TESTS OF PHYSICOCHEMICAL PROPERTIES OF FUEL AND BALLAST FRACTIONS FROM WASTE PROCESSING INSTALLATIONS

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Abstract
Economic development of a country as well as growing consumption causes a rise in the amount of wastes, mainly municipal wastes. Basic sources of the municipal wastes are households and public buildings. When Poland joined European Union, it was necessary to introduce many changes related to the waste management. Gradually implemented actions aim at limiting the amounts of municipal wastes deposited in landfills and reducing biodegradable fraction of wastes. Production of fuel from the municipal waste fraction constitutes an important element of modern waste management system. Moreover, it becomes an alternative to exhaustible resources of fossil fuels and a valuable source of energy to be used in industry, e.g. in cement industry.
The article presents characteristics of a selected production plant of alternative fuel, which operates in the area of Silesian Voivodship. The purpose of the test was to analyse the quality of the readymade alternative fuel and ballast fraction formed in the device. Achieved test results were applied to the valid legal regulations in the context of the best possible waste management.

Streszczenie
Rozwój gospodarczy kraju i wzrastająca konsumpcja powoduje wzrost ilości odpadów, głównie pochodzenia komunalnego. Podstawowymi źródłami powstawania odpadów komunalnych są przede wszystkim gospodarstwa domowe oraz obiekty infrastruktury publicznej. Przystąpienie Polski do Unii Europejskiej spowodowało konieczność wprowadzenia wielu zmian związanych z gospodarką odpadami. Wprowadzane sukcesywnie działania mają na celu ograniczenie ilości deponowanych odpadów komunalnych oraz zmniejszenie udziału w nich frakcji biodegradowalnej. Wytwarzanie paliwa z frakcji komunalnej stanowi ważny element nowoczesnego systemu gospodarki odpadami. Dodatkowo jest alternatywą dla wyczerpywalnych zasobów paliw kopalnych i cennym źródłem energii dla przemysłu np. cementowniczego.
W artykule scharakteryzowano wybraną instalację do produkcji paliwa alternatywnego działającą na terenie woj. Śląskiego (Polska). Celem badań była analiza jakości gotowego paliwa alternatywnego oraz frakcji balastowej powstającej na instalacji. Otrzymane wyniki badań odniesiono do obowiązujących przepisów prawnych w kontekście możliwości optymalnego ich zagospodarowania.

Keywords: **Municipal solid waste; Fuels; Ballast; Waste management; Technical analysis: Elementary analysis.**

1. INTRODUCTION

For many years Poland has been facing a problem with the stream of municipal wastes. The stream of the collected municipal wastes depends, among others, on the geographic location, climate, society's wealth, density of population, habits, urbanization of the area, etc. [1] The amount of the municipal wastes created in Poland in 2014 decreased about 9% in relation to 2013 and equalled 10.28 million Mg. However, 10.33million Mg of municipal wastes were collected which is an increase of about 8.3% in relation to 2013 (Fig. 1). At the moment, an average of 268 kg of municipal wastes is collected for one inhabitant of Poland [2]. For comparison – an average amount of municipal waste per one inhabitant of European Union in 2013 was 481 kg [3].

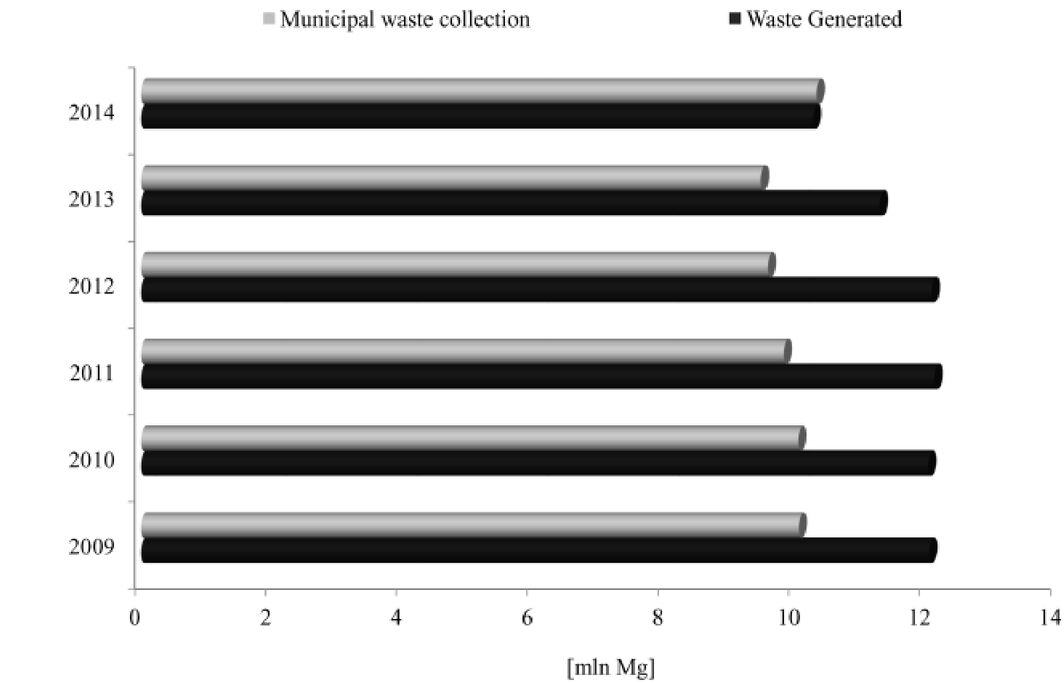

Figure 1.
The amount of generated and collected wastes in Poland [2, 3]

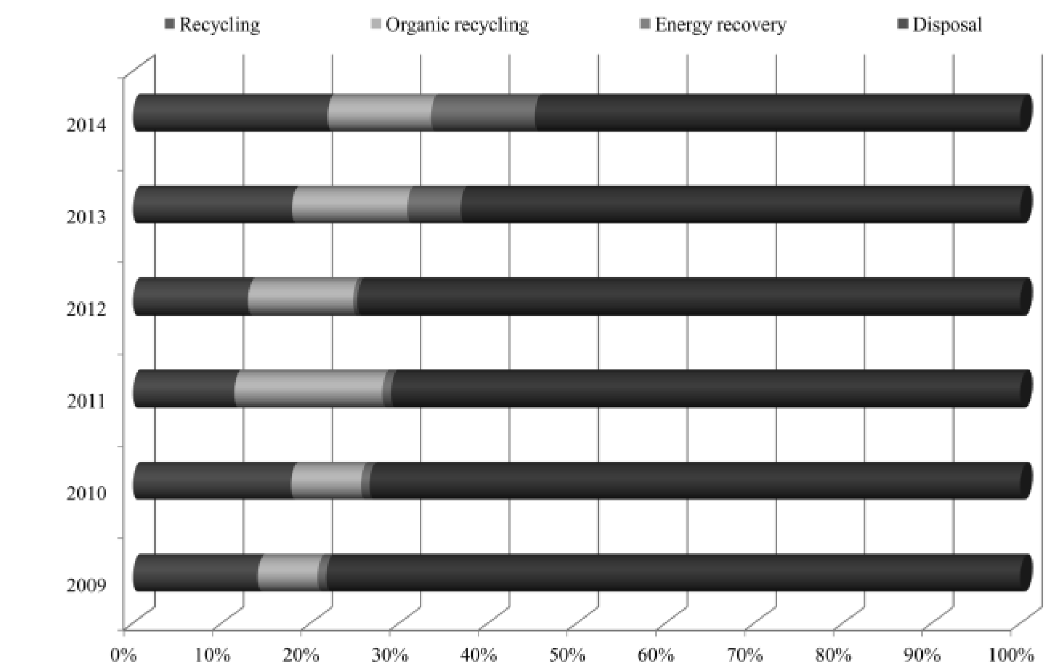

Figure 2.
Directions of municipal wastes management in Poland [2, 3]

Between 2010–2013 the amount of collected wastes noticeably dropped. On the one hand this could have been related to the decreasing number of inhabitants in the country or improper management of the municipal wastes. On the other hand it might be contributed to the consciously undertaken actions to prevent from the generation of wastes and to the wide ecological education [2, 3].

By virtue to the Act dated 2012 on wastes (Journal of Laws item 21) priorities in waste management were determined. The greatest emphasis is put on prevention and minimisation of the production of wastes. Otherwise, collected municipal wastes need to be recycled or submitted for recovery of, for example, energy [4-7]. In Poland, in 2014 still the basic way of municipal waste treatment was depositing them in landfills (approximately 53%) (Fig. 2). Main Statistic Office informs that 5.3 mln Mg of total amount of wastes was disposed of. 21% of wastes (2.2 Mln Mg) was recycled and 15% was submitted for recovery of energy. 11% of collected municipal wastes was directed for biological processing [2].

The most important legal act concerning waste management which forces search for new solutions of the waste management is an Order [8], which in consequence by 1 January 2016 forbids storage of wastes of parameters specified in Table 1.

Table 1.
Criteria for allowing waste to be stored in landfills of wastes other than hazardous [8]

Parameters	Unit	The limit values
Total organic carbon (TOC)	% d mean	5
Loss On Ignition (LOI)	% d mean	8
Gross Calorific Value (GCV)	MJ/kg d mean	max 6

d means – dry

The idea of energetic use of combustible fraction of municipal waste is beneficial as on the one hand it contributes to the decrease of their amount in the landfills and on the other hand it constitutes an alternative for decreasing resources of conventional fuels [5, 6, 7, 9, 10].

Directions of municipal wastes management in Poland [2, 3]

2. ALTERNATIVE FUELS

In Poland alternative fuels produced from wastes are formally and legally treated as wastes of code 19 12 10 [11]. At the moment there is no clear definition of alternative fuel. It is considered as separated and processed wastes which have certain calorific value and which can replace conventional fuels [12, 13].

Modern installations which produce fuels from wastes other than hazardous and neutral become an alternative for MSW (municipal solid wastes) accumulation of which brings about social protest. Installations for processing of wastes into fuels are a good way of management and reuse of the stream of municipal wastes.

For the production of alternative fuel used in the process of energetic recovery in cement industry municipal wastes may be applied together with fractions selectively collected – group 20.

At the moment the main recipients of alternative fuel in Poland are large plants of the cement industry. Every year a percentage of the use of alternative fuel, which is a replacement for the fossil fuel gradually, increases. One may say that the technology that takes advantage of alternative fuel in cement plant is a "no waste" technology as solid combustion products (e.g. ashes, gravel) are used in cement clinker [12-14].

Alternative fuels for cement plants produced from mixed municipal waste need to meet proper quality standards in order to guarantee compliance with the environment protection requirements and assure safety of the process [12, 15, 16].

Introduction of uniform regulations for the classification and methodology for quality tests of fuel made from the wastes will guarantee that the products received have certain determined properties and can be used as an energy carrier not only in cement plants but also in professional energy industry. Classification proposed by CEN is based on three parameters: calorific value, chlorine content and mercury content. Selected parameters will allow evaluation of given fuel in the light of economy, technology and environment (Table 2) [17, 18].

Table 2.
Values of classification parameters for the solid derived fuels according to CEN [17, 18]

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
		80th percentile mg/MJ ar	≤ 0.04	≤ 0.06	≤ 0.16	≤ 0.30	≤ 1.00

ar – as received, d – dry

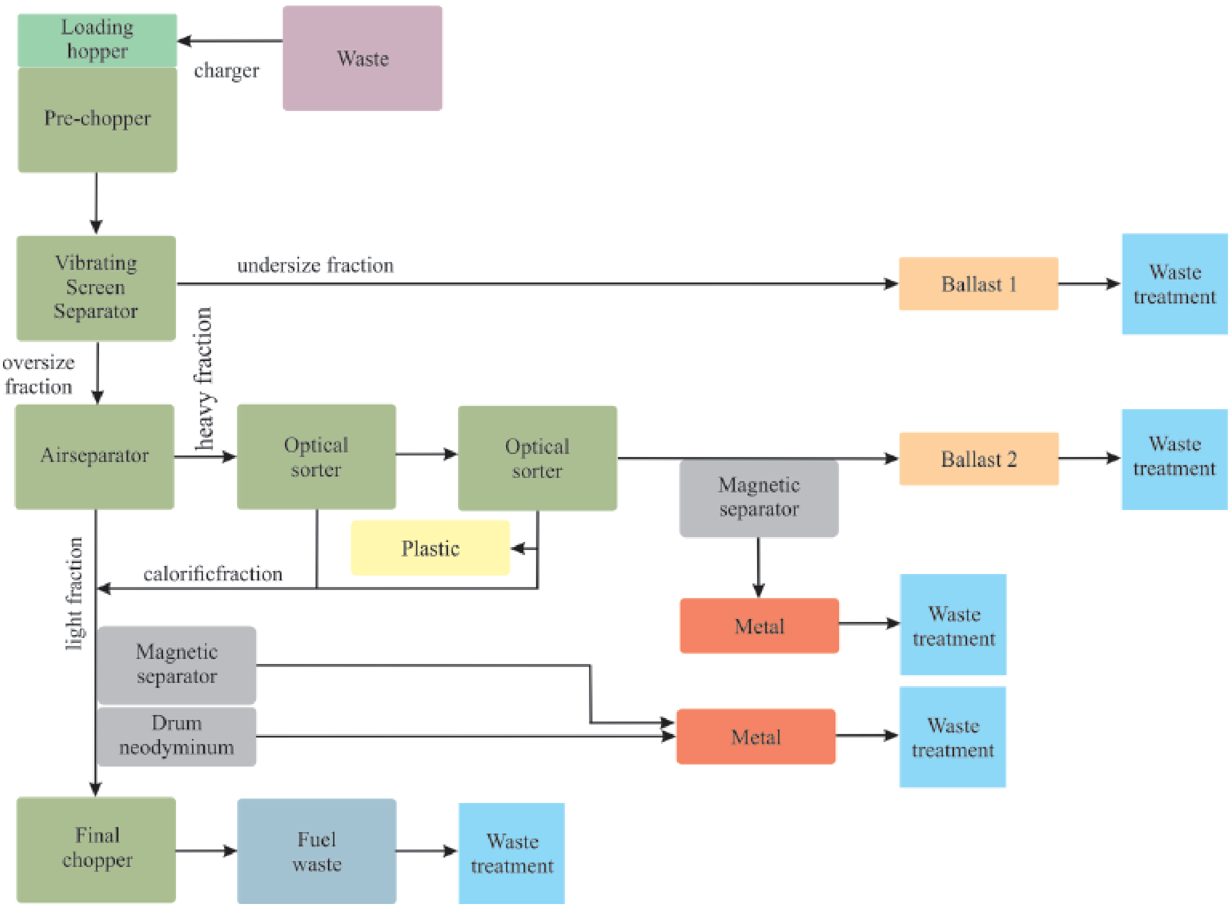

Figure 3.
Block diagram of the installation for the production of alternative fuels (prepared by M. Czop on the basis of [19])

Production potential and use of solid alternative fuels in Europe is growing. Production of solid alternative fuels from the wastes should be a basic element of modern integrated system of waste management. New system for classification and quality of alternative fuel will allow to eliminate any environmental threats [15, 16].

3. CHARACTERISTICS OF THE INSTALLATION FOR THE PRODUCTION OF ALTERNATIVE FUELS

In the Alternative Fuels Production Installations, about 40 thousands Mg of highly calorific alternative fuel and 60 thousand Mg of ballast fraction is produced every year from 140 thousands Mg of municipal waste. To the Alternative Fuels Production Installation mainly wastes from households in a few Silesian cities are directed (in Poland). The plant has a modular structure, i.e. the production capacity can be increased any time by adding new elements. At the moment production technology of alternative fuels in the described plant consists on mechanical segregation of municipal wastes in order to identify metal and highly calorific wastes (Fig. 3) [19].

From the highly calorific wastes, alternative fuel is produced by crushing it in the choppers. The remaining wastes are directed to containers and once appropriate amount is collected they are directed for further processing. Wastes are transported to the plant with road transport. After admission and weighing the wastes are directed to storage boxes. Municipal wastes from the selective collection are directly introduced with loader to loading hopper of the pre-chopper. Chopper has to crush larger wastes and open packaging (ex. bags). The purpose of this process is to identify those wastes that will be processed at the next stage and eliminate the wastes which might destroy the production line. Preliminarily crushed wastes are directed with the conveyor belt to the vibrating screen separator. Undersize fraction is transferred through conveyor belts system to the con-

Figure 4.
Tested wastes formed in the installation a) Alternative fuels, b) Ballast 1 (fine), c) Ballast 2 (thick) (performed by M. Czop)

tainers with ballast. Oversize fraction is delivered with the conveyor belt to the air separator. Separated light fraction is transferred with conveyor system through metal separator and neodymium drum to the final chopper. Separated metals are brought to containers [19].

Waste from the final chopper in the form of alternative fuel is transported with the conveyor belt to the readymade alternative fuel hall. Heavy fraction, following air crushing is transported with other conveyors to other separators. They have to separate calorific elements from this fraction, e.g. plastics, wood, cartoon, etc. [19].

Elements separated in such a way are sent directly to conveyor belt that is transporting wastes to final chopper, where the waste in the form of alternative fuel is obtained. Other unseparated wastes are transported with the conveyor belt to metal separators. Separated metals are stored in different containers. After separation of metals, wastes are directed to the conveyor belts and to containers as ballast [19].

4. MATERIALS AND TEST METHODS

4.1. Characteristics of tested wastes

The following materials were included in the tests for the analysis of possibilities of their use:

- Alternative fuels, come from highly calorific fractions of wastes (Fig. 4a).
- Ballast 1(fine) – so called undersize fraction comes from preliminary crushing, separated in the vibrating screen (Fig. 4b).
- Ballast 2 (thick) – so called oversize fraction, separated in optical sorters (Fig. 4c).

4.2. Determination of physicochemical properties

The purpose of the test was to determine the basic quality parameters of the readymade alternative fuel with regards to the requirements of cement industry. Ballast fraction sampled directly from containers was tested for its further use. Scope of tests covered the following markings: Total moisture content (M_t), combustible and volatile matter (V), ash content (A), heat of combustion (GCV), net calorific value (NCV), elemental composition (C, H, S, N, Cl, O) and loss on ignition (LOI) and organic carbon (TOC). All the tests were carried out in accordance with the standards presented in Table 3.

Table 3.
Standards

Fuel properties	Unit	Symbol	Standard
Determination of moisture content.	%	M_T	PN-Z-15008-02:1993
Determining combustion heat and calculating calorific value.	MJ/kg	GCV, NCV	PN-Z-15008-04:1993
Determination of ash content.	%	A	PN-EN 15403:2011
Determination of volatile matter by weighting.	%	V_l	PN-EN 15402:2011
Determination of carbon and hydrogen.		C, H	PN-Z-15008-05:1993
Determination of nitrogen with Kjeldahl method.	%	N	PN-G-04523:1992
Determination of sulfur with Eschka method.	%	S	PN-ISO 334:1997
Determination of chloride using Eschka mixture.	%	Cl	PN-ISO 587:2000
Determination of pH, content of organic substance, organic carbon, nitrogen, phosphorus and potassium	%	TOC	PN-Z15011-3:2001
Determination of loss on ignition in waste, sludge and sediments.	%	LOI	PN-EN 15169 :2011
Determination of bulk density.	kg/m^3	d_n	PN-EN 15103:2010

Table 4.
Technical analysis of readymade alternative fuel [author: M. Czop]

Parameters	Unit	Fuel	Coal references	Requirements cement plant 19 12 10
Total moisture content	%	22.47	19.26	<20
Moisture Air Dried	%	3.04	3.80	unlimited
Bulk density	kg/m^3	27.50	*	unlimited
Combustible substances, Air Dried	%	92.44	77.00	unlimited
Ash, Air Dried	%	7.56	16.50	unlimited
Combustible substances, As Received	%	71.67	65.07	unlimited
Ash, As Received	%	5.86	15.66	<20
Volatile matter, Air Dried	%	79.06	29.23	unlimited
Gross Calorific Value, Air Dried	MJ/kg	23.66	24.03	unlimited
Net Calorific Value, Air Dried	MJ/kg	22.62	23.06	unlimited
Gross Calorific Value, As Received	MJ/kg	18.29	20.30	>20
Net Calorific Value, As Received	MJ/kg	16.97	19.11	unlimited
Mercury	mg/kg	<0.4	*	2
	mg/MJ	<0.024	*	

* no data

5. RESULTS AND DISCUSSION

The quality of alternative fuel needs the necessity to respect environment protection standards and provide appropriate conditions for thermal process. However, in cement industry, which is the major recipient of these fuels, it is important that the combustion product (ash) which forms part of the clinker does not have a negative impact on its quality.

In the tested alternative fuel, produced at the discussed here installations, participation of the packaging wastes reaches approximately 41%. In the packaging group plastics and paper are the main fractions (58% and 25% respectively). Multi-material wastes form 11% of the total. Participation of wastes other than packaging is approximately 59%. Dominant fractions in fuels are plastics – approx. 35%, paper – 24%, textiles – approx. 16% and organic wastes – approx. 8%.

Test results of energetic properties of alternative fuel are presented in Table 4. Moisture content is an important indicator of fuel quality. In cement plant it is a parameter that influences the price of the fuel. Therefore, measurement of moisture content is important from the practical point of view and constitutes one of the most important indexes for the technological evaluation of the fuel. Moisture content in tested fuel is 3% higher than in hard coal and reaches 22.5%. Content of volatile matter in working state is comparable to the values for the hard coal.

Table 5.
Elemental analysis, Air Dried [author: M. Czop]

Parameters	Unit	Fuel		Coal References		Requirements cement plant 19 12 10
		As Received	Air Dried	As Received	Air Dried	
Carbon (C)	%	34.63	43.29	52.10	61.65	unlimited
Hydrogen (H)	%	3.42	4.27	3.42	4.05	unlimited
Sulphur (S)	%	0.47	0.59	1.23	1.44	< 1.0
Nitrogen (N)	%	0.88	1.10	0.48	0.57	unlimited
Chlorine (Cl)	%	0.41	0.51	*	*	≤ 0.7
Oxygen (O)	%	31.86	39.64	7.85	11.99	unlimited

* no data

But ash content reaches 6% while for hard coal this value is 16%. Content of volatile matter in fuels from wastes is 79%, and is more than twice as high as this value in hard coal. Calorific value of the referenced hard coal in operational state equals approximately 19 MJ/kg while for tested fuel it equals 17 MJ/kg.

Mercury is a metal that can be emitted in gas state therefore, its amount in fuels needs to be particularly controlled. Mercury content in analysed fuel was <0.4 mg/kg, which means that it meets the cement industry requirements which allow the mercury content up to 2 mg/kg.

Table 5 presents results of elemental analysis of the combustible substance of the alternative fuel, i.e. average gram amounts of particular elements with reference to the working state and to analytical state. Chlorine content in dried state equals 0.51%, and is smaller than the permissible value which is 0.75%. Sulphur content, which is approximately 0.59%, is half smaller thn the permissible value in the cement plant. On the basis of the guidelines (Table 1) of European Committee for Standardization (CEN) the tested alternative fuel is of class 322.

Table 6 presents test results of tests of ballasts defined as remains from the production of alternative fuel. Marked parameters of TOC, LOI and heat of combustion limit a possibility to deposit ballast in landfills.

The wastes have high calorific value of approximately 10 MJ/kg and so theoretically their autothermic combustion would be possible. Ballast fraction may be directed to Municipal Solid Waste Incineration (MSW). Due to high content of organic coal (>25%) they should undergo process of stabilization e.g.

Table 6.
Technical analysis of the ballast generated in the device [authors' data]

Parameters	Unit	Ballast 1	Ballast 2
Total moisture content	%	11.60	11.23
Moisture Air Dried	%	1.70	4.20
Combustible substances, Air Dried	%	77.84	94.53
Ash, Air Dried	%	20.46	1.27
Combustible substances, As Received	%	69.98	87.50
Ash, As Received	%	18.39	1.18
Gross Calorific Value, Air Dried	MJ/kg	15.80	10.97
Net Calorific Value, Air Dried	MJ/kg	13.98	10.17
Gross Calorific Value, As Received	MJ/kg	13.97	9.74
Net Calorific Value, As Received	MJ/kg	12.09	8.78
Degradable organic substances	%	62.20	68.29
Total organic carbon	% d mean	29.20	32.10
Loss On Ignition	% d mean	78.10	82.50
Mercury	mg/kg	<0.40	<0.40

Table 7.
Elemental analysis ballast, Air Dried [authors' M. Czop]

Parameters	Unit	Ballast 1		Ballast 2	
		As Received	Air Dried	As Received	Air Dried
Carbon (C)	%	32.73	36.40	37.97	40.98
Hydrogen (H)	%	7.10	7.90	2.79	3.10
Sulphur (S)	%	0.09	0.10	0.44	0.49
Nitrogen (N)	%	1.26	1.40	2.18	2.42
Chlorine (Cl)	%	1.08	1.20	0.38	0.42
Oxygen (O)	%	27.73	30.84	42.37	47.12

In the elemental composition of the tested fraction, the content of carbon of > 35% draws special attention (Table 7). Tested ballast fraction has low sulphur content. Both samples contained relatively large amounts of nitrogen, which may cause significant emissions of nitrogen oxides during thermal recovery with the use of these wastes. Chloride content in ballast 2 was low and in ballast 1 chloride content was >1%, and may be presumed that the thermal processing can result in excessive emission of chloride compounds including dioxins and furans.

6. CONCLUSION

Combustible fraction selected from the municipal wastes constitutes a precious source of electrical or heat energy. Development of technologies for the production of alternative fuels and higher ecological awareness of the society allow to produce high quality fuels that may be co-combusted in the existing production systems.

Conducted tests of alternative fuels confirmed their good quality. Average parameters of the produced fuel are as follows:

- Average moisture content of alternative fuels is 22.47%, while permissible value determined by cement plants is < 25%,
- Ash content is 7.56% (according to the requirements of cement plant it should be < 20%),
- Average calorific value is approximately 17 MJ/kg,
- Sulphur content around 0.59%, falls within the limits of cement plant that requires < 1%,
- Average chlorine content is 0.51%, when value acceptable by cement plant is 0.7%).

Physicochemical tests of fine and thick ballast as remains from the production of fuel showed as follows:

- Total moisture content equals 11%,
- Organic coal content is approximately 30%,
- Volatile matter content is >70%,
- Average calorific value is around 10 MJ/kg.

Co-combustion of alternative fuels in the existing devices brings significant economic and ecological advantages through:

- Decrease of the use of conventional fuels of limited resources,
- Significant limiting of the amount of municipal wastes deposited in landfills, and increase of recovery level,
- Increase profits of the plant due to lower price of fuels from wastes when compared to fossil fuels,
- Decrease in emission of CO_2 (saving limits of CO_2 emission imposed on each production branch).

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