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The Composition and Properties of Polish Waste Focused on Biostabilisation in MBT Plants during the Heating Season

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Received: 15 January 2020; Accepted: 25 February 2020; Published: 1 March 2020



Abstract: This paper presents the morphological composition of fraction <80 mm, being separated from municipal solid waste (MSW) and delivered in the winter season to the 21 mechanical-biological treatment (MBT) plants throughout several regions of Poland. This fraction is hereinafter referred to as OFMSW (organic fraction of municipal solid waste). Their properties are considered while using parameters such as: moisture, loss on ignition and organic carbon content, as well as moisture and loss on ignition of screen fractions <10 mm and 10–20 mm that are found within. The main aim of this research was to test waste from 21 industrial installations, and to prove that ash content (fine fractions) in waste intended for MBT was about 1/3 of the mass of overall OFMSW mass. These quantities exceed the limits that were approved for the correct operation of MBT installations. The effect of their high content in MSW during the heating season is low moisture (from 25.4% to 58.3%) and the low loss on ignition (from 23.1% to 54.3% DM [dry matter]), which might even determine their inaptness in terms of biological treatment and incineration. The <10 mm fraction contained on average 31.7 ± 7.5% of water and showed a loss on ignition of 29.8 ± 7.1% DM. These values for the 10–20 mm fraction were respectively: 36.6 ± 12.5% DM and 37.3 ± 8.8% DM, respectively.

Keywords: municipal solid waste; combustion wastes; ash; winter season

1. Introduction

Combustion wastes generated in household furnaces pose a significant environmental problem. In Poland, the number of households that are heated using solid fuels is estimated at over three-million.

For the manual feed, the round and rectangular boilers and furnaces of these households, from 10 to 13 million tonnes of solid fuels are burnt, including various types and sizes of coal biomasses in the form of firewood and pellets. This heating method generates waste in the form of slags and ashes, to an amount that exceeds 2.5 million tonnes per year [1–3].

In Poland, independent local governments are responsible for the handling of combustion wastes that were produced by households. Some communes organise the collection of ash and slag from residents—it usually takes place once a month during the winter season; that is, from October even up to the end of April. Ash can also be disposed of at to local Selective Collection Points for Municipal Waste. However, the majority of local self-governments still allow for residents to throw their furnace waste into containers for mixed municipal solid waste (MSW). In 2015, combustion wastes accounted for approximately 23% of the total amount of municipal waste produced (approximately 10.9 million/year). While considering that these wastes are mainly generated during the heating season, their share in the MSW mass in this period may reach up to 40%. In Poland, akin to many other EU countries,

the technology for the mechanical and biological treatment of waste (MBT) plays a key role in achieving European objectives in terms of reducing the amount of biodegradable waste that is disposed of in landfills [4–6]. At the end of 2016, were recorded 192 MBT plants in Poland with a processing capacity of approximately 11 million Mg of waste per year [7]. Increasing the targets that have been set out under waste directives [8–10] concerning reusing and recycling of municipal and packaging waste and municipal waste storage (up to <10% of their total generated volume, as of 1st January, 2036) will practically remove MBT technology from the market [11]. The environmental impact of different waste management scenarios shows that the recycling process provides growing environmental investments, as well as for energy recycling processes. These investments are higher if the energy recovery shows higher yields for the energy recovery process [12,13]. The conditions that must be met in order for the waste to lose its "waste" status and thus become a fuel are therefore of key importance [13].

Ashes that are produced from waste and coal incineration in household furnaces found in MSW pose a technical problem for MBT plants and waste incineration plants [14–16]. In MBT plants, the entire amount of combustion wastes (ashes, fraction <20 mm) pass into the organic fraction of municipal solid waste (OFMSW), and are then subject to composting or methane fermentation. The high content of these wastes in OFMSW adversely impacts the key parameters determining its bio-stabilisation process, such as: organic matter content, particle size, moisture content, C:N ratio, and non-compostable components content [17–23]. Ashes that are produced from incinerating waste with a high alkaline compounds content are characterized by a much greater tendency to form deposits than ashes from coal combustion. The lower melting temperature makes the ash layer (partially molten slag) that is found on the pipes more prone to new particles deposits. There is therefore a rapid increase in sludge, faster than when burning coal alone, as well as a loss in heat transfer. This mechanism is particularly visible in the boilers' high-temperature elements. The mineralogical characteristics of coal have a major impact on the slag ash propensity; therefore, slag coals should be avoided in boilers where waste is incinerated [15–17].

Problems that result from the presence of combustion wastes in MSW are unheard of in most European countries. It results from the specific structure of energy consumption in national households, as compared to other European Union countries (Figure 1). The total production of hard coal in the EU-28 was 100.3 Mt in 2015. Poland was the largest producer with 72.2 Mt, followed by the United Kingdom with 8.7 Mt, the Czech Republic with 8.2 Mt, Germany with 6.7 Mt, Spain with 3.0 Mt, and Romania with 1.5 Mt [24].

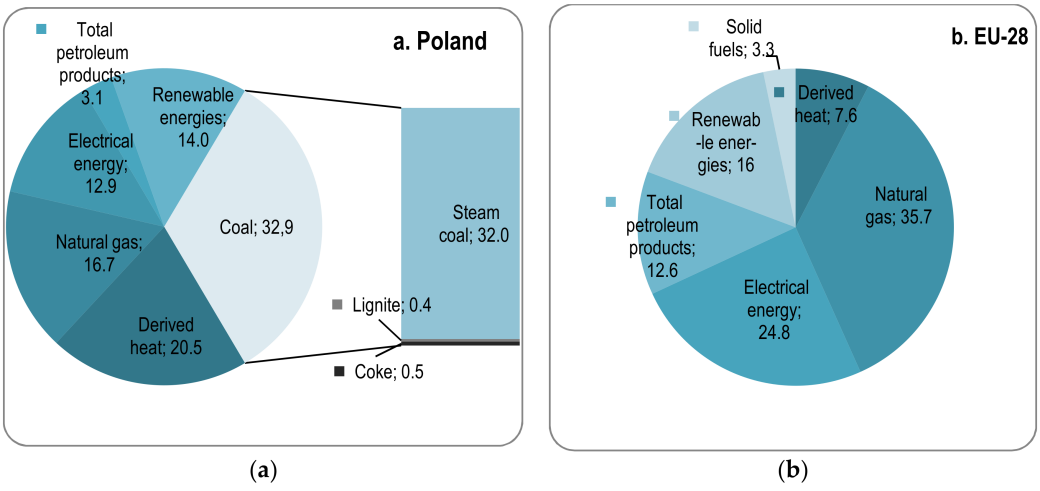


Figure 1. Structure of energy consumption in households by individual energy carriers in 2015, (**a**) in Poland and (**b**) in the EU-28, (percentage share) [24].

No other European country uses as much solid fuels to satisfy the energy demand in the housing sector. Over 86% of the coal burned in European countries' households can be attributed to Poland.

Outside of Poland, a high share of solid fuels in household energy generation in 2015 was also recorded in Ireland, the Czech Republic, and Bulgaria (Figure 2) [24].

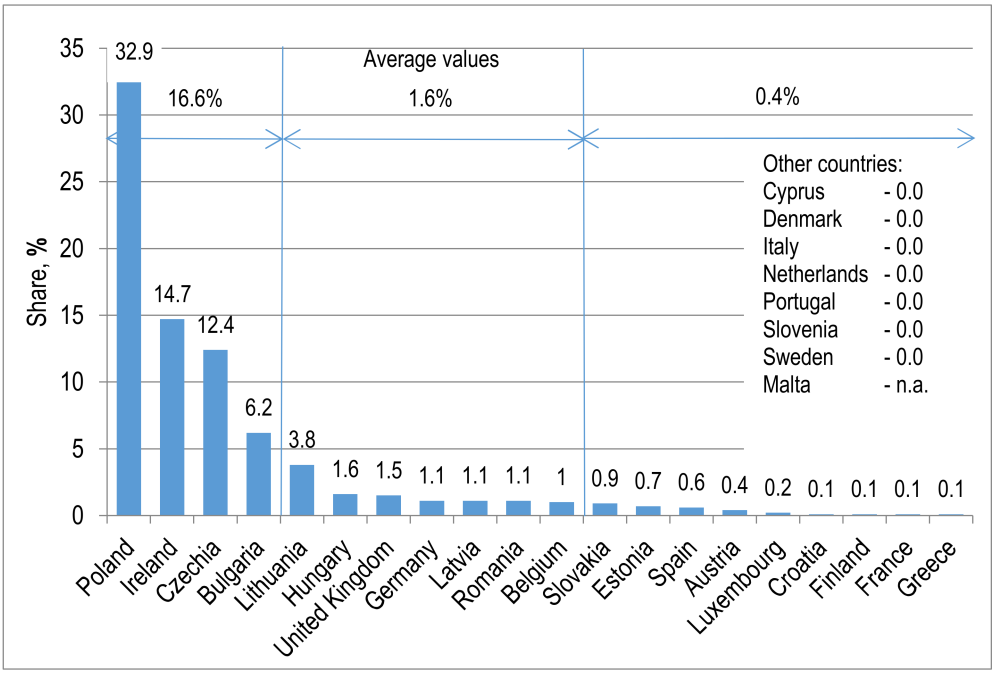


Figure 2. Share of solid fuels to the final residential energy consumption in UE28, expressed in per cent of the total consumption in 2015 (Data from [24]).

In addition, in Poland, many citizens unfortunately tempted to burn their rubbish in solid fuel boilers. From the average user's point of view, burning waste provides "free" heat, and a solution to their rubbish problems. By saving on fuel purchase costs and waste collection fees, they fail to consider the environmental and human health aspects [11]. The United Nations Climate Change Conference in Madrid (COP25, 2019) strongly recommended that cities and that regions should play a key role in the fight against global warming. Locally reducing coal burning will not only lower air pollution and reduce the greenhouse effect, but also improve the biological treatment options for municipal waste, as there will be no mineral ashes present in mixed waste.

In the professional literature there is a lack of widely documented data concerning the morphological composition of OFMSW (<80 mm) subject to biological treatment in MBT plants, and in particular, a lack of information on the properties of these wastes during the heating season, when combustion wastes are produced in household furnaces and disposed of within the mixed municipal solid waste.

The article presents the morphological composition, moisture, loss on ignition (LOI), and total organic carbon content (TOC) of <80 mm fraction separated from MSW, delivered to 21 MBT plants in Poland from January to February (the winter season). The content of screen fractions at <10 mm and 10–20 mm, their moisture, and loss on ignition, as well as the impact of these parameters on the OFMSW properties were also determined [25].

The data presented in this article provides additional knowledge regarding the quality of OFMSW during the heating season, as well as on their suitability for biological treatment in MBT plants.

2. Materials and Methods

The waste that was used in this study was OFMSW (sub-screen fraction <80 mm) separated in the mechanical part of the MBT plants from MSW delivered to these plants during the winter

season (January–February), intended for biological treatment. The representative samples came from 21 full-size MBT plants in Poland that use different kinds of waste treatment technologies (Table 1).

Table 1. Mechanical and biological treatment of waste (MBT) systems covered by research.

System	Designed Operation Capacity [1000 Mg/year]		Intensive Phase of Bio-Stabilization		Maturation in Windrows, Days
	Mechanical Part	Biological Part	Reactor	Duration, Days	
MBT1	70	18	Meso-philic dry fermentation of fraction <60 mm, after removal of Fe and hard particles	25	20
MBT2	50	30	Thermo-philic dry fermentation of fraction <40 mm without Fe and 40–80 mm after removal of Fe and hard particles	26	21
MBT3	210	95	Reinforced concrete cells in the hall, with forced aeration and waste transfer	24	42
MBT4	59	19		28	33
MBT5	80	33		25	41
MBT6	65	32.5	Reinforced concrete reactors with reinforced concrete roofing	64	20
MBT7	45	26		29	42
MBT8	70	16		35	24
MBT9	157	100		24	33
MBT10	100	48		20	20
MBT11	80	21	Reinforced concrete reactors with reinforced plastic roofing	23	19
MBT12	72	16		29	55
MBT13	27	13		27	41
MBT14	60	30	Cells with gates and roofs covered with GORE®laminates	30	47
MBT15	85	28		22	63
MBT16	65	20	Steel reactors (containers)	18	35
MBT17	50	25	No reactor, the entire process is carried out in windrows within an open area	-	134
MBT18	150	75	Foil sleeves	51	-
MBT19	44	16		50	
MBT20	60	26	Windrows with GORE®laminates	56	20
MBT21	150	60	Bio-drying in piles in the hall	25	-

The OFMSW bulk samples were prepared by taking 10 incremental samples with a minimum mass of 10 kg each, from the plant lines at the location of their manufacture, at regular intervals. Three samples of MSW and OFMSW were collected from each plant. The research used the modified European SWA Tool method that was developed by Jędrczak and Szpadt [26], which is recommended in Poland by the National Fund for Environmental Protection for the purposes of investment projects in the waste sector. The main categories of waste were adopted in accordance with the SWA-Tool methodology [27]. In the sieve analysis, sieves were used to manually separate the waste fraction. These consisted of boxes measuring 0.66 m × 0.66 m with side heights from 0.15 to 0.20 m, (the sieves were square). The testing laboratory is accredited in the field of waste sampling, sieve and morphological analysis, as well as waste technological properties.

The screen and material composition of 20–80 mm screen fractions was determined on-site. The screen analysis included separating the waste sample into fractions: <10 mm, 10–20 mm, and 20–80 mm. The scope of material analysis included dividing 20–80 mm fraction into components: organic (food waste, green and garden waste, wood, and other organic waste types), paper, plastics, glass, textiles, metals, hazardous, composite, inert, and others.

The samples of sorted materials were directly transported to the laboratory, where they were kept for a maximum of 24 h at the temperature of 4 °C to delay biological activity. In the laboratory, following their proper homogenisation, representative samples were taken from the provided samples and prepared for laboratory analysis, including the indications: moisture, dry matter (DM) loss on

ignition (LOI), and total organic carbon content (TOC) (in duplicate). Material, physical, and chemical analyses were carried out on the waste in accordance with the standards and procedures that were in place at the accredited laboratory [28–30].

3. Results and Discussion

3.1. The Morphological Composition of OFMSW

Figure 3 shows the average morphological composition of <80 mm fraction that was separated from MSW samples intended for biological treatment in 21 MBT plants. Results were expressed as a percentage of the total wet weight. In the MSW fraction of <80 mm intended for the bio-processing step of the MBT system, "organic waste" was the component with the largest share. Its share was, on average, 27.9 ± 10.5%, including the share of food waste of 10.5 ± 6.7%, green and garden waste of 16.6 ± 9.9%, and wood of 0.6 ± 0.9%.

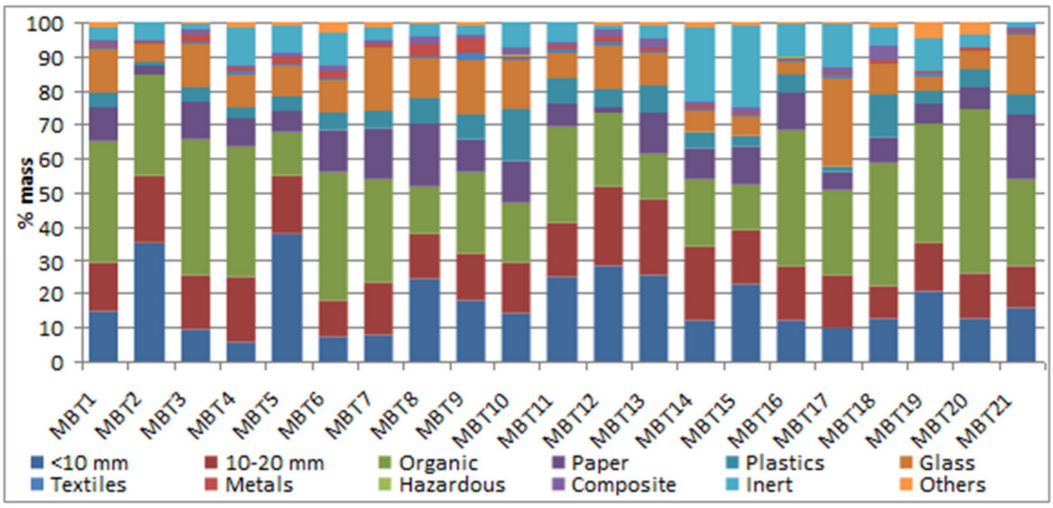


Figure 3. The average morphological composition of the sub-screen fraction (0-80 mm) from 21 MBT plants included in this research.

In OFMSW, fine fractions (<20 mm) also occurred in large quantities, with an average 33.7 ± 10.8%. In three plants, the share of this fraction that was found in the waste was above 50%, and in two other plants, it was above 40%. In these waste samples, 53% to 69% of the weight of <20 mm fraction was made up from the ash fraction (<10 mm) (Figure 4).

The total share of the paper and cardboard, plastic, glass, and metal fractions that were found in OFMSW varied greatly and ranged from 9.2% to 43.0%. On average, the OFMSW contained 27.6 ± 9.8% of these components, with a variation coefficient of 34%. In four of the plants, their share was more than 40%: MBT21 (43.0%), MBT10 (42.8%), MBT8 (41.1%), and MBT7 (40.1%). However, in two of the plants it was extremely low: MBT2 (9.2%) and MBT19 (14.4%). The factors determining such differences were: the efficiency of selective waste collection and the structure of regions with the share of cities and villages.

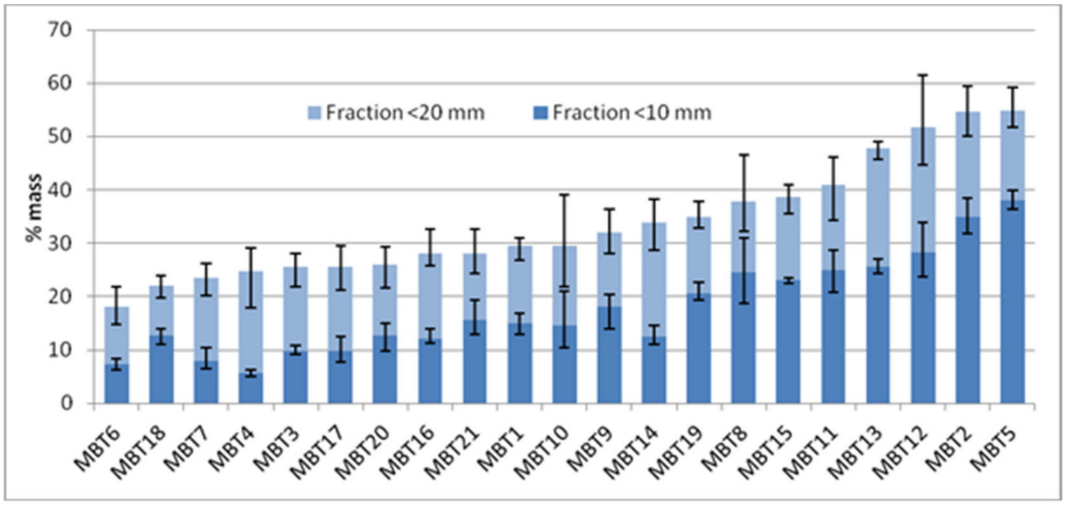


Figure 4. The share of <10 mm and <20 mm fractions in a mass of <80 mm sub-screen fraction taken from the plants included in this research (average value - bars, min and max values - whiskers).

3.2. Moisture and Values of Loss on Ignition and Total Organic Carbon Content in OFMSW

Figure 5 presents the moisture and values of loss on ignition and total organic carbon content in sub-screen fractions separated from mixed municipal solid waste.

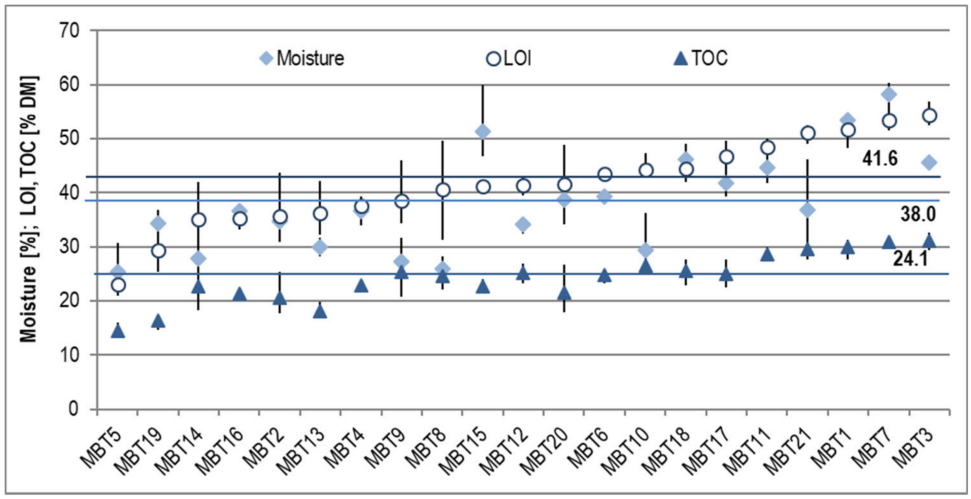


Figure 5. Average values of moisture and content of organic substances (LOI) and total organic carbon (TOC) of organic fraction of municipal solid waste (OFMSW) samples intended for biological treatment in the plants covered by the research (average value - points, min and max values - whiskers).

The OFMSW contained an average of 38.0 ± 9.3% of water (from 25.4% to 58.3%). The average moisture content, which was higher than 50%, considered to be optimal for biological treatment [11,17,18], indicated sub-screen fractions collected in three plants. Wastes from other plants required irrigation prior to biological treatment. Very low moisture for OFMSW, below 30%, was found in waste from six MBT plants.

The average value of the loss on ignition was 41.6 ± 7.9% DM (from 23.1% to 54.3% DM). The organic carbon content in OFMSW ranged from 14.3% to 31.2% DM, with an average value of 24.1 ± 4.6% DM.

The threshold value of the share of organic matter in waste, which enables biological treatment, is assumed to be a loss on ignition of more than 30% [18]. The OFMSW from two plants was not suitable for biological treatment, and it indicated loss on ignition of over 50% DM from four of the plants. There was no relationship between loss on ignition and moisture. The correlation index (R2) for this relationship is low, amounting to 0.53. In turn, the linear relationship between the loss on ignition and the content of organic carbon content shows a very high correlation index (R2)-0.91.

3.3. Moisture and Loss on Ignition Values of Fine Fractions

Figures 6 and 7 present moisture and loss on ignition and organic carbon content values in the 0–10 mm and 10–20 mm fractions.

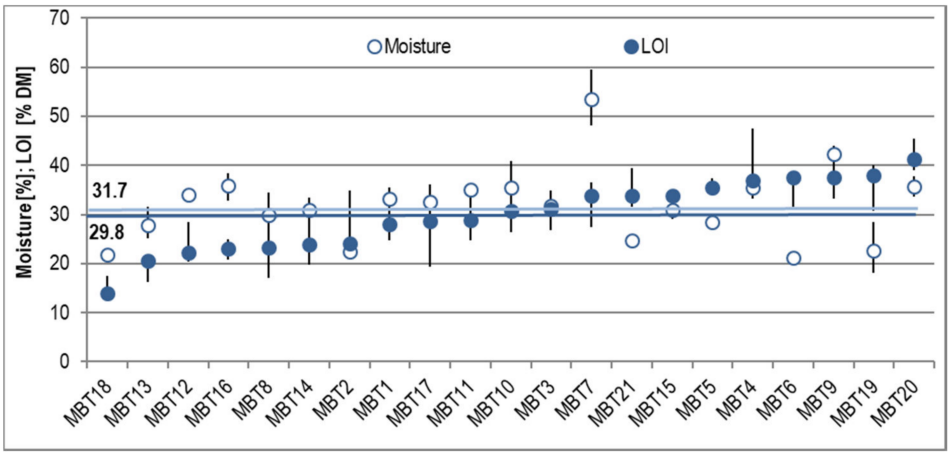


Figure 6. Average values of moisture and organic substances content (LOI) of 0–10 mm fraction from the plants covered by this research (average value-points, min and max values-whiskers).

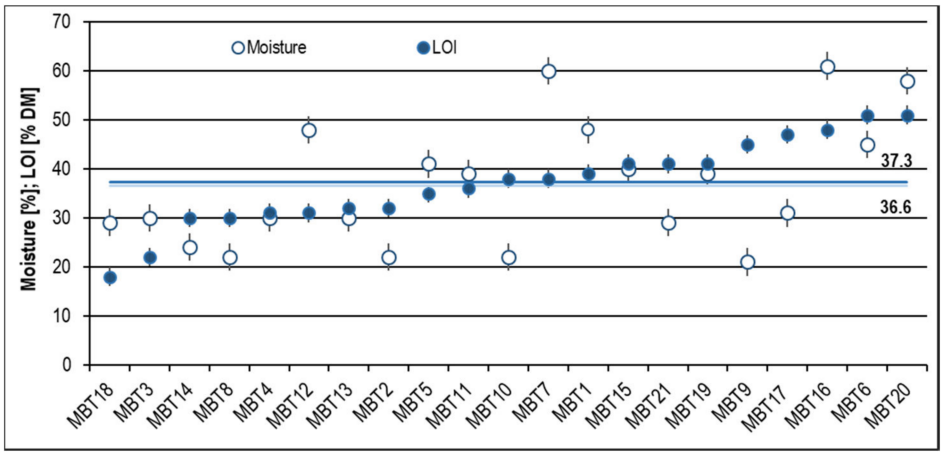


Figure 7. Average values of moisture and organic substances content (LOI) of 10–20 mm fraction from the plants covered by this research (average value-points, min and max values-whiskers).

The <10 mm fraction contained, on average, 31.7 ± 7.5% of water (from 21.1 to 53.6%). The average value of loss on ignition was 29.8 ± 7.1% DM (from 14.0 to 41.3% DM).

The 10–20 mm fraction contained, on average, 36.6 ± 12.5% of water (from 21.2% to 61.2%). The average value of loss on ignition was 37.3 ± 8.8% DM (from 17.2% to 51.5% DM). The 10–20 mm fraction contained more water and showed a higher loss on ignition than the <10 mm fraction.

There was no significant relationship between the moisture of these fractions and the share of fractions <20 mm, even though a significant relationship between these parameters was expected. The increase in the amount of dry ashes (fraction <20 mm) in mixed solid waste showed the relationship with the total moisture content of the waste (Figure 8).

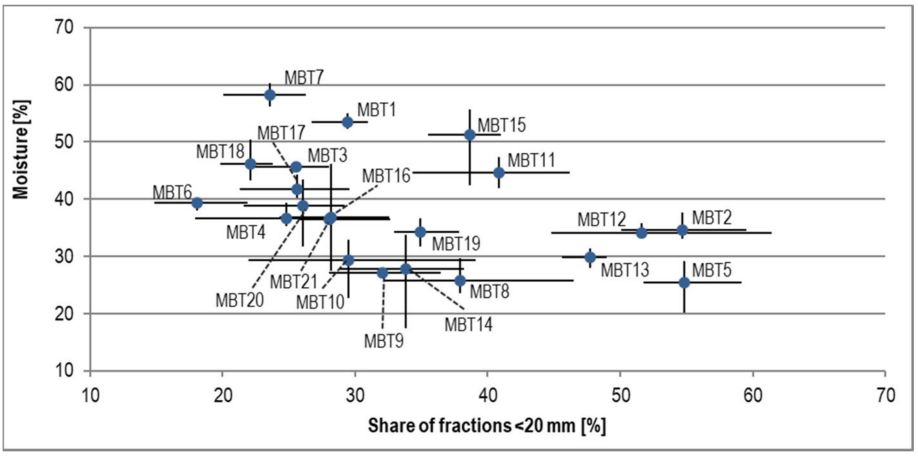


Figure 8. Relationship between the moisture of OFMSW and the fine fractions content (0–20 mm).

4. Conclusions

In the MSW-fraction that was intended for the bio-processing stage of MBT (<80 mm), the share of material classed as "organic waste" was the largest. Its share was, on average, 27.9 ± 10.5%, of which the share of food waste was on average 10.5 ± 6.7%, green and garden waste of 16.6 ± 9.9%, and of wood 0.6 ± 0.9%. The main aim of the research was to test waste from 21 industrial installations in various regions of Poland, and prove that the ash content (fine fractions) that was found in waste intended for MBT was about 1/3 of the overall MSW mass. These quantities go beyond the limits approved for the correct operation of MBT installations. In three of the studied plants, this fraction was the dominating component (share > 50%), and in 80% of plants its share was more than 25% of the overall mass. Consequently, in eight of the plants, the share of organic fractions did not exceed 25%. The loss on ignition of the OFMSW in 2 MBT plants was lower than 30%, which means that these wastes cannot be subjected to biological treatment. Another consequence of the large amount of combustion wastes found in the OFMSW was the waste's low moisture content. Very low moisture content (less than 30%) was found in wastes from six of the MBP plants. The OFMSW in most of the plants (all except three) required irrigation prior to biological treatment.

The MBT technology is currently a proven MSW management solution, and allows us to achieve the objectives set out in the Landfill Directive in terms of eliminating the storage of biodegradable waste. In all of the MBT plants' technological solutions, the main issue is how to reuse the final products of this process, or the total disposal of these final products, the mass of which might exceed 50% of the plants incoming waste mass. However, research has confirmed that in countries with such large share of households heated with solid fuels (including in Poland), another significant problem is the high combustion wastes content found in MSW.

The high content of these wastes adversely affects the OFMSW's moisture and organic matter content, and it results in limitations for using this waste, as well as environmental problems, and it limits the recovery of material fractions within MBT plants.

In addition, if ash is disposed of container with other wastes, it "makes them dirty", which, in turn, makes it much harder to select them and transfer them for recycling. The high content of combustion wastes that are found in OFMSW causes increased erosion of the equipment used in MBT plants, as well as an environmental problems, such as increased dust in the halls where the municipal solid waste screening and sorting lines are located, as well as at the ripening sites for heaps of waste.

There is also the issue of increased dust pollution (and therefore a lower quality) of the recovered material fractions (metals, paper, plastics, and glass) in MBT plants.

Author Contributions: Conceptualization, A.J. and S.M.; methodology, A.J.; validation, A.J., S.M.; formal analysis, J.P.; resources, A.J., S.M., J.P.; writing—original draft preparation, A.J., S.M., J.P.; writing—review and editing, S.M.; visualization, A.J.; S.M.; supervision, A.J., S.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding

Conflicts of Interest: The authors declare no conflict of interest.

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