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MICROPLASTICS IN COMPOSTS AS A BARRIER TO THE DEVELOPMENT OF CIRCULAR ECONOMY

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Abstract

The philosophy of sustainable development imposes on waste management systems solutions that are technically correct, economically effective and socially acceptable. One of the elements of these systems is the management of organic waste in two streams: municipal organic waste and the so-called green waste. Their composition is different, but some properties and technological processing possibilities are identical. The possibilities of using organic recycling products are also completely different. However, in both cases, such treatment is necessary, regardless of the type of waste, to either use it as much as possible or to store only bio-stable waste.

A big problem all over the world, not only for cities, is nano- and microplastics. It is estimated that 2–5% of all plastics produced are discharged into the oceans. High-density polymers settle to the bottom of water bodies, imitating food for bottom invertebrates. Conversely, low-density microplastics floating on the surface of the water pose a threat to zooplankton and smaller fish. However, the conducted research indicates that the pollution of terrestrial environments may be even 4 to 23 times greater than that of the ocean. While flowing through the sewage treatment plant, microplastics are accumulated in sewage sludge, and in the case of natural use of the sludge, they can end up in the soil and in the food chain of animals and humans. Composts are another source of soil contamination, especially from municipal organic waste and green waste. On January 16, 2018, the European Commission published the European Strategy for Plastics in a Circular Economy, which outlines how plastic products are designed, manufactured, used and recycled.

The aim of the paper is to present the initial results of preliminary tests on organic waste in terms of the possibility of identifying microplastics in them [1–3].

Keywords: **Organic waste; Composting; Microplastics.**

1. INTRODUCTION

Sustainable development is the basic and key assumption of the ecological policy of the European Union countries. The principle of sustainable development, formulated by the United Nations in 1972 in the Polish Environmental Protection Law (Journal of Laws 2008. 25.150) is defined as "socio-economic development in which the process of integrating political, economic and social activities takes place, while maintaining the natural balance and durability of basic natural processes, in order to guarantee the possibility of satisfying the basic needs of individual communities and citizens of both the present and future generations". Waste management is currently both one of the areas of the economy and industry. The provisions on waste management introduced by law impose new obligations on the whole society. All these regulations are subject to the philosophy of sustainable development. This development philosophy imposes on waste management solutions that are technically correct, economically effective and socially acceptable. Waste management should follow the hierarchy: prevention of waste generation "at source", preparation for re-use, recycling and use of consumable materials, other recovery methods, eg incineration with or without energy recovery, final disposal of processing residues. According to these assumptions, properly conducted municipal waste management is to reconcile the conflict between human activity and the natural environment. A properly conducted waste management system allows the processing of all waste streams, including organic waste, which is one of the significant components of the entire stream. It is also one of the most difficult links to organize collection and processing. In the light of EU regulations, Member States should develop a national strategy for reducing the amount of biodegradable waste going to landfills. Such a strategy should include measures to achieve the targets, in particular through recycling, composting, biogas production and material and energy recovery. The strategy must ensure a certain degree of reduction in the amount of municipal waste compared to the production level in 1995. Therefore, the following measures should be undertaken:

- no later than 5 years, biodegradable municipal waste going to landfills must be reduced to 75% of the total amount (by weight) of biodegradable municipal waste produced in 1995,
- no later than 8 years, biodegradable municipal waste going to landfills must be reduced to 50% of the total weight of waste generated in 1995,
- no later than 15 years, biodegradable municipal waste going to landfills must be reduced to 35% of the total weight generated in 1995 [3–4, 5–9].

As an EU member state, Poland implements the provisions of EU directives into national law. Subsequent legal regulations implement the assumptions of the reduction of the waste stream through their greatest possible use in recovery and recycling processes and the safe disposal of residues. The main legal regulations containing provisions on the principles of proper waste handling in our country are:

- Act of December 14, 2012 on waste (Journal of Laws 2013. 0. 21 as amended)
- Act of 25 January 2013 amending the act on maintaining cleanliness and order in municipalities (Journal of Laws 2013. 0. 228 as amended) [1, 10].

2. METHODS OF ORGANIC RECOVERY AND RECYCLING

According to the Waste Act (Journal of Laws 2013. 0. 21, as amended), recovery is any process whose main result is that the waste serves a useful purpose by replacing other materials that would otherwise be used to meet a given function, or as a result of which waste is prepared to fulfill such a function in a given plant or in the economy in general. One form of recovery is also recycling, including organic recycling, but not energy recovery and reprocessing into materials that are to be used as fuels or for backfilling purposes [10].

Waste recovery should only be understood in terms of recycling and use of waste, because in this way we reduce their quantity and harmful nature, and reduce the amount of waste deposited in the landfill. If this is not the case, the waste management system becomes an economically scarce and environmentally harmful system. For the proper functioning of such a system, it is necessary to organize the collection of all types of waste generated in the region of segregation and collection of secondary raw materials, including green waste, and if possible and necessary, also organic waste of municipal origin. For example, waste from gastronomy or mass catering can be collected selectively, or home composting in single-family housing can be promoted.

Green waste from the care of organized green areas, from tree felling, as selectively collected fractions, is sent for processing.

Organic municipal waste (from households and infrastructure) is most often collected together with mixed waste and separated at the level of a sorting installation in sieves or in mechanical-biological processing installations, from where it is directed for further biological processing. Among the methods of organic recycling, the following are distinguished:

- methane fermentation,
- composting [10–14].

2.1. Methane fermentation

Methane fermentation is an anaerobic process of decomposition (mineralization) of complex high-molecular organic substances contained in biomass, leading to the stabilization of the properties of the biomass. Parameters of the methane fermentation process [11, 15]:

- pH value of the input to the process – affects the efficiency and stability of methane formation, optimal gas production occurs at pH 7.0;

- the correct composition of the input to the process is one in which the ratio of the mass of carbon to the mass of nitrogen C: N is from 10: 1 to 25: 1, and the ratio of the mass of carbon to the mass of phosphorus and sulfur N: P: S is 7: 1: l. In addition to the above-mentioned nutrients, soluble forms of potassium, sodium, iron, magnesium and calcium as well as trace elements are also needed for the growth of microorganisms;
- substrate moisture, water content in the mass of processed waste is decisive in the course of the fermentation process, its amount in the fermented batch determines the division into wet (w = 85–100%) and dry (w = 60–80%) fermentation;
- depending on the temperature, the fermentation process can be divided into psychrophilic (t = 5–25°C), mesophilic (t = 30–35°C) and thermophilic (t = 52–55°C) fermentation; Depending on the process temperature, different types of bacteria take part in it, the most common is the mesophilic temperature range.

In the process of anaerobic fermentation, post-fermentation sludge (digestate) and biogas are obtained. The fermentate, depending on the input and type of processed waste, after meeting the requirements, can be used as reclamation material or deposited in a landfill, after meeting the standards for landfilling. After passing through the water separator, the biogas provides fuel for gas boiler sand gas electricity generators[16–17].

2.2. Composting

Waste composting technology is a method of oxygen treatment of organic waste, based on natural biochemical reactions, intensified in artificially created optimal conditions, ensuring the possibility of controlling these processes. The process takes place with the participation of numerous groups of microorganisms, mainly aerobic. Although it is an aerobic process, like in nature, it can take place under aerobic-anaerobic conditions. The composting process also involves physical and chemical processes, such as mineralization, humification, rot, rotting and carbonization [9, 11, 15].

In order to assess the suitability of the substrate for processing, it is necessary to know the composition of the composted material, that is:

- organic matter content (the limit value for the proportion of organic matter in waste, which allows it to undergo biological treatment, is assumed to be losses on ignition > 30%),
- the content of fertilizing ingredients: carbon, nitrogen, phosphorus and potassium, which are the basic nutrients for microorganisms (organisms also need microelements and trace elements, i.e. boron, calcium, chlorine, cobalt, copper, iron, magnesium, manganese, molybdenum, selenium, sodium and zinc). The measure of the susceptibility of organic ingredients to microbial decomposition is the weight ratio C: N. Composting is most effective when the C: N ratio of the composted material is in the range of 25-35: 1.
- low content of heavy metals, toxic substances and other non-biodegradable ingredients in the input material, e.g. glass, stones.

In addition to ensuring the correct parameters of waste intended for composting, it is necessary to maintain the correct parameters of the process [11–15]. They include:

- Maintaining the pH in the range of 6.5–7.5 in the mass of composted waste during the entire process (provides appropriate conditions for the development of microorganisms),
- Adequate waste humidity in the range of 50–55%, especially in the initial stage of the process,
- Proper temperature, approx. 45–55°C, for at least 10 days, allows to maintain appropriate conditions for biochemical transformations and additionally is important for hygienization and the destruction of pathogenic organisms in the mass of composted waste,
- Adequate oxygenation – microorganisms responsible for composting require oxygen. Its concentration in the air contained in the pores should be within the range of 12 to 14% and depends on the phase of the process. However, too intensive aeration may dry the heap and inhibit the process,

Typically, the technology of the composting process includes 2 stages:

- stage I – intensive composting, from which we obtain the so-called fresh compost,
- stage II – maturation – the so-called mature compost.

Composting in piles or piles is carried out in static conditions or with the transfer of processed organic waste. It is an uncomplicated technology often used in households to process municipal or green organic waste. Composted waste is piled into piles or flat piles [11,15]. In large technological processes, the following composting methods are distinguished:

- static composting in which the aeration of the composted material is organized by molecular diffusion and thermal air convection. The operation of the composting plant is limited to the formation of piles, their dismantling after the completion of composting as well as cleaning and refining the product. The process takes 16–20 weeks.
- composting in flipped over, where the composted material is regularly thrown to improve aeration conditions. The method guarantees better aeration and homogenization of the rainfall mix, but requires the use of more equipment, which increases operating costs. The composting time in the shifted heaps is shorter and ranges from 9 to 12 weeks.

Composting in composting drums is the first step in a two-step process. The first stage of the process takes place in the biostabilizer for at least 3 to 4 days. In it, the fragmentation of soft components of waste takes place, thorough mixing and homogenization of the mass, and initiation of the processes of biochemical decomposition of organic waste components. After the intensive composting process in the drum, it is necessary to re-compost in a static or quasi-dynamic (shifted) system for a period of 6–12 weeks [6–8].

3. ORGANIC RECYCLING EFFECT

Organic recycling defined as the aerobic treatment including composting, or the anaerobic treatment of waste in which the organic waste is biodegradable under controlled conditions using microorganisms, result in the production of organic matter and / or methane. Depending on the substrates used in biological processing, the possibilities of using their solid end products may be different [12–13, 18].

3.1. Processing of organic kitchen waste

In the case of processing (by composting or methane fermentation) of organic waste obtained from municipal waste "at source" or at the level of sorting plant or mechanical-biological treatment installation, it is not possible to use the product of the permanent process and its reuse. Then the so-called stabilized material, classified with the waste code from group 19 (waste from installations and devices for waste management, from sewage treatment plants and from the treatment of drinking water and water for industrial purposes). It is waste that should be stored in a landfill for non-hazardous and inert waste, and its properties allowing it to be deposited are specified in the regulation (Journal of Laws of 2015, item 1277) [4, 19].

3.2. Processing of green waste

In the case of green waste processing and a properly conducted technological process, it is possible to obtain a solid product for use from both processes (both composting and methane fermentation).

Good compost should be dark in color and with an earthy smell. It should be a homogeneous material, with a uniform particle size and a moisture content of less than 50%. The basic nutrients in composts are nitrogen, phosphorus, potassium, magnesium and calcium (N, P, K, Mg and Ca). The fertilizing value of compost is characterized by their total content in the product and the proportion of soluble and available forms for plants. In addition to compost, the composting process produces carbon dioxide, water and heat.

The possibilities of using compost depend on its properties, which are defined in the industry standard BN-89 / 9103-09. The standard characterizes compost in terms of organoleptic characteristics (color, smell, structure) and physicochemical parameters. In terms of physicochemical parameters according to the standard, there are 3 compost classes [20]:

- 1st class of compost – used for agricultural purposes,
- 2nd compost – for arranging urban green areas,
- 3rd class of compost – for reclamation of degraded areas.

4. POSSIBILITY OF OCCURRENCE OF MICROPLASTICS IN COMPOSTS

It is estimated that 2–5% of all plastics produced may end up in the oceans. High-density polymers settle to the bottom of water bodies, imitating food for bottom invertebrates. Conversely, low-density microplastics floating on the surface of the water pose a threat to zooplankton and smaller fish. However, the conducted research indicates that the pollution of terrestrial environments may be even 4 to 23 times greater than that of the ocean. Microplastics are transferred through a sewage treatment plant to sewage sludge and then to the soil. Composts are another source of soil contamination, especially from municipal organic waste and green waste. On January 16, 2018, the European Commission published the European

Strategy for Plastics in a Circular Economy, which places great emphasis on how plastic products are designed, manufactured, used and recycled.

Most of the plastics available today defined as biodegradable decompose under certain conditions, which are not always readily available in the environment, and therefore may still cause damage to ecosystems. Biodegradation in the marine environment is particularly difficult. In addition, plastics that are labeled "compostable" are not always suitable for home composting. Mixing compostable and conventional plastics can have an impact on the quality of the recyclate. For consumer uses, it is essential to have a well-functioning system for the separate collection of organic waste [3, 6–9, 18, 12–14, 21–25].

5. RESEARCH METHODOLOGY

5.1. Material used for research

The material used for the research in terms of the presence of microplastics in it was organic waste from a household composter located on a single-family housing estate (Fig. 1).

Figure 1.
A sample of backyard compost used for research (photo: Author)

5.2. Grinding in a cutting mill

The first stage of compost processing is the grinding of the collected material into the smallest possible forms with the use of a knife mill. The mechanism of the knife mill operation is to cut the material into smaller pieces with the help of attached blades. These blades have a counter blade that locks the material in place allowing fragmentation. This method allows you to achieve objects at the level of a few micrometers.

5.3. Grinding in a planetary ball mill

The next stage of crushing the compost structures was grinding in a planetary ball mill. The operating principle of the planetary ball mill is based on the circular motion and the centrifugal force acting inside the grinding bowl. The end material from the cutting mill was transferred to the grinding bowl. Crushing took 5 minutes at 400 rpm.

Figure 2.
Compost ground in a planetary-ball mill (photo: Author)

5.4. Homogenization grinding

The final stage of the compost grinding was homogenization grinding in order to break down the flocculants formed after grinding in a ball mill. The homogenizer was operated with a double knife at 30500 rpm.

5.5. Filtration

As the last process, before qualitative analysis of the obtained suspension, liquid filtration was performed in order to separate nano structures from micro structures. For this purpose, syringe filters with a pore diameter of 450 nm were used. The thus obtained solution of nanoparticles in distilled water was subjected to particle size distribution measurements in a DLS analyzer.

Table 1.
Description of tested beams

Another measurements	Compost samples					
	Particle size 1 [nm] –	Area Percentage 1 [%]	Particle size 2 [nm]	Area Percentage 2 [%]	Particle size 3 [nm]	Area Percentage 3 [%]
1	1060.0	87.5	197.1	12.5	0	0
2	996.5	93.1	151.1	6.9	0	0
3	831.3	100.0	0.000	0.0	0	0
4	3484.0	61.9	529.1	38.7	0	0
5	265.9	92.6	155.8	7.4	0	0
6	741.0	96.7	5560	3.3	0	0
7	1312.0	86.5	193.60	13.5	0	0
8	1051.0	72.4	5015	21.4	135.3	6.1
9	864.1	67.5	4708	26.7	152.3	5.8
10	2420.0	73.9	359.6	26.1	0	0
Average particle size [nm]	1302.6		1686.93		143.8	

Source: Own study

6. THE RESULTS OF THE DLS METHOD

The DLS (Dynamic Light Scattering) method is an analytical method based on dynamic light scattering. It allows the measurement of particles in the range of 0.5-10.000 nm. The laser beam striking the sample interacts with it and produces scattered radiation which is then collected by the detector. Measurements with this method do not cause damage to the sample or structural changes in the sample. Most often, the DLS method is used to measure the particle size in the liquid phase.

In this study, each compost solution was made just before the analysis, which allows for the most accurate reflection of the content of the samples. The compost particle size distribution was determined using the DLS Zetasizer Nano Zs analyzer by Malvern. For each research material, 10 measurements were made. Measurements were carried out at 25°C using distilled water as the dispersing phase at an angle of 173° at a wavelength of 633 nm. Other measurement parameters: viscosity 0.887 cP and refractive index RI = 1.330. The test results are presented in Table 1.

The number of particles in the household compost was measured ten times (Table 1). This sample was analyzed in terms of division into three particle sizes, depending on the intensity, i.e. the share of a given particle size in the percentage of the entire sample area (Tab. 1), so the measurements in turn provide us with information about the percentage of the sample in a particular particle size range, and so sequentially:

Measurement 1 – 87.5% of the sample are 1060 nm particles, while 12.5% of the sample are 175.1 nm particles.

Measurement 2 – approx. 93% of the sample are 996.5 nm particles, and approx. 7% are 151 nm particles.

Measurement 3 – 100% of the sample consists of 831.3 nm particles.

Measurement 4 – 61.9% of the sample are particle sizes such as 3484 nm, and 38.7% of the sample are particles of 529.1 nm.

Measurement 5 – 92.6 percent of the sample are 265.9 nm particles, while 7.4% are 155.8 nm particles.

Measurement 6 – 96.7% of the sample are 741 nm particles, and only 3.3% are particles with a size of 5560 nm, which may indicate the formation of agglomerates and combinations of several or even a dozen particles into one compact.

Measurement 7 – 86.5% of the particles have a size of 1312 nm and 13.5% have a size of 193.5 nm.

Measurement 8 – 72.4% of the particles are 1051 nm, 21.4% are particles of 5051 (possibly agglomerates), and a peak 3 appears: 6.1% of the sample are 135nm particles.

Measurement 9 – 67.5% of the sample are 864.1 nm particles, 26.7% are 4708 nm particles and 5.8% are 152.3 nm particles.

Measurement 10 – 73.9% of the sample is 2420 nm, and 26.1% is 359.6 nm.

Based on the research, it can be said that the analyzed samples of home compost contain microplastics of an average size of 1302 nm. In the analyzed samples, the presence of many smaller individual particles, even about 135–150 nm in size (Fig. 3), can be noticed. It shows the particle size distribution of microplastics present in a sample of household compost from the intensity (% share of a given size in the sample). We can notice that in the compost sample there are microplastics with an average size of around 1300 nm and also smaller around 130 nm. It is most likely the result of contamination of the organic fraction from municipal waste sent to the composting process and may be a significant limitation of the possibility of using compost as a reclamation material.

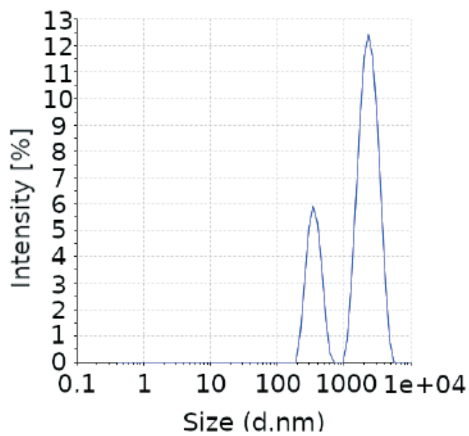

Figure 3.
Average particle size distribution in household compost (own elaboration)

7. SUMMARY AND CONCLUSIONS

- Organic waste is always one of the municipal waste streams, and in typically urban municipalities, it can constitute up to 40–50% of the mass of the entire mass stream. In rural communes, where the buildings are dispersed, there is much less of them, even up to about 15% of the mass, due to the composting and utilization processes carried out. However, it has been observed that the characteristics of waste from rural areas are similar to those of urban waste [5].
- Bio-waste is waste that has a tendency to putrefy quickly, and as a result it is a significant nuisance and a threat to people and the environment. Limiting their negative impact requires segregating them, processing and, if possible, using the products of the process as organic recycling. This will eliminate the negative impact on the environment, and at the same time contribute to its improvement through, for example, reclamation of degraded areas. Collection and proper processing of organic waste should ensure: production of full-value organic material that can be used or safely stored in a landfill, reduction of the volume of organic waste to about 50% and elimination of processes that take place in unprocessed waste [19].
- Biodegradable municipal waste (including green waste) should be processed into environmentally safe organic material that can be used for remediation or sold. If biodegradable waste is household waste from kitchens (collected selectively or recovered in sorting screens), it is necessary to stabilize them in order to obtain stabilization and to deposit them in a waste landfill. However, there is always a risk that the collection or treatment of bio-waste will not proceed properly, resulting in, for example, an increase in costs (if the process was insufficient and needs to be repeated) or obtaining a product that cannot be used and will have to be landfilled. The presence of microplastics in waste will be part of this risk and will limit the possibilities of using organic material [3–4, 16–17]
- The paper presents the results of research on organic material from the composting of organic waste from a single-family household, subjected to shredding and homogenization processes. The obtained results indicate the presence of microparticles of plastics in the household compost with an average size of approx. 1302 nm and individual particles much smaller in size of approx. 135 nm. Taking into account that in single-family households, the "source" segregation of organic waste sent for composting is quite accurate, it can be concluded that most of the waste from residents will be contaminated with microplastics, which may result in significant limitations in the use of organic recycled materials.

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