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ANALYSIS OF THE MAIN METHODS OF SOLID WASTE MANAGEMENT

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Abstract. The world's growing population and, as a result, higher consumption of goods and services have led to a rapid increase in municipal solid waste. This situation creates serious environmental problems that require clear strategies for managing this waste. Improving the efficiency of recycling to restore quality materials, saving resources and maintaining waste in landfills are among the most pressing problems of our time. The article considers the existing methods of solid waste management in order to select the most optimal waste management system in the context of sustainable development.

Keywords: municipal solid waste, composting, incineration, pyrolysis.

1. Introduction

Currently, the problem of the accumulation of municipal solid waste (MSW) is extremely relevant. Household waste is a symbol of the inefficiency of modern society and a picture of misallocated resources. Solid waste management is a worldwide problem, and it is becoming increasingly important due to population growth, urbanization, industrialization and changes in our way of life. Nowadays, most of the generated waste in Ukraine is taken to landfills and, this way, huge areas of land are occupied for MSW. This is especially true for unauthorized landfills that do not meet sanitary requirements, leading to environmental and health problems caused by poor hygiene. The most developed countries of the world successfully use modern technologies and measures aimed at reducing the burden of solid waste on the environment and effectively managing them.

The aim of this article is a thorough analysis of the literature review and a critical analysis of each proposed method of household waste management to select the most optimal waste management system in the context of sustainable development.

2. Analysis of existing methods of MSW management

Currently, in practice, biological and physico-chemical methods of disposal, landfilling and waste processing methods are used for the disposal of MSW. Schematic representation of variants of methods of solid waste management is shown in Fig. 1.

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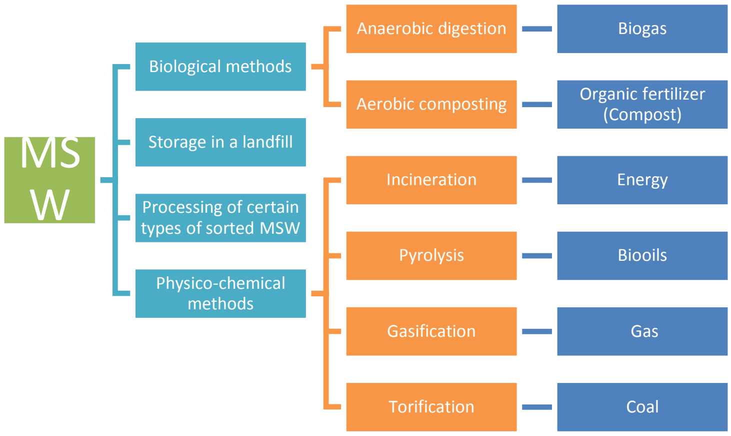

Fig. 1. Schematic representation of variants of methods of solid waste management

2.1. Depositing at landfills

Landfilling which is practised in Ukraine is the most common method of waste management. Accumulation of waste in landfills and dumps causes pollution of the atmosphere, hydrosphere, disrupted the functioning of ecosystems, the withdrawal of land. In addition, landfill gas emissions have a negative impact on climate change.

Regardless of the conditions of solid waste disposal in landfills, waste often ignites because there are a lot of organic and flammable substances. This causes air pollution by harmful combustion products - carbon monoxide, nitrogen oxides, dioxins, furans, etc. However, for the developed countries, members of the European Union, this form of solid waste management is not acceptable both from the environmental point of view and from the point of resource potential of MSW, as well as the allocation of a large number of areas for landfills. It is known that landfills are designed for a certain period of operation or a certain maximum amount of solid waste accumulation. In Ukraine, the problem of allocating appropriate sites for solid waste disposal is not so critical. Thus, according to official statistics, there are about 4,500 of them. Moreover, 5 % of them are overloaded, and 25% do not meet environmental safety standards (Ishchenko et al., 2012). The waste management systems that are based on waste collection and transportation to landfills are outdated. It has been estimated that collection costs range from 40 to 60% of community solid waste management costs (Jouhara H., et al., 2017). The landfill is considered to be the least preferred method of disposal, and the EU Landfill Directive (Directive EU, 1999), announced in 1999, requires the Member States to reduce the amount of buried biodegradable material. Landfilling, from the point of view of secondary use, causes the loss of valuable components that are part of MSW, so besides environmental impact, waste can also be beneficial. This is because they can be both a source of energy and a source of valuable resources that can be reused. Therefore, the accumulation of waste without further use is even economically unprofitable. All of the above suggests that depositing MSW in landfills and dumps should be a thing of the past, as it is in many developed countries. Therefore, Ukraine must gradually abandon the storage of solid waste and move to their maximum processing.

It is necessary to create a balanced waste management system, identify long-term strategic priorities that will combine environmental efficiency and rational consumption of material and energy resources. That is why the EU policy in solid waste management is not aimed at preventing the generation of waste but at building the most environmentally friendly system of waste management. According to Directive № 2008/98/EU, the choice of solid waste management methods is based on the principle of the waste hierarchy: waste prevention, reuse, recycling, composting, incineration and disposal (IFC, 2015).

Due to the intensification of environmental problems, the issues of determining promising areas for the disposal of organic waste, namely, the study of the prospects of biological processing of organic waste to get useful products - compost and biogas, are most relevant.

2.2. Biological methods of waste disposal

Biological methods (belong to the methods of waste processing) involve the decomposition by live microbes (bacteria and fungi) which use biodegradable organic substances as a source of food for growth and reproduction. Microbes secrete specialized enzymes that digest the biodegradable components of waste (such as cellulose, lignin, starch and other complex polysaccharides, proteins and fats) to simple nutrients – sugars, amino acids, and fatty acids that they absorb. As microbes grow and reproduce, most of these nutrients are converted into heat, carbon dioxide and water. This leads to a lot of weight loss during the process. There are two main types of environments in which such microbes live. Therefore, there are two main types of biological processes used to treat biodegradable waste: aerobic - in the presence of oxygen and anaerobic - in the absence of oxygen. Biological methods can be used to treat mechanically separated organic waste from mixed solid waste, as well as from sorted sources, which provide a cleaner organic flow. Food and green waste are suitable raw materials for these technologies. Paper, cardboard and wood can also be treated, but degradation takes longer (DEFRA, 2015).

Composting is a natural aerobic process of biological stabilization of organic waste that reduces weight and volume and produces compost which provides the nutrients needed for new plants. This final product can be used for agricultural purposes, as its inclusion in the soil under appropriate conditions increases fertility. Figure 2 shows an assessment of the life cycle of organic waste.

Fig. 2. Assessment of the life cycle of organic waste

Vermicompost is a relatively advanced method of composting and involves the stabilization of solid organic waste through the consumption of earthworms, which convert waste into ebbs of earthworms. Although microorganisms biodegrade organic matter, earthworms are a crucial driver of the process, as they aerate, process and fragment the substrate, dramatically improving the activity of microbes (Jouhara et al., 2017).

The second biological method of waste disposal is **anaerobic digestion** which is also called methane fermentation.

Microorganisms convert biodegradable material into biogas in a number of biological processes without the presence of oxygen. The most popular raw materials for anaerobic digestion are various types of organic waste such as manure, agricultural residues, crop residues, wastewater and solid waste. **Anaerobic digestion** is completed after four successive phases: hydrolysis, acidogenesis, acetogenesis and methanogenesis. In hydrolysis, monomers are obtained from complex polymers by enzymes which are subsequently converted into volatile fat acids (acetic, propionic and butyric acids) and hydrogen at the second stage of the process – acidogenosis. In acetogenesis, acetate, carbon dioxide and H2 are formed from volatile fat acids, and finally they are converted into methane during methanogenesis (Jouhara et al., 2017).

Biogas is a mixture of methane, carbon dioxide and other gases in small quantities that can be converted into heat or electricity. It contains a high concentration of methane (50-80%), which makes it suitable for use as an energy source for combustion engines, turbines or boilers both alone and mixed with other fuels. In its simple application, biogas can feed gas stoves. It can be said that a properly maintained anaerobic digestion process is one of the best ways to reduce greenhouse gas emissions, promote the use of waste for energy and increase the value of fertilizers from processed products (Insam et al., 2010).

2.3. Physico-chemical methods of waste disposal

Physico-chemical methods of waste disposal include waste treatment processes based on changes in certain physical parameters, such as temperature, pressure or the presence in the environment of oxidants or reducers without the use of living organisms. As a result, waste undergoes physical and chemical changes that make waste less harmful and even turn it into useful products. The most desirable waste conversions include weight and volume reduction, energy release with its use and separation of other valuable components from waste. Thermo-chemical methods such as incineration, pyrolysis and gasification are used in centralized waste management systems. Biological or medical waste is sometimes subjected to high pressure and temperature at the same time to ensure sanitary safety. This process is called sterilization (Jouhara et al., 2017).

Incineration. The first waste incineration plants (WIP) appeared in the United States, and the incineration process became widespread in 1970. WIPs are environmentally hazardous as harmful substances are released into the atmosphere due to the burning of morphologically different solid waste. According to the world requirements of environmental standards, the content in gaseous emissions of harmful substances should be dust - not more than 10 mg/m^3, SO_2 – 50, HCl – 10, HF – 1, CO – 50, NO_x – 200, dioxins - 0.1 mg/m^3. The content of oxides of heavy metals should not exceed 3 mg/m^3, including cadmium, mercury, lead - 0.1 mg/m^3 (Darulys, 2000).

The advantage of incineration is that this process can significantly reduce the weight of waste, as well as eliminate such unpleasant properties as odour, the release of toxic liquids and bacteria. One of the main advantages of the method is the additional energy that can be used to generate electricity or premises heating. The disadvantage of this method is that during combustion, highly dispersed dust (25–50 kg/t of MSW) and harmful gases are emitted into the atmosphere. The composition of highly dispersed volatile ash includes mineral particles and unburned particles of organic matter. It is a carcinogenic component. Gaseous emissions consist of carbon dioxide CO_2 and water vapour, which lead to the “greenhouse effect”, heavy metal compounds, incomplete combustion products, such as polyaromatic hydrocarbons, halide-containing hydrocarbons, the so-called polychlorine (bromine) bibenzodiofluorons and polybenzenesulfonyl. Slag, the amount of which reaches 15–30 % of the original solid waste, is also a danger – it is a secondary solid waste that is contaminated with toxic substances and requires neutralization or disposal. During cooling the slag with water, washing the sludge from the filters, etc. wastewater is formed, which becomes toxic due to the accumulation of water-soluble compounds of heavy metals and particles of volatile ash. These substances are very dangerous to human health, cause acid rain and affect climate change. During incineration, ash contaminated with hazardous substances (e.g. heavy metals) is formed (hazard class III), which by weight is 15–40 % of the original weight of the waste. Due to its chemical and physical properties, such ash cannot be buried in ordinary landfills (Lunova, 2012). Therefore, the incineration process requires complex multi-level treatment equipment due to increased sanitation. Modern power plants that process energy can export it with a very low impact on the environment.

Incineration with highly efficient energy recovery is understood as waste recovery, which should be avoided as much as possible, leaving it at a stage when the use of recycling methods is no longer possible due to the potential negative impact on the environment. However, anaerobic digestion is considered to be a method of processing.

Pyrolysis is the process of thermochemical decomposition of organic matter at high temperatures into coal and condensed gases. Part of the condensable gases can be further decomposed into secondary products, including CO, CO_2, H_2 and CH_4. In comparison with incineration, pyrolysis occurs without the presence of oxygen, at temperatures of 300 °C - 650 °C (Mohan et al., 2006).

The result and chemical composition of pyrolysis products depend on the properties of the raw material, the pyrolysis temperature and the heating rate. Based on the heating rate, pyrolysis can be classified as slow or rapid pyrolysis. In rapid pyrolysis, the residence time of the vapours is a few seconds, and the main products are bio-oil and gas. With slow pyrolysis, the residence time is longer, and the main product is coal (Basu, 2013).

Organic pollutants and heavy metals mainly remain in the liquid and coal fractions, respectively. The volatility of some heavy metals, such as Zn and Pb, was reduced during pyrolysis compared to incineration. From this study, it was concluded that pyrolysis is the best choice for solid waste treatment in terms of heavy metal contamination control (Yu et al., 2016).

Gasification, in its turn, is a process that takes place in an oxygen-poor atmosphere and during which gas is formed. This process is flexible in creating a combination of solid, liquid and gaseous products in different proportions, only changing the operating parameters, such as temperature, heating rate, reaction time. This makes it possible to convert low-energy-density materials into high-energy fuels.

Recently, more and more attention is paid to a new technology that includes thermal gasification of plasma for solid waste treatment. The advantages of the technology are the improvement of energy recovery efficiency associated with fast reaction time, low amount of oxidant and high heat flux density. Studies have shown that the high temperature of the plasma arc can reduce the formation of resin and other undesirable products in the synthesis gas (Byun et al., 2010). Solid residues are produced in the form of vitreous slag, which can be used in construction.

Torrefaction is light and slow pyrolysis which is carried out at temperatures from 200 °C to 350 °C. The process usually operates under ambient pressure with an inert atmosphere to avoid oxidation and combustion of the feedstock (Van der Stelt et al., 2011). The length of stay can vary from a few minutes to several hours. The process of torrefaction is initiated by evaporation of moisture with subsequent partial decontamination. Coal, which is the main product, has a much higher energy density than the raw material. The advantages of torrefaction are increased energy density, improved grinding, reduced moisture content and reduced susceptibility to microbial degradation. Coal can be used as a high-quality fuel in a variety of applications, including drying in power plants, gasification with forced flow and small combustion plants (Uslu et al., 2008). Types of materials used as raw materials include polyfoam, PVC plastic, old tires and wood residues.

Pyrolysis is considered as an incomplete process of gasification, and torrefaction is the initial stage of gasification and pyrolysis, that is, it is not a completely separate process. Combustion is also a process of thermochemical transformation but with heat or power as the main output. In Figure 3(Matsakas et al., 2017), the main differences between combustion, gasification, pyrolysis and torrefaction are illustrated for operational conditions and transformation products.

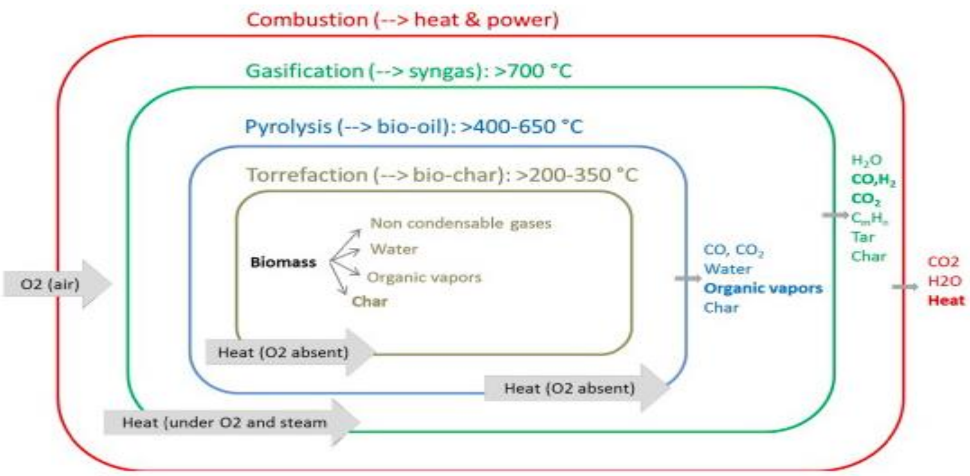

Fig. 3. The main differences between combustion, gasification, pyrolysis and torrefaction

The advantages of physico-chemical conversion of solid waste over conventional incineration of solid waste are related to increased energy efficiency, production of value-added products and improved pollution control. Intermediates of this transformation can be suitable for a wide range of applications from high quality fuels to finely divided chemicals (Klinghoffer et al., 2013).

2.4. Waste recycling

According to the EU Waste Directive 2008/98/EU, recycling is a recovery operation in which waste is recycled into products, materials or substances for a specific purpose. This operation includes the recycling of organic materials for a particular type of waste but does not include energy recovery or recycling into materials to be used as fuel or refill materials, which is already included in the next 4th step of the waste hierarchy. Recycling depends on separate collection and sorting, which should precede the 2nd, 3rd, 4th and 5th steps of the waste hierarchy. Separate collection is necessary to ensure high-quality processing. The following waste categories are sorted: paper, metal, plastic and glass from both households and other sources. The processing of each of these wastes has its technology. These wastes become valuable if the requirements for their separate collection are met. Moreover, energy costs for their processing are much lower than in new production. Separate collection is most effective at waste generation sites (Voytsikhovska et al., 2019). In Ukraine, unfortunately, sorting, due to the mentality of the population, cannot quickly and efficiently find practical use. The advantages of physico-chemical conversion of solid waste over conventional incineration of solid waste are related to increased energy efficiency, production of value-added products and improved pollution control. Intermediates of this transformation can be suitable for a wide range of applications, from high-quality fuels to finely divided chemicals.

The National Waste Management Strategy in Ukraine until 2030 foresees an increase in the amount of waste intended for recycling up to 15 % by 2023 and up to 50 % by 2030.

3. Conclusions

The problem of waste disposal is relevant due to the negative impact on the environment, the allocation of extensive areas of land for landfills, resource depletion, increasing global warming through methane and other greenhouse gas emissions.

The main goal of any waste management system is to reduce the amount (mass and volume) of waste generated. The right waste management policy should be based on the principles of sustainable development. The structure and functions of waste management depend on the location and the political, socio-economic, informational, and cultural framework.

The most commonly used method of waste disposal, such as landfilling, should be a thing of the past due to environmental hazards and further threats to human health. Therefore, for Ukraine, the most effective way to manage solid waste will be the introduction of separate sorting of waste and its further processing and disposal with priority to reduce the amount of solid waste, as well as work towards creating a closed cycle of production and use – without waste, which should be regulated by law.

As the experience of developed countries shows, the level of waste use can reach 60% of their annual generation. Such measures will lead to an improvement in the environmental situation as a whole, as well as the possibility of obtaining significant economic benefits through the use of secondary raw materials. In conditions of constant shortage of natural resources, while processing waste, its thermal potential should be used to get fertilizers for agricultural purposes.

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