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Changes in Selected Fuel Properties of Sewage Sludge as a Result of its Storage

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***Abstract*—**The article presents test results on the changes occurring in sewage sludge during the process of its storage. Tests were conducted on mechanically dehydrated sewage sludge derived from large municipal sewage treatment plants equipped with biological sewage treatment systems. In testing presented in the paper the focus was on the basic fuel properties of sewage sludge: moisture content, heat of combustion, carbon share. In the first part of the article the overview of the issues concerning the sewage sludge management is presented and the genesis of tests is explained. Further in the paper, selected results of conducted tests are discussed. Changes in tested parameters were determined in the period of a 10-month sewage storage.

***Keywords*—**fuel properties, laboratory tests, sewage sludge, storage

I. Introduction

Management of sewage sludge from municipal sewage waste treatment plants is still an unsolved problem in a number of countries, including Poland.

Major problems related to the management of this waste result, among others, from the following facts:

- it is generated in large quantities,
- the sources of its generation are dispersed,
- its high moisture content,
- its pathogen content,
- its heavy metal content.

Now, in the European Union there are approximately 10 million Mg of dry sludge generated (including: in Poland about 0.55 million Mg and in Italy over 1 million Mg) [1]. In reality the mass of the waste that needs to be managed is considerably larger, as the water share in the sludge leaving wastewater treatment plants most frequently exceeds 70%.

A group of methods allowing for the effective treatment of sewage sludge includes thermal methods with, among others, combustion and co-combustion. In this century, in a number of countries the share of these methods in the sewage sludge management has increased. The increase of this share took place, inter alia, in Switzerland, the Netherlands, Germany and Austria [2]. It is worth noting that Switzerland treats 100% of sludge with the application of thermal methods, while Germany about 50%. Also in Poland, in the last two years, seven sewage sludge combustion plants have been completed or are about to be completed.

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Additionally, due to a large number of power plants supplied with hard coal and lignite, there are potential conditions to conduct there the co-combustion process of sewage sludge and coal. At present, mostly due to the applicable legal regulations and the absence of plants for NOx removal from flue gases in power facilities, the co-combustion is not carried out. However, preparations for the replacement of old power units with new ones have been commenced now. In the nearest future, legal regulations are also to be subject to change, and after changes they are to allow for the classification of energy obtained from sewage sludge combustion as renewable energy. It allows to forecasts that within a few years it will be possible also in Poland to implement the sewage sludge co-combustion within a broad range. It is worth mentioning that in Germany over a half of the sludge subject to the thermal treatment is co-combusted in power plants.

As early as in 1990s, during the commissioning and testing conducted by the author of this paper at the first waste thermal treatment plant in Poland, the deterioration of fuel properties of sewage sludge was observed as a result of its storage for several weeks. It was noticed that in particular in the summer time, after a few weeks of storage in a file, sludges dried and then burned much worse.

In the case of the application of thermal methods, the necessity of a periodic sludge storage may result from a number of reasons, e.g.:

- overhaul outages of the thermal treatment plant,
- irregularity of sludge supplies to the sludge thermal treatment plant (in the event when the plant serves a few sewage treatment plants),
- seasonal sludge storage in the summer time - in case of conducting co-combustion processes in heat-generating and heat and power generating plants.

Under Polish conditions, the issues of the change in sludge fuel properties is the more important that according to [1], in 2009 in Poland, within the premises of sewage treatment plants over 450 000 Mg of sewage sludge was stored (the quantity corresponding to approx. 80% of the sludge mass generated during a year). Appreciating the importance of the above issues, in 2009 the Polish Ministry of Science and Higher Education granted funds for the performance of research aimed at examining the impact of sewage sludge storage time on fuel parameters of the sludge.

II. Testing Methodology

Due to the fact that in Poland it is projected that, at first, the sewage sludge from large municipal sewage treatment plants will be subject to thermal treatment processes, tests were conducted on the sludge derived from such plants. Treatment plants had capacities of above 30 000 m3/day. All sewage treatment plants from which sewage was taken were mechanical and biological treatment plants. In the plant, the sewage sludge was subject to anaerobic fermentation and mechanical dewatering processes. This paper presents test results of eight sewage sludge samples (hereinafter individual sewage sludges were marked with numbers from I to VIII). Sludge initial parameters, analysed further in the paper, such as moisture content, heat of combustion and carbon share, are presented in table I. In testing, batches of sludges of over 1.2 m3 were sampled from sewage treatment plants. The sludge taken was subsequently placed in a special container with the capacity of over 1 m3. During testing, the conditions of sludge storing in natural conditions - storing in a pile - were simulated. Thus, the containers were open at the top and exposed to the atmospheric conditions. Sides of the containers were insulated and the bottom of the container enabled the leachate drainage. Sludge subject to testing was stored in layers with thickness of about 1.2 m. As part of testing, from the sludge stored in such manner samples (of approx. 1 dcm3) were taken for analytical determinations. Samples were taken from the depth of approx. 1 m (hereinafter "Sludge bottom") and 0.20 m ("Sludge top") – measured from the surface layer of the stored sludge. Sludges were stored in the period from May to October (different samples, in different 10-week cycles from this interval). The atmospheric conditions in the presented tests were found to be disturbing factors.In the case of each tested sludge, samples for analytical determinations were taken at the beginning of the sludge storing process and then they were taken at two-week intervals for the period of 10 weeks. Thus, the article presents the results concerning six dates of sample taking. Within the framework of conducted tests, ten-odd parameters were determined, including: gross calorific value, moisture content, fraction of combustible and volatile matter, elemental composition, aggressive substance content.

Further in the paper, the results of the following analyses are presented:

- moisture content - tests were performed in accordance with the standard PN-80/G-04511 [2];
- heat of combustion - tests were performed in accordance with the standard PN-ISO 1928:2002 [3];
- carbon content - tests were performed in accordance with the standard PN-87/C-04301 [4].

It should be noted that all values presented further in the paper (e.g. on graphs) are average values obtained based on the threefold repetition of each determination.

III. Test Results

Due to the fact that the most advantageous part of the combustion process of sewage sludge is its drying, one of the important issues raised during testing was to determine changes in moisture content of the stored sewage sludge.Table I presents selected statistical parameters describing presented tests. The table presents the following parameters for the beginning and the end of testing: range, mean values and standard deviations of the mean value.These values are presented for the sludge both from top and bottom layers. Ranges of tested parameters presented in table 1 for the beginning of testing differ due to a separate performance already from the moment of the commencement of tests to determine properties of sludge deposited in top and bottom layers of laboratory stands. Thus, changes in ranges allow to estimate roughly the heterogeneity of tested sludge samples.In the case of parameters presented in the paper, greater differences occurred, among others, exactly in case of the moisture content, and to be precise in case of the lower limit of the range. For sludges derived from the top layer it amounted to 63.52%, and for sludges from bottom layers 66.03%. During the development of test results, in order to limit the impact of heterogeneities occurring randomly in case of individual sludges, the focus was on determining trend lines for mean values. The moisture content of the top layer of stored sludges was, due to obvious reasons, contingent upon meteorological conditions. On the average, for all 8 sludge samples about 4.9% increase in moisture content of sludges in top layers was discovered. This value, right only for the conditions of the conducted experiment, is, however, an argument for a recommendation that in case of the storage of sewage sludge subject later to thermal processes, sludges should be stored under a roof and a drain from the landfill should be provided. More interesting are processes occurring in the bottom part of the stored sludge layer. The moisture content of tested sludges amounted at the beginning from approx. 63.5% to over 83%, while at the end of tests from about 74.5% to over 83.5%. For the tested period of sludge storage, conducted correlation analyses did not demonstrate a relation between meteorological parameters and the moisture content of the sludge at the depth of 1 m. Fig. 1 presents results of conducted tests. This figure presents observed changes in the moisture content in case of all 8 sludge samples and a trend line determined for mean values. During a 10-week storage, in case of nearly all tested sewage sludges, an increase in the moisture content of sludges in bottom parts of testing stands was observed. An exception is sludge V for which from the 6th week until the end of testing a lower moisture content of sludge was discovered than the one observed at the beginning of testing (the difference between the first measurement and the last one amounted in the case of this sludge to 0.66%, with the standard deviation amounting for this value to 0.17%). Mostly single decreases in the moisture content visible in the figure in the case of other sludges are the result - as mentioned above - of the heterogeneity of the mass of stored sludge from which analytical samples were taken. For practical purposes, it is interesting to know the equation describing the observed changes. Such an equation has been determined for mean values obtained based on test results of all eight sludges.

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TABLE I
SELECTED STATISTICAL VALUES DESCRIBING TESTS

Determination		Unit	Sludge top			Sludge bottom		
			Range	Mean value	Standard deviation	Range	Mean value	Standard deviation
Moisture content	beginning	%	63,52-83,14	73,53	2,71	66,03-83,29	74,25	2,06
	end		74,57-83,61	78,43	1,15	72,76-84,94	77,31	1,50
Heat of combustion	beginning	kJ/kg	13431-19331	15284	722	12919-19 327	15221	749
	end		11792-18682	14805	856	11908-19526	15247	895
Carbon share	beginning	%	27,66-44,76	34,28	2,62	28,70-44,87	33,76	2,39
	end		27,82-44,04	32,62	2,09	27,50-43,62	33,15	2,05

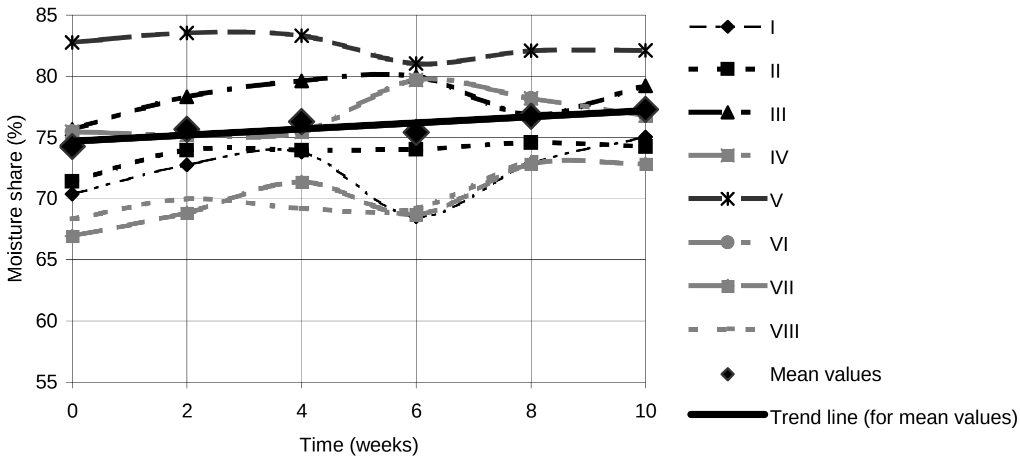

Fig. 1 Changes in time of the moisture content in stored sludge at the depth of 1 m

The equation has the following form y=0.25x+74.7. It proves the relatively small average increase in the sludge moisture content in the period covered with the test (2.5% absolute increase). A linear correlation coefficient for mean values of the moisture content and storage time amounts to 0.874. An analysis of the significance of the linear correlation coefficient proves the occurrence of the analysed relation in population general at the significance level of 0.05 (a critical value of the Pearson's linear correlation coefficient for the significance level of 0.05 and four degrees of freedom amounts to 0.811). Moreover, during storage, approx. 30% narrowing of the range size was observed (in absolute values the range size decreased from about 17% to 12%). Another important parameter allowing to make conclusions on fuel parameters of sludge is the heat of combustion of its dry matter. Table 1 presents ranges, mean values and standard deviations of the heat of combustion of tested sludges at the beginning and end of tests. Fig. 2 presents changes in combustion heat values of sludge from top layers. The initial combustion heat values of the dry sludge amounted to approx. from 12 900 kJ/kg to over 19 300 kJ/kg. And the minimum heat of combustion of sludge from top layers amounted to over 13 400 kJ/kg.

Thus, as a result of the natural heterogeneity, it was by around 500 kJ/kg (i.e. almost 4%) higher than in the case of sludges taken from bottom layers. Obtained in a similar manner as in the case of the moisture content, the equation took the following form y=-44.47x+15 000. And like in the previous case, due to the different initial level of the combustion heat value in case of sludges from different sewage treatment plants, the value of the slope is significant. The value indicates the possibility, on the average, of under a 3% decrease of the combustion heat value in the period in question. However, in the case of this correlation coefficient equation it amounts only to 0.493. In the case of sludges located at the depth of 1 m, no changes in the combustion heat value of sludge dry matter were discovered de facto (the slope amounted to -0.02). A partial explanation of the combustion heat value may be the change in the carbon share in sludges.These changes are presented in Fig. 3.

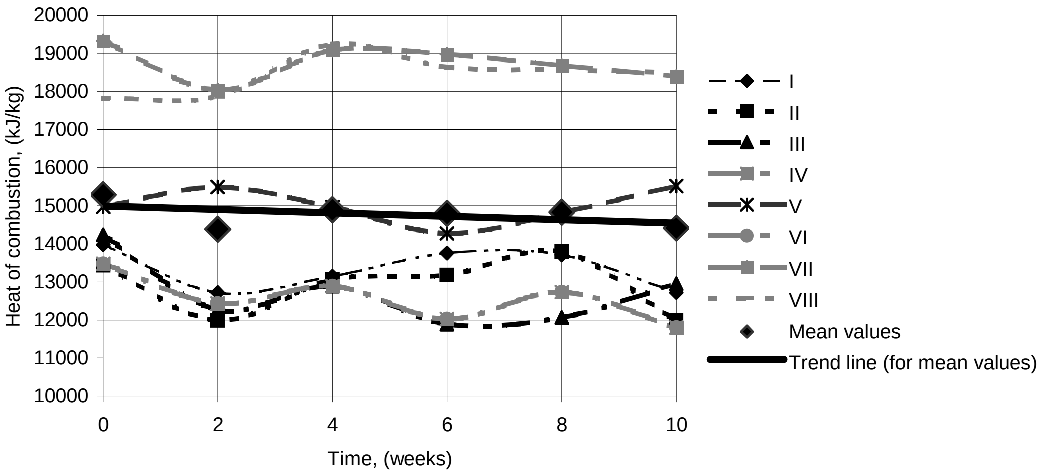

Fig. 2 Changes in combustion heat values of sludge from the top layer (dry sludge), kJ/kg

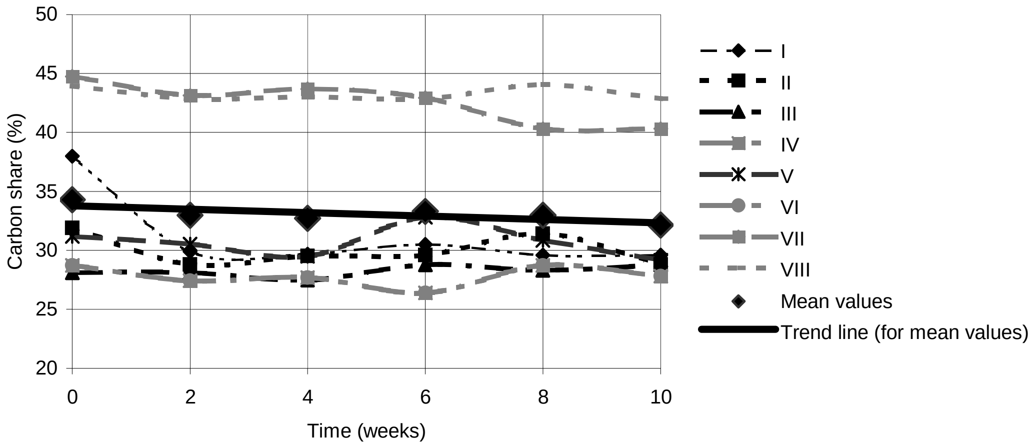

Fig. 3 Changes in the carbon share in sludges from the top layer (a dry sample), %

The regression line equation describing changes in the carbon share in the top sludge layer took the following form: y=-0,145x+33,784. It allows to estimate the average decrease in the carbon share in sludges during the conducted tests to amount to over 4% of the initial value (relative value) or almost 1.5% of the absolute value. In the case of this equation the correlation coefficient amounts to 0.763. An analysis of the significance of the linear correlation coefficient proves the occurrence of the analysed relation in population general at the significance level of 0.1 (a critical value of the Pearson's linear correlation coefficient for the significance level of 0.1 and four degrees of freedom amounts to 0.729). In the case of the bottom layer of sludges the following regression line equation was obtained: y=-0,086x+33,869. It allows to estimate the average decrease in the carbon share during the conducted tests to amount to slightly over a half of the one observed in top layers. In the case of this equation the linear correlation coefficient amounts to 0.596.

Based on the presented results we can explain the fact of the decrease in the combustion heat value in top layers with the fact of the decrease in the carbon share in sludges. This decrease, in turn, should be explained by processes of the organic matter decomposition occurring in top sludge layers. And in bottom layers these processes occur at a much slower rate.

IV. Conclusion

Thermal methods are the more frequently applied methods of sewage sludge treatment. As it was shown, the necessity of the periodic sludge storage, as a part of the implementation of the process of the sludge thermal treatment, may result from a number of reasons.

The paper presents test results (including relationships) obtained based on tests conducted for a relatively large number of sludges derived from different biological sewage treatment plants. One of the objectives of such extensive tests was to minimize the impact of the natural heterogeneity of sludges on the obtained results and the possibility to use the obtained relationships for a large group differing in terms of the sludge initial values. The initial moisture content of sludges taken into account in tests amounted from approx. 63 to 83%, and the heat of combustion from 12 900 to 19 300 kJ/kg.

Conducted tests demonstrated that during a 10-week storage period, an actual deterioration of sewage sludge fuel properties occur. This deterioration results from the still occurring processes of their biological decomposition and the movement of water in the sludge pile, as well as from the absorption of moisture from precipitation.

As it was demonstrated, in the bottom layers a constant increase in the sludge moisture content is observed, due to the permeation of water from upper layers. In the top layer, in turn, water from precipitation collects. For the period of 10 weeks, in bottom layers the average of approx. 2.5% increase in the moisture content (absolute value), and in top layers (Poland, period from May to October) of 4.8% was observed.

Slight changes in the calorific value of sludge dry matter from bottom layers were observed. In the case of top layers, an almost 3% decrease in the heat of combustion was observed. The confirmation of observed changes in the calorific value are the observed changes in the carbon share. A decrease in the share of this chemical element amounted, on the average, in bottom layers to 0.8% and to about 1.5 in top layers (absolute values).

Test results presented in the paper allow to estimate the impact of the sewage sludge warehousing/storage time on sewage sludge fuel properties.

However, the results obtained do not explain fully the significant deterioration of fuel properties of the stored sludge observed in industrial plants (sludge thermal treatment plants).

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