MIDDLE POMERANIAN SCIENTIFIC SOCIETY OF THE ENVIRONMENT PROTECTION

Rocznik Ochrona Środowiska

Volume 22. Year 2020 ISSN 1506-218X 680-692

Laboratory Research on the Possibility of Producing Fuels from Municipal Sewage Sludge, Rubber Waste and Biomass

Krzysztof Rećko
Czestochowa University of Technology, Poland
corresponding author's e-mail: krecko@is.pcz.czest.pl

1. Introduction

The intensive development of sewerage systems results in a rapid increase in the construction of municipal sewage treatment plants. Consequently, with the construction of new sewage treatment plants and the modernization and extension of existing ones, an upward trend can be expected in the generation of municipal sewage sludge that needs to be managed (Ministerstwo Środowiska 2018). According to the National Waste Management Plan (KPGO 2015), it is estimated that every year the amount of municipal sewage sludge per dry mass will increase by about 2.5%. In Poland, the management of municipal sewage sludge has been conducted for many years through:

- agricultural use (provided the sanitary conditions are met) (Siuta 2015),
- reclamation of industrial areas and waste landfills;
- development of sewage treatment plant areas and storage of sludge in these areas,
- production of compost,
- landfilling at municipal waste landfills,
- thermal transformation (Zabielska-Adamska 2015).

According to the Ministry of the Environment, the strategy for managing municipal sewage sludge for the years 2019-2022 provides for the management of municipal sewage sludge through:

- the use of municipal sewage sludge on the earth's surface,
- composting,
- the use in biogas plants,
- thermal transformation (Ministerstwo Środowiska 2018).

As can be seen from the strategy for managing municipal sewage sludge, it is impossible to store municipal sewage sludge in municipal landfills. This results from the Ordinance of the Minister of Economy (RMG 2015) of 16 July 2015 on the acceptance of waste for landfill (Journal of Laws 2015, item 1277), which prohibits the storage of untreated sewage sludge in municipal waste landfills. Currently, the municipal sewage sludge is commonly used in agriculture and nature (Obarska-Pempkowiak et al. 2015) due to the high content of organic matter and nutrients for plants such as nitrogen, phosphorus, and microelements (Ministerstwo Środowiska 2018). This form of municipal sewage sludge management can be applied if fertilisation with municipal sewage sludge does not pose a threat to the environment. According to the data of the National Waste Management Plan, the share of municipal sewage sludge management through its thermal transformation is expected to increase in the coming years (KPGO 2015). Currently, thermal processing of municipal sewage sludge represents the most prospective technology due to the search for alternative sources of energy such as municipal sewage sludge (Czechowska-Kosacka et al. 2015).

The use of thermal methods (incineration, co-incineration) to manage sewage sludge usually requires initial drying. Sewage sludge drying is performed in sludge dryers, including mechanical and solar dryers. The effective drying process in natural conditions requires large areas, whereas negative temperatures in winter can cause freezing of sewage sludge. Mechanical drying is expensive due to large amounts of energy required for the process. Processes of sewage sludge drying have an impact on the environment as they lead to the formation of odours and pose the risk of dust explosion and spontaneous combustion (Bień et al. 2016).

In recent years, there has been a dynamic development of the automotive industry in the world, which results in an increasing amount of used rubber waste (Duda 2017). The mass percentage of rubber elements with tyres in the structure of a passenger car is approximately 5-7% of the vehicle mass (Abramek & Uzdowski 2011). Used tires from the disassembly of end-of-life vehicles (ELVs) represent the largest source of rubber waste while the remaining part consists of all kinds of gaskets, seals, belts and rubber elements used to absorb energy (Rećko 2012). Currently, the global production of car tyres and rubber is more than 15 billion Mg (Sulman et al. 2016). It is estimated that around 13 to 17 million Mg of tire waste is generated every year (Czajczyńska et al. 2017). According to world data (Ambrosiewicz-Walacik & Danielewicz 2015), the global stocks of used tyres amount to approx. 29 million Mg. The report published by the International Organization of Motor Vehicle Manufacturers (Raport 2017) states that ca. 190,000 Mg of rubber waste in Poland is produced every year, including ca. 150,000 Mg of worn tyres. Used tyres, due to their quantity, composition and structure, are a noxious waste, while their material recycling is much more difficult and expensive than in the case of steel and glass (Rećko 2012). In Poland, environmental law prohibits the storage of used tyres in whole or in part (Ustawa o odpadach 2012). An alternative to managing used tyres is to use them as alternative fuels for energy generation in the cement industry due to their high calorific value.

The production of walnuts and hazelnuts is constantly increasing due to the growing demand in the food market. The increase in the production and consequently the consumption of these nuts results in increasing volumes of production waste in the form of shells. As waste from the food industry, walnut and hazelnut shells are classified as biomass, which, due to its low water and ash content, is a good waste material for fuel production (Bryś et al. 2017)

In Poland, the cement industry is a leading sector in European countries in terms of replacing hard coal with alternative (refuse-derived) fuels. According to the Association of Cement Producers (SPC 2020), the current rate of coal replacement by alternative fuels in the cement industry in Poland is ca. 70% and some plants are even approaching the level of 85-90%, which puts Poland in the group of countries such as Austria and Germany. The average for the entire European Union is 44% (SPC 2020). The cement industry uses mainly RDF fuel based on municipal waste, while the remaining alternative fuels used in cement plants include used tyres, rubber waste, waste from mineral processing, sewage sludge, and waste from power plants (Nowak & Szul 2016).

The possibility of using a mixture of sewage sludge with beech sawdust and sewage sludge with lignite was presented in the paper (Constantinescu et al. 2018), which describes the use of sewage sludge and biomass as an alternative fuel.

Other authors (Chalamoński & Syczak 2017) report the possibility of using a mixture of sewage sludge with the waste of wood, rapeseed and rye straw, pine bark and coal in various mass proportions as an alternative fuel.

It was also demonstrated (Dąbrowski & Dąbrowski 2016) that it is possible to co-fire sewage sludge as a mixture with rubber waste at specific mass ratios.

This study presents the results of laboratory tests of production of a secondary fuel from municipal sewage sludge, rubber waste from ELVs, and hazelnut and walnut shell waste at different mass ratios. These fuels were subjected to proximate and ultimate analysis in order to determine the basic qualitative properties determining their energy use in the cement industry.

2. Materials used in the study

Municipal sewage sludge, rubber waste and hazelnut and walnut shell waste were analysed in the study.

Municipal sewage sludge was collected from the Warta sewage treatment plant in Częstochowa, Poland, after dewatering on mechanical presses at various points. The sewage sludge is shown in Figure 1.

Fig. 1. Sewage sludge

Rubber waste came from end-of-life vehicles (ELVs) at a car tyre disassembly station. The used car tyres are a multi-material waste, therefore only the elements constituting the rubber layer were separated. Rubber waste is shown in Figure 2.

Fig. 2. Rubber waste

Hazelnut shell and walnut shell waste came from the segregation of own municipal waste. Hazelnut and walnut shell waste is shown in Figure 3.

Fig. 3. Hazelnut shell waste (a) and walnut shell waste (b)

3. Methodology

The research consisted in the determination of basic fuel parameters for municipal sewage sludge, rubber waste and hazelnut and walnut shell waste in terms of energy use in the cement industry. The tests were performed in accordance with the following standards:

- water content was determined using the dryer method: Part 3: water content in the general analytical sample according to PN-EN 15414-3:2011
- volatile matter content was evaluated according to PN-EN 15402:2011
- ash content was determined according to PN-EN-15403: 2011
- carbon and hydrogen contents were determined using the LECOTru Spec CHN/S automated analyser according to ISO 29541:2010
- sulphur content was determined using a LECOTru Spec CHN/S automatic analyser according to ISO 19579:2006
- chlorine content was evaluated according to PN-ISO 587:2000
- combustion heat was evaluated according to ISO 1928:2009.

4. Results

The initial stage of the research included the proximate (as received state) and ultimate (analytical state) analysis of materials used for testing, consisting in determining the parameters characterizing secondary fuels.

Table 1 presents the results of the proximate and ultimate analysis of municipal sewage sludge.

The sludge studied was characterized by a high water content of 80%. Such a hydration of sewage sludge has a negative effect on the efficiency of the combustion process, as it significantly reduces energy value. The volatile matter content of the tested sewage sludge was 59.75%, whereas ash content was 33.54%.

Table 1. Proximate and ultimate analysis of sewage sludge

Parameter	Unit	Sewage sludge from the Warta sewage treatment plant in Częstochowa, Poland
Water content W	%	80.22
Volatile matter content V	%	59.75
Ash content A	%	33.54
Carbon content C	%	30.50
Hydrogen content H	%	3.60
Sulphur content S	%	1.36
Chlorine content Cl	%	0.08
Calorific value Q_i	MJ/kg	0.89

Table 2 presents the results of the proximate and ultimate analysis of rubber waste.

Table 2. Proximate and ultimate analysis of rubber waste

Parameter	Unit	Rubber waste
Water content W	%	0.80
Volatile matter content V	%	70.61
Ash content A	%	22.80
Carbon content C	%	54.01
Hydrogen content H	%	4.73
Sulphur content S	%	1.49
Chlorine content Cl	%	0.21
Calorific value Q_i	MJ/kg	29.48

Rubber waste was characterized by a high calorific value of 29.48 MJ/kg, low water content of 0.80% and sulphur content of 1.49%.

The proximate and ultimate analysis of hazelnut and walnut shell waste is presented in Table 3.

Table 3. Proximate and ultimate analysis of hazelnut shell waste and walnut shell waste

Parameter	Unit	Hazelnut shells	Walnut shells
Water content W	%	8.26	7.86
Volatile matter content V	%	89.01	92.28
Ash content A	%	2.20	0.80
Carbon content C	%	45.55	44.08
Hydrogen content H	%	6.04	6.25
Sulphur content S	%	0.02	0.00
Chlorine content Cl	%	0.12	0.15
Calorific value Q_i	MJ/kg	17.58	17.59

Both hazelnut and walnut shells had low water content, which was on average 8%, ash content was on average 2.2% in hazelnut shells and 0.8% in walnut shells, volatile matter content was 90%, and the comparable calorific value was 17.6 MJ/kg.

Based on the examinations of the waste materials, an appropriate composition of fuel blends was prepared. Choosing the right proportions in the blend allows for obtaining a fuel with appropriate parameters. The composition of fuel blends is presented in Tables 4 and 5.

Table 4. Percentage of components in the OL fuel blend

Examination	Percentage of OL components		
	Sewage sludge [%]	Rubber waste [%]	Hazelnut shells [%]
I	50	25	25
II	40	20	40
III	30	30	40
IV	25	25	50

Table 5. Percentage of components in the OW fuel blend

Examination	Percentage of OW components		
	Sewage sludge [%]	Rubber waste [%]	Hazelnut shells [%]
I	50	25	25
II	40	20	40
III	30	30	40
IV	25	25	50

The preparation of the composition of mixtures consisted in thorough mixing of waste materials in variable proportions of municipal sewage sludge, rubber waste and hazelnut and walnut shells. Before mixing, rubber waste was fragmented to the size of rubber dust with size of 0-1 mm, as shown in Figure 4.

Fig. 4. Fragmented rubber waste

Similar to rubber waste, hazelnut and walnut shells were crushed on a jaw crusher and then ground in a laboratory vibration grinder to dust, as shown in Figure 5.

Fig. 5. Crashed and ground hazelnut shell waste (a) and walnut shell waste (b)

Compositions of blends presented in Tables 4 and 5 are marked as OL and OW fuels. These fuels differed in the percentage of individual components and the type of nutshells used in the study. The prepared waste mixtures were granulated in a granulator. The granulator was equipped with a conical tank to which the prepared fuel blend was supplied. The amount of the blend supplied to the granulation chamber could be adjusted by a feeder equipped with a flow rate scale. From the tank, the blend was supplied to the granulating chamber, where a pair of cylindrical rollers pressed the material into the cylindrical holes of the flat matrix. The fuel obtained in the form of granules with a diameter of 6 mm is shown in Figure 6.

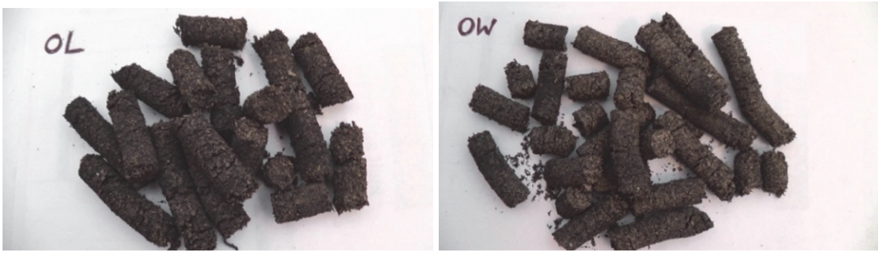

Fig. 6. OL and OW fuels in the form of granulates

The next stage of the research was to determine the basic parameters of fuels as-received state such as water content, volatile matter content, ash content, carbon content, hydrogen content, sulphur content, and calorific value. The results of tests I, II, III, IV are presented in Tables 6, 7, 8 and 9.

Table 6. Fuel parameters obtained in test I

Parameter	Unit	Fuel OL	Fuel OW
Water content W	%	39.94	39.01
Volatile matter content V	%	72.33	75.52
Ash content A	%	15.90	15.70
Carbon content C	%	31.43	30.61
Hydrogen content H	%	7.27	7.33
Sulphur content S	%	0.63	0.60
Calorific value Qi	MJ/kg	13.21	13.43

Table 7. Fuel parameters obtained in test II

Parameter	Unit	Fuel OL	Fuel OW
Water content W	%	30.44	30.82
Volatile matter content V	%	73.09	75.43
Ash content A	%	17.70	18.00
Carbon content C	%	36.98	36.01
Hydrogen content H	%	6.81	6.89
Sulphur content S	%	0.54	0.51
Calorific value Qi	MJ/kg	16.23	16.52

Table 8. Fuel parameters obtained in test III

Parameter	Unit	Fuel OL	Fuel OW
Water content W	%	23.28	22.58
Volatile matter content V	%	72.38	77.93
Ash content A	%	15.20	14.70
Carbon content C	%	41.74	39.99
Hydrogen content H	%	6.61	6.69
Sulphur content S	%	0.47	0.45
Calorific value Qi	MJ/kg	19.19	19.36

Table 9. Fuel parameters obtained in test IV

Parameter	Unit	Fuel OL	Fuel OW
Water content W	%	18.66	17.93
Volatile matter content V	%	72.20	76.25
Ash content A	%	16.80	16.30
Carbon content C	%	47.24	46.03
Hydrogen content H	%	6.69	6.71
Sulphur content S	%	0.39	0.36
Calorific value Qi	MJ/kg	21.44	21.51

Tables 6 to 9 present the results of tests of basic parameters of OL and OW fuels obtained in tests I to IV. In the case of OL and OW fuels, the results obtained in the test I did not indicate the possibility of obtaining a fuel with good parameters. Both the obtained calorific value of 13 MJ/kg, water content of above 39% and the sulphur content of 0.6% differed from the requirements for alternative fuels. Since 2017, the requirements for alternative fuels used in the cement industry have been as follows:

- water content ≤ 20%,
- ash content < 20%,
- sulphur content < 0.5%,
- chlorine content ≤ 0.8%,
- calorific value ≥ 21 MJ/kg (Hryb et al. 2017).

Subsequent tests allowed to obtain fuel with parameters meeting the requirements for alternative fuels intended for co-firing in cement furnaces. Test IV (Table 9) presents the results which clearly indicate that the obtained calorific value of OL and OW fuels at the level of ~21.5 MJ/kg, water content of ~18%, ash content of ~16% and sulphur content of 0.36-0.39% meet the requirements for alternative fuels.

5. Conclusions

The mixtures in the form of municipal sewage sludge, rubber waste and hazelnut and walnut shell waste examined in terms of fuel parameters are assessed as OL and OW fuels meeting the requirements set by cement plants for alternative fuels used in the co-firing process.

The results obtained in the study lead to the following conclusions:

- the fuels produced had water content of 17.9-18.6%,
- the ash content in fuels ranged from 16.30% to 16.80%,
- the sulphur content in the fuels tested did not exceed the value of 0.5% required by the cement plants,
- OL and OW fuels had a calorific value that exceeded the required 21 MJ/kg,
- the fuels obtained from municipal sewage sludge did not require an energy-intensive drying process.

The developed method of fuel production based on municipal sewage sludge meets the criteria for using the co-firing process in the cement industry. An additional advantage of this method is that it does not require the process of pre-drying of the municipal sewage sludge.

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Abstract

The paper presents the results of laboratory tests aimed to analyse the opportunities for fuel production based on municipal sewage sludge, rubber waste from end-of-life vehicles (ELVs) and hazelnut and walnut shells in terms of their thermal transformation in the process of co-firing in the cement industry. The parameters of solid fuels used in the cement industry were determined for the fuels obtained in the study. The following parameters were determined in fuels: water content, ash content, sulphur content, and calorific value.

The fuel composition and process of fuel preparation were designed so as not to use the energy-intensive process of pre-drying of municipal sewage sludge. However, it should be emphasized that the maximum percentage of municipal sewage sludge in fuel should not exceed 25% in order to maintain the parameters required by the cement industry. The analysis of the obtained parameters of OL and OW fuels demonstrated that the fuels obtained in the study meet the requirements for fuels used in the cement industry.

Keywords:
sewage sludge, rubber waste, hazelnut and walnut shell waste, alternative fuels

Badania laboratoryjne nad możliwością wytwarzania paliw z komunalnych osadów ściekowych, odpadów gumowych i biomasy

Streszczenie

W publikacji przedstawiono wyniki badań laboratoryjnych nad możliwością wytwarzania paliw na bazie komunalnych osadów ściekowych, odpadów gumowych pochodzących z pojazdów wycofanych z eksploatacji (PWE) i łupin orzechów laskowych oraz włoskich pod kątem ich termicznego przekształcania w procesie współspalania w przemyśle cementowym. Dla otrzymanych paliw wykonano oznaczenia parametrów charakteryzujących paliwa stałe stosowane w przemyśle cementowym. W paliwach oznaczono takie parametry jak: zawartość wilgoci, zawartość popiołu, zawartość siarki oraz wartość opałową.

Skład i proces przygotowania paliw został tak opracowany, aby nie stosować energochłonnego procesu podsuszania komunalnych osadów ściekowych. Należy jednak podkreślić, że maksymalny udział komunalnych osadów ściekowych w paliwie nie powinien przekraczać 25%, aby zostały zachowane parametry wymagane przez przemysł cementowy. Analiza otrzymanych wyników parametrów paliw OL i OW pozwalają zatem stwierdzić, że otrzymane paliwa spełniają wymagania stawiane paliwom stosowanym w przemyśle cementowym.

Słowa kluczowe:
osady ściekowe, odpady gumowe, odpady łupin orzechów laskowych i włoskich, paliwa alternatywne