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SOLUTION OF THE PROBLEM OF SOLID WASTE DISPOSAL: WORLD EXPERIENCE

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The article outlines that the accumulation and disposal of waste is becoming a global environmental problem, accumulating in large volumes, spoilage and rotting of solid household waste under the influence of the environment occurs. It is substantiated that the accumulation of waste in landfills negatively affects the environment, it becomes a source of access for harmful chemical and biological substances that enter groundwater and surface water, atmospheric air and soil.

It is determined that the problem of disposal and recycling of municipal solid waste (MHW) is one of the main problems in the world, which is associated with the complexity of their morphological composition and their toxicity. Municipal solid waste, which is formed as a result of human activity, contains ferrous and non-ferrous metals, plastics, paper, textiles, glass, food and vegetable waste, rubber, wood and other waste, which must be recycled.

The methods of MSW processing are systematized, including landfilling, composting, incineration, and secondary processing – recycling. The main trends in waste generation and management in the EU countries in dynamics are determined, the trend towards a decrease in the volume of MSW generation and its landfilling in landfills is outlined, while the volume of its reuse is increasing. The use of MSW landfills to produce biogas through anaerobic digestion is gaining popularity both in the EU and in Ukraine.

The solution to the problem of effective management of municipal solid waste is implemented through their sorting, and then their disposal by incineration with the production of thermal or electrical energy, or repeated separate processing of various waste components, which also requires additional sorting at the production site (selection of different colors of glass, different types of paper, different types of metal, etc.). In different countries, residents sort municipal solid waste into 5-10 or more items, and in Japan more than 35 items of different types of raw materials.

***Key words**: waste, municipal solid waste, disposal, recycling, landfill, anaerobic digestion.*
Fig. 5. Table. 3. Ref. 21.

1. Problem formulation

For a city or any other settlement, the problem of disposal or disinfection of solid household waste (hereinafter referred to as MSW) is primarily an environmental problem. It is important that the problems of MSW disposal do not violate the ecological safety of the settlement, the normal functioning of the municipal economy from the point of view of sanitation and hygiene.

Ukraine is literally drowning in household waste. On average, 250-300 kilograms of garbage fall on one person. 93% of garbage is taken to landfills and landfills, more than 2% is burned, and 4.5% goes for recycling. Year after year, the country's territory is turning into a huge landfill and, if nothing is done, a large-scale environmental disaster awaits us tomorrow.

Today in Ukraine, landfilling of MSW remains the cheapest of all types of MSW management. The MSW landfill tax rate in Ukraine is 0.15-0.45 EUR/t, while in EU countries it is 5-50 EUR/t (Fig. 1) [1].

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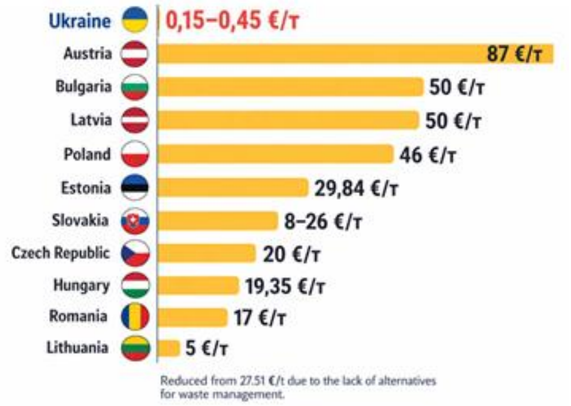

Fig. 1. Tariff for municipal waste landfill in Ukraine and some EU countries, 2020 [2]

In general, waste generation problems are critical in the world and, according to the World Bank, the level of waste generation is only increasing. Thus, due to population growth and the expansion of urban areas, the volume of waste generation in the world is expected to increase by 70%, according to some estimates, between 2016 and 2050.

2. Analysis of recent research and publications

On average, each person in the world generates about 1 kg of municipal waste per day. Today, each inhabitant generates: in the United States about 2 kg of waste (720 kg per year), in Belgium, Germany, and France, each person generates (410–690) kg of household waste annually. The average annual amount of MSW per person for a number of European countries, as well as trends in waste generation volumes from 1995 to 2023 based on Eurostat data [3], are given in Table 1.

Table. 1

Volumes and trends in MSW production volumes in selected European countries

Country	MSW volumes (kg per person per year)				
	1995	2000	2004	2018	2023
Belgium	456	468	469	409	689
Germany	533	610	600	606	601
France	489	531	567	557	530
Italy	454	509	538	502	486
Hungary	460	445	506	384	429
Finland	414	503	455	551	468
Sweden	386	428	464	434	392
Turkey	438	464	458	424	380
EU	487	563	577	500	511

According to experts, in the USA the amount of household waste per capita increases by 10% every 10 years, the situation is similar in other developed countries. As can be seen from Table 1, in 9 years in the EU the average annual volume of household waste has increased by 18.5%. The mass of the world flow of MSW is about 400 million tons annually, of which 80% is destroyed by burial underground. More than 85 million tons of organic carbon enter the biosphere with garbage, for comparison, the natural intake of this element in the soil of the planet is 40 million tons per year.

The research of the problems of waste generation and effective waste management is devoted to the works of a number of scientists, including M.O. Barinov, V.I. Bredun, Ya.V. Gontaruk, I.V. Goncharuk, O.E. Ilyash, G.M. Kaletnik, N.V. Pryshlyak, etc. and foreign scientists, including F. Neuwahl, G. Cusano, H. Saveyn, P. Eder, M. Ramsay, G. Thonier, F. Schorcht, I. Kourti, B. M. Scalet, etc. Despite significant achievements, the problems of effective waste management remain unresolved. There is a need to generalize the best practices of recycling and waste disposal

3. The purpose of the article

The purpose of the study is to systematize the experience of managing solid household waste in countries around the world and characterize the main methods of managing them.

4. Results and discussion

The research was conducted in the following areas: 1. World experience in solid waste processing: 2. Methods of solid waste processing: landfilling of solid waste, composting of solid waste, incineration as a separate system of solid waste utilization, secondary processing - recycling.

1. World experience in solid waste processing.

In industrially and economically developed countries, an effective solution to the problem of solid waste processing is a strategic direction of state environmental policy.

The European Union has adopted a number of programs aimed at reducing the amount and increasing the volume of waste processing. The main documents are: Directive No. 1999/31/EC of 26 April 1999 on the landfill of waste (Landfill Directive) [4], aimed at reducing the amount of untreated organic waste sent to landfills for disposal, and the Waste Framework Directive No. 2008/98/EC of 19 November 2008 on the disposal of waste (Waste Framework Directive) [5], which establishes a hierarchy of desirable waste management. The best for a state, region, enterprise or consumer is the first level - prevention of waste generation. This is followed by reuse. The following levels are the actual processing of waste or its recovery (recycling). The last, least undesirable option is the disposal of waste in landfills and landfills. As a rule, it is resorted to only when nothing else can be done. In addition, there is another level such as incineration. Within the framework of a circular economy, the energy from combustion should be used for good – for example, for heating buildings.

Directions for effective MSW processing: prevention, reuse, waste processing (biothermal (aerobic composting, anaerobic fermentation) and thermal treatment (incineration)) or its recovery (recycling), waste disposal in landfills, producer responsibility and economic incentives.

1. *Prevention of MSW generation*. Each EU country has its own programs to prevent the generation of various types of waste, focused on households, municipalities, agriculture, industry. Most concern food waste, packaging, batteries, etc.

A project is being implemented in the UK to distribute biodegradable packaging materials. All major retail chains are involved. In Belgium, Flanders, reuse centers are developing that collect, sort, repair and resell used items – from clothing to household appliances. In Hungary, the reuse of building materials and their exchange between construction companies is practiced.

2. *Reuse of MSW*. This most often concerns auto parts, furniture, household appliances, computers, clothing, etc. Special centers are created to collect all these items, where they are updated and given a new life.

3. *Waste recycling or recovery*. A separate type of MSW recycling is aerobic fermentation - composting, when bioorganic residues are converted into a humus-like substance (compost) - a valuable organic fertilizer or biofuel. In the Italian Piedmont, the “Home Composting” program is successful: local communes provide households with special equipment, and the quality of composting is monitored by eco-volunteers.

The most common method of processing food waste is anaerobic fermentation, which produces biogas. After the cleaning procedure, carbon dioxide is separated, and the biogas can be used, for example, as a vehicle fuel or for heating. In addition to biogas production, organic matter is used for fertilizer production [6].

According to Directive No. 1999/31/EC of 26 April 1999 (Landfill Directive), waste with a heat of combustion of more than 6.0 MJ/kg cannot be taken to landfills. This is due to the thermal processing or combustion of MSW for the production of heat and electricity. It is estimated that when burning 1 ton of MSW, 1300-1700 kW of heat energy or 300-350 kW of electricity can be obtained.

Combustion of MSW at a thermal power plant is economically feasible, the average cost of obtaining electricity is almost 10 times lower than at a solar power plant and twice as high as at a wind power plant [7].

Recycling. This is the processing of waste into other products that can be used in various areas of life. In the Scandinavian countries, about half of the waste is recycled, in Germany - two thirds, in France - over 40%. And over time, European countries are increasing the indicators.

In Sweden, the so-called recycling centers that accept bulky and hazardous waste have proven themselves well. There are about 6 thousand recycling stations specializing in packaging recycling. In Germany, 68% of paper, 94% of glass and 45% of steel are produced through secondary processing of materials. Recycling plastic bottles alone saves so much energy that it can supply Berlin for up to 130 days.

Sorting waste is a necessary prerequisite for recycling. Currently, in the EU, it is sorted into at least four fractions (glass, paper, metal, plastic), and containers for biodegradable waste and non-biodegradable waste are often added. falls into more than one category.

4. Finally, the last link in the EU waste management hierarchy is *landfilling* in specially equipped places. Moreover, state policy is aimed at minimizing this share. Only certain types of waste are taken there,

with the condition that at a certain stage the municipal solid waste landfills will be closed and the surrounding ecosystem restored. Germany, for example, has already closed more than half of its 300 landfills, in Sweden only 0.4% of waste is subject to landfilling, in Finland – 1%, in Denmark – 0.9%.

5. An important element of the EU's comprehensive waste management system is *extended producer responsibility (EPR).* Its various variations began to develop since the early 90s of the last century. In Germany, the 1991 packaging law was revolutionary, as it for the first time transferred responsibility for its collection and disposal to manufacturers, importers, and distributors of goods.

At the same time, the company Der Grüne Punkt was founded, which initiated the so-called dual waste disposal system. Manufacturers pay a license fee, which covers the costs of removing, sorting and recycling packaging. The sign of a company's participation in this program is a green dot, which is marked on the product. The money from the license fee goes to companies that remove and recycle waste. In this case, residents pay nothing, because the entire financial burden falls on the manufacturer. The "Green Dot" has long since gone beyond Germany and is registered as a trademark in 170 countries around the world.

Currently, in the EU, the R&D strategy also extends to the recycling of batteries, accumulators, and vehicles. Manufacturers are also responsible for the recycling of tires, used oil, paper, and construction waste. In some EU countries, agricultural plastic, pharmaceuticals and medical waste, plastic bags, chemicals, pesticides, lamps, light bulbs and fittings are subject to the EWC.

6. *Economic incentives are the basis for organizing waste recycling.* Other incentives for MSW recycling include the so-called "green" public procurement. According to the European Commission's definition, "green" procurement is characterized by the fact that the public customer, during the procurement, gives preference to goods, works and services with a limited impact on the environment. In this way, the state supports producers of environmentally friendly products.

In addition to incentives, there is a high fee for waste disposal and a system of fines for violators.

The fee for waste disposal in Sweden is 160 euros per ton, in Germany – 140 euros, in Italy – 120 euros.

At the same time, stiff fines were applied for violators, without which the waste management system would hardly function effectively. In Germany, they range from 120 euros for a discarded cigarette butt, 150-600 euros for improper garbage sorting, up to 25 thousand euros for illegal burial of construction waste, and in some cases the offender is threatened with corrective labor.

Thus, in Europe, the efforts of the state and the private sector have been effectively combined to clean the environment from garbage.

And all this is happening against the background of the development of waste sorting and recycling infrastructure. Because no good intentions are realized if there is a catastrophic lack of incinerators, sorting stations and separate waste collection points.

An analysis of the waste management system in the European Union showed that over the period 1995-2023 there was a decrease in the volume of landfilling in favor of recycling (Fig. 2).

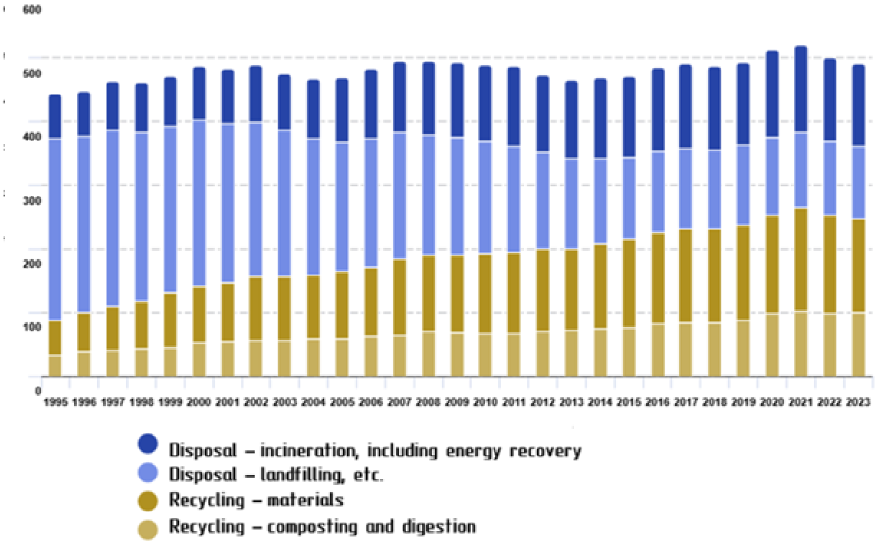

Fig. 2. MSW management in EU countries, 1995-2023, kg/person [8]

The leaders in MSW recycling are Austria – 70%, Germany and the Netherlands – 67%. The leaders in MSW incineration are Sweden and Switzerland – 49%.

2. MSW recycling methods.

2.1. MSW landfill. The biological decomposition time for MSW landfilling ranges from 10 days to 1000 years (Table 2).

MSW disposal occurs in three ways: landfill, landfill, sanitary landfill.

A *landfill* is a place of unauthorized disposal of waste on a land plot not intended for this purpose, which entails maximum contamination of the environment.

Table. 2

Biological decomposition time for MSW landfilling

Types of MSW	MSW decomposition time
Food waste	From 10 days to 1 month
Newspaper	From 1 month to 1 year
Cardboard boxes	Up to 1 year
Paper	2 years
Wooden boards, iron fittings, iron cans, old shoes	Up to 10 years
Brick fragments, concrete, foil, electric batteries	Up to 100 years
Rubber tires	More than 100 years
Plastic bottles	More than 100 years
Glass	More than 1000 years

Disposal of MSW in landfills and violation of environmental and sanitary and epidemiological requirements during their disposal create a number of problems associated with a negative impact on the environment, including:

- pollution and littering of land;
- contamination of upper aquifers with toxic substances contained in the leachate formed at MSW landfills;
- release of large volumes of biogas, mainly containing methane and carbon dioxide, which leads to climate change, as well as to ignition and burning of MSW landfills;
- smoke during ignition of landfills.

One of the most common, cheapest and most durable ways of recycling and neutralizing MSW is landfill disposal.

A landfill is an environmental facility for centralized collection and neutralization of waste. It provides environmental protection from pollution and prevents the spread of pathogenic microorganisms. Its lands are subject to a mandatory remediation procedure.

When constructing a landfill, a waterproofing layer is first laid out, which will prevent liquids from penetrating the soil and groundwater during the process of burying waste. Fire extinguishing and leachate treatment systems are being built, as well as a system for monitoring the state of air, soil and groundwater in the landfill.

Waste is placed in landfills in layers, with sanitary powder for each layer. In essence, a landfill resembles a “layer cake”. One layer consists of solid municipal waste, the second - earth, construction waste, stones. This system is used to prevent waste from igniting, as it releases gas during the decomposition process. Bulldozers work on the landfill body, forming sealing layers. This system has nothing to do with the accumulations at unauthorized landfills, which most often lead to fires in forest areas and near settlements.

When disposing of MSW, material and energy resources that could have been reused are irretrievably lost.

A *sanitary landfill* is a landfill with a landfill gas (biogas) collection system.

It is believed that biogas energy utilization is advisable to use at landfills with an average MSW layer thickness of at least 10 meters and an accumulated amount of MSW of at least 1 million tons. The duration of accumulation of the required amount of waste is also of great importance. Typically, these conditions are met by landfills that accept waste from settlements with a total population exceeding 200 thousand inhabitants.

Biogas collection at a landfill or landfill is an effective environmental measure. As a result of biogas combustion (in power plants or on a flare), greenhouse gas emissions into the atmosphere are reduced, volatile organic compounds associated with unpleasant odors are destroyed, and the likelihood of MSW fires at landfills is reduced or eliminated. In addition, MSW biogas is a local and renewable energy source that can replace any type of fossil fuel - coal, oil, natural gas [9].

The dynamics of the number of biogas plants operating at MSW landfills in Ukraine for the period 2012-2012, according to the Bioenergy Association of Ukraine [10] is shown in Fig. 3.

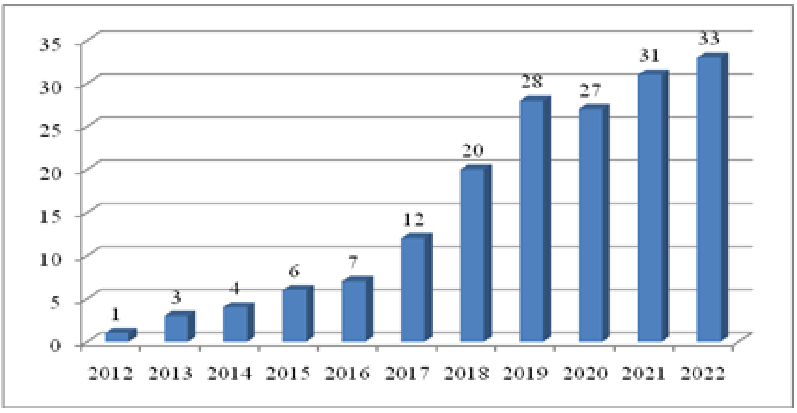

Fig. 3. Number of biogas plants operating at MSW landfills in Ukraine, units

2.2. MSW composting. The simplest method of MSW disposal and processing is field composting, which takes place in 6–18 months, depending on climatic conditions. Composting is a complex biological process accompanied by intense heat release. Easily rotting organic matter decomposes to form mobile forms of humic acids that are well absorbed by plants. As a result of composting, humus is synthesized, which is the main component of soil. MSW composting is carried out at sites located near landfills. For the successful course of the composting process, the following conditions must be met: MSW moisture content must be at least 50–60% by weight; food waste content must be at least 25–30% by weight; the C:N (carbon to nitrogen) ratio in MSW is 25:30. Composting corresponds to the natural cycle of substances to the maximum extent, ensuring the neutralization and utilization of MSW [11].

Abroad, there is considerable experience in processing MSW into composts. The positive effect of many years of applying MSW composts on soil properties, on the accumulation of organic matter and water-resistant structural aggregates, on the improvement of other agrochemical and biological properties has been proven. Composts are used as fertilizers to improve the mineral nutrition of plants to accelerate the growth of crops. The disadvantages of composting the organic component of MSW are the significant period of time required to obtain compost from waste (from several months to a year), the laboriousness and multi-operational nature of the process, the availability of production areas for placing compost piles, and environmental pollution.

An analysis of the state of industrial waste processing (waste sorting plants) in Sweden [12] showed that the previously popular method of eliminating garbage and waste by composting them did not justify itself for the following reasons:

- the compost is not clean, it pollutes the soil, there is no demand for it;
- the secondary raw materials are also contaminated - paper, metal, glass, textiles;
- the industrial process of waste sorting requires further improvement.

In this regard, of the 25 former waste processing plants in Sweden, more than half have been converted to incineration, and the construction of new composting plants has been stopped.

2.3. Incineration as a separate system of MSW utilization. One of the main directions of waste utilization in the world today is their incineration, but not so much for the purpose of their destruction, but for the purpose of obtaining electrical and thermal energy.

The main advantage of incineration is a reduction in the volume of waste by more than ten times, and its mass by three times.

The first "incinerator" in the world was built in 1874 in England near London (in Germany - in 1882, in the USA - in 1885). The development of industry led to the appearance of waste with a relatively high calorific value. All garbage was burned, without disassembly for several decades. Then metals began to be removed from the slag. In England, in 1914, 200 furnaces for burning waste were already operating in 160 cities (with 65 of them being used to obtain energy from steam generators installed there). In the 1930s, furnaces were developed for continuous combustion of MSW at a temperature of 800-1000°C. To date, layer-by-layer combustion of MSW is used quite often in world practice. Since the mid-1970s, the height of the global energy crisis has led to intensive development of waste disposal technologies. In 1998-2007, in Germany and France, the total productivity for thermal waste processing increased by 1.4 times, and in Italy - by more than 2.3 times [13].

The term "Waste-to-Energy" (WtoE, W2E) includes not only the incineration of a mixed stream of MSW, but also the production of renewable fuels from household and/or industrial waste – RDF (Refuse

Derived Fuel), SRF (Solid Recovered Fuel) and biogas with their subsequent utilization in a thermal power plant, a combined heat and power plant or in power plants of industrial enterprises [14].

For example, in Sweden, 7 million tons of waste are burned, a quarter of which is received from other countries, and the energy obtained is used to heat 1.25 million apartments and provide electricity to another 680 thousand. According to the Swedish association of waste management municipalities Avfall Sverige, Sweden receives more energy from waste than any other European country – approximately 3 MWh per ton. Much attention is paid to multi-stage flue gas purification and it is necessary to constantly monitor the quality of exhaust gases [12].

MSW can be incinerated in various types of installations, including moving grate and rotary kiln installations, as well as fluidized bed installations. The main useful product of waste incineration is the heat of waste gases, which is used as a secondary energy resource for generating steam, electricity, and hot water for industrial and domestic needs.

As a method of treating MSW, incineration is used for partially sorted waste containing no more than 10…15% inert material. Only waste with a sufficiently high calorific value (more than 6.0 MJ/kg) can be used for incineration. In the case when the moisture content is <50%, ash content is <60%, and carbon content is >25%, the waste is suitable for incineration without auxiliary fuel [15].

The heat of combustion of MSW and its components is in the range from 3 to 40 MJ/kg (Table 3) [1; 16].

Table. 3

Heat of combustion for MSW used as fuel in EU countries

MSW type	Q, MJ/kg
Wood	16
Paper, cardboard	3-16
Textiles	40
Plastics	17-40
Rubber	26
Industrial sludge	8-14
Agricultural waste	12-16

The scope of application of thermal methods is limited to the properties of the reaction products. When the organic part of the waste is burned, carbon dioxide and oxide, water vapor, nitrogen and sulfur oxides, and aerosols are formed. Thermochemical methods are undesirable to use for waste processing if the latter contain phosphorus, halogens, and sulfur.

Three main types of thermal waste processing are used for MSW combustion: incineration (complete oxidative combustion) - the most common process, pyrolysis (thermal destruction of organic material without oxygen) and gasification (partial oxidation).

1. *Incineration* is the most technically developed of all methods of industrial MSW processing. This is a controlled process of oxidation of solid, liquid, or gaseous combustible waste. During combustion, carbon dioxide, water, and ash are formed. In addition to gaseous products, solid particles are also formed during waste incineration: metals, glass, slag, etc., which require further disposal or disposal.

This method has its advantages and disadvantages. Thus, the advantages include the possibility of obtaining electricity and heat. The main disadvantage is that during the operation of waste incineration plants, secondary extremely toxic waste is formed, which then, together with heavy metals, enter the environment with flue gases, wastewater and slag. A significant disadvantage of waste incineration is its low efficiency. The coefficient of thermal energy utilization even at the best waste incineration plants in the USA does not exceed 65%. In addition, a significant amount of additional liquid fuel is used to burn waste (up to 265 l per 1 ton of waste burned) [17].

For the combustion of MSW, grate combustion technologies, rotating furnaces, and various modifications of the fluidized bed are used [1].

2. *Pyrolysis* is the process of decomposition of organic substances without access to oxygen at relatively low temperatures of 450–800°C. This process is more energy efficient than simple combustion. The result of pyrolysis is the production of combustible gas and a solid residue. Then both products are burned in the furnace without any additional processing. Part of the pyrolysis gases after condensation can be removed from the system and converted into liquid fuel. Pyrolysis has the same disadvantages as direct combustion of waste. Pyrolysis gas must be cleaned of acid gases such as hydrogen chloride (HCl), as a result of which this process becomes quite expensive due to the use of special equipment and the use of caustic or soda ash. In this case, environmental pollution with heavy metals cannot be avoided [18].

3. *Gasification* is a variant of thermal recycling, in which at the first stage the oxidation of fuel is accompanied by the formation of "synthesis gas", at the second stage the combustible synthesis gas is burned in a secondary combustion device to obtain heat or in gas engines/turbines to generate electricity.

The gasification process occurs at a temperature of 800–1300°C in the presence of a small amount of air. In this case, the resulting gas is a mixture of low-molecular hydrocarbons, which are then burned in the furnace [19].

In Germany, an environmentally friendly thermal processing technology has been developed, on the basis of which energy-efficient modular installations are created that process MSW and generate electricity.

The process of converting MSW into electricity is based on the development of a fundamentally new technology of gasification in a layer of organic components of MSW and the utilization of the obtained energy carriers in the form of fuel gas and resins into electricity in a turbo unit.

Having common advantages of waste incineration plants and power plants (elimination of landfills and landfills, since in Germany and Switzerland there are no landfills for storing MSW, use of secondary resources, obtaining a significant share of energy for household needs, etc.), plants operating on this technology have advantages inherent only to them:

- the process of gasification and subsequent utilization of energy carriers in a turbo unit allows for rational, step-by-step control of solid waste processing modes, characterized by a change in composition and properties within wide limits, without the use of additional energy resources;
- the process is generally characterized by high efficiency (energy efficiency with an intermediate energy carrier is 80-90%, the efficiency of the turbo unit is about 50%);
- during the gasification process, harmful substances such as dioxins contained in solid household waste are effectively destroyed, and during its utilization, new harmful substances that pollute smoke emissions are not formed;
- the process of cleaning the obtained combustible gasification products is characterized by high efficiency and relatively low cost of equipment;
- the ecological cleanliness of the installations allows them to be placed in residential areas of large cities, which reduces the costs of preparation, transportation of MSW and increases the number of jobs in these areas, while solving the social problem of large cities.

The requirements for MSW when processed in gasification mode do not exceed the requirements for their direct combustion, and, in general, the proposed process may include any additional technologies for extracting secondary raw materials (metals, paper, glass, etc.).

2.4. Secondary processing - recycling (Recycling). Recycling (reuse) is a key element of an integrated approach to waste processing. The advantage of this approach to waste processing is that waste is converted into marketable products that are accumulated, stored, and transported. Many components of MSW can be recycled into useful products.

Glass is usually processed by crushing and remelting (it is desirable that the original glass be of the same color). Low-quality glass cullet after crushing is used as a filler for building materials (for example, the so-called "glassfalt").

Steel and aluminum cans are melted down to obtain the corresponding metal. At the same time, smelting aluminum from soft drink cans requires only 5% of the energy required to produce the same amount of aluminum from ore [20].

Various types of paper waste have been used for many decades alongside conventional cellulose to produce pulp - the raw material for paper. Mixed or low-quality paper waste can be used to make toilet or wrapping paper and cardboard. Paper waste can also be used in construction to produce thermal insulation materials and in agriculture - instead of straw on farms [21].

Recycling of plastics is generally a more expensive and complex process. Some types of plastic (for example, PET - two- and three-liter transparent bottles for soft drinks) can be used to obtain high-quality plastic with the same properties, while others (for example, PVC) can only be used as building materials after recycling [16].

However, the advantage of secondary use over destruction does not always apply. Thus, materials are recycled only if it is technically, economically and environmentally feasible. Otherwise, waste is destroyed:

- when waste destruction is a more acceptable solution from an environmental point of view;
- when the cost of waste processing is significantly higher than the cost of the final product produced.

Examples of solid household waste recycling technology are presented in Fig. 4-5.

Paper production from waste paper consists of the following stages (Fig. 4): paper pulp grinding; paper pulp production (pulp) on a paper machine (dilution with water and cleaning of the pulp from impurities, casting, pressing and drying, as well as primary finishing); regeneration - recovery, bleaching, neutralization; final finishing (calendering, cutting); sorting and packaging.

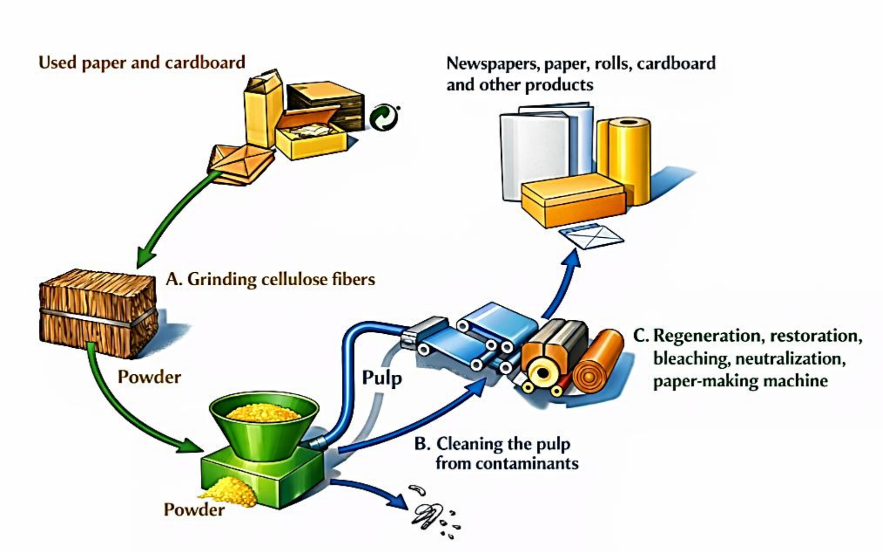

Fig. 4. Technology for producing paper from waste paper (used paper)

The technology for recycling lightweight plastic packaging (Fig. 5) consists of several sequential processes: raw material preparation (crushing and separation); drying and remelting; extrusion; product manufacturing; quality control and packaging.

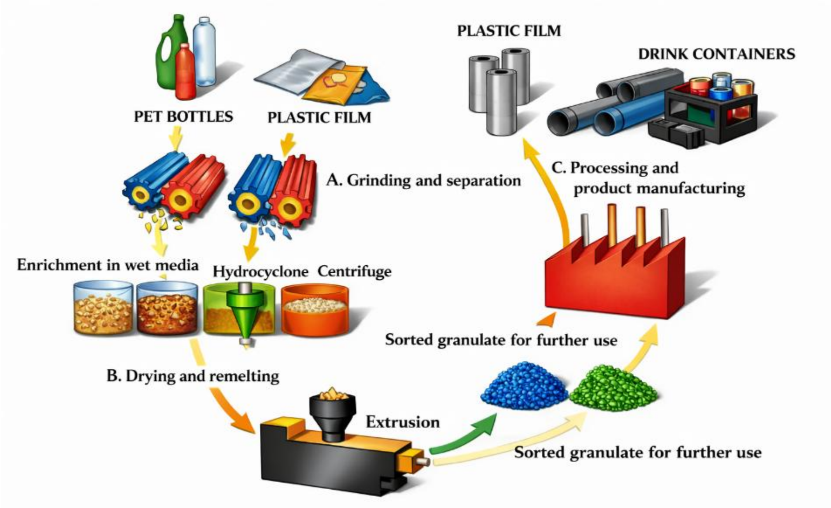

Fig. 5. Technology for recycling lightweight plastic packaging

Technologies for recycling glass, aluminum and tin packaging have also been developed, which also allows the necessary material resources to be returned to production.

5. Conclusion

Based on the analysis of world experience, in particular the European Union countries, the most effective approaches to MSW management have been systematized:

- waste management hierarchy – prevention → reuse → processing (composting, anaerobic fermentation, recycling) → incineration with energy recovery → landfill;

- waste sorting – a necessary prerequisite for effective recycling, which involves separating MSW into several fractions (in the EU – at least 4, in Japan – over 35);

- extended producer responsibility (EPR) – shifting part of the costs of recycling to producers of goods;

- economic incentives – high landfill tariffs, state support for "green" technologies, a system of fines for violators.

- The main methods of MSW disposal in countries around the world today are:

1. landfill – the most common, but environmentally undesirable method, which leads to environmental pollution and loss of secondary resources. The EU is actively reducing the share of landfilling, while Ukraine still largely depends on this method;

2. incineration with energy recovery is a method that allows not only to reduce the volume of waste, but also to obtain heat and electricity. In European countries (Sweden, Switzerland, Germany), it is actively implemented as an alternative to landfill, with an appropriate environmental control system;

3. recycling (secondary processing) is the most priority method from an environmental point of view, which involves the reuse of materials (paper, glass, plastic, metals). Effective implementation of this method requires large-scale waste sorting both at the household level and in production. In developed EU countries, the share of recycling has reached 50–70%, while in Ukraine this indicator remains extremely low;

4. composting is a biothermal process that allows processing organic waste into useful fertilizer. At the same time, the method has a number of limitations, in particular the duration of the process and the need for careful sorting. Sweden and other countries are reducing the volume of industrial composting due to the low quality of the resulting product;

5. anaerobic digestion and the use of biogas is a promising technology that allows converting the organic component of MSW into a renewable energy source. In the EU and Ukraine, the number of landfills equipped with biogas collection and processing systems is increasing.

The creation of new technologies with proper sorting of solid household waste makes it possible to return part of the resources in the form of heat, electricity and material resources. And also solves an important environmental issue of environmental cleaning, which directly affects the health of people who use and live in these areas.

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ВИРІШЕННЯ ПРОБЛЕМИ УТИЛІЗАЦІЇ ТВЕРДИХ ПОБУТОВИХ ВІДХОДІВ: СВІТОВИЙ ДОСВІД

У статті окреслено, що накопичення та утилізація відходів стає світовою екологічною проблемою, накопичуючись у великих об'ємах відбувається псування та перегнивання твердих побутових відходів під дією навколишнього середовища. Обґрунтовано, що накопичення відходів на звалищах, негативно впливає на навколишнє середовище, воно стає джерелом доступу шкідливих хімічних та біологічних речовин, які потрапляють в ґрунтові та поверхневі води, в атмосферне повітря та ґрунт.

Визначено, що проблема утилізації та переробки твердих побутових відходів (ТПВ) є однією з основних проблем в світі, що пов'язано із складністю їх морфологічного складу та їх токсичністю. Тверді побутові відходи, що утворені внаслідок життєдіяльності людей, містить в собі чорні та кольорові метали, пластмасу, папір, текстиль, скло, харчові та рослинні відходи, резину, дерево та інші відходи, потрібно переробляти.

Систематизовано методи переробки ТПВ, що включають захоронення, компостування, спалювання, та вторинну переробку – рециклінг. Визначено основні тенденції утворення і поводження з відходами в країнах ЄС у динаміці, окреслено тенденцію до зменшення обсягів утворення ТПВ та їх захоронення на полігонах, натомість, збільшуються обсяги їх повторного використання. Набирає популярності як в ЄС, так і в Україні використання полігонів ТПВ для отримання біогазу шляхом анаеробного зброджування.

Вирішення проблеми ефективного поводження з твердими побутовими відходами реалізується через їх сортування, а потім їх утилізацію спалюванням із отриманням теплової або електричної енергії, або повторною окремою переробкою різних складових відходів, що також потребую додаткового сортування на виробництві (відбір різного кольору скла, різного типу паперу, різного виду металу та ін.). В різних країнах мешканці сортують тверді побутові відходи на 5-10 і більше позицій, а в Японії більше 35 позицій різного виду сировини.

Ключові слова: *відходи, тверді побутові відходи, утилізація, рециклінг, полігон, анаеробне зброджування.*
Рис. 5. Табл. 3. Літ. 21.

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