Comparison of the effectiveness of the MBT process in the processing of biodegradable components separated mechanically and from mixed or unsorted municipal waste from three localities

Porównanie bilansu składników biodegradowalnych dla oddzielanych mechanicznie i zmieszanych lub niesortowanych odpadów komunalnych przetwarzanych w procesie MBP wytwarzanych w trzech miejscowościach

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The aim this present paper is to determine the biodegradable waste composition in the Municipal Waste Recovery and Disposal Plant in Leśno Górne. It presents the analysis of the material composition of two fractions of 20-80 mm and > 80 mm in diameter, separated from municipal solid waste supplied to the MBT plant from three localities. The waste delivered to the plant within one year was analysed, the analyses were conducted once a month. On the basis of the percentage share of individual fractions and their material composition, having considered the mass of organic waste separated at the sorting stand, biodegradable waste balance (treated and intended for landfilling) was determined. Separate fractions 0-20 mm, 20-80 mm and > 80 mm constitute, 18.43%, 29.83 %, and 50.21% of the municipal waste mass, respectively. The content of individual fractions in waste mass showed seasonal fluctuations and differences depending on the place of waste generation. However, no statistically significant interactions were found regarding the share of particular fractions and the season and/or place of waste generation. The share of biodegradable waste in the granular size of 20-80 mm constituted, on average, approx. 60% of the mass, whereas the fraction of > 80 mm approx. 40%. The research showed that, approx. 50% of biodegradable waste is stabilized and the remaining share, together with the fraction of > 80 mm, is to be landfilled in the untreated form or sent to waste incineration plant.
Key words: municipal solid waste, mechanical-biological treatment of waste, material composition; mixed municipal solid waste

Celem niniejszej pracy jest określenie bilansu odpadów biodegradowalnych dla Zakładu Odzysku i Składowania Odpadów Komunalnych w Leśnie Górnym (woj. Zachodniopomorskie). Badano skład morfologiczny dwóch frakcji o uziarnieniu 20-80 mm oraz > 80 mm wydzielonych ze stałych odpadów komunalnych dostarczanych do zakładu MBP z trzech miejscowości: Szczecin, Police, Trzebież. Odpady badano przez jeden rok analizując je dla każdej miejscowości raz w miesiącu. Dla frakcji o uziarnieniu 0-20 mm przeprowadzono badania właściwości fizyko-chemicznych. Na podstawie procentowego udziału poszczególnych frakcji oraz ich składu morfologicznego, a także przy uwzględnieniu masy odpadów organicznych wydzielonych w obrębie trybuny sortowniczej określono bilans odpadów biodegradowalnych (przetworzonych oraz kierowanych do składowania). Wydzielone frakcje odpadów 0-20 mm, 20-80 mm i >80 mm stanowią odpowiednio 18,43 %, 29,83 %, 50,21 % masy odpadów komunalnych. Zawartość poszczególnych frakcji w masie odpadów podlegała wahaniom sezonowym, a także różniła się zależnie od miejsca wytworzenia. Nie stwierdzono jednak występowania statystycznie istotnych interakcji między udziałem poszczególnych frakcji, a sezonem lub/i miejscem ich wytworzenia. Udział odpadów biodegradowalnych o uziarnieniu 20-80 mm stanowił średnio około 60% masowych, zaś we frakcji > 80 mm około 40%. Jak wynika z przeprowadzonych badań, procesowi kompostowania poddawanych jest ok. 50% odpadów biodegradowalnych, pozostała część tych składników kierowana jest, wraz z frakcją > 80 mm, na składowisko w postaci nieprzetworzonej lub do spalarni odpadów.
Słowa kluczowe: stałe odpady komunalne, mechaniczno-biologiczne przetwarzanie odpadów, skład materiału; zmieszane odpady komunalne stałe

Introduction

Under the EU Directive 1999/31/EC on the landfill of waste, the member states are obliged to implement technologies of municipal solid waste (MSW) management other than landfilling. Nevertheless, landfilling is still predominant in the treatment and disposal of waste worldwide [7, 42]. For example, out of 342 kg of waste generated in 2020 per capita in Poland [14], only 12.0% from the selective collection was intended for treatment by composting or fermentation. The largest amount of waste (39.8%) was landfilled directly, 26.6% was recycled and 21.6% was thermally disposed. According to the GUS [13], in 2023, out of the total amount of

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municipal waste generated in the European Union, 49% underwent material recycling and composting, 26% was thermally disposed, 23% was landfilled.

In the light of the above, numerous countries, including Poland, decided to implement the mechanical-biological treatment of waste (MBT). Currently, this technology is increasingly gaining precedence over other forms of mixed municipal waste treatment in many European countries [10, 33, 54] as well on other continents [1]. However, in less developed countries, MBT installations are not competitive due to low fees for waste landfilling [28]. Nonetheless, the introduction of the said technology has contributed to, among others, the reduction in the number of landfills in Poland. This was enabled by establishing, within the existing MBT plants, the so-called Regional Installations for Municipal Waste Treatment [41]. In 2019 the Regional Installations for Municipal Waste Treatment changed their name to the Communal Installations. There were 279 active municipal waste landfills (of an area 1670 ha) in 2019 [13], whereas in 2009 there were as many as 803 (of an area 2820.7 ha) GUS [12].

The main reason behind the introduction of MBT technology was the necessity to meet the requirements of reducing the amount of biodegradable waste landfilled without prior treatment [5]. Nevertheless, the process also results in the general reduction of the amount of waste sent to landfills [36]. The technology is in fact a series of mechanical and biological processes and the output components, besides the stabilized waste, also include the refuse derived fuels (RDF), recyclable materials and possibly compost [2, 3, 21, 35, 37, 40, 46]. Nowadays, MBT technology constitutes the key element of municipal solid waste management in Europe and in Poland [24, 32, 48]. According to Jędrczak [17] at the end of 2016 in Poland, there were 192 MBT installations of the capacity of approx. 11 million Mg of waste per year, whose service life was estimated by Siemiątkowski [43] at least 15–20 years. Individual plants operating in Poland, particularly a few years ago, used various sizes of mesh size for mechanical sorting of waste. The Municipal Waste Disposal Plant in Zgorzelec (ZUOK, Zgorzelec) used a sieve with a mesh size of 70 mm [19] in Waste Disposal Plant in Gorzów Wlkp. (ZUO, Gorzów Wlkp.) [29] and Municipal Waste Treatment Lipówka II in Dąbrowa Górnicza [27] sieves with a mesh size of 20 and 80 mm were used, in Waste Disposal Complex in Bydgoszcz – 22 and 100 mm [45], and in Remondis Plant in Bydgoszcz – 20 and 250 mm [34].

Just as any other technology dedicated to waste treatment, MBT shows some negative effect to the environment. The plants generate a certain equivalent of CO_2 and SO_2 and consequently affect climate change [57]. As it was argued by Koci and Tecakova [22], the greatest impact on the environment in terms of waste management, apart from landfilling without energy recovery, is generated by MBT plants with aerobic treatment. The model developed by Grzesik and Malinowski [11] shows that MBT plants processing mixed municipal waste may have a negative effect on the environment – the significant impacts being the formation of photochemical ozone, eutrophication of waters, acidification of the environment and toxicity to humans.

However, globally, the use of MBT technology offers environmental advantages [1, 15, 49] and the treatment of municipal solid waste with MBT technology can significantly reduce the negative environmental effect of landfilling. Leachate parameters (ChZT, BZT_5, Corg. and Ntot.), as well as biogas production rate following MBT are found to reduce to values lower than 90% of the values for the untreated waste [31, 46]. Such substantial differences result from bio-waste stabilisation and the reduction of mass obtained during biological treatment which, according to Wiśniewska and Lelicińska-Serafin [56], can amount to approx. from 15% to over 80%.

In the light of the existing analyses, it should be noted that a considerable amount of waste accepted in MBT plants is still indicated for controlled landfilling without any treatment. This is confirmed by Jędrczak [18] who states that less than a half of bio-waste generated in the EU member states underwent composting or fermentation, and the majority of waste is incinerated or landfilled with other wastes.

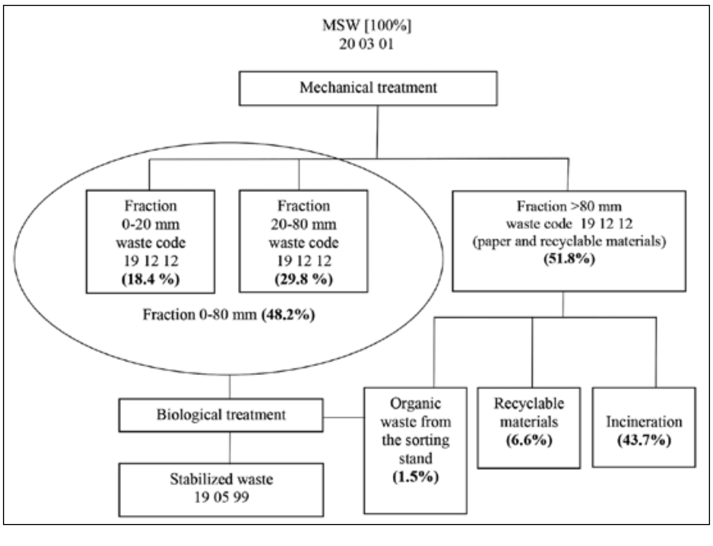
The aim of the present paper is to determine the biodegradable waste composition (treated and intended for landfilling/incineration without treatment) in the plant in Leśno Górne (Zachodniopomorskie voivodship) on the basis of the results for waste supplied by three different localities. The composition was determined on the basis of the percentage share of individual fractions and their material composition.

Materials and methods

The paper presents the results of the analyses of municipal solid waste (MSW) generated in three localities (Szczecin, Police and Trzebież) treated in Municipal Waste Recovery and Disposal Plant (ZOiSOK) in Leśno Górne with the use of MBT technology.

ZOiSOK in Leśno Górne was established in 2001 on a former gravel pit area neighbouring agricultural wasteland and forest land. The closest drinking water intake is located in a 800 m distance, outside water intake protection zone [23, 47]. The plant uses drum sieves allowing separation of the mixed municipal waste stream into fractions of the following granulation: 0-20 mm, 20-80 mm and over 80 mm, and aerobic waste treatment reactors. Fractions 0-20 mm and 20-80 mm are intended for composting, and the fraction > 80 mm (following the manual sorting of recyclables and organic waste) is currently sent to waste incineration plant in Szczecin. Until the waste incineration plant in Szczecin became fully operational (till May 2019), fraction of more than 80 mm in diameter had been landfilled on-site. The waste treatment process scheme in ZOiSOK in Leśno Górne is presented in Fig. 1

Fig. 1. Diagram of the MBT process used at ZOiSOK in Leśno Górne
Rys. 1. Schemat procesu MBP stosowanego w ZOiSOK w Leśnie Górnym



According to the Statistical Office in Szczecin [2018], the population of the city of Szczecin on 31 December 2018 was 403,883 and of the city of Police 41,545. Trzebież is a village in the district of Police and its population is 2,136 [52]. The population density for 2014, the Police town and the city of Szczecin were above the national average [51].

The studies were conducted for a period of one year, the analyses of MSW for individual localities were conducted once a month (the total number of measurements was 36). The mass of MSW supplied to the plant by following the routine waste collection route amounted to, on average, 10.2 Mg in Szczecin, 15.9 Mg in Police and 10.6 Mg in Trzebież. Mass of three fractions separated from waste were analysed: 0-20 mm, 20-80 mm and over 80 mm in diameter. The material composition of two fractions of 20-80 mm and > 80 mm in diameter was analysed. The aggregate samples of individual MSW fractions were prepared by collecting dozens waste samples and mixing them followed by reducing the mass to approx. 100 kg each. The following components were differentiated in the morphological analysis: organic waste, paper and cardboard, wood, plastics, glass, metals, textiles, sanitary waste, fraction of less than 10 mm in diameter and other mineral waste. Physicochemical properties of the fraction of 0-20 mm in diameter were identified.

On the basis of the percentage share of individual fractions and their material composition, also taking into consideration the mass of organic waste separated at the sorting stand, composition of biodegradable waste (treated in aerobic process and others) was determined. The obtained ratio of biodegradable waste presents the following:

1. percentage share of biodegradable waste which could not be segregated in the technological process used in the plant (OBS), intended for landfilling/ or incineration **(a)**, with reference to the total mass of biodegradable waste supplied to the plant in MSW stream **(d)**.
2. percentage share of biodegradable waste to be treated (OBP) i.e., intended for composting **(b)**, recycling **(c)** (paper, cardboard separated at the sorting stand), with respect to the total mass of biodegradable waste supplied to the plant in MSW stream **(d)**.

For the purpose of determining the percentage ratio of biodegradable waste intended for landfilling/ or incineration without prior treatment (OBS), with respect to the total mass of biodegradable waste supplied to the plant in MSW stream, the following equation was used (1):

$$OBS\left[\%\right]=\frac{a\cdot 100\%}{d} \qquad (1)$$

For the purpose of determining the percentage ratio of biodegradable waste intended for treatment (OBP), with respect to the total mass of biodegradable waste supplied to the plant in MSW stream, the following equation was used (2):

$$OBP\left[\%\right]=\frac{\left(b+c\right)\cdot 100\%}{d} \qquad (2)$$

Explanation of symbols used in mentioned above formulas:

a – mass of biodegradable waste intended for landfilling calculated from (3):

$$a\ [kg]= =\frac{\frac{(\%\ biodegradable\ waste}{100\%}\ \underline{fraction>80\ mm)\cdot}}{\cdot\,(kg\ mass\ fraction>80\ mm)} \qquad (3)$$

b – total mass of waste:
- biodegradable waste separated at the sorting stand
- biodegradable waste of 20-80 mm fraction (e), calculated from (4):

$$e= =\frac{\frac{(\%\ biodegradable\ waste}{100\%}\ \underline{fraction\ 20-80\ mm)\cdot}}{\cdot\,(kg\ mass\ fraction\ 20-80\ mm)} \qquad (4)$$

c – mass of paper and cardboard separated at the sorting stand

d – total mass of biodegradable waste supplied to the plant in mixed municipal waste stream, calculated from: **d = a + b + c**

The samples of the fraction 0-20 mm were dried (105°C) and then ground in a mortar – during grinding only the metal waste was removed. Having prepared the samples in this way, the following were determined:
- loss on ignition – by incineration of the material in the muffle furnace at 550°C;
- pH – with potentiometry in water extract;
- content of organic carbon, total nitrogen and total sulphur using the elemental analyser CNS Coestech.

Results and discussion

The study results showed that out of the three fractions separated from the waste under analysis, the oversize fraction (>80 mm) was predominant. It was not statistically proven that its content was different depending on the size of the agglomeration. In the case of waste supplied from Szczecin, the fraction >80 mm amounted to 54.4%, in the mass of waste supplied from Police 48.7% and from Trzebież – 47.6% (Fig. 2). By comparison with another MBT plant in Poland, the amount of waste intended for landfilling in 2017 and 2018 was, respectively, 33.2 and 32.3% [39]. The analysis of the share of the oversize fraction shows its predominance in the waste generated in the summer season (56.4%) and its smallest share in the winter season (43.7%). Considering both research factors (locality and season), the greatest share of the fraction >80 mm (61.8%) was recorded in summer in waste supplied from Szczecin, and the smallest in waste supplied in winter from Trzebież – 39.1%. This is to be attributed to the increased share of ash from furnace in waste generated in the winter season as well as an increased share of street sweepings from single-housing areas, as has also been demonstrated by Jędrczak [17-18] and Jędrczak et al. [20].

The share of 20-80 mm fraction in waste mass also showed variability depending on the place of its generation and season, for all the measurements it amounted to, on average, 29.8%. Cimpan and Wenzel [4] demonstrated that the fraction to be biologically treated (20-80 mm), previously mechanically segregated in MBT plant in the Netherlands, amounts to as much as 40.9% of the mass of all treated waste. The highest average share of this fraction, determined in own studies, was identified for waste from Police (32.7%), and the smallest from Trzebież (27.7%). The simultaneous analysis of the locality and season factors demonstrates that the smallest share (21.6%) was recorded in waste supplied in the summer from Szczecin, and the highest (40.3%) in waste supplied in the winter from Police.

Among the three identified fractions, the smallest share was found with respect to 0-20 mm fraction. The fraction of 0-20 mm constituted the greatest share in waste supplied from Trzebież (23.6%), and the smallest in waste from Szczecin (14.4%). With respect to seasons, the average share of 0-20 mm fraction was the same as for 20-80 mm fraction. The greatest share of both fractions was found in waste supplied in winter, and the smallest in those supplied in summer. However, no statistically significant interactions between the share of the fractions under analysis, the season or/and place of waste generation was found. Jędrczak [17] in 21 MBT installations in Poland, show that the share of organic waste in the fraction <80 mm ranged considerably from 17.5 to 62.2%. The content of the said components in the undersize fraction significantly varied, as was confirmed by another study by Jędrczak et al. [20]. The share of organic waste in the fraction of <80 mm in diameter amounted to, on average, 27.9 ± 10.5%, including the

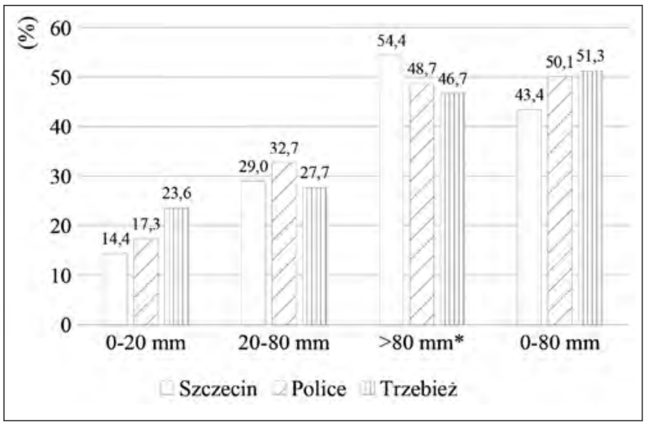


Fig. 2.
Percentage content of individual fractions of the MSW separated from waste from the compared towns.
*** – without organic waste separated within the sorting stand**
Rys. 2. Procentowa zawartość poszczególnych frakcji MSW wydzielonych z odpadów z porównywanych miast.
**** – bez odpadów organicznych wydzielonych w obrębie stanowiska sortującego***

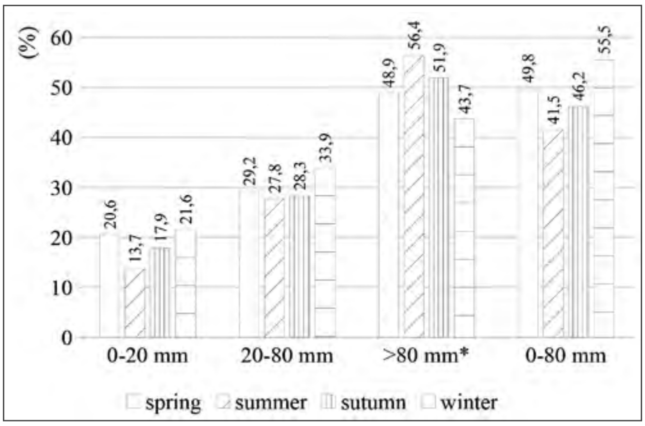


Fig. 3.
Percentage of the individual fractions of the MSW separated in each season of the year.
*** – without organic waste separated within the sorting stand**
Rys. 3. Procentowa zawartość poszczególnych frakcji MSW wydzielonych z odpadów w poszczególnych porach roku.
**** – bez odpadów organicznych wydzielonych w obrębie stanowiska sortującego***

Połomka and Jędrczak [39] demonstrate that in MBT plant in Marszów (Poland), the average amount of the undersize fraction (0-80 mm) is significantly higher than that of the oversize fraction (>80 mm), the mass ratio being 1.4. In own studies, the mutual ratio of both fractions was found to be similar, with the predominance of the fraction > 80 mm (on average 50.2%) over the 0-80 mm fraction (48.3%). In their study on MBT installation in Poświętne [55] determined the share of the undersize fraction (0-80 mm) to be in the range from 48 to 57%. Maćków et al. [27] determined the following share of individual fractions for MBT in Dąbrowa Górnicza: 0-20 mm – 26.0%, 20-80 mm – 27.5%, > 80 mm – 37.0%.

The average contents of particular morphological components, calculated according to data presented in Table 1, of the fraction 20-80 mm allow the following classification: organic components (51.60%), glass (15.14%), Ø <10 mm (11.37%), paper and cardboard (9.96%), plastics (4.81%), other mineral (4.78%), metals (1.50%), textiles (0.29%), sanitary waste (0.16%), wood (0.10%).

In the fraction 20-80 mm, biodegradable waste was predominant – on average 60-65% of fresh weight. Soboniak and Jurand [44] estimated, with respect to biodegradable fraction (0-80 mm) separated from waste supplied to MBT plant in Subczyn, the share of biodegradable waste to be more than 80% of their amount in MSW. However, the studies conducted by

Tab. 1. Material composition of the waste fraction with a diameter of 20-80 mm
Tab. 1. Skład materiałowy frakcji odpadów o średnicy 20-80 mm

Locality	Season	Organic	Wood	Paper and cardboard	Plastics	Glass	Metals	Textiles	Sanitary	Fraction <10 mm	Other mineral
		(%)									
Szczecin	Spring	55.29	0.25	9.79	5.15	12.83	1.64	0.00	0.00	11.98	3.07
	Summer	54.95	0.00	11.41	4.20	13.36	0.89	0.44	0.90	8.11	6.19
	Autumn	51.95	0.00	10.66	2.89	16.83	1.20	0.67	0.00	10.84	4.95
	Winter	51.72	0.00	11.94	4.24	17.64	2.91	0.00	0.20	8.45	2.90
Police	Spring	54.04	0.00	9.38	4.28	20.36	1.33	0.41	0.00	7.72	2.49
	Summer	45.11	0.22	18.55	7.71	15.25	0.73	1.05	0.05	9.66	1.67
	Autumn	56.47	0.24	14.14	5.42	14.95	1.25	0.09	0.27	5.55	1.62
	Winter	54.81	0.00	7.19	2.68	14.76	1.05	0.00	0.31	13.65	5.56
Trzebież	Spring	47.95	0.45	6.05	7.65	16.60	2.52	0.35	0.00	10.66	7.77
	Summer	40.75	0.00	8.36	4.86	19.36	0.46	0.05	0.00	21.14	5.01
	Autumn	64.28	0.08	5.78	3.49	11.18	0.91	0.31	0.24	10.59	3.14
	Winter	41.86	0.00	6.24	5.20	12.28	3.16	0.14	0.00	18.11	13.02

Tab. 2. Material composition of the waste fraction with a diameter greater than 80 mm
Tab. 2. Skład materiałowy frakcji odpadów o średnicy większej niż 80 mm

Locality	Season	Organic	Wood	Paper and cardboard	Plastics	Glass	Metals	Textiles	Sanitary	Fraction <10 mm	Other mineral
		(%)									
Szczecin	Spring	23.95	0.76	24.52	27.43	4.60	2.92	8.21	2.15	4.05	1.41
	Summer	20.53	3.24	27.01	23.96	3.66	1.07	10.85	6.75	1.81	1.13
	Autumn	13.50	3.89	38.60	24.77	2.95	3.27	6.02	0.86	2.39	3.73
	Winter	11.56	1.28	29.83	26.81	8.22	3.41	8.75	5.84	1.80	2.51
Police	Spring	13.34	0.87	25.17	27.90	5.43	3.41	8.93	8.21	1.61	5.13
	Summer	12.72	1.03	24.68	35.29	4.01	2.10	11.73	5.21	1.02	2.22
	Autumn	13.83	0.44	25.50	26.31	1.75	1.61	15.96	6.38	2.47	5.76
	Winter	12.34	1.47	28.73	26.66	2.80	2.79	13.01	5.23	4.30	2.67
Trzebież	Spring	8.48	1.08	18.50	36.90	4.46	4.35	11.68	8.20	3.81	2.53
	Summer	17.06	1.15	15.11	30.97	5.18	2.59	11.40	7.71	6.28	2.55
	Autumn	14.35	1.24	20.10	34.26	2.34	3.67	10.61	4.58	2.48	6.36
	Winter	14.14	0.15	16.11	30.56	3.37	3.27	13.42	11.61	2.69	4.68

share of food waste, on average, 10.5 ± 6.7%, green and garden waste 16.6 ± 9.9%, wood waste 0.6 ± 0.9% Jędrczak et al. [20]. The material composition of the analysed fractions is also dependent on the mesh size of the sieve used in plants, for example in the fraction of Ø > 60 mm separated from municipal waste in ZOiS-OK, the percentage share of organic waste was only 20.4% [30]. As for this fraction, there is a considerable share of glass and components of Ø <10 mm (Tab. 1). Glass wastes constitute approx. 15% of the said fraction, whereas the highest share was found in waste supplied from Police in spring – 20.36%, and the smallest in waste from Trzebież in autumn – 11.18%. The average content of Ø <10 mm components was highly dependent on the locality in which waste was generated. As for waste generated in Szczecin, it amounted to, on average, 9.85%, similar values were recorded for Police (9.15%), whereas the highest amount was found for waste generated in Trzebież (15.13%). Such a large average share of fine components (Ø <10 mm) in the fraction of 20-80 mm in diameter, separated from waste generated in Trzebież, is related to individual heating systems being used in households. This has also been confirmed in the studies by Primus and Rosik-Dulewska [41]. The content of paper in the analysed samples showed differences with respect to the place of waste generation. The fraction of 20-80 in diameter supplied from Police contained, on average, 12.31% of paper and cardboard, whereas for Trzebież it was only 6.61%. In this fraction of waste, plastics constitute approx. 5%, their greatest share in 20-80 mm fraction was found in waste supplied from Police in summer – 7.71% and the smallest from Szczecin in autumn – 2.89%. In waste supplied from Szczecin, the content of plastics in this fraction was lower than that in waste from Police and Trzebież. There were no statistically significant interactions found between the season and/or the size of the agglomeration in which waste was generated and the share of particular morphological components.

Given the average content of particular morphological components in the fraction of > 80 mm in diameter (Tab. 2), the classification is as follows: plastics (29.32%), paper and cardboard (24.49%), organic components (14.65%), textile (10.88%), glass (4.06%), sanitary waste (6.06%), other mineral (3.39%), Ø <10 mm (2.89%), metals (2.87%), wood (1.38%). Also for this fraction, there were no statistically significant interactions between the content of particular morphological components and the size of the agglomeration or season of waste generation. Plastics represented the greatest share of the waste in this fraction. However, the smallest share of plastics in this fraction was found for municipal waste supplied in summer from Szczecin – 23.96%, and the greatest in waste supplied in spring from Trzebież – 36.90%.

The study also identified a high share of paper and cardboard. The amount of paper and cardboard was the highest in the group of waste supplied from Szczecin – 29.99%, and the smallest content of these components in the fraction of > 80 mm was found for waste from Trzebież – 17.46%. The maximum content of paper and cardboard was found in the fraction of > 80 mm selected from waste supplied in autumn from Szczecin (38.60%), whereas the smallest was found in waste supplied in summer from Trzebież (15.11%). According to Leikam and Stegmann [26] in fraction > 80 mm, the share of materials of high calorific value (paper and plastics) amounts to almost 70%. In own studies, the share was found to be in the range of 46.1 to 63.4% (on average, 53.8%). The total share of biodegradable waste (organic, paper and cardboard, wood) in the fraction of 20-80 mm in diameter was, on average, approx. 60% of the mass waste, whereas in the fraction > 80 mm approx. 40%. Comparable content of biodegradable waste in fractions selected in MBT installation in Siedliska (Poland) was identified by Den Boer and Jędrczak [6], amounting to, on average: fraction 20-80 mm – 86.6%, >80 mm – 41.5%. Variability of the share of biodegradable waste in fractions depending on the season is also indicated by Primus, Rosik-Dulewska [41]. According to the authors, the oversize fraction selected in three MBT plants in Poland contained the following share of biodegradable waste: spring – 30.5%, summer – 48.2%, autumn – 49.6%, winter – 41.5% [41]. Similar variability was also identified in own studies, with the content of biodegradable waste in the oversize fraction in spring 54,15%, summer 57.61%, autumn 57,71% and winter 51.22%.

As is demonstrated by the study and the adopted methodology, from 50.1% of biodegradable waste in the case of MSW supplied to the plant in Szczecin to 57.8% of MSW generated in Police undergoes the composting process (Fig. 4). Plavac et al. [36] indicate that the use of sieves with mesh size of 80 mm allows separation of approx. 63% biodegradable waste for further treatment. Soboniak and Jurand [44] estimate the share of biodegradable waste in the fraction of 0-80 mm to be more than 80% of their amount in MSW. As is stipulated by Leikam and Stegmann [26], the use of mesh sieve of 80 mm in the process of mechanical separation of waste allows the separation of 90% biodegradable waste in the undersize fraction. However Den Boer And Jędrczak [6] point to the fact that bio-waste is mainly found in the fraction of 20-40 mm in diameter, and only to a lesser extent in the fraction of 40-80 mm. High variability in the amount of treated biodegradable waste (OBT) was also found with respect to seasons in a year (Fig. 4).

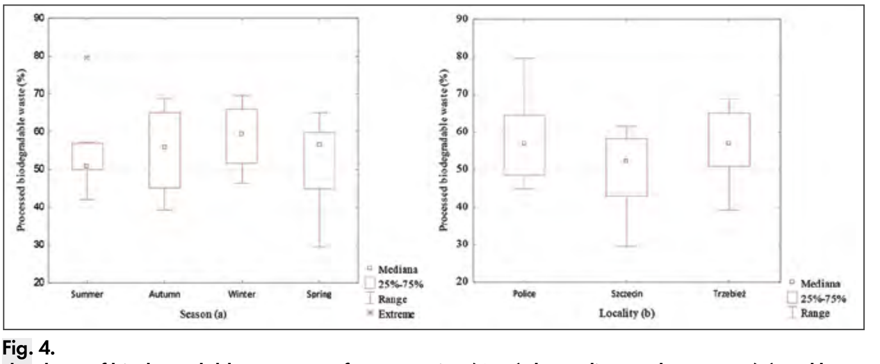


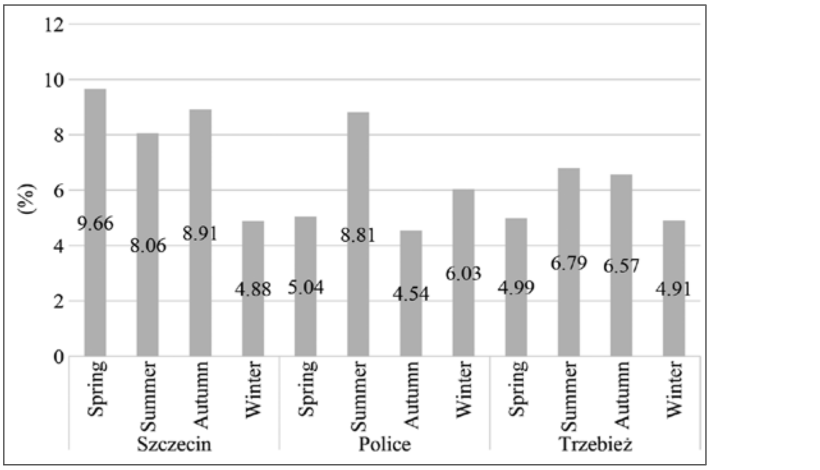
Fig. 4.
The share of biodegradable waste sent for processing (OBP) depending on the season (a) and locality (b)
Ryc. 4. Udział odpadów biodegradowalnych kierowanych do przetworzenia (OBP) w zależności od pory roku (a) i miejscowości (b)

The highest percentage of treated biodegradable waste (OBP) was identified for the winter season (Fig. 4). Until the waste incineration plant in Szczecin became fully operational, the remaining share of biodegradable components (untreated – OBS) had been intended for landfilling (together with fraction > 80 mm), and from mid-2019 to the incineration plant in Szczecin. According to Suchowska-Kisielewicz et al. [48], meeting the indispensable recovery rate requires a series of actions, yet the introduction of waste separation "at source" is the primary and crucial step.

The study by Jędrczak [17] presents the share of organic waste for a fine fraction of < 20 mm separated in MBT installations in Poland to be, on average, 24.6 ± 7.3%, of paper 15.1 ± 4.9% and for textiles 3.8 ± 1.7%. In own study, the focus was on the analysis of the physicochemical properties of the said fraction (Tab. 3). The analysed fraction of 0-20 mm in diameter showed considerable differences in pH depending on a season and locality of waste generation. By far higher pH values measured in water extract were found in the winter season and waste generated in Trzebież. Worth noting is the variability of average content of organic matter in the said fraction depending on the locality of waste generation. A significantly higher loss on ignition, with respect to 0-20 mm fraction, was identified by Jędrczak [17] – on average 38.1 ± 7.2% (from 25.5 to 50.7%). However, Jędrczak et al. [20] found high variability in the organic matter content for two fractions: Ø<10 mm and 10-20 mm, with values of, respectively 29.8 ± 7.1% and 37.3 ± 8.8%. Following Jędrczak [17], the content of organic matter in the fraction of 20-80 mm may show considerable variability between particular MBT installations. The author demonstrated that the content of organic matter in 20-80 mm fraction was lower than the threshold value (30%) for waste intended for biological treatment. Similarly low amounts of organic matter in 0-20 mm fraction was identified in the installation under analysis (Tab. 3). According to Jędrczak [18], in the case of bio-waste treatment, methane fermentation is to become increasingly important due to a series of favourable parameters as compared with composting. The conducted analyses confirm this stipulation as is evidenced by a low, regarding composting, C:N ratio, and optimal C:S ratio for methane fermentation (Tab. 3). This confirms that the fermentation should be applied there instead of the composting processes.

As is presented in the study, the recovery of secondary raw materials (with respect to the total mass of supplied waste) amounts to, on average, 6.60% (Fig. 5).

Fig. 5.
The amount of recyclable materials in the tested MBT installation, taking into account the season and place of production
Rys. 5. Ilość surowców wtórnych w badanej instalacji MBP z uwzględnieniem pory roku i miejsca wytwarzania odpadów



The greatest amount of raw materials was obtained from waste supplied from Szczecin (7.88%), followed by Police (6.11%), and the smallest from waste supplied from Trzebież (5.81%). Based on the available literature on the subject, it can be concluded that in this type of installations, the recovery rate of raw materials only sporadically is given as higher than 10 % [16, 53], Usón et al. [2012]. Dziedzić et al. [8] determine the recovery of raw materials in MBT installation at 5.31%, whereas Tyagia et al. [50] calculate the value to be 11.9%.

Conclusions

On the basis of the studies carried out in ZOiSOK in Leśno Górne, the following can be concluded:

1. The separated fractions of waste 0-20 mm, 20-80 mm, and > 80 mm constitute, respectively, 18.43%, 29.83%, and 50.21% of the municipal waste mass.
2. There were differences in terms of material composition between the analysed fractions. In 0-20 mm fraction, mineral components were predominant, 20-80 mm – biodegradable components, and in > 80 mm – plastics and paper.
3. Within the technological process adopted in the plant, it is possible to separate, on average, approx. 50% of biodegradable fraction from waste supplied to the plant.
4. With respect to the total mass of waste supplied to the plant, in the process adopted therein, less than 7% of raw materials was separated.

Tab. 3. Physicochemical properties of the fraction with a diameter of 0-20 mm
Tab. 3. Właściwości fizykochemiczne frakcji o średnicy 0-20 mm

Season	Locality	pH H_2O	LOI* (%)	Corg ($g \cdot kg^{-1}$)	N tot. ($g \cdot kg^{-1}$)	S ($g \cdot kg^{-1}$)	C:N	C:S
Summer	All	6.86 a	20.7 a**	115.4 a	5.62 a	5.18 a	16.8 a	20.2 a
Spring	All	6.89 a	20.8 a	127.8 a	6.91 a	6.48 a	20.6 a	23.8 a
Winter	All	7.03 ab	21.5 a	138.8 a	7.03 a	7.29 a	20.9 a	34.0 a
Autumn	All	8.25 b	21.9 a	144.7 a	7.08 a	7.63 a	23.8 a	38.4 a
All	Szczecin	6.60 a	19.8 a	121.7 a	5.89 a	4.69 a	17.75 a	21.15 a
All	Trzebież	7.50 ab	21.2 a	136.1 a	6.37 ab	7.24 a	21.73 a	28.13 a
All	Police	7.61 b	23.0 a	137.8 a	7.78 b	8.00 a	21.78 a	38.30 a

* – losses of ignition
** – homogeneous groups

REFERENCES

[1] Beylota A., Vaxelairea S., Zdanevitch I., Auvinetc N., Villeneuvea J. 2015. Life Cycle Assessment of mechanical biological pre-treatment of Municipal Solid Waste: A case study, Waste Management, Vol. 39, May 2015, p. 287-294.

[2] Bezama A., Pablo A., Odorico K., Rodrigo N., Lorber K.E. 2003. Investigations on mechanical biological treatment of waste in South America, Towards more sustainable MSW management strategies, Waste Manag. 2007, 27(2), p. 228-37.

[3] Cimpan C., Maul A., Jansen M., Pretz T., Wenzel H. 2015. Central sorting and recovery of MSW recyclable materials, A review of technological state-of-the-art, cases, practice and implications for materials recycling, Journal of Environmental Management, 2015, 156, p. 181-199.

[4] Cimpan C., Wenzel H. 2013. Energy implications of mechanical and mechanical–biological treatment compared to direct waste-to-energy, Waste Management 33, p. 1648–1658.

[5] De Morais Limaa P., Colvero D.A., Gomes A.P., Wenzel H., Schalch V., Cimpan C. 2018. Environmental assessment of existing and alternative options for management of municipal solid waste in Brazil, Waste Management 78, p. 857-870. DOI:10.1016/j.wasman.2018.07.007

[6] Den Boer E., Jędrczak A. 2017. Performance of mechanical biological treatment of residual municipal waste in Poland, E3S Web of Conferences 22, 00020, DOI: 10.1051/e3sconf/20172200020.

[7] Di Foggia G., Beccarello M. 2021. Designing waste management systems to meet circular economy goals, The Italian case, Sustainable Production and Consumption, 26, p. 1074–1083.

[8] Dziedzic K., Łapczyńska-Kordon B., Malinowski M., Niemiec M., Sikora J. 2015. Impact of aerobic biostabilisation and biodrying process of municipal solid waste on minimisation of waste, Chemical and Process Engineering 36 (2), p. 125-133.

[9] Ec Directive 1999. Council Directive 1999/31/EC of the Council of the European Union on the landfill of waste, Official Journal of the European Communities, L 182/1, 16.07.1999, Luxembourg.

[10] Gronba-Chyła A. 2022. The noise exposure, at a municipal mechanical-biological waste treat-

ment plant. Instal 2/2022, p. 16-18. DOI 10.36119/15.2022.2.3

[11] Grzesik K., Malinowski M. 2017. Life Cycle Assessment of Mechanical–Biological Treatment of Mixed Municipal Waste, Environmental Engineering Science Vol. 34, No. 3. Doi.org/10.1089/ees.2016.0284.

[12] GUS 2010. Ochrona środowiska 2010, p. 1-553.

[13] GUS 2020. Ochrona środowiska 2020, p. 1-190.

[14] GUS 2023. Ochrona środowiska 2021, p. 1-188.

[15] Haytham S. 2019. Reducing Methane Emissions from Municipal Solid Waste Landfills by Using Mechanical, Biological Treatment (Case Study Wady Alhaddeh (MBT) Plant, in Tartous), Waste Management in MENA Regions, s. 241-258.

[16] Jędrczak A. (2018b), Composting and fermentation of biowaste – advantages and disadvantages of processes. Civil And Environmental Engineering Reports. Civil and Environmental Engineering Report, 28 (4), p. 071-087, DOI:10.2478/ceer-2018-0052.

[17] Jędrczak A. 2008. Biologiczne przetwarzanie odpadów, PWN, Warszawa 2008, p. 1-468.

[18] Jędrczak A. 2018a. Properties of the Organic Fraction Directed to Biostabilization in MBT Installations During the Heating Season, Civil and Environmental Engineering Report, 28 (3), p. 065-078, DOI: 10.2478/ceer-2018-0035.

[19] Jędrczak A., Haziak K. 2001. Skład morfologiczny biofrakcji wydzielanej z odpadów komunalnych przez mechaniczne sortowanie, Systemy gospodarki odpadami, Mat. IV Międzynar. Forum Gospodarki Odpadami. Poznań-Piła, 27-30 maja 2001, p. 369-381.

[20] Jędrczak A., Myszograj S., Połomka J. 2020. The Composition and Properties of Polish Waste Focused on Biostabilisation in MBT Plants during the Heating Season. Energies, 13 (5), p. 1072, DOI:10.3390/en13051072.

[21] Kissera J., Wirtha M., De Gussemeb B., Van Eekertd M., Zeemane G., Schoenborn A., Vinnerås B., Finger C.D., , Repinc S., Bulc T.G., Bani A., Pavlova D., Staicu L.C., Atasoy M., Cetecioglu Z., Kokko M., Haznedaroglu B.Z., Hansen J., Istenič D., Canga E., Malamis S., Camilleri-Fenechu M., Beesley L. 2020. A review of nature-based solutions for resource recovery in cities, Blue-Green Systems 2 (1), p. 138–172, DOI: 10.2166/bgs.2020.930.

[22] Koci V., Trecakova T. 2011. Mixed municipal waste management in the Czech Republic from the point of view of the LCA method, The International Journal of Life Cycle Assessment, Vol. 16, p. 113–124.

[23] Kruszyńska E., Kaliński L. 2001. Gospodarka odpadami komunalnymi w gminie Police. Kalendarium z przygotowania i realizacji budowy Zakładu Odzysku i Składowania Odpadów Komunalnych w Leśnie Górnym, Międzynarodowa konferencja Gospodarka Odpadami Komunalnymi – Doświadczenia Polskie i Europejskie, Police, 28-29 września 2001, p. 83-92.

[24] Kühle-Weidemeier M., Langer U., Hohmann F. 2007. Plants for Mechanical-Biological Waste Treatment, Summary of the Final Report, Environmental research program of the Federal Ministry of Environment, Environmental Protection and Nuclear Safety, Waste Management Federal Environmental Agency, Germany, June 2007, p. 1-17.

[25] Kulhawik K. 2016. Direct landfill disposal versus Mechanical Biological Treatment (MBT), Environmental Protection and Natural Resources, Vol. 27, No. 3(69), p. 19-23.

[26] Leikam K., Stegmann R. 1999. Influence of mechanical-biological pretreatment of municipal solid waste on landfill behaviour, Waste Management & Research 1999 (17), p. 424-429.

[27] Maćków I., Szpadt R., Chojnacka A., Szypryt A. 2005. Wyniki wstępnych badań przetwarzania odpadów w ZPOK Lipówka II w Dąbrowie Górniczej, Efektywność gospodarowania odpadami, Materiały VI Międzynarodowego Forum Gospodarki Odpadami, Poznań – Licheń Stary maj/czerwiec 2005, Wyd. Futura i PZITS, p. 595-607.

[28] Makovetska Y., Omelianenko T., Omelchenko A. 2021. Prospects for environmentally safe mechanical biological treatment of municipal solid waste in Ukraine, E3S Web of Conferences 255 (3-4), p. 01002 ISCMEE 2021, Doi.org/10.1051/e3sconf/202125501002.

[29] Meller E., Malinowski R., Nędzusiak J. 2007b. Preliminary studies on material composition of residue obtained after municipal waste mechanical segregation in Leśno Górne, Prace Instytutu Nafty i Gazu 145, p. 177–182.

[30] Meller E., Sammel A., Suchenia M. 2007a. Skład morfologiczny i właściwości nawozowe kompostów wytwarzanych z frakcji organicznej odpadów komunalnych w Zakładzie Utylizacji Odpadów w Gorzowie Wielkopolskim, Zesz. Nauk. Uniwersytetu Zielonogórskiego, Nr 133, Inżynieria Środowiska 13, p. 311-318.

[31] Münnich K., Mahler C.F., Fricke K. 2006. Pilot project of mechanical-biological treatment of waste in Brazil, Waste Management, 26(2), p. 150-157.

[32] Nelles M., Morscheck G., Grünes J. 2012. MBT in Germany and Europe – Development, Status and Outlook, International 9th ASA Recycling Days MBT as a Supplier of Secondary Raw Materials, 29th of February – 2nd of March 2012, Germany, p. 1-16.

[33] Nowak M., Stelmach S., Sajdak M. 2019. Significant waste properties in terms of applicability in the power industry, Environment Protection Engineering Vol. 45, No. 4, DOI: 10.37190/epe190406.

[34] Pawlak B., Gaca J. 2006. Standardy gospodarki odpadami i ich realizacja na podstawie doświadczeń Firmy Remondis Bydgoszcz, Gospodarka odpadami komunalnymi, Praca zbiorowa pod red. Kazimierza Szymańskiego. Koszalin 2006, p. 13-25.

[35] Pires A., Martinho G., Chang N.B. 2011. Solid waste management in European countries, A review of system analysis techniques, J. Environ. Manage., 92, 4, s. 1033.

[36] Plavac B., Sutlović I., Filipan V. 2016. Flexibility of mechanical biological treatment plants, Tehnički Vjesnik 23, 6, p. 1871-1877.

[37] Plavac B., Filipan V., Sutlović I., Svetičič J. 2017. Sustainable waste management with mechanical biological treatment and energy utilization, Tehnički vjesnik 24, 4, p. 1283-1289.

[38] Połomka J., Jędrczak A. 2019. Efficiency of waste processing in the MBT system. Waste Management, Vol. 96, 1, p. 9-14.

[39] Polska w liczbach [https://www.polskawliczbach.pl].

[40] Primus A., Chmielniak T., Rosik-Dulewska C. 2021. Concepts of energy use of municipal solid waste, Archives of Environmental Protection Vol. 47, No. 2, p. 70–80.

[41] Primus A., Rosik-Dulewska Cz. 2018. Potencjał paliwowy frakcji nadsitowej odpadów komunalnych i jego rola w krajowym modelu gospodarki odpadami, Zeszyty Naukowe Instytutu Gospodarki Surowcami Mineralnymi i Energią Polskiej Akademii Nauk, nr 105, p. 121–134.

[42] Schiopu A.-M., Gavrilescu M. 2010. Municipal solid waste landfilling and treatment of resulting liquid effluents, Environmental Engineering and Management Journal, 9, p. 993-1019.

[43] Siemiątkowski G. 2014. Ocena efektywności procesu mechaniczno-biologicznego przetwarzania odpadów z nawilżaniem i bez nawilżania, Prace Instytutu Ceramiki i Materiałów Budowlanych [ICiMB] 2014, nr 18, p. 108–132.

[44] Soboniak E., Jurand J. 2015. Proces mechaniczno-biologicznego przetwarzania zmieszanych odpadów komunalnych wedle nowych przepisów w instalacji Regionalnego Zakładu Zagospodarowania Odpadów w Sobuczynie, Inżynieria i Ochrona Środowiska, t. 18, nr 4, p. 483-495.

[45] Sokołowska E., Gaca J. 2006. Problemy eksploatacji kompleksu utylizacji odpadów w Bydgoszczy, Gospodarka odpadami komunalnymi, Praca zbiorowa pod red. Kazimierza Szymańskiego. Koszalin 2006, p. 27-36.

[46] Soyez K., Plickert S. 2002. Mechanical-Biological Pre-Treatment of Waste, State of the Art and Potentials of Biotechnology, Acta Biotechnol. 22, 3-4, p. 271-284.

[47] Stefaniak A. 2001. Założenia projektowe i zakładane efekty ekologiczne Zakładu Odzysku i Składowania Odpadów w Leśnie Górnym jako podstawowego elementu sprawnie funkcjonującego systemu gospodarki odpadami w gminie Police, Międzynarodowa Konferencja Gospodarka Odpadami Komunalnymi – Doświadczenia Polskie i Europejskie, Police, 28-29 września 2001, p. 93-117.

[48] Suchowska-Kisielewicz M., Sadecka Z., Myszograj S., Płuciennik E. (2017), Mechanical-biological treatment of municipal solid waste in Poland – Case studies, Environmental Engineering and Management Journal February 2017, Vol.16, No. 2, p. 481-491.

[49] Trulli, E., Ferronato, N., Torretta, V., Piscitelli, M., Masi, S., Mancini, I. 2018. Sustainable mechanical biological treatment of solid waste in urbanized areas with low recycling rates. Waste Manag. 71, p. 556–564.

[50] Tyagia V.K., Kapoorb A., Arorac P., Banud J.R., Dase S., Pipesha S., Kazmia A.A. 2021. Mechanical-biological treatment of municipal solid waste, Case study of 100 TPD Goa plant, India, Journal of Environmental Management Volume 292, 15 August 2021, 112741, Doi.org/10.1016/j.jenvman.2021.112741.

[51] US 2016. Warunki życia mieszkańców w województwie zachodniopomorskim w latach 2012-2014, https://szczecin.stat.gov.pl/publikacje-i--foldery/warunki-zycia/warunki-zycia-ludnosci-w-wojewodztwie-zachodniopomorskim-w-latach-2012-2014,1,3.html.

[52] US 2018. Ludność, ruch naturalny i migracje w województwie zachodniopomorskim w 2017 r., https://szczecin.stat.gov.pl/publikacje-i-foldery/ludnosc/ludnosc-ruch-naturalny-i-migracje-w-wojewodztwie-zachodniopomorskim-w-2017-r.

[53] Usón A.A., Ferreira G., Vásquez D.Z., Bribián I.Z., Sastresa E.L. 2012. Estimation of the energy content of the residual fraction refused by MBT plants, A case study in Zaragoza's MBT plant, Journal of Cleaner Production, Vol. 20, Issue 1, January 2012, p. 38–46.

[54] Velis C.A., Longhurst P.J., Drew G.H. Smith R., Pollard S.J.T. 2009. Biodrying for mechanical--biological treatment of wastes, A review of process science and engineering, Bioresource Technology, Vol. 100, Issue 11, June 2009, p. 2747-2761.

[55] Wiśniewska M., Lelicińska-Serafin K. 2019. The role and effectiveness of the MBT installation in Poland based on selected examples, Civil and Environmental Engineering Reports, CEER 2019, 29 (2), p. 001-012.

[56] Wiśniewska M., Lelicińska-Serafn K. 2018. The effectiveness of the mechanical treatment of municipal waste using the example of a selected installation, E3S Web of Conferences 45, 00102 (2018), DOI.org/10.1051/e3sconf/20184500102.

[57] Zhang Z., Pan X., Zhang J., Xu H. 2020. Effect of Particle Size on the Hydraulic Characteristics of Mechanically and Biologically Treated Waste, Hindawi Advances in Civil Engineering Volume 2020, DOI.org/10.1155/2020/8888550.