33	1,27	9,75	0,30
Biomass	8,27	70,53	4,55	15825	40,90	6,07	2,73	37,30	0,18
Sewage sludge A	4,94	51,44	36,44	12574	30,77	3,92	4,26	18,23	1,44
Sewage sludge B	6,74	46,40	38,16	11104	27,50	3,72	4,24	18,73	0,91
Sewage sludge C	5,31	52,59	32,46	13801	32,43	4,30	5,47	18,42	1,61

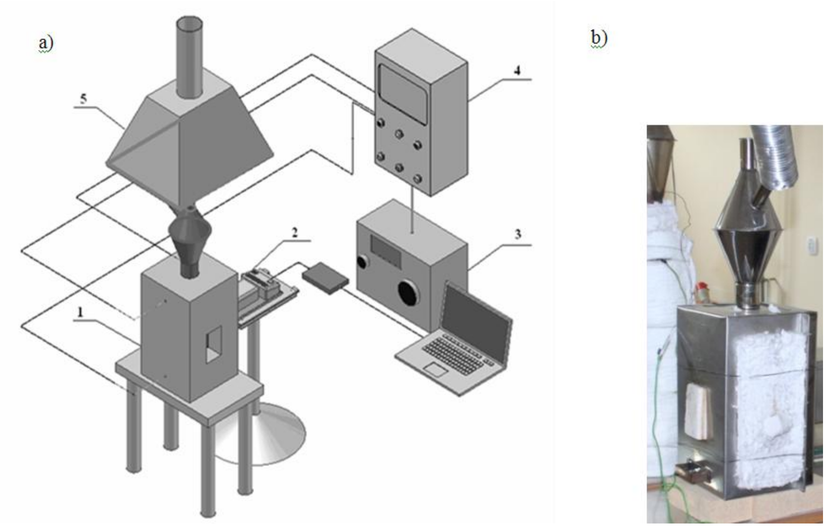


Fig.3.1. Diagram of combustion chamber for fuel samples (no air intake): 1 - combustion chamber, 2 - measuring system, 3 - power controller, 4 - temperature control system, 5 - flue gas exhaust

The study consisted in observing and recording the process of fuel sample combustion placed in a specially shaped "basket" made of Pt-PtRh10 thermocouples, located in two thin quartz tubes, which were also the extension arm of an electronic laboratory scales (Mensor WM 002) of a measurement range up to 20 g and accuracy of 1 mg (Fig. 3.2). Such a design of the measurement system enabled registering changes in temperature inside and on the surface of the fuel sample and registering weight loss during the combustion process. One of the welds of the Pt-PtRh10 thermocouple was in fact in the fuel, while the second thermocouple weld, bent in the shape of a supporting "basket", touched the underside of the fuel surface. Fuel sample was introduced into the combustion chamber by means of a specially designed chassis. In order to register study results, thermocouples and the scales were connected to a measurement card connected to a computer.

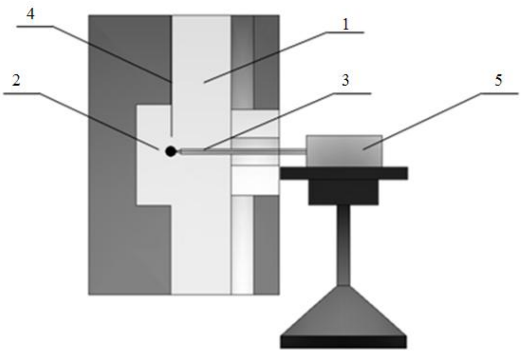


Fig.3.2. Diagram of the measurement system: 1 - combustion chamber, 2 - fuel sample, 3 –Pt-PtRh10 thermocouples, 4 - NiCr-Ni thermocouple, 5 – scale

The research material forming sewage sludge was taken from a wastewater treatment plant in a large urban-industrial agglomeration. Sludge is created in a process line, in which the sludge together with the primary sludge, upon concentration, get to an oxygen-free digestion chamber in order to undergo the process of stabilization. Next, the sludge is dehydrated mechanically and dried to form hygienic granules of moisture content below 10%. Sewage sludge samples are in the form of spherical granules obtained from the wastewater treatment plant.

Coal and biomass samples were in the form of briquettes made using a briquetting machine prepared specifically for the test. For this purpose, it was necessary to prepare biomass and coal dust by grinding and sieving the fuel through a sieve (below 100 μm).

4. Experimental studies results

The essence of the issue of combustion of coal fuel, also in form of coal-water slurry fuel, as well as its co-combustion with biomass and mechanism of sewage sludge combustion under a variety of process conditions, was described, among others in the following papers: [21-25].

Studies indicated that high content of volatile matter in the fuel intensifies the initial stages of combustion, distinguished by more intensive reacting of the fuel, as evidenced by the change in mass of fuel mileage.

The fuel, upon introduction to a high-temperature unit (combustion chamber), slightly changes its size (depending on the type of fuel) in the subsequent stages of combustion, due to evaporation of water, release of volatiles and after-combustion of solid substances. The shortest combustion process takes place in case of fuels characterized by a lower carbon content and high proportion of volatiles.

Registering of the process of combustion of fuels indicated that the moment, when the surface of fuel reaches the maximum temperature corresponds to the moment when the volatile components emitted from the fuel are combusted upon ignition of degassed carbonising agent, which is visible as a "peak" in the graph illustrating temperature changes on the surface of the fuel. Analyzing the changes in temperature and mass of fuel samples with a diameter of 7,5 mm, at a temperature of 850°C (Fig.4.1-4.3), it can be stated that upon introduction of fuel into the combustion chamber, its ignition takes place via the volatiles emitted from the fuel.

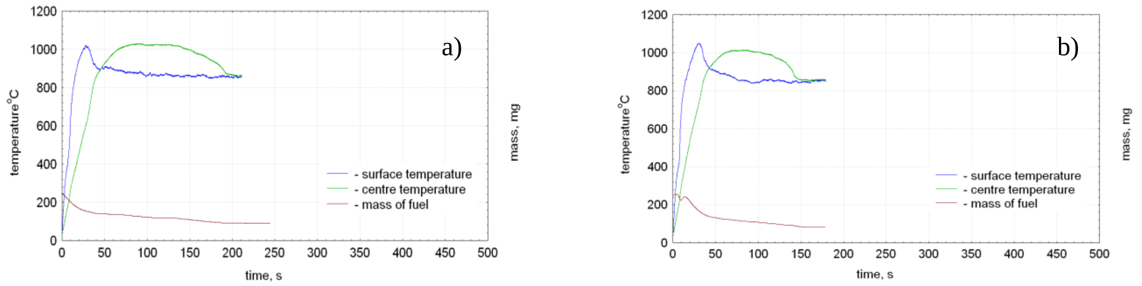


Fig. 4.1. The course of changes of surface and centre temperature and mass loss of sewage sludge A (a) and sewage sludge B (b)

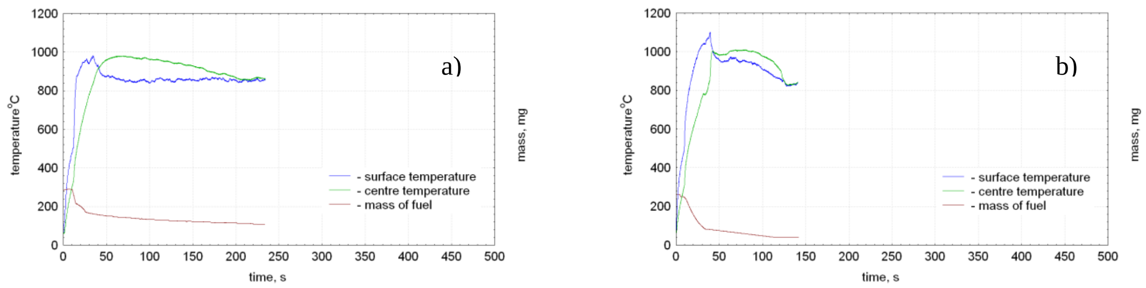


Fig. 4.2. The course of changes of surface and centre temperature and mass loss of sewage sludge C (a) and biomass (b)

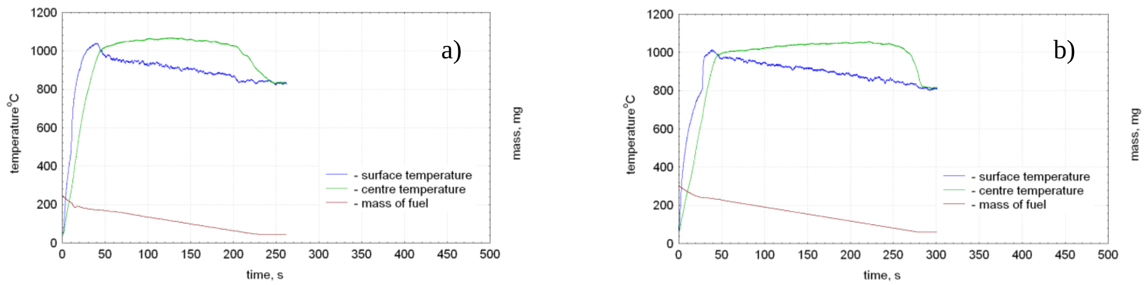


Fig. 4.3. The course of changes of surface and centre temperature and mass loss of brown coal (a) and hard coal (b)

From the moment of fuel ignition by means of volatiles, fuel surface temperature increases intensively, to eventually obtain the maximum value. Fuel ignition by means of volatiles also leads to an increase in temperature inside the fuel.

Studies into sewage sludge as well as coal and biomass showed much greater intensity of the process of combustion of sewage sludge and biomass as compared to coal, by, among others, lowering the ignition temperature. The high content of volatiles matter and lower content of moisture in fuel lead to shorting of ignition time of fuel. In the case of sewage sludge and biomass, degassing and combustion of volatile matter is an important step in the process of combustion. High content of moisture and oxygen in the sewage sludge and biomass makes the zone of combustion of volatiles emitted from the fuel more extensive in comparison to coal. The high content of volatiles matter and lower content of carbon element in fuel and its lower caloric value lead to decreasing of average temperature of fuels combustion.

Figure 4.4 presents the visualisation of process, at the different stages of fuels combustion.

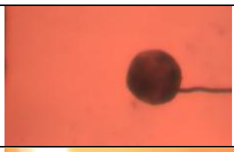
Fuel	Sewage sludge (A)	Biomass	Brown coal	Hard coal
1				
2				
3				
4				
5				

Fig.4.4. The visualisation of fuels combustion: 1 - heating, dewatering and devolatilisation, 2,3,4 - devolatilisation and volatiles combustion, 5 - char combustion; t=850^{0}C

5. Conclusions

1. According to the forecasts, the production of sewage sludge will grow. This is due to the one hand with the lifestyle changes of society, but also from the growing percentage of the population connected to the sewerage network.
2. Legal constraints impose the choice of method of disposal of sewage sludge.
3. The shortest combustion process takes place in case of fuels characterized by a lower carbon content and high proportion of volatiles.
4. The composition and properties of the biomass and sewage sludge lead to intensification of the combustion process, resulting in, among others, reducing the fuel ignition temperature, compared to coal.
5. The high content of volatiles matter and lower content of moisture in fuel lead to shorting of ignition time of fuel.
6. The high content of volatiles matter and lower content of carbon element in fuel and its lower caloric value lead to decreasing of average temperature of fuels combustion.

References

1. Bień J.B.: Sludge - theory and practice. Second revised and supplemented. Publisher University of Czestochowa, Czestochowa, 2007.
2. National Waste Management Plan 2014, Warsaw 2010.

3. Central Statistical Office. Environmental Protection in 2013.

4. Moron W., Szydełko A., Krol K. et al : Physical and chemical properties and suitability for burning waste paper sludge and municipal waste. Archiwum Spalania 12 (2012), 4, p. 185-194.

5. Bień J.: Experiences from co-combustion of sewage sludge in a fluidized bed boiler with a layer of bubble. Materials IV National Training Conference "Methods of sewage sludge management ", 11-12.02.2013, Starachowice.

6. Słowik K., Stelmach S., Wasilewski R.: Sewage sludge co-combustion in coal-fired boilers. Archives of Waste Management and Environmental Protection 13 (2011), p . 41-50.

7. Werle S.: Multivariate analysis of the possibility of co-combustion of sewage sludge in coal-fired power boilers. Archives of Waste Management 13 (2011), 1, p. 21-38.

8. Werle S.: Energy from waste-water. Thermal methods of sewage sludge management. Professional and thermal Power, 9 (2010) , p . 28-31.

9. Werther, J., Ogada, T.: Sewage sludge combustion. Progress in Energy and Combustion Science 25 (1999), p. 55–116.

10. http://geoland.pl/dodatek/jakosc-normalizacja-certyfikacja-13/osady-sciekowe-zrodlem-energii-alternatywnej-2/

11. Pająk T.: Drying and incineration of sewage sludge - in Poland and other EU countries. VI National Training Conference drying and thermal treatment of sewage sludge. Warsaw 19-21 September 2012.

12. Kijo - Kleczkowska A.: Analysis combustion process of coal -water fuel. Archives of Mining Sciences, vol.54, 1, p.119 -133, 2009.

13. Heidrich Z., Witkowski A.: Equipment for sewage treatment. Design examples of calculations. Second Edition, Publishing House "Seidel – Przywecki", Warsaw 2010.

14. Pająk T.: Projects incineration of municipal waste and sewage sludge in the waste management strategy. Engineering and Environment 13 (2010), p. 53-66.

15. Podedworna J., Umiejewska K.: Technology sewage sludge. Publishing House of Warsaw University, Warsaw 2008.

16. Protection of the Environment, 2000-2013.

17. Bien J.B., Wystalska K.: Thermal processes in the disposal of sewage sludge. Publisher University of Czestochowa, Czestochowa, 2008.

18. Kijo - Kleczkowska A.: Research on coal-water fuel combustion in a circulating fluidized bed. Archives of Mining Science, vol. 57, 1, p. 79-92, 2012.

19. Kijo - Kleczkowska A.: Analysis of the co- combustion process of coal -water slurries and biomass. Archives of Mining Science, vol. 55, 3, p. 487 -500, 2010.

20. Bień J., Gandor M.: The kinetic parameters of combustion of sewage sludge in an atmosphere of O_2/CO_2. Archiwum Spalania 11 (2011) , No. 3-4 , p. 171-179.

21. Regulation of the Minister of Economy of 8 January 2013 on the criteria and procedures for the release of waste to the landfill type (Journal of Laws 2013 p.38).

22. Sroda K., Kijo - Kleczkowska A., Otwinowski H.: Thermal treatment of sewage sludge. Ecological Engineering, 28, p. 67 -81, 2012.

23. Kijo - Kleczkowska A., Sroda K., Otwinowski H.: Study into combustion of sewage sludge as energetic fuel. Archives of Mining Science, vol. 58, 4, p. 1085-1110.

24. Li P.-S., Hu Y., Yu W., Yue Y.-N., Xu Q., Hu S., Hu N.-S., Yang J.: Investigation of sulfur forms and transformation during the co-combustion of sewage sludge and coal X-ray photoelectron spectroscopy. Journal of Hazardous Materials 167 (2009), p. 1126-1132.

25. Kijo - Kleczkowska A.: Combustion of coal -water suspensions. Fuel, vol. 90, p. 865-877, 2011.