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Alternative Fuel Production Based on Sewage Sludge Generated in the Municipal Wastewater Treatment

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1. Introduction

One of the most interesting types of waste which can be used in power industry in the most effective and environmentally friendly way is the sewage sludge produced in municipal wastewater treatment plants [9,10]. It is estimated that sewage sludge constitutes approximately 3% of the volume of all treated wastewater. Extension of sewerage networks and construction of new wastewater treatment plants resulted in a rapid increase in the sewage sludge volume and caused problems with its disposal [3].

The above-mentioned issues constitute a problem mainly in the EU Member States, including Poland, where sewerage networks have been considerably extended in the recent years. The EU Directives 86/278/EEC [2] and 99/31/EC [1] significantly restrict the use of sewage sludge in agriculture and impose a ban on its storage. Therefore, seeking new solutions for safe sewage sludge disposal becomes a necessity. The main problems related to sewage sludge management include: high sludge humidity, odour emission, concentration of heavy metals and other potentially hazardous substances. These factors make the utilization of sewage sludge one of the most difficult processes of environment protection [5]. Even though the use of sewage sludge as an agricultural fertilizer may have a beneficial effect on the environment, it may also negatively influence people and soil productivity [5,7,11,13].

Presently, the most common methods of sewage sludge disposal include the use for agricultural purposes and storage [4]. Sewage sludge is deposited in landfills designed exclusively for this purpose, in lagoons or together with municipal waste.

Thermal methods of sewage sludge utilization have recently been drawing more and more attention [8]. In the field of sludge management this tendency, widespread in Europe, is governed by the following hierarchy of priorities: avoidance, minimization, recycling and application of thermal methods with energy recovery.

Thermal processes enable a significant sewage sludge mass and volume reduction. The content of heavy metals in sewage sludge prevents its use in agriculture. Additionally, the fact that there are no lands suitable for agricultural use situated in the vicinity of municipal wastewater treatment plants encourages the development of thermal methods. The application of thermal methods of sewage sludge utilization depends on the sludge properties: the heat of combustion (calorific value) and sludge composition (including the humidity level). The calorific value of crude sludge equals approximately 17 MJ/kg, of activated sludge – about 15 MJ/kg and of stabilized sludge – roughly 11 MJ/kg. Thermal energy contained in sewage sludge can be recovered through the combustion process carried out in combustion plants designed for the treatment of municipal wastewater [6, 16] or through the process of co-combustion with other energy carriers carried out e.g. in power plants, thermal power stations or municipal waste combustion facilities [12, 14, 15, 17].

The aim of this study was to determine the possibilities for the utilization of sewage sludge produced in mechanical-biological wastewater treatment plant as an alternative fuel in clinker production.

2. Methods

Samples of sewage sludge produced in ”Hajdów“ Wastewater Treatment Plant were taken for testing. First, the tests on the hydration level of the mechanically dewatered sludge were carried out. Further on, the dry mass content was determined and the following values were calculated:

- energy required to heat a sample of sewage sludge from 20 to100°C,
- the total energy required to dry 1 kg of sludge,

- the calorific values of wet and dry sludge calculated with the use of the following formulas.

In the course of the experiment, the analysis of the cement kiln waste gases was carried out with the use of the oxides of nitrogen analyzer and gas chromatograph, as well as with the application of traditional methods (e.g.: SO_2 – iodometric method, NO_2 – measured spectrophotometrically). The analyses of the solid samples, e.g. the chemical composition of clinker and sludge were carried out by means of ASA and ICP methods after prior mineralization of the tested material in a CEM microwave oven.

3. Results and discussion

When it comes to the use of sewage sludge as a fuel in a cement burning kiln, the most significant – and in fact the decisive – factor is the energy balance of the mechanically dewatered sludge. There are no doubts that the attractiveness of sewage sludge as a fuel increases together with its calorific value. From the point of view of environment protection the chemical composition of sludge is of great importance, especially when it comes to the components of the kiln waste gases (Table 1.)

Mineral substances contained in sewage sludge should in the vast majority be bound up with clinker, thus undergoing the total and lasting immobilisation. The said components are: Ca, Fe, Si, K, P, A and heavy metals. During the combustion process sulphur can be released to the gas phase and emitted to the atmosphere together with the waste gases. Its content in sewage sludge (in dry mass) is rather significant and comparable to that in the low quality hard coal. Therefore, the problem of sulphur liberation in the sludge combustion process must be taken very seriously.

The dry mass content of organic substances varies within the range of 52.6–58.4%, ensuring a positive energy balance for the sludge.
The value of the dried sludge combustion changes within the narrow range of 14.4–14.5 MJ/kg (Table 2). Thus, the dried sludge is a fuel comparable in thermal terms to wood whose calorific value varies within the range of 14–19 MJ/kg. It must be emphasised that the dried sludge combustion heat value is extremely stable which is definitely related to its virtually stable level of content of organic substances.

Table 1. Chemical composition of sewage sludge
Tabela 1. Skład chemiczny osadów ściekowych

Parameter	Unit	Average concentration	Range (based on 10 tests)
CaO	g/kg d.m	384	299.0–412.0
Fe_2O_3	- ” -	188	142.0–208.0
SiO_2	- ” -	139	102–156.0
S	- ” -	19.4	15.2–24.6
P_2O_5	- ” -	93	46.0–157.0
K_2O	- ” -	18.3	14.6–21.8
Al_2O_3	- ” -	22.4	16.8–28.4
H_2O	%	77.0	75.0–79.2
Residue on ignition (600°C)	%	9.7	8.63–11.4

Table 2. Energy balance of sewage sludge
Tabela 2. Bilans energetyczny osadów ściekowych

Sample no.	Dry mass content	C_s [1)]	Q_{H2O} [2)]	W_U^S [3)]	W_U^M [4)]
	g/kg	MJ/kg	kJ/kg	kJ/kg	kJ/kg
1	247.80	14.51	2023.86	3595.58	1571.72
2	250.00	14.50	2018.43	3625.00	1606.57
3	238.80	14.49	2046.18	3460.21	1414.03
4	232.00	14.48	2063.02	3359.36	1296.34
5	228.50	14.44	2017.71	3299.54	1227.83
6	216.00	14.50	2102.68	3132.00	1029.32
5	208.10	14.50	2122.24	3017.45	895.21
8	221.34	14.52	2089.53	3214.77	1125.24
9	227.63	14.43	2040.88	3285.11	1244.24
10	237.60	14.39	2055.86	3419.06	1363.20
11	243.00	14.43	2035.78	3506.49	1470.71
12	246.00	14.57	2028.34	3584.22	1555.88

[1)] C_s – dried sludge combustion heat value
[2)] Q_{H2O} – energy needed for drying up 1 kg of wet sludge
[3)] W_U^S – calorific value of the substance contained in 1 kg of wet sludge
[4)] W_U^M – total net calorific value of 1 kg of wet sludge

The analysis of the amount of energy required for sewage sludge drying, that is the energy to be used for heating water from 20 up to 100°C and for its vaporization, is proportional to the amount of water and varies within the range of 2018–2122 kJ/kg of wet sludge.

The calculated wet sludge value varies within the range of 895–1607 kJ/kg. Therefore, the dewatered sewage sludge can hardly be treated as an attractive fuel; however, the combination of its utilization with a possible application in the cement kiln burning process should be treated as economically justified.

At present, when the number of wastewater treatment plants equipped with mechanical sludge dewatering stations is growing, sewage sludge is becoming an increasingly valuable alternative fuel.

4. Utilization of sewage sludge in cement kilns

Combustion of sewage sludge was carried out in one of the cement plants in Lubelskie Voivodship region. Sewage sludge was added to the clinker slurry in the proportion of 2%. The addition of such small amount of sludge resulted in a slight change of its chemical composition and, in particular, in a slight increase of the content of volatile substances with subsequent dilution of the mineral components of the cement slurry. The phenomenon described above is presented in Table 3.

Table 3. Chemical composition of the Portland cement slurry with and without the addition of sewage sludge
Tabela 3. Skład chemiczny szlamu portlandzkiego z dodatkiem i bez osadu ściekowego

Parameter	Without the addition of sewage sludge	With 2% addition of sewage sludge
Loss on ignition	36.4%	37.5%
SiO_2	13.7%	13.4%
Al_2O_3	2.5%	2.5%
Fe_2O_3	1.2%	1.2%
CaO	45.2%	44.3%

The process of utilisation was carried out over the time of 8 hours. During the experiment, the analysis of exhaust gases and dust emissions was carried out in the rotary kiln no. 3, while the cement samples used for the cement quality analysis were taken both from kiln no. 3 and kiln no. 4.

Measurements of dust emissions and of the composition of waste gases were carried out two days before the experiment, on the day of the experiment – in the eighth hour of the tests – and on the day following the completion of the experiment.

In fact, no negative processes which would have led to increased emissions of gases and dust were observed. However, the tests revealed a reduction in the dust and sulphur emissions from kiln no. 3 fed with the clinker slurry containing sewage sludge in the proportion of 2%, while the level of nitrogen oxides emission remained unchanged. The results of the analysis were provided by the cement plant laboratory (Table 4).

Table 4. Results of the measurements of dust emission (measurements taken behind the electro-filter)
Tabela 4. Wyniki pomiarów emisji pyłowej (miejsce pomiaru za elektrofiltrem)

			Before the experiment	During the experiment	After the experiment
Chemical composition of exhaust gases	CO_2	%	12.6	13.5	12.6
	CO	%	0.1	0.1	0.1
	O_2	%	10.1	10.1	10.1
	N_2	%	61.4	60.6	61.4
	H_2O	%	15.8	15.6	15.8
Average emission of SO_2		kg/h	8.0	10.6	7.9
SO_2 emission coefficient		kg/t	0.4	0.6	0.4
Average emission of NO_2		kg/h	19.0	18.6	19.0
NO_2 emission coefficient		kg/t	0,9	0.9	1.0

Based on the results obtained it is not possible to state unequivocally whether the observed reduction in dust and SO_2 emission results directly from the fact that sewage sludge was added to the process. We need to consider further experiments enabling thorough understanding of the phenomenon to be carried out in future. The emission of organoleptically detectable odorous substances was undoubtedly the negative effect of the combustion of sewage sludge supplied to the kiln together with clinker slurry. In order to regulate the emission of such substances to the atmosphere, it is necessary to modernise the cycling of the cement kiln waste gases.

The analysis of the chemical and phase composition of the Portland cement revealed slight fluctuations (Table 5). Therefore, it needs to be emphasised that the utilization of sewage sludge had absolutely no influence on the quality of the product obtained.

Table 5. Chemical and phase composition of the Portland cement clinker (in%)
Tabela 5. Skład chemiczny i fazowy klinkieru portlandzkiego w% wag.

Compound	Before the experiment	During the experiment	After the experiment
Loss on ignition	0.3	0.3	0.34
SiO_2	22.1	21.7	22.0
Al_2O_3	5.0	5.2	5.2
Fe_2O_3	2.1	2.1	2.0
CaO	65.8	66.4	67.6
MgO	0.7	0.7	0.8
SO_3	0.4	0.4	0.4
Free CaO	1.2	1.1	1.1
C_3S	61.0	60.2	60.7
C_2S	19.9	19.6	19.4
C_3A	9.2	9.6	10.0
C_4AF	6.1	6.2	6.2

5. Conclusions

The results of the tests performed made it possible to draw the following conclusions:

- Combustion of sewage sludge in rotary cement kilns does not lead to increased dust, sulphur dioxide or nitrogen oxides' emissions to the atmosphere. However, odorous substances (detectable) are emitted which requires adequate modernization of the cycling of the cement kiln waste gases to be carried out.

- The dry sludge combustion heat value varies within a narrow range of 14.43–14.57 MJ/kg, which makes this type of waste a fuel comparable in energy terms to wood, the calorific value of which varies between 14 and 19 MJ/kg.
- The calorific value of wet sludge varies within the range of 895–1607 kJ/kg, and therefore the mechanically dewatered sludge can hardly be regarded as an attractive fuel.
- The stability of the sewage sludge combustion heat value is related to the stable content of organic substances.
- Co-combustion of sewage sludge with clinker slurry seems to be a justified method of its utilization, especially because it does not in any way affect the quality of the product obtained.

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Wytwarzanie alternatywnego paliwa z wykorzystaniem osadów ściekowych z miejskiej oczyszczalni ścieków

Streszczenie

Problem osadów ściekowych, towarzyszy nierozłącznie procesom oczyszczania ścieków i nigdy nie był traktowany równorzędnie z ich oczyszczaniem. Jeszcze do niedawna przyjmowane były proste rozwiązania przeróbki osadów polegające na odsączaniu i suszeniu, które miały wpływ na późniejsze ich wykorzystanie. Każda z metod zagospodarowania osadów ściekowych ma swoje zalety i wady. Najbardziej radykalną metodą utylizacji osadów ściekowych jest ich spalanie. Podstawą tego procesu jest maksymalne wykorzystanie ciepła spalania i zmniejszenie objętości osadu. Przy prawidłowym doborze technologii osad może być spalony bez znacznego dodatku paliwa. W piecach cementowych przy wysokiej temperaturze i dużej stabilności gwarantowany jest

całkowity rozkład substancji organicznej i uniemożliwia powstawanie wtórnych zanieczyszczeń charakteryzujących procesy spalania. W takich warunkach substancje organiczne przechodzące przez strefę wysokich temperatur w piecu do wypalania klinkieru, ulegają pirolizie i spaleniu do prostych związków nieorganicznych. Powstające popioły nie stanowią większego problemu, gdyż ulegają wbudowaniu w klinkier.

Spalanie osadów ściekowych w chwili obecnej ma największą szansę rozwoju, tym bardziej, że wraz ze wzrostem zużycia energii przez przemysł, rolnictwo i indywidualną konsumpcję ludności rośnie proporcjonalnie emisja gazów spalinowych, ścieków i odpadów stałych. Wymienione powyżej czynniki, jak i szereg innych powodują, że poszukuje się alternatywnych źródeł energii, ale również dąży się do wykorzystania materiałów odpadowych jako źródło dodatkowej energii. Powszechnie obowiązująca praktyka składowania odpadów w litosferze, nie tylko wiąże się z bezpowrotną utratą cennych terenów i energii zawartej w osadach ściekowych, lecz dodatkowo powstające w wyniku tych procesów gazy i ścieki mogą zanieczyszczać środowisko.

Przeprowadzone badania miały na celu rozeznanie możliwości wykorzystania osadów z mechaniczno-biologicznej oczyszczalni ścieków jako paliwa do wypału klinkieru.

W wyniku przeprowadzonych badań stwierdzono, że ciepło spalania wysuszonego osadu ściekowego zmienia się w wąskim zakresie 14,4–14,5 MJ/kg, a wiec jest paliwem porównywalnym energetycznie z drewnem,. co związane jest ze stałym poziomem zawartości substancji organicznych. Wartość opałowa mokrego osadu zmienia się w zakresie 895–1607 kJ/kg, zatem trudno uznać mechanicznie odwodnione osady ściekowe za atrakcyjne paliwo. Jednak połączenie utylizacji z ewentualnym wykorzystaniem osadu do opalania pieca cementowego zyskuje ekonomiczne uzasadnienie. Przeprowadzone badania w skali technicznej wykazały, że dodanie osadów ściekowych do szlamu klinkierowego w ilości 2% powoduje niewielkie zmiany ich składu chemicznego, w szczególności zwiększa nieznacznie ilość substancji lotnych. Zaobserwowane wahania składu chemicznego i fazowego cementu portlandzkiego są niewielkie i należy stwierdzić, że utylizacja osadów ściekowych nie wpływa w żaden negatywny sposób na jakość otrzymanego produktu.

Słowa kluczowe:
osady ściekowe, spalanie, paliwa alternatywne

Keywords:
sewage sludge, combustion, alternative fuels