

## Features of Refuse Derived Fuel in Poland – Physicochemical Properties and Availability of Refuse Derived Fuel

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### ABSTRACT

Refuse Derived Fuels are used as energy carrier mainly in cement plants; however, more and more often they are applied in power plants as a substitute for fossil fuels. In order to prepare a proper waste-to-energy investment, the availability of the fuel, as well as fuel properties should be determined. The article presented the amounts of generated RDF in Poland, number installation which produced RDF in 2019 and 2020 and amounts of incinerated RDF in cement and incineration plants. The amount of generated RDF is rather constant – about 2.5 million Mg/year. RDF is mainly incinerated in cement plants – about 1.5 million Mg/year. The article also presented general physicochemical analysis of several RDF samples and coal. Some of the RDF samples reached high energy parameters – low heating value up to 25 MJ/kg; however, the properties vary a lot, due to their heterogeneous character, technological process of their production and other factors. In practice, the requested parameters and amount of RDF are established and the RDF producer prepares and delivers the fuel according to the concluded contract.

**Keywords:** waste management, waste incineration, waste to energy, refuse derived fuel.

### INTRODUCTION

Refuse Derived Fuels (RDF) are non-hazardous wastes labeled with the code 191210 [Regulation of the Minister of Climate, 2020]. They can be produced from different raw materials – municipal, industrial or mixed waste. The RDF quality, quantity and composition strongly depend of the waste substrate [Wilén et al., 2004]. Refuse Derived Fuels are often composed of paper and cardboard, plastics and textile [Zhao et al., 2016; Akdag et al., 2016]; however wood, rubber and sawdust [Wagland et al. 2011] can also be present. RDF producers are mainly specialized in processing various types of combustible waste from external suppliers in order to produce an energy carrier with a high calorific value meeting the quality requirements of the final recipient. RDF can also be produced in Municipal Waste Processing Facilities. Such facilities use energy fractions, derived from mechanical and biological processing of mixed municipal waste, which are not suitable for recycling. The introduction of a

legislative ban on the storage of selected types of combustible waste (the heat of combustion value of which exceeds 6 MJ/kg), including the waste labeled with the code 191212, which are generated in Municipal Waste Processing Facilities [Regulation of the Minister of Economy, 2015], played an important role in the development of the production of municipal waste fuels.

Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste [Directive 2018/851] introduced new approach to waste evidence. Article 35 of the directive extends the obligation of evidence also for non-hazardous waste.

The Member states are obliged to create an electronic registry or registries, which collect the data on hazardous waste; however, they can also collect data on other waste streams.

In Poland, the provisions of the abovementioned directive are implemented by the Act of 4th July 2019 amending the Waste Act and certain other Acts [The Act on Waste, 2019].

The Act introduced full digitization in terms of collecting data on waste and entities which carry out waste treatment through the Database on packaging products and waste management (in Polish in brief BDO). The amendment to the act contains provisions enabling, i.a.:

- keeping the records of waste, reporting, keeping a register of entities introducing products and products in packaging, establishments or undertakings which carry out waste treatment, all in electronic form through BDO (since 1<sup>st</sup> January 2020);
- submitting applications in paper form will be available only for foreign entities, which do not appoint an authorized person to represent them in Poland;
- registration in BDO for separate collection points run independently by the commune;
- possibility of electronic submission by BDO of documents confirming collection, recovery and recycling of packaging waste, waste from lubricating oils and tires, waste electric and electronic waste and also waste batteries and accumulators (since 1<sup>st</sup> January 2021).

In assumption, the solutions included in the amendment introduce a number of simplifications for entrepreneurs and environmental protection inspection. The record module is supposed to allow for a tighter control of waste transfer, in particular municipal waste collected from property owners. On the other hand, the reporting module is supposed to make it easier for entrepreneurs operating in the waste management industry to submit reports on their activities to voivodship marshals, and make it easier for the marshals to analyze the obtained data. The BDO record and reporting modules are supposed to be important tools for environmental protection inspection to fight against irregularities in waste management.

The data on the RDF production and processing, presented in the article, were acquired from the Department of Environmental Instruments of the Ministry of Climate and Environment, after submitting a proper application, since such data is not generally available in the BDO. There is only a general access to the database, which include a register of entities that carry out the waste management. There is a possibility to search the establishment or undertaking by the name, surname, register number, tax identification number, address or place of operation. Sections and tables of the application, type of processing R1-R13, D1-D15 and

waste codes can also be selected. After selecting the appropriate parameter there is a list of entries. The list includes a name, register number, tax identification number and address. Identification data are also available, as well as the information about the implemented quality systems. There is also possible to view the kind of section of waste management the entity carry out and a list of granted permits (waste processing, generation or collection permits, integrated permit).

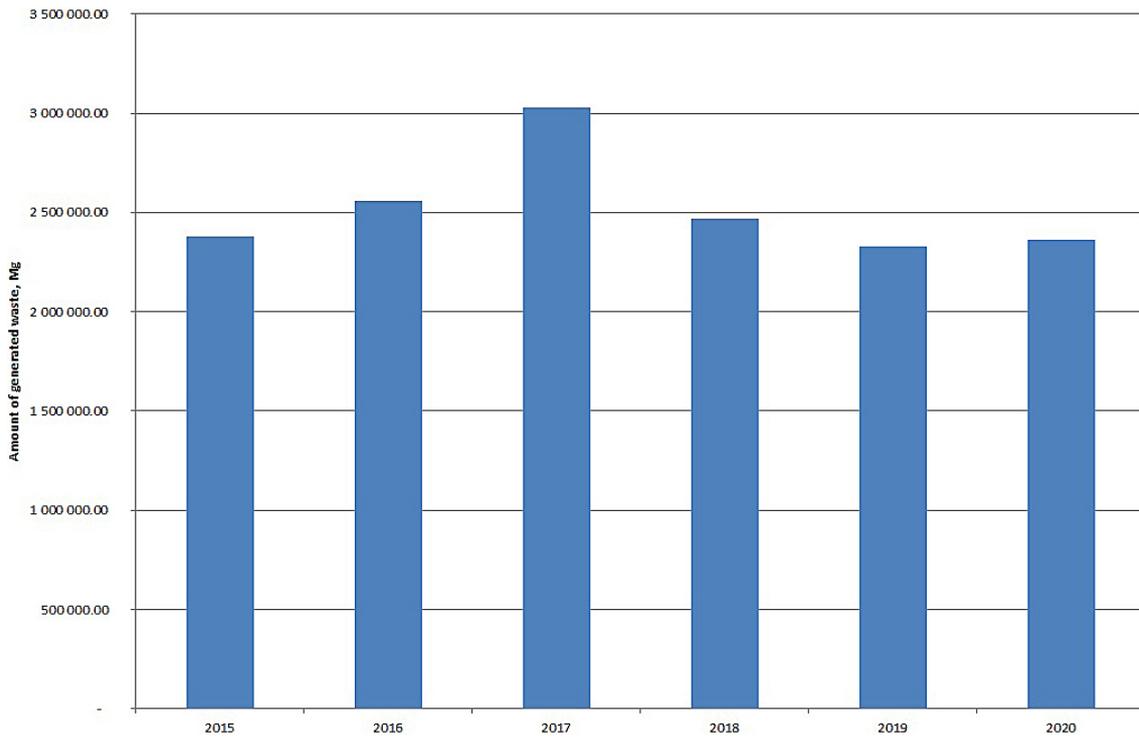
In order to know how much waste is generated by a given entity an application must be applied to the Department of Environmental Instruments of the Ministry of Climate and Environment. A response for such application is possible by means of regulations from an Act of 3<sup>rd</sup> October 2008 on providing information on the environment and its protection, public participation in environmental protection and environmental impact assessments [The Act on sharing information, 2008]. The disclosure of the requested information takes place immediately; however, no later than a month after receiving the application. In practice, the time is about three weeks.

The requested data on RDF included amount of generated and processed (in R1 and R12 processes) waste in 2019-2020. Such data are crucial in order to recognize the SRF market, which is a basic element of pre-investment activity in the field of energy and heat recovery from waste in modern waste management system.

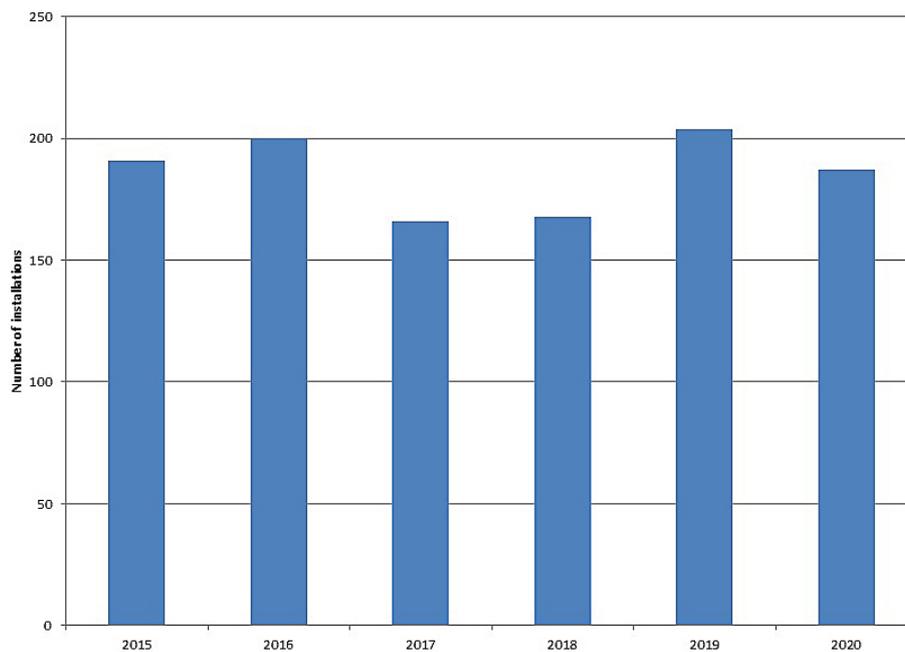
Before the introduction of BDO the data were mostly generally available on voivodship office websites in the form of voivodship reports. If the reports were not published on the website, an application was sent to the voivodship office and the requested data were received. Before the BDO, the access to the data on all waste generation and processing were much simpler, the data was always available and we did not have to wait few weeks for the information.

## RDF MARKET IN POLAND

Figures 1 and 2 present the amounts of generated and processed RDF in 2015-2020. The data were obtained from the voivodship reports (for 2015–2018) and directly from the Ministry (for 2019–2020). Figure 1 shows the amount of generated RDF in 2015–2020. In this period of time, there are no major differences in the RDF generation, the level of about 2,5 million Mg is



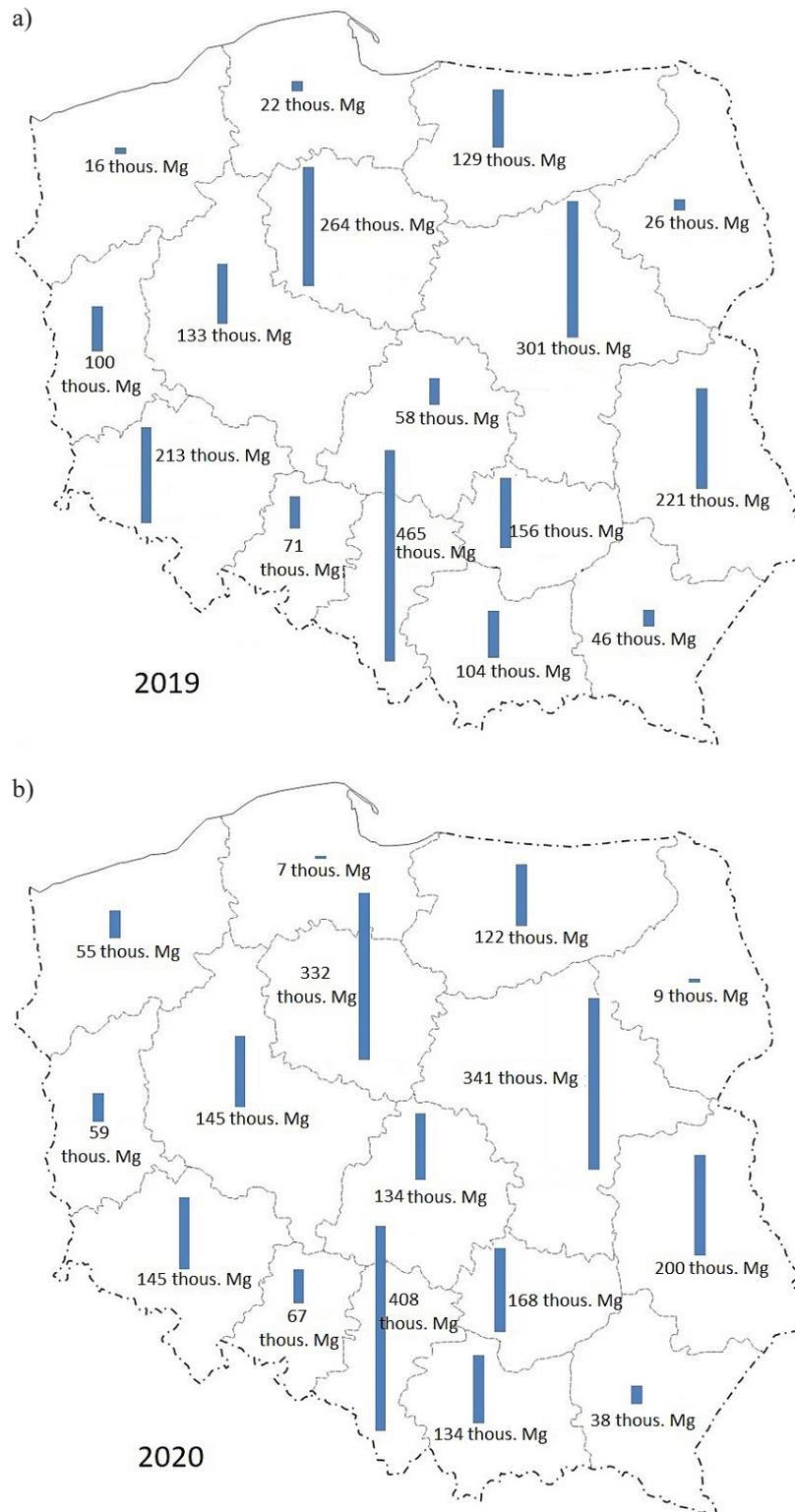
**Figure 1.** Amount of generated RDF in 2015–2020, Mg



**Figure 2.** Number of installation which produce RDF in 2015–2020

rather constant. The highest generation of RDF was in 2017 – over 3 million Mg. Figure 2 shows the number of installations generating RDF in 2015–2020. The number is more or less constant, the average of 186 installations. The largest number of installations generated waste in 2019 – 204 installation, the fewest number in 2017 and 2018 – 166 and 168, respectively.

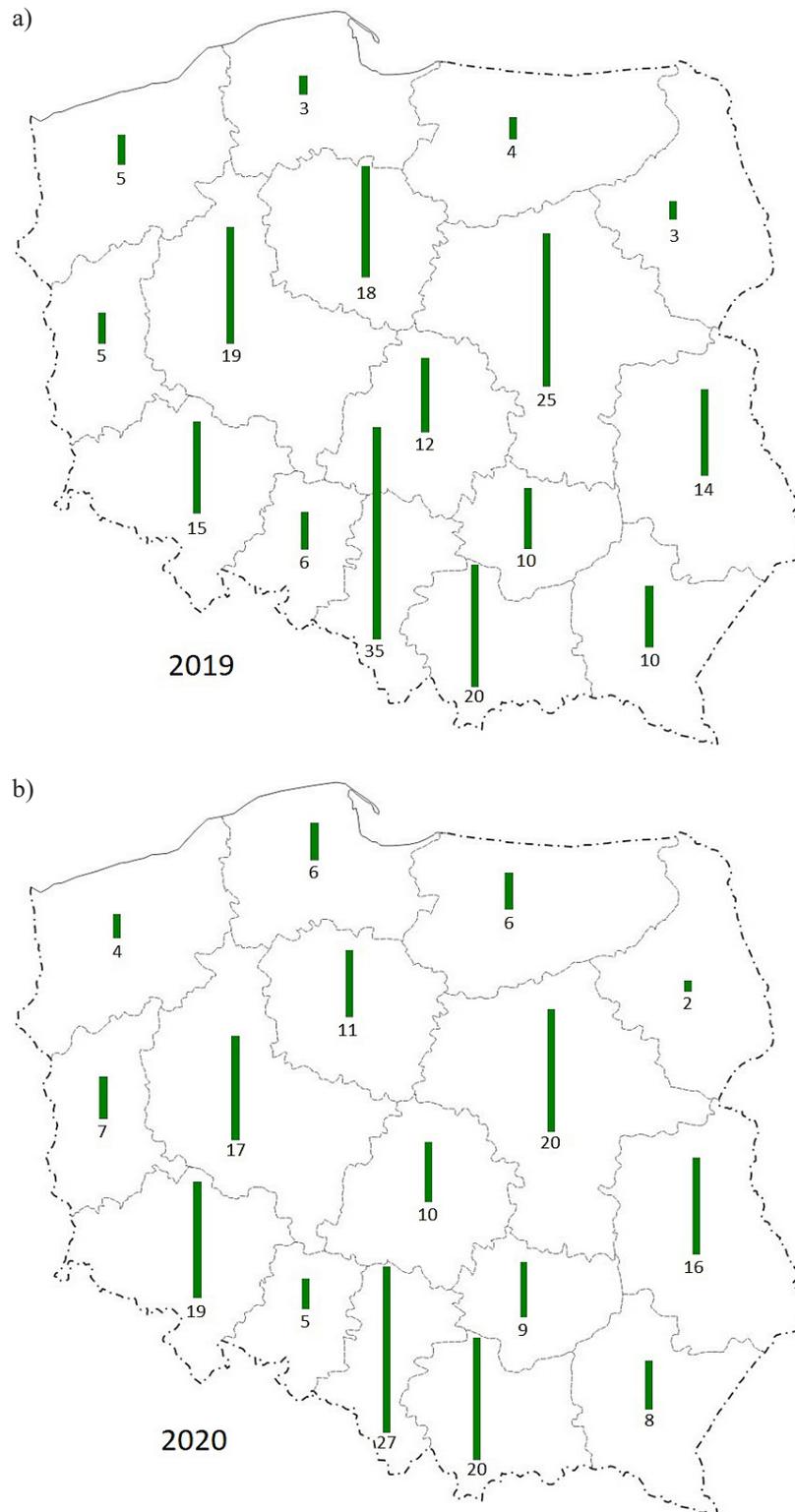
Figure 3 presents the amounts of generated wastes in each voivodship in 2019 and 2020. The distribution of waste generation in Poland is diversified; rather large differences can be seen between the voivodships. The greatest amount of RDF is generated in the śląskie (over 400 thousand Mg) and mazowieckie (over 300 thousand Mg) voivodships. The least amount of waste was



**Figure 3.** Generation of RDF in (a) 2019 and (b) 2020 in each voivodship

generated in the zachodniopomorskie (over 16 thousand Mg in 2019 and over 55 thousand Mg in 2020), pomorskie (over 22 thousand Mg in 2019 and about 7 thousand Mg in 2020) and podlaskie (over 26 thousand Mg in 2019 and over 8 thousand in 2020) voivodships.

Figure 4 shows the number of installations generating waste in each voivodship in 2019 and 2020. In this case, as the amount of generated waste, the distribution of installations is also diversified, there are large differences among the voivodships. The largest number



**Figure 4.** Number of installations generating RDF in (a) 2019 and (b) 2020 in each voivodship

of installations is in the śląskie voivodship – about 30 – and here also is the highest generation of SRF. The smallest number of installations is in the podlaskie (5 w 2019 and 6 in 2020) and zachodniopomorskie (3 in 2019 and 4 in 2020) voivoships.

Table 1 and Figure 5 show the amount of incinerated (in R1 process) RDF in 2019 and 2020. Over 90% of all incinerated RDF is incinerated in cement plants (about 1.5 million Mg per year). In the incineration plants about less than 100 thousand Mg were incinerated in 2019; however, an

**Table 1.** Amount of incinerated RDF in 2019–2020

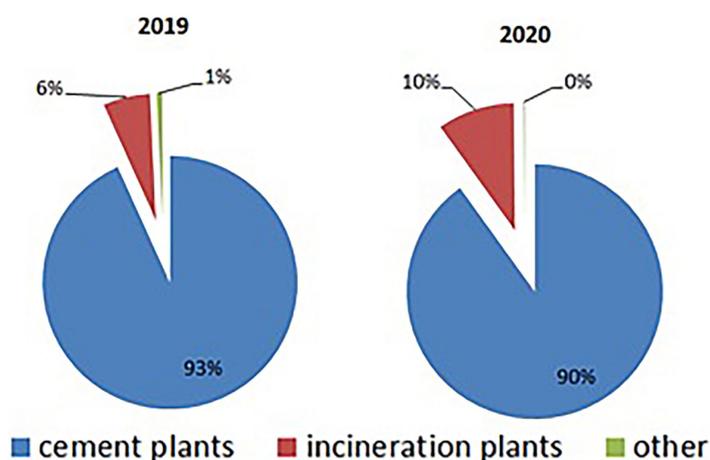
Installation	Type of installation	Amount of incinerated RDF in Mg	
		2019	2020
Lafarge Cement S.A. Bielawy	Cement plant	171 996.28	183 016.80
Cement Ożarów S.A. Rejowiec Fabryczny	Cement plant	387.01	0.00
Cemex Polska Sp. z o.o. Chełm	Cement plant	305 093.01	290 921.65
Cementownia „Warta” S.A.	Cement plant	85 710.23	47 145.71
Cementownia „Odra” S.A.	Cement plant	32 027.82	30 970.00
Góraźdże Cement S. A.	Cement plant	337 897.84	415 732.31
Cemex Polska Sp. z o.o. Rudniki	Cement plant	33 487.68	67 832.60
Cement Ożarów S.A. Karsy	Cement plant	299 517.25	309 189.19
Dyckerhoff Polska Sp. z o.o. Nowiny	Cement plant	126 030.49	114 890.56
Lafarge Cement S.A. Małogoszcz	Cement plant	118 499.44	128 132.47
Miejskie Przedsiębiorstwo Oczyszczania W M.St. Warszawie Sp. z o.o.	Incineration plant	0.00	5 882.48
Przedsiębiorstwo Usługowo-Handlowo-Produkcyjne „Lech” Sp. z o.o. Białystok	Incineration plant	118.28	0.00
Zakład unieszkodliwiania odpadów Sp. z o.o. Szczecin	Incineration plant	14 054.25	4 778.25
Promarol-Plus Sp. z o.o.	Incineration plant	40.71	90.22
Fortum Silesia S.A.	Incineration plant	44 895.26	101 737.80
Stora Enso Narew Sp. z o.o. Ostrołęka	Incineration plant	37 606.20	59 213.70
Bioenergy Farm Stanowice Sp. z o.o.	Incineration plant	0.00	44.50
„Naprzód” Sp. z o.o.	Other	11 933.42	2 526.54
Przedsiębiorstwo Produkcyjno-Handlowe „Hegard” Sylwia Fryca	Other	30.00	15.00
Total	-	1 619 325.17	1 762 119.78

increase to about 170 thousand Mg can be observed in 2020. There is an increase of incinerated RDF in waste-to-energy plant Fortum in Zabrze (from about 45 thousand Mg in 2019 to over 100 thousand Mg in 2020) and waste-to-energy plant in Ostrołęka (from about 37 thousand Mg in 2019 to almost 60 thousand Mg in 2020). Other installations are waste management

facilities – mechanical and biological treatment installation and paper materials production.

### SELECTED PROPERTIES OF RDF

Basic laboratory analysis (technical, elemental analysis and heavy metals content) was



**Figure 5.** Distribution of plants which incinerate RDF in 2019 and 2020

performed for a few samples of RDF (RDF1, RDF2, RDF3), which were obtained from different RDF producers from Poland and the results are shown in Tables 3–4. The analyses were performed in Laboratory of Analytical Chemistry of Institute of Energy and Fuel Processing Technology. Additionally, in order to compare the RDF samples, there are also shown parameters for coal and parameters of RDF published in other articles: RDF4 [Dianda et al., 2018], RDF5 [Bras et al., 2020], RDF6 [Hemidat et al., 2019], RDF7 [Hryb et al., 2018], RDF8 [Mlonka-Mędrala et al., 2021], RDF9 [Compagnone et al., 2006]. Table 2 shows the technical analysis (moisture, ash, volatile matter content and lower heating value) of 9 RDF samples and 1 coal sample. It can be noticed that the parameters are

very diversified – the moisture content is in the range 6.4–36.45% for the RDF parameters, in comparison to 5.3% moisture content in coal. The ash content in the range 4.8–20.23% for the RDF samples and in the case the ash content for coal is higher – 22.7%. Volatile matter content for RDF samples varies from 8.82–75.8% and the coal sample consists of 32.9% of volatile matter. The lower heating value is also diversified for the RDF samples and equals 10.95–24.96 MJ/kg, in comparison to 23.78 MJ/kg for coal.

Table 3 shows the elemental analysis of 9 RDF samples and 1 coal sample for comparison. Similarly to the technical analysis, the parameters are diversified. The C content for RDF samples varies from 45.43–62.3%, while the C content in coal is 65.5%. The H content is in the range 4.98–11.5%

**Table 2.** Technical analysis of RDF and coal samples

Parameter	Unit	Coal	RDF1	RDF2	RDF3	RDF4	RDF5	RDF6	RDF7	RDF8	RDF9
Moisture	%	5.3	6.5	36.45	10.8	6.4	22.2	25.5	14.7	5.8	8.1
Ash content	%	22.7	15.8	20.23	13.4	9.2	9.07	18.15	4.8	8.0	16.3
Volatile matter content	%	32.9	61.69	-	87.77	8.82	59.4	-	-	75.8	-
Lower heating value	MJ/kg	23.78	23.77	10.95	21.39	24.96	23.4	15.21	18.62	23.10	17.8

**Table 3.** Elemental analysis of RDF and coal samples

Parameter	Unit	Coal	RDF1	RDF2	RDF3	RDF4	RDF5	RDF6	RDF7	RDF8	RDF9
C content	%	65.5	62.3	47.42	54.7	49.75	45.43	-	-	56.62	55.1
H content	%	3.57	4.98	5.63	7.05	9.04	6.12	-	-	9.08	11.5
N content	%	1.11	1.16	-	1.2	10.77	0.56	-	-	0.99	3.1
O content	%	-	-	-	20.0	28.55	57.02	-	-	17.11	13.7
Cl content	%	0.2	1.084	0.46	0.81	-	0.45	0.99	0.55	-	-
F content	%	0.011	0.010	-	0.01	-	-	-	-	-	-
S content	%	0.52	0.37	0.33	0.26	1.89	0.48	-	0.25	0.13	0.04

**Table 4.** Heavy metals content in 8 RDF samples and 1 coal sample

Parameter	Unit	Coal	RDF1	RDF2	RDF3	RDF5	RDF6	RDF7	RDF8	RDF9
Sb content	mg/kg	1.45	42.9	11.58	65.0	-	-	-	-	81
As content	mg/kg	3.81	2.82	1.67	0.9	-	0.99	-	-	0.7
Cd content	mg/kg	0.271	2.83	3.7	2.96	0.23-3.5	2.95	-	-	0.8
Cr content	mg/kg	27.8	645	49.15	111.0	2.3-3.5	66.0	-	-	76
Co content	mg/kg	6.43	8.70	0.47	2.87	-	-	-	-	
Cu content	mg/kg	22.6	67.3	115.5	84.40	6.5-19	-	-	-	320
Hg content	mg/kg	0.088	0.074	0.19	0.62	0.011	<0.03	0.1	0.25	0.5
Pb content	mg/kg	15.4	102	57.95	99.2	1.9-22	-	-	-	880
Mn content	mg/kg	152	192	-	105	4.4-33	-	-	-	66
Mo content	mg/kg	-	-	1.9	5.5	-	-	-	-	
Ni content	mg/kg	34.2	21.8	9.9	19.9	0.31-1.7	58.50	-	-	166
Zn content	mg/kg	-	-	300.5	363.0	200-2600	270.0	-	-	445
V content	mg/kg	4.56	25.0	-	16.1	-	-	-	-	-

for RDF samples and equals 3.57% for coal. From the environmental point of view, the Cl and S contents are crucial. Waste should contain less than 1% of Cl in order to be incinerated at 850 °C in the incineration plants. The wastes with the Cl content higher than 1% should be incinerated at 1100 °C [The Regulation of the Minister of Development, 2016]. The Cl content in the presented samples varies from 0.46–1.084%, while the coal sample contains 0.2% of Cl. The S content for RDF samples is in the range 0.04–1.89% in comparison to 0.52% in the coal sample.

The heavy metal content is crucial from the environmental point of view due to their toxic properties. Additionally, heavy metals influence the technological processes in which RDF is applied, e.g. the zinc content has a negative impact on the iron ore sintering process [Stecko et. al., 2018; Niesler et. al., 2021]. Again, the heavy metal content differs a lot among the presented samples, like in the case of elemental and technical analysis. The heavy metals content is presented in Table 4.

The presented laboratory analyses show that Refuse Derived Fuel is a very diversified material. Their parameters can be influenced by the following factors: morphological composition, season, type of storage, technological process of RDF production. In practice, when the RDF is applied in cement or power industry, the requested parameters of RDF are established and the RDF producer prepares and delivers the fuel according to the concluded contract.

## CONCLUSIONS

Refuse Derived Fuels are used as energy carrier mainly in cement plants; however, more and more often they are applied in power plants as a substitute for fossil fuels. In order to prepare a proper waste-to-energy investment, the availability of the fuel, as well as the fuel properties should be determined. At present, the quantitative data on RDF in Poland are not publicly accessible and in order to obtain such data, an application to the Ministry of Climate and Environment should be sent. The generation of RDF in 2015–2020 was average about 2.5 million Mg/year and the average number of RDF producers was 186 in 2015–2020. The RDF generation in Poland is very diversified, there are voivodships in which the production exceeds 300 thousand Mg (śląskie,

mazowieckie, kujawsko-pomorskie), while in the podlaskie and pomorskie voivodships the generation of RDF was below 10 thousand Mg in 2020. The number of installations generating RDF is also diversified, in the śląskie, mazowieckie and małopolskie voivodships were over 20 producers, while in podlaskie only 3 (in 2019) and 2 (in 2020). The RDF is mainly managed by cement plants, about 1.5 million Mg is incinerated there every year. However, an increase in RDF incineration can be observed in other facilities, e.g. in waste-to-energy plant Fortum in Zabrze, where incinerated RDF increased from about 45 thousand Mg in 2019 to over 100 thousand Mg in 2020.

The basic physicochemical analysis of RDF shows that this material is very diversified. The lower heating value of the presented RDF samples varies from 10.95 MJ/kg to 24.96 MJ/kg, the moisture content varies from 6.4–36.45%, the volatile matter content is in the range 8.82–75.8% and the ash content is 4.8–20.23%. The elemental analysis and heavy metals content also shows the diversity of RDF, from the environmental point of view, the Cl, S and Hg content is crucial and the lower the values, the better. It can be observed that some of the RDF samples have parameters similar to coal. The parameters of RDF can be influenced by many factors: morphological composition, season, type of storage or technological process of RDF production. In practice, the requested parameters of RDF are established and, the RDF producer prepares and delivers the fuel according to the concluded contract.

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