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POSSIBILITIES OF USING POST-CONSUMER WOOD WASTE AS A FUEL IN A CEMENT PLANT

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Abstract
The energetic use of wood waste in cement plants, as well as in the commercial power industry and district heating can bring measurable economic and environmental benefits. The article presents an analysis of the possibility of using selected post-consumer wood waste as an alternative fuel. For this purpose, a series of tests were carried out to determine the physico-chemical properties of the waste. The tests confirm the usefulness of post-consumer wood waste in cement plants as a separate fuel or one of the alternative fuel components.

Keywords: **Post-consumer wood waste; Fuel; Cement plant; Technical analysis; Elementary analysis.**

1. INTRODUCTION

In Poland, in 2014, 11 million Mg of municipal waste were collected, of which an average of 268 kg of waste per one inhabitant. In Europe, this number is almost twice as large and amounts to 475 kg of waste. This does not mean, however, that these countries have more problems with the management of generated waste [1, 2]. Figure 1. shows how the management of municipal waste in the European Union countries is shaped.

It was noted that the countries with high levels of energy recovery also have a high level of municipal waste recycling. The presented data also show that in other EU countries waste storage prevails, and much less waste is directed to recycling or thermal transformation [3].

Hence, a number of executive acts have been introduced to improve, inter alia, the level of recycling or recovery, e.g. energy. Noteworthy is the Communication published last year by the European Commission, among others on the role of energy recovery from the waste in the circular economy (CE) [4]. The current waste management system, according to the Waste Act of 2012, should include energy recovery, which according to the waste hierarchy should only include waste that lost properties qualifying it for recycling and reuse, but have significant energy qualities allowing for using them in the production of both heat and electricity. Production and management of fuels generated from municipal and industrial waste is an important element of proper waste management development. On the domestic market, the main recipient of waste-based fuels is the cement industry so far, according to the regulations they carry out the recovery process with the use of energy- R1. However,

Figure 1.
Municipal waste management in the EU in 2016 [3]

the Communication indicates that in justified cases thermal recovery may prove more beneficial than material recycling, taking into account, inter alia, economic or environmental effects. It should be emphasized that both the Communication and the CE strategy focus on existing plants for energy recovery [4-7].

2. QUANTITATIVE RESOURCES OF ALTERNATIVE FUELS

In 2014, conventional fossil fuels represented a 59% share in the European cement industry, while alternative fuels from waste accounted for 41%. According to the literature, it has been estimated that this sector can on average replace up to 60% of traditional waste fuels. As shown in the data from 2014, the use of fuels from the waste in cement plants is at various levels in the European Union. The top are such countries as Germany, the Czech Republic for which the share of energy from alternative fuels replacing conventional fuels in cement plants is above 60%, for Belgium and Poland it is above 50%. In turn, the lowest is in Greece with a share of less than 10% [4, 8]. The share of substitution of conventional fuels with alternative fuels from the waste in the cement industry in 1990 to 2016 in the world, Europe and Poland are shown in Fig. 2 [4].

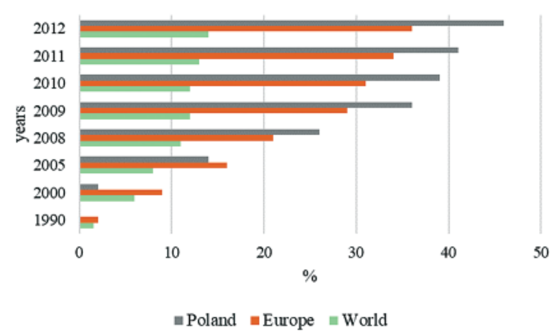

Figure 2.
The share of substitution of conventional fuels with alternative fuels from the waste in the cement industry [4]

Table 1.
Preferred parameters of an alternative fuel [9]

Parameter	Unit	Value
Moisture content	%	<20
Calorific value	MJ/kg	>15
Sulphur content	%	<1

Data from 2015 show that there are 13 cement plants in Poland. It should be mentioned that some of them obtain as much as 80% of the share of waste utilization in the total stream. The maximum use of waste contributes to reducing the need for additional investments related to the possibility of transforming waste into Energy [4, 6, 8]. In 2014, cement plants in Poland accepted 1372.9 thousand Mg of fuels from waste, including 1091 thousand Mg was RDF fuel (municipal waste fuel). According to estimates of the Association of Cement Producers, approximately 1.2

Table 2.
Exemplary requirements set by cement plants for alternative fuels [6]

Requirements	Unit	Cement plants status for 2008	Cement plants status for 2015	Cement plants status for 2017
Bulk density	[kg/m^3]	-	-	150-200
Moisture content	[%]mas.	≤15	≤18	≤20
Ash	[%]mas.	≤20	-	<20
The calorific value of the fuel going to the calciner	[MJ/kg]	≥18	≥18.5	≥16
The calorific value of the fuel going to the main burner	[MJ/kg]	≥21	≥21	≥21
Chlorine	[%]mas.	≤0.8	< 0.7	≤0.8
Sulfur	[%]mas.	≤0.5	< 0.5	<0.5
Mercury	[mg/kg$_{sm}$]	<5	< 2	<0.5
Metal content: Sb+As+Pb+				
Cr+Co+Cu+Mn+Ni+V	[mg/kg$_{sm}$]	<2500	<2500	<1000
Metal content: Cd+Th+Hg	[mg/kg$_{sm}$]	-	<10	-
Metal content: Cd + Tl	[mg/kg$_{sm}$]	< 50	-	<30

- no requirements

million Mg of RDF type fuel is currently being developed. That is why solutions are needed to increase the use of fuels from waste generated in the recovery process. New customers of fuels could be modernized or newly created power plants and combined heat and power plants [4, 8].

3. CHARACTERISTICS OF FUELS FROM WASTE

Waste used as an alternative fuel must meet the quality criteria set [6, 9, 12]. The quality parameters of alternative fuels have a direct impact on the firing process as well as the quality of the clinker produced in the rotary kiln.

The producer of fuel from waste is obliged to deliver to the cement plant a product that meets the requirements for alternative fuels by cement plants, and which have been determined by the Association of Cement Producers in 2008 – Table 1.

The requirements of individual cement plants regarding the quality of waste fuels are slightly different. They concern the following parameters: moisture content, calorific value, chlorine and sulfur content, heavy metals content including mercury. The appropriate division is also required, the fuel fed to the calciner should have up to 30 mm granulation and the fuel delivered to the main furnace burner below 25 mm [6]. Table 2 shows how the requirements posed by cement plants changed over the years. In turn, Table 3 presents the requirements for fuels from waste, among others due to the presence of heavy metals.

Table 3.
Requirements for the quality of the alternative fuel dosed to the calciner and the main burner in the selected cement plant [6]

Requirements	Unit	Cement plants status for 2017
Arsenic	ppm	< 10
Cadmium	ppm	< 20
Tal	ppm	<10
Antymony	ppm	< 50
Cobalt	ppm	< 50
Nickel	ppm	< 50
Fluoride	ppm	<100
Lead	ppm	< 250
Chromium	ppm	< 250
Copper	ppm	< 250
Manganese	ppm	< 250
Vanadium	ppm	< 250
Scrap content	%	up 0.5%

According to the literature [10, 11], the presence of potentially hazardous elements such as: As, Be, Co, Ni, Cd, Cu, Sn, in the environment not only influences the landscape but primarily affects organisms.

In PN-EN 15359:2012 "Solid recovered fuels – Technical requirements and classes" CEN (European Committee for Standardization) has concluded the SRF (solid recovered fuels) classification system,

Table 4.
Values of classification parameters for the solid derived fuels according to CEN [1, 12]

Classification Property	Designation	Unit	Classes				
			1	2	3	4	5
Net calorific value	NCV	MJ/kg ar	25	20	15	10	3
Chlorine	Cl	% d mean	0.2	0.6	1.0	1.5	3.0
Mercury	Hg	median mg/MJ ar	0.02	0.03	0.08	0.15	0.50
		80^{th} percentile mg/MJ ar	0.04	0.06	0.16	0.30	1.00

ar - as Received, d- Dry

which is based on three parameters to which five classes are assigned (Table 4). The introduction of uniform rules of classification and methodology for testing the quality of fuels from waste would allow obtaining a product with specific properties that can be used as an energy carrier not only in cement plants but also in the commercial power industry [1, 8].

The mentioned parameters (Tables 2–3) are important because they allow cement plants to comply with the emission standards contained in the Regulation of the Minister of the Environment of March 1, 2018 (Journal of Laws No. 2018 item 680) and criteria for conducting the process of thermal treatment of waste, which is regulated by the Regulation of the Minister of Development of January 1, 2016 (Journal of Laws of 2016, item 108) [13, 14].

The most commonly used types of alternative fuels include in particular: fragmented, segregated combustible fractions from municipal and industrial waste, whole and shredded tires, dried municipal sewage sludge, meat and bone meal, biomass, liquid waste (e.g. mixtures of used oils, solvents) Fig. 3 [15–17].

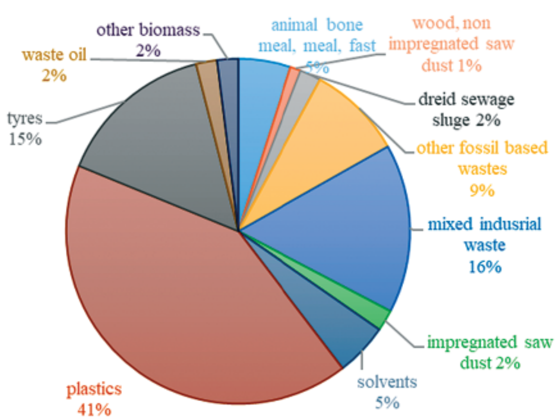

Figure 3.
The morphological composition of alternative fuels used in the cement industry, data from 2014 [17]

4. MATERIAL AND METHODOLOGY OF RESEARCH

One of the many fractions that can be directed to the cement plants are wood waste, both post-consumer and industrial waste. It should be noted that the wood waste sector shows two paths: recycling and energy recovery from biomass. At the moment, it is not clearly defined which direction is more favorable. Not all wood waste is recyclable, and in the incineration process and co-incineration with other fuels can be a source of alternative energy. An example may be an alternative fuel, so-called PAS-i (Impregnated Solid Fuel) resulting from the mixing of liquid and solid substances with increased absorptivity. These include sawdust, waste from the demolition of buildings, contaminated and impregnated wood waste such as wooden pallets or packages, as well as cellulose boards, fabrics and cleaning cloths [16, 18, 19].

The article presents the results of research on the properties of various groups of post-consumer wood waste in the context of their use as fuel in cement plants.

4.1. Research material

The research for use in the cement industry covered selected wood waste, including :

mixed floor panels based on HDF boards of various abrasion classes; waterproof panels based on wood-based panels and insulating material; soundproofing panels; bamboo floor made of natural exotic wood covered with varnish; a parquet block made of natural wood covered with varnish; a wooden window frame covered with many layers of varnish; door leaf based on MDF board; furniture based on chipboard; wall panelling made of natural wood covered with varnish; wooden roof truss covered with impregnation; wooden roof soffit covered with impregnation and varnish.

Table 5.
Physicochemical properties of selected post-consumer wood waste

Floor woodwork						
Parameter	Unit	Floor panels	Silencing panels	Waterproof panles	Natural bamboo floor	Parquet floor
Carbon	%	48.64	34.02	65.90	49.68	60.00
Hydrogen	%	4.18	1.51	3.10	4.99	4.41
Oxygen	%	28.05	46.54	21.59	36.85	27.36
Nitrogen	%	12.56	6.95	0.06	0.04	0.15
Sulphur	%	0.18	0.03	0.40	0.55	0.17
Chlorine	%	0.34	0.76	0.36	0.73	p.o.
Moisture content	%	5.08	3.55	3.11	5.97	7.90
Ash content	%	0.97	6.64	5.48	1.49	0.10
Valatile parts	%	75.02	66.63	87.28	72.81	69.70
Heat of combustion	MJ/kg	19.10	18.61	27.76	16.46	20.23
Calorific value	MJ/kg	18.04	18.18	26.90	15.18	19.16
Joinery and other						
Parameter	Unit	Window woodwork	Door leaf	Mixer and furniture plate	Wall paneling	Roof soffit
Carbon	%	48.31	47.96	47.00	50.76	23.68
Hydrogen	%	4.30	3.95	3.19	5.86	3.74
Oxygen	%	34.79	31.60	36.07	37.62	14.31
Nitrogen	%	0.81	8.98	3.19	0.03	1.20
Sulphur	%	0.63	0.26	0.50	0.39	0.45
Chlorine	%	p.o.	0.21	0.79	0.21	p.o.
Moisture content	%	7.33	6.36	8.55	4.94	10.99
Ash content	%	3.83	0.71	0.71	0.19	45.63
Valatile parts	%	76.08	74.25	73.00	80.68	46.90
Heat of combustion	MJ/kg	20.19	15.25	20.31	19.30	10.20
Calorific value	MJ/kg	19.04	14.20	19.37	17.86	9.11

p.o. – below the limit of quantification

4.2. Methodology of research

The paper presents an analysis of the physicochemical properties. The aim of the analysis was to determine specific fuel properties, such as moisture, ash content, the content of volatile components, flash-point, calorific value and elemental composition (C, H, O, N, S, Cl).

The waste was obtained as a result of renovations of residential buildings. The tests were carried out with the standards in force (PN-ISO 579:2002, PN-EN 15403:2011, PN-G-04516:1998, PN-ISO 1928:2002, PN-G-04523:1992, PN-ISO 334:1997, PN-EN-15407:11, PN-ISO 587:2000) [20–27]. The analyzes were carried out with a minimum of three replicates.

5. RESEARCH RESULTS

Table 5. presents physicochemical properties of the analysed waste.

Of all tested wood waste, four have a calorific value above 18.5 MJ/kg. The highest calorific value was noted for water-resistant panels at the level of 26.90 MJ/kg, which is affected by the addition of plastics, while the lowest calorific value of 9.11 MJ/kg has a roof soffit waste. Such a low value is caused by non-flammable additives. Waste is characterized by low moisture content below 11% and low ash content below 7%, except for roof soffit waste with an ash content of 45.63%. The content of volatile parts is at a high level, ranging from 66.63% to 87.28% (roof soffit – 46.90%).

When comparing the elemental composition of the investigated waste, attention should be paid to the

Table 6.
Metals content in selected wood wastes

Value	Unit	Floor panels	Door leaf
Arsenic	ppm	0.05	0.03
Cadmium	ppm	0.15	0.17
Tal	ppm	-	-
Antimony	ppm	-	-
Cobalt	ppm	1.40	0.67
Nickel	ppm	0.62	0.79
Lead	ppm	1.07	0.61
Chrome	ppm	1.74	1.53
Copper	ppm	2.24	2.84
Manganese	ppm	88.92	97.45
Vanadium	ppm	-	-
Mercury	ppm	<0.1	<0.1

- no data

excessive nitrogen content for wood waste of the HDF and MDF types, this value ranges from 6.95% to 12.56%. Such high nitrogen content is influenced by additives used in the form of urea-formaldehyde, melanin-formaldehyde and phenol-formaldehyde resins. In addition, low sulfur content was found in the waste, the lowest value has a waste of silencing panels at the level of 0.03%, and the highest – waste of window joinery on the order of 0.63%. Of which only two waste exceeded 0.50% of the sulfur content, the requirements posed by cement plants. All waste tested has a chlorine content below 0.8%, thus meeting the cement plant requirement for the above parameter.

6. CONCLUSIONS

The research shows that waste from post-consumer wood constitutes a wide range of waste characterized by various forms, granulation and homogenization. They are often contaminated with hazardous substances due to the specificity of their function as a consumer product. Therefore, it should be taken into account how important, from the point of proper management method, appropriate sorting of this waste is. Waste less polluted can be used in recycling. And those that are unsuitable for this process can be used as an alternative fuel.

Referring to the results of research on the usefulness of post-consumer wood waste for cement plants, it can be stated that the examined waste in most of the considered parameters meet the requirements set by cement plants.

They can be successfully one of the components of RDF type fuel or alternative fuels like PAS-i or PAS-r. In the case of PAS-impregnated fuels, wood waste is used as a material with higher absorption, which is mixed with liquid waste. And in the case of PAS-r fuels, wood waste is one of many fuel components.

The use of wood waste as a fuel brings many economic and environmental benefits. These include: a lower heat price, increased production of electricity from renewable sources, an increase in the level of waste recovery, a lower price of fuels from waste compared to conventional fuels, fuels from waste are an alternative to depleting conventional fuel resources.

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