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Sewage Sludge as a Source of Renewable Energy

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1. Introduction

The problem of energy supply is becoming one of the most significant challenges facing human civilization in the modern world. One the one hand, there emerges a real possibility that fossil fuels will be depleted soon and on the other hand, the Panel for Climate Change is alarming that the Earth temperature increase is caused by the increasing emission of CO_2 produced by fossil fuel burning. For the record we need to refer here to the opinion expressed by a prominent American climatologist Richard S. Lindzen [9] who calls into question the actual scale of the Earth's surface temperature increase.

In the recent years we have been observing a rapid progress in the use of biomass as an energy source. The leading role here is played by the European Union which, by introducing a wide range of legal and economic instruments, is intending to become the leader in the field of low carbon economy solutions [7]. Even such countries as China or India, which nowadays are ranked among the biggest CO_2 emitters, have undertaken actions aiming at limiting the CO_2 emission. However, it has to be noted that Pimentel has published his works which draw the world's attention to the negative aspects of the wide use of biomass for energy production. Applying the LCA technology he proved that the use of liquid bio-fuels not only does not contribute to the decrease of CO_2 emission but on the contrary, it increases such emission by almost 60% [6, 14].

In the recent decades we have observed a major change in the mode of utilization of sewage sludge. Before 1998 sludge was dumped at sea or used as an agricultural fertilizer [12]. Alternatively, it was incinerated or simply deposited in landfills. Since 1998 in order to protect the marine environment the European legislation has banned sewage sludge disposal at sea. Parallel to this regulation another one prohibiting sewage sludge disposal in landfills was introduced. However, it needs to be noted here that approximately 40% of sludge is still landfilled in Europe. At some period of time agricultural use of sewage sludge had become one of the methods of its disposal. Presently 37% of sewage sludge is used for agricultural purposes, 11% is incinerated, 40% still deposited and 12% used in such spheres as for example forestry and land reclamation. The most recent trends in sludge disposal are: incineration, wet oxidation, pyrolysis, gasification and co-combustion with other types of materials aiming at the use of energy contained in sludge. All the above enumerated methods have won a wide scientific interest [2–4, 13].

When it comes to agricultural use of sewage sludge the main focus is laid on its content of nitrogen and phosphorus – the elements essential for plant growth. However, sludge may also contain other unwanted elements which may turn hazardous when entering the food chain, namely heavy metals. Therefore, a greater attention should be paid to the possible use of sewage sludge for energy production.

In Poland the process of anaerobic digestion has gained growing interest in the recent years. The final product of this process is biogas which is treated as an alternative fuel used in the production of "green" energy and a fermented product meeting the requirements for organic fertilizers. Thanks to its placement on the market and introduction to the Polish legal system anaerobic digestion process has become an attractive method of utilization of biomass generated in agriculture and in municipal waste management. Anaerobic digestion of sewage sludge is currently applied at approximately 45% of the Polish wastewater treatment plants. The following factors should be enumerated as the barriers impeding the implementation of that new technology:

- low level of mineralization of organic matter (10–40%),
- difficulties with the use of anaerobic digestion residues as a fertilizer stemming from the regulations related to the process seasonality.

Another possibility for the utilization of sewage sludge is its application in the intensification of the biogas production in municipal waste disposal sites [11]. According to Cao anaerobic digestion is the most profitable method of sewage sludge treatment [1].

In Europe the most commonly applied method of sewage sludge disposal still is its incineration and one should expect that in the long term perspective this method of sludge utilization will gain even wider interest [10].

In the recent years various modern incineration technologies have been introduced offering an alternative trend to the sewage sludge disposal, especially with the decreasing availability and the increasing price of land. Thermal processes involve removing of the organic part of sludge, leaving for the final disposal only the ash component. Sewage sludge is a type of biomass fuel and its calorific value is similar to that of coal. The principal goal of thermal processing of sewage sludge is the utilization of the energy stored in sludge and at the same time the minimization of the environmental impacts which is necessary for the increasingly stringent standards to be met. It is commonly known that sludge contains high moisture contents and therefore the majority of energy released during thermal processes is used to heat water up to 100^0C in order for this water to evaporate to reduce the moisture [5]. The main problem related to the application of thermal processes in sewage sludge disposal is the necessity to supply significant amounts of external energy needed to produce high temperatures [8].

The purpose of this study was to analyze the possibilities for the use of sewage sludge produced by the biological wastewater treatment plant as an alternative fuel in the clinker burning process.

The scope of the study comprised the preparation of homogenized heating oil and wet sludge mixtures and determination of the method with the use of which the so prepared fuel should be fed into a rotary kiln.

2. Material and methods

In the subject analysis the authors used sewage sludge from the biological treatment plant and EKOTERM heating oil produced by PetrochemiaPłock S.A. (Płock Petrochemical Plant) with the calorific value of 43.2 MJ/kg (Table 1 and 2).

The mineral substances contained in sewage sludge should in the vast majority be bound up in clinker, in fact undergoing total and permanent immobilization. During the combustion process sulfur, whose content in sewage sludge is rather significant, can be liberated into the gaseous phase and together with waste gases emitted into the atmosphere.

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

Parameter	Unit	Average content	Range (10 samples)
CaO	g/kg s.m.o.	382	298–415
Fe_2O_3	g/kg s.m.o.	183	141–205
SiO_2	g/kg s.m.o.	137	105–161
S	g/kg s.m.o.	19.4	15.1–24.4
P_2O_5	g/kg s.m.o.	89	45–162
K_2O	g/kg s.m.o.	19.3	14.1–22.1
Al_2O_3	g/kg s.m.o.	21.9	16.9–29.1
H_2O	%	78.1	74.9–78.2
Residue on ignitron/Ash (600°C)	%	9.63	8.59–10.9

Table 2. Physico-chemical parameters of heating oil
Tabela 2. Parametry fizyko-chemiczne oleju opałowego

Parameter	Unit	Result
Density in 20°C	kg/m^3	850
Dry mass content	%	< 0.01
Watercontent	%	< 0.03
Ash content – 600°C	%	0.027
Sulfurcontent	%	1.57
Choridescontent	%	< 0.01
Calorificvalue	kJ/kg	43 128

Analysis of the sludge hydration level and as a result the dry mass content in sewage sludge – carried out with the application of a gravimetric method.

The analyzed fuel mixture was obtained by mixing sewage sludge with heating oil with the additive of two easily available (domestic production) non-ionic surfactants: Rokafenol N8 and Rokacet S7.

Samples of fuel mixtures were burnt in a laboratory tube kiln with the use of air. Analyses of waste gases were carried out during the experiment using nitrogen oxides' analyzer, gas chromatography as well as traditional methods (e.g. SO_2 – iodometric method, NO_2 – spectrophotometrically).

3. Production of wet sewage sludge and heating oil mixture and its combustion in laboratory conditions

To obtain stable emulsions containing water, liquid hydrocarbons and sewage sludge additional thorough and costly studies are required.

From numerous methods used for the purpose of obtaining emulsions containing water and liquid hydrocarbons the simplest and the least complicated one has been selected to be applied in the planned experiment conditions. The mixture of sludge and oils does not have to be extremely stable, it must only secure that a relatively homogenous fuel mixture is fed into a rotary kiln. Therefore, tests on the possibilities for homogenized mixtures to be obtained with the use of generally available non-ionic surfactants were carried out. The said surfactants are:

- Rokafenol N-8,
- Rokacet S-7.

The following parameters seem to be decisive when determining whether a given substance can be considered useful as a fuel:

- calorific value,
- stability – measured based on the time needed for the stratification of the water and organic layer to occur,
- viscosity – determining a possible supply of the mixture to the kiln with the use of a lance or a burner.

Tests were carried out on the mixtures containing 27.5; 37.5 and 47.5% of wet sewage sludge and up to 5% of each of the surfactants (separately and simultaneously). Mixtures were produced in a laboratory homogenizer at the cutting blades rotation speed of 500 rpm and the mixing time of 10 minutes.

Additionally, attempts to obtain stable mixtures with the use of compressed air were made.

Following preliminary consultations with the representatives of the cement plant management it was decided that the minimum calorific value of the fuel mixture generated with the use of sewage sludge must equal 16 MJ/kg which determines the minimum limit for the content of the heating oil for the level of approximately 40%.

The results of the tests are presented in Table 3.

Table 3. Basic parameters of the heating oil and sewage sludge mixture
Tabela 3. Podstawowe parametry mieszanin oleju opałowego i osadów ściekowych

Sewage sludge content [%]	Surfactantcontent [%]		Stability [day]	Viscosity [^{O}E]	Calorific value/ [MJ/kg]
	anionic	non-ionic			
27.5	–	5	Stable	203	30.49
37.5	–	5	Stable	218	25.34
47.5	–	5	Stable	258	21.64
27.5	5	–	Stable	183	30.56
37.5	5	–	Stable	194	25.18
47.5	5	–	Stable	226	21.58
27.5	2.5	2.5	4	93	30.58
37.5	2.5	2.5	5	119	25.26
47.5	2.5	2.5	4	142	21.61
48.5	1	2	Stable	176	21.83
48	1	3	1	173	21.77
47	1	5	2	169	21.63
48.5	2	1	Stable	164	21.96
48	3	1	1	173	21.68
47	5	1	1	161	21.43

Mixtures of sewage sludge and heating oil containing 2.5% of each of the surfactants prove to possess the most favorable parameters. Such mixtures show stability lasting for 4–5 days which makes their longer storage possible. The mixture containing 47.0–48.5% of sludge was selected for the technical tests. Even though its viscosity is significantly high it does not prevent the mixture to be fed into the rotary kiln with the use of a burner or a lance.

Attempts to obtain a stable mixture of sewage sludge and heating oil with the use of compressed air did not bring the expected results.

4. Combustion of the mixture of sewage sludge and heating oil

In the cement plants applying the "wet" method of clinker production fuel and liquid combustible wastes are most often fed into the zone with the temperature of approximately 1200–1600°C. For that reason the combustion of the obtained fuel mixtures was carried out in the temperatures of 1200, 1400 and 1600°C with the air blast into the tube kiln many times exceeding its stoichiometric demand. A sample combustion time varied between 35 and 55 seconds. The content of SO_2 in waste gases was determined using the iodometricmetod and of NO_2 – the colorimetric method after prior gas sorption in the NaOH solution.

Additionally, attempts were made to carry out the clinker burning process in a tube kiln with the use of Portland slurry mixed with the fuel mixture containing 47.5% of sewage sludge and 47.5% of (heating or waste) oil and 2.5% of each of the surfactants. 1 g of mixture was added to a sample containing 19g of slurry. Next, the sample was homogenized and burnt in the temperatures of 1200, 1400 and 1600°C. The burning time of a quickly (1 min.) dried sample equaled 120 minutes. The results of the tests are presented in Tables 4 and 5.

Table 4. Results obtained while combusting 1 g of fuel (containing 47.5% of sewage sludge, 47.5% of oil and 2.5% of each of the surfactants).
Tabela 4. Wyniki spalania 1 g paliwa (po 47,5% osadów ściekowych oraz po 2,5% substancji powierzchniowo czynnych)

Type of oil in the mixture	Process temperature [°C]	Amount of generated SO_2 [g/kg of fuel]	Amount of generated NO_2 [g/kg of fuel]
Heating oil	1200	18.6	1.6
	1400	18.4	1.9
	1600	18.6	3.9

Table 5. The results of the clinker burning process in a laboratory kiln – Portland slurry with the additive of 5% (1g) of fuel (47.5% of sewage sludge, 47.5% of oil and 2.5% of each of the surfactants).
Tabela 5. Wyniki wypalania klinkieru w piecu laboratoryjnym – szlam portlandzki z dodatkiem 5% (1g) paliwa (po 47.5% osadów ściekowych i oleju oraz po 2,5% substancji powierzchniowo czynnych.

Type of oil in the mixture	Process temperature [°C]	Amount of generated SO_2 [g/ kg of fuel]	Amount of generated NO_2 [g/ kg of fuel]
Heating oil	1200	3.5	2.3
	1400	4.1	2.7
	1600	3.9	3.1

The tests prove that the amount of the generated NO_2 does not depend on the type of the high-temperature process but on the temperature itself. The amount of the emitted NO_2 increases (it is even doubled) together with the temperature increase from 1200 to 1600°C. The amount of SO_2 generated during fuel burning results from the total oxidation of sulfur contained in the mixture. Mixing of fuel with the Portland slurry causes it to bind up in 70–80% most probably into the form of sulfates.

5. Conclusions

The tests proved that:

- Combustion of sewage sludge does not have a negative effect on waste management in a cement plant.
- Preparation of a stable mixture of sewage sludge and heating oil with a required calorific value is not a big problem. It seems that from the economic point of view it should be recommended that such mixture should preferably be prepared in the very place of combustion. However, application of this type of fuel requires modernization of the system of the kiln waste gases circulation.
- Despite the fact that no detailed economic analysis has been made, undoubtedly the costs of the energy generated with the use of the sewage sludge and heating oil mixture exceed at least twice the cost of energy generated with the use of coal dust which at the present time makes such a solution impossible to be recommended. However, it concerns only the economic aspect of the process.
- From the point of view of the protection of the environment against waste, sewage sludge utilization should be taken into account as one of alternative methods of this type of waste utilization and disposal.

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Osady ściekowe jako źródło energii odnawialnej

Streszczenie

W ostatnich dziesięcioleciach nastąpiła zasadnicza zmiana w sposobie wykorzystania osadów ściekowych. W latach 90-tych komunalne osady ściekowe zatapiano w morzach lub wykorzystywano jako nawóz na gruntach rolnych. Alternatywą było spalanie osadu lub składowanie. Od roku 1998 r. celem ochrony środowiska morskiego zakazano usuwania osadów zatapiając go

w morzu. Równolegle z tym zapisem zabroniono składowania osadów na składowiskach odpadów. Obecnie jednak 37% osadów wykorzystywane jest rolniczo, 11% poddawanych jest spalaniu, 40% w dalszym ciągu jest składowane, natomiast 12% wykorzystywane jest w takich dziedzinach jak np.: leśnictwo czy melioracje. Inną możliwością jest zastosowanie osadów ściekowych do intensyfikacji powstawania biogazu na składowiskach komunalnych. Najnowszymi jednak trendami które wywołały znaczne zainteresowanie naukowe są: spalanie, mokre utlenianie, piroliza, gazyfikacja i współspalanie z innymi materiałami zmierzające do wykorzystania energii w nich zawartej.

Celem niniejszej pracy było rozeznanie możliwości wykorzystania osadów ściekowych pochodzących z biologicznej oczyszczalni ścieków jako paliwa alternatywnego do wypału klinkieru.

W badaniach wykorzystano osady ściekowe pochodzące z Miejskiej Oczyszczalni ścieków "Hajdów" w Lublinie oraz olej opałowy EKOTERM produkcji Zakładów Petrochemia Płock S.A. o wartości opałowej 43,2 MJ/kg.

Mieszaninę paliwową uzyskano poprzez zmieszanie osadu ściekowego z olejem opałowym stosując jako emulgatory dwie niejonowe substancje powierzchniowo czynne: Rokafenol N8 i Rokacet S7.

Otrzymane próbki mieszanin paliwowych spalano w laboratoryjnym piecu rurowym w atmosferze powietrza.

Przeprowadzone badania wykazały, że:

- Spalanie osadów ściekowych nie wpływa ujemnie na gospodarkę odpadami cementowni.
- Sporządzenie trwałej mieszaniny osadu ściekowego z olejem opałowym o odpowiedniej wartości opałowej nie stanowi większego problemu. Wydaje się, że z ekonomicznego punktu widzenia godne polecenia jest ewentualne wykonywanie mieszaniny w miejscu spalania. Zastosowanie jednak tego rodzaju paliwa wymaga modernizacji obiegu gazów odlotowych z pieców obrotowych.
- Pomimo, że nie przeprowadzano dokładnej analizy ekonomicznej nie ma wątpliwości, że koszty energii uzyskanej z mieszaniny osadów ściekowych z olejem opałowym przekraczają co najmniej dwukrotnie koszt energii otrzymywanej z pyłu węglowego. W chwili obecnej nie pozwala to polecić tego rozwiązania do realizacji. Dotyczy to jednak aspektów ekonomicznych.
- Z punktu widzenia ochrony środowiska przed odpadami, utylizacja osadów ściekowych winna być rozważona jako jedna z alternatywnych metod wykorzystywania i unieszkodliwiania tego rodzaju odpadów.