Fuels from Waste in the Circular Economy as an Element of Multi-Sector Synergy

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The paper presents the current status of managing the combustible part of the waste (code 191210) as components for the production of alternative fuels. In 2017, about 2.3 million tons of fuels from waste were produced, while only about 1.3 million tons were recycled for energy, of which 97% in the cement industry. Oversupply on the alternative fuels market forces their producers to be more flexible in adapting their products to the growing requirements of customers. The article presents the results of tests of components for the production of alternative fuel used in the cement industry. An alternative fuel, not subjected to the comminution process, was used for the tests, which made it possible to segregate and name its individual fractions. A series of analyses were performed for the selected samples to determine their physicochemical parameters. The last element of the research was to create, based on the analyses and using the available components, fuel mixtures that meet the requirements for fuels of this type so that they meet the imposed standards, and at the same time are attractive for customers from the cement industry. The analysis of the obtained results made it possible to create optimum fuel mixtures with parameters that meet the requirements for this type of fuel. The mixtures obtained are a compromise between high-calorific products with a low chlorine content, the mass fraction of which was limited to such an extent that they could be used as a whole, and ingredients with an increased chlorine content, even a small amount of which exceeded the assumed content of this element.

Keywords: *alternative fuels, SRF, cement industry*

1. Introduction

Recycling of waste is one of the main objectives of circular economy, whose hypotheses are currently introduced in the European Union countries.[1] One of the possibilities of reusing the combustible part of waste is energy recycling. The production of alternative fuels is an opportunity to use this part of waste plastics for energy purposes, which is not recycled as a result of various factors. In Poland, every year, the process of reuse is subject to increasing amounts of waste classified as non-hazardous with the code 191210. The European Union has introduced uniform conditions for its member states for the classification of solid fuels from waste (under the name of Solid Recovered Fuels – SRF) and a research methodology for determining the quality of these fuels. [2,3] Standardizing this type of fuels will strengthen their presence on the market of energy carriers, as well as extend the scope of their current application in other energy-intensive industries. In Poland, the main recipients of alternative fuels are cement plants, which, due to the specificity of their production process, are particularly predisposed to use this type of fuel. On the other hand, in some EU countries, fuels produced from waste are increasingly more often used in industrial applications. The areas of application of waste fuels, apart from the cement industry, also include professional power engineering and heating, which seems to be justified both for economic and environmental reasons [4-9].

2. Production and use of alternative fuels in Poland

The production of alternative fuels, apart from material recycling, is one of the basic elements of the rational waste management system, in line with the assumptions of the circular economy. In Poland, the producers of this type of fuel are specialized companies processing the waste into high-energy fuels that meet additional quality requirements set by individual recipients. Another producer is the Regional Municipal Waste Processing Installations (Polish: RIPOK), mainly producing alternative fuels with lower quality parameters. Analysing the data contained in the reports regarding particular provinces, it can be noted that in 2015–2017 the amount of alternative fuels produced fluctuated slightly at the level of approx. 0.24 million Mg to reach the level of 2.36 million Mg in 2017. During this period, the number of systems for processing waste code with 19 12 10 ranged from 166 to 200. [10-11]

Table 1 presents the amounts of the produced and used alternative fuels in individual provinces, according to the data for 2017.

At that time, the energy use of alternative fuels ranged from 1.15 million Mg in 2015 to 1.32 million Mg in 2017, maintaining a slight upward trend. The data provided shows that the stream of produced alternative fuels is almost twice as high as the amount that is processed for energy production purposes. When analysing the data contained in Table 1, we can also notice a large dispersion both on the market of producers and recipients of alternative fuels. These factors increase competition on the alternative fuels market, and thus force their producers to be more flexible in adapting their products to the growing requirements of customers. Among the recipients of alternative fuels in Poland, the dominating one is the cement industry, which in 2017 processed 97% of the stream of all thermally transformed alternative fuels. The thermal energy recovered from combustion accounted for approx. 47% of the total energy used in the clinker combustion process. In the coming years, the cement industry is planning to increase the share of alternative fuels – the expected de-

Tab. 1. Amounts of produced and used alternative fuels in Poland

Tab. 1. Ilości wytwarzanych i wykorzystywanych paliw alternatywnych w Polsce

Voivodship	Number of generating installations	Quantity of alternative fuels produced	Quantity of alternative fuels used
	[pcs]	[Mg]	[Mg]
Silesian	28	384 736	51 764
Greater Poland	25	173 164	0
Masovia	22	643 156	38 658
Lublin	18	248 576	275 670
Lesser Poland	18	88 571	0
Kuyavia-Pomerania	13	209 880	161 937
Świętokrzyskie	8	94 298	461 228
Lodzkie	6	56 026	8 585
Opole	5	46 616	323 999
Subcarpathia	5	34 369	0
Warmia-Masuria	5	134 885	0
West Pomerania	5	145 640	1 942
Lower Silesia	3	73 828	0
Pomerania	3	14 121	0
Lubusz	2	15 137	0
Podlaskie	0	0	0

Tab. 2. Requirements set by cement plants for alternative fuel

Tab. 2. Wymagania stawiane przez cementownie dla paliwa alternatywnego

Parameter	Cement plant 1	Cement plant 2	Cement plant 3
Calorific value, MJ/kg	>20	≤18	18-22
Moisture content, %	<10 (10-15)	≥15	≥15
Ash content, %	<15 (15-20)	≤20	-
Sulphur content, %	≥0.5	≥0.5	≥0.5
Chlorine content, %	≥0.5	≥0.8	≥0.6
Granulation, mm	<40	<40	<25 (torch), 35 (cold end of the kiln)

mand is approx. 1.85 million Mg of fuel per annum. [12] The fuel used in the cement industry should be characterized primarily by a high calorific value, low chlorine and sulphur content, and homogeneous structure. This is important because it greatly influences the process, emissions and the final product. Controlling the combustion process itself and the quality of the fuel has a significant impact on obtaining clinker and cement that will meet the applicable standards. Apart from the physicochemical properties that are the basis for the use of alternative fuel, the fuel suitability is determined by such factors as granulation, not exceeding 30 mm and the absence of undesirable impurities. [13] Table 2 presents examples of the quality requirements for alternative fuels used in the cement industry.

3. Research methodology

The test was performed with the use of alternative fuel produced in accordance with the R12 recovery procedure. The research included a physical and chemical analysis as well as the content of chlorine in post-utilization materials with a polymer matrix. The analysis of the content of sulphur and elemental carbon was carried out with the use of the LECO SC 144 DR analyser. Combustion heat analysis was performed using the IKA C 2000 calorimeter. Qualitative analysis was performed with the Spectroscan V sequence spectrometer via synchronized rotation of the crystal around its axis and the detector in a circle, with continuous registration of the counter readings. A semi-quantitative analysis was also performed. The method allows to estimate the content of a given element with an error of up to 20%. In each spectral series (K, L or M) certain lines have dominant intensities and they have been chosen as the best indicators of the presence of a given element. The ash content analysis was performed according to the PN-EN 15403:2011 standard, and the moisture content according to the PN-EN 15414-3:2011 standard.

4. Research results

In order to produce a suitable reusable fuel, an analysis of the individual components had to be performed. An alternative fuel that has not yet been subjected to the comminution process was used for the tests, which made it possible to segregate and name its individual fractions. From the weight of 20 kg of the primary sample, 13 types of waste were selected, and the percentages of individual materials in the total weight of the sample were determined. Selected types of waste along with the assigned sample numbers are presented in Table 3.

The material for testing was prepared according to the applicable standards: for laboratory samples according to PN-EN 15443:2011, and for analytical samples according to PN-EN 15413: 2011. For the samples thus prepared, a series of analyses were performed to determine their physicochemical parameters, their results are presented in Table 4

The analysis of individual parameters shows a large discrepancy in the results for individual components included in the base sample. Due to the material diversity of which they were made and the form in which they appear (smooth elements, sponges, plastics), the waste groups obtained in the selection process are characterized by a large discrepancy in terms of moisture content. The highest humidity, from 20% to 30%, was characteristic for samples containing materials showing increased absorbency: synthetic fabrics (No. 4, No. 9), sponge (No. 7), artificial bristles (No. 8). On the other side of the scale, we have materials with closed structures that do not absorb water, mainly various types of rubber (No. 2, No. 5, No. 10, No. 11), for which the moisture content ranged from 1.3% to 2.9%.

Analysing the results of ash content in individual groups of selected waste, we see that in half of the cases this value does not exceed 15%. The exception here are four samples (No. 4, No. 7, No. 8, No. 9) also characterized by increased humidity, in which the ash content ranged from almost 38% to over 44%. Such an increased ash content seems to be related to the con-

Tab. 3. Results of analyzes of alternative fuels components

Tab. 3. Wyniki analiz komponentów paliw alternatywnych

Number	Name	Number	Name
1	conduit for carrying power cables	**8**	car seat covers
2	bicycle handles	**9**	synthetic fabrics 2
3	tires	**10**	rubber mounting elements
4	synthetic fabrics 1	**11**	pram tires
5	rubber covers for car pedals	**12**	plastic
6	rubber lagging	**13**	inner tubes , seals
7	sponge filling of car seats		

Tab. 4. Results of analyzes of alternative fuels components

Tab. 4. Wyniki analiz komponentów paliw alternatywnych

Name	Sulfur	Carbon	Moisture	Ash	Calorific value	Chlorine
	[%]	[%]	[%]	[%]	[kJ/kg]	[%]
1	0.160	14.42	11.3	20.5	26075	0.04
2	0.087	15.92	1.7	13.5	24033	5.30
3	0.328	21.86	8.1	13.0	33112	0.04
4	0.742	34.68	29.9	32.7	12695	0.01
5	0.488	37.84	2.9	9.7	33321	10.60
6	0.305	29.6	6.5	34.3	21862	> 0.04
7	0.053	26.69	29.9	18.0	19390	0.14
8	0.570	21.70	24.2	27.0	21800	0.00
9	0.035	33.42	20.3	32.7	13127	0.00
10	0.702	36.52	1.5	27.9	21432	1.68
11	0.032	23.89	1.3	4.3	41006	> 0.04
12	1.979	19.75	7.9	0.5	42663	> 0.04
13	0.116	20.64	7.7	14.5	23847	> 0.04

Tab. 5. Parameters of produced alternative fuels

Tab. 5. Parametry wytworzonych paliw alternatywnych

Name	Sulfur	Carbon	Moisture	Ash	Calorific value	Chlorine
	[%]	[%]	[%]	[%]	[kJ/kg]	[%]
Mix 1	0.57	33.00	6.70	13.90	27352	0.91
Mix 2	0.42	30.86	12.08	18.74	26091	0.82
Mix 3	0.49	28.21	9.41	16.59	26253	0.52
Mix 4	0.41	24.97	12.46	17.61	25632	0.03
Mix 5	0.43	31.99	18.38	20.12	25889	0.38

tamination of wet waste with mineral parts stuck to it, creating an additional undesirable ballast.

In the analysed groups of components, the calorific value ranged from approximately 13 MJ/kg for synthetic materials (No. 4 and No. 9) to over 42 MJ/kg for pram tires (No. 11) and plastics (No. 13). These discrepancies result from the variety of plastics from which the waste from individual selected groups is made. For four of them (No. 4, No. 7, No. 8, No. 9), the ballast contained in the samples also has a significant impact on the calorific value. In the increased form, the moisture content ranges from over 20% to almost 30% and the ash content significantly different from the other groups, ranging from about 28% to about 34%.

The last element of the research was to create fuel mixtures that meet the requirements for this type of fuel based on the analyses and the use of available components, so that they meet the imposed standards, and at the same time are attractive to customers from the cement industry.

It was assumed that such fuels should have the following parameters:

- calorific value above 25,000 kJ/kg
- chlorine content below 1.0%
- sulphur content below 0.5%
- ash content below 20%

The analysis of the results presented in Table 4 allowed for the selection of component blends so that the alternative fuels produced on their basis met the adopted assumptions. As a result of further work, 5 different fuel blends were produced from selected fractions, which, according to the assumptions, should meet the above-mentioned quality criteria. Samples were prepared from the prepared mixtures and then subjected to a set of analyses in the same scope as for individual components.

When analysing the results of the analyses of the fuel mixtures presented in Table 5 below, it can be observed that they meet the hypotheses adopted at the beginning of their formation. Only in the mixture 5 a slight excess of the assumed ash content was noted.

The mixtures are a compromise between high-calorific products with a low chlorine content, the mass fraction of which was limited to such an extent that they could be used as a whole, and ingredients with an increased chlorine content, even a small amount of which exceeded the assumed content of this element. For example, such a mixture should include a relatively small amount of rubber elements: tires, tubes, gaskets, which due to the high calorific value would be ideal for creating such fuels. Considerable amount of car recycling waste, such as synthetic fabrics, limited only by the increased ash content. And also very limited quantities of the following: car pedal covers or rubber installation elements containing large amounts of chlorine. Correctly composed mixtures of semi-finished products allow for the production of high-quality alternative fuel using the entire range of semi-finished products included in the primary sample

5. Conclusion

The changes taking place in the alternative fuels market in the recent years indicate that the phenomenon of oversupply will continue in the coming years. Such a situation on the market forces the producers to be more flexible in adapting their products to the growing requirements of customers. The presented research results allow to conclude that by optimizing the selection of components, it is possible to produce alternative fuels, the use of which seems to be justified both for economic and ecological reasons. For this purpose, it would be necessary to conduct research on individual components used in the production of alternative fuels and to monitor the received waste used for their production on an ongoing basis. This will allow for the production of high-quality alternative fuels with a guarantee of repeatability of parameters, which will translate into an increase in their competitiveness on the market of this type of fuel. And also, with appropriate legislative support, it may translate into the extension of their use as part of a fuel stream in the energy and heating sectors, simultaneously reducing the oversupply, minimizing pathologies related to their storage and being more fully in line with the assumptions of the circular economy.

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Optymalizacja parametrów paliw alternatywnych dla przemysłu cementowego

W pracy przedstawiono aktualny stan zagospodarowania palnej części odpadów o kodzie 191210 jako komponentów do produkcji paliw alternatywnych. W roku 2017 wyprodukowano około 2,3 mln tony paliw pochodzących z odpadów, natomiast odzyskowi energetycznemu poddano tylko około 1,3 miliona ton z czego 97% w przemyśle cementowym. Nadpodaż na rynku paliw alternatywnych wymusza na ich producentach większą elastyczność w dostosowaniu swoich produktów do rosnących wymagań odbiorców. W artykule przedstawiono wyniki badań komponentów do wytwarzania paliwa alternatywnego wykorzystywanego w przemyśle cementowym. Do badań zostało wykorzystane paliwo alternatywne nie poddane jeszcze procesowi rozdrabniania, co umożliwiło wysegregowanie i nazwanie poszczególnych frakcji wchodzących w jego skład. Dla tak przygotowanych próbek wykonano szereg analiz mających określić ich parametry fizykochemiczne. Ostatnim elementem badań było wytworzenie na bazie wykonanych analiz oraz przy wykorzystaniu dostępnych komponentów mieszanek paliwowych odpowiadających wymaganiom stawianym paliwom tego typu tak by spełniały narzucone normy, a jednocześnie były atrakcyjne dla odbiorców z przemysłu cementowego. Analiza otrzymanych wyników pozwoliła na stworzenie optymalnych mieszanek paliwowych, o parametrach spełniających wymagania stawiane tego typu paliwom. Otrzymane mieszanki są kompromisem pomiędzy wysoko kalorycznymi produktami o niskiej zawartości chloru, których udział masowy ograniczono do takiego stopnia by wykorzystać je w całości, a składnikami o podwyższonej zawartości chloru, których nawet nie wielka ilość powodowała przekroczenie założonej zawartości tego pierwiastka.

Słowa kluczowe: *paliwa alternatywne, SRF, przemysł cementowy*