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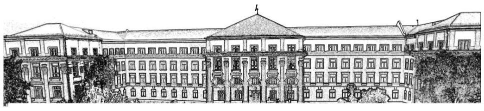
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# INNOVATIVE SOLUTIONS FOR MINIMIZING THE ECOLOGICAL FOOTPRINT OF SOLID DOMESTIC WASTE

**Annotation.** Kazakhstan is undergoing an active modernization of its municipal solid waste management system, prioritizing the reduction of landfilling and the expansion of recycling processes. The transition toward circular economy principles entails the introduction of innovative, environmentally sound, and resource-efficient technologies designed to promote waste reutilization and mitigate adverse environmental impacts. The development of the waste-processing sector contributes to lowering the geo-ecological burden associated with landfill operations; however, the continued use of existing disposal sites and the subsequent need for their reclamation present ongoing challenges that require considerable natural resources. In this context, the utilization of processed waste as secondary raw materials emerges as a significant strategic direction, particularly for the production of materials used in landfill remediation. This approach supports more rational resource management, reduces technogenic pressures on the environment, and aligns with broader objectives of sustainable ecological development.
**Keywords:** waste, recycling, cullet, man-made soil, landfills, secondary raw materials.

## *Introduction*

In recent years, the Republic of Kazakhstan has experienced an active transformation of its municipal solid waste (MSW) management system. The emphasis has been shifting from a traditional disposal-oriented model toward increasing the share of resource reuse and implementing modern technologies for waste processing, neutralization, and environmentally safe disposal. Priority is increasingly given to innovative, energy-efficient, and resource-saving solutions that help minimize the environmental impacts of MSW and align national practices with international environmental standards.

The transition to a circular-economy framework serves as a foundation for the development of the waste-processing sector. The core principle of this model is to significantly reduce the volume of waste directed to landfills and to ensure its conversion into safe and stable processed products. As a result, the geoecological burden associated with landfill operation decreases, due to the reduced scale of soil, groundwater, and atmospheric pollution [1,2].

However, addressing the waste problem cannot be limited to improving recycling technologies alone. Existing landfills continue to operate and, as they reach their design capacity, require reclamation measures. The restoration of disturbed areas necessitates substantial natural resources, particularly soil materials used for waste isolation, slope formation, and the construction of protective layers. This increases the need for comprehensive resource management and the search for alternative solutions.

In this context, the effective utilization of the resource potential inherent in the waste itself becomes especially relevant. One of the most promising directions is the use of processed MSW as a raw material for producing various construction and technical materials, including those applicable to landfill development and reclamation. This approach fully corresponds to the principles of the circular economy: waste is converted into a valuable resource, while the technogenic pressure on environmental components- soils, groundwater, and landscapes—is substantially reduced.

Municipal solid waste consists not only of an organic fraction but also of a considerable amount of mineral, i.e., non-combustible components. These materials include metals, ceramics, and glass. Within the mineral fraction, a particularly important role is played by the glass component, which in household waste is predominantly represented by cullet. According to typical MSW morphological compositions, cullet accounts for approximately 7% of the total waste volume. The major contribution to this fraction comes from used glass packaging—bottles, jars, and other containers discarded after consumption of food and household products. Therefore, cullet represents one of the key constituents of the mineral fraction of MSW, highlighting the necessity of its proper accounting and processing within modern waste-management systems [4–6].

The utilization of recycled glass plays a crucial role in mitigating the environmental impact associated with glass waste in municipal solid waste streams. Incorporating secondary glass into the production of glass batch materials substantially reduces the demand for primary raw resources traditionally used in glass manufacturing, such as silica sand, soda ash, and limestone. This substitution not only conserves natural mineral reserves but also contributes to lowering energy consumption during the melting and forming stages of production. Moreover, the use of cullet in glass furnaces decreases the temperature required for melting, which in turn leads to reduced fuel use and a corresponding decline in atmospheric emissions generated during thermal processing of raw materials. Consequently, the integration of recycled glass into industrial processes represents an important measure for enhancing resource efficiency and minimizing the overall environmental footprint of the glass industry [7,8].

Among the various components of municipal solid waste, glass cullet constitutes a particularly significant fraction. Due to its chemical inertness and extremely slow degradation rate, waste glass represents a persistent environmental contaminant. Accumulated glass fragments pose additional risks, as they may cause injuries to humans and wildlife and remain in the environment for extended periods without undergoing natural decomposition.

According to approximate calculations based on average waste generation rates, one resident produces nearly 400 kg of municipal solid waste annually. With the glass cullet content estimated at approximately 8%, this corresponds to roughly 32 kg of waste glass per person each year. Such figures highlight the substantial contribution of glass waste to the overall volume of TKO and emphasize the need for effective collection, recycling, and reuse strategies to reduce its long-term environmental impact.

*Materials and methods of research*

A set of laboratory analytical methods was employed in the course of this study to perform the experimental component, alongside techniques of information analysis and synthesis, system analysis, expert evaluation procedures, and elements of mathematical and statistical data processing.

The experimental work was carried out in the laboratories of the Research and Testing Center "Sapa" and the Research Institute “Construction Materials, Construction, and Architecture.”

The “Aktas-1” municipal solid waste landfill, located in the city of Shymkent, commenced its operations in March 2015. Covering an area of 34 hectares, the facility is designed to receive approximately 550–600 tons of municipal solid waste per day. Of the total territory, 29 hectares are designated for waste disposal operations, while 5 hectares are occupied by waste-processing plants.

The facility, which complies with all sanitary and environmental regulations, is owned and operated by *Greenline LLP*. The processing plant conducts systematic sorting of incoming waste streams according to all major categories suitable for recycling. In addition, continuous efforts are undertaken to expand the share of recyclable materials through technological improvements and optimization of processing methods.

The proportion of waste that underwent recycling reached 18.1% in 2018, increased to 22.7% in 2019, and further rose to 25.1% by 2020. In the previous year, the landfill received approximately 209.1 thousand tons of waste, of which 52.5 thousand tons were successfully processed and recycled. The recycled material streams included, among others:  14.8 tons of cardboard, 2.3 tons of paper, 1.1 tons of adhesive materials, 26.1 tons of PET bottles, 5.1 tons of plastic waste, 1.8 tons of glass bottles, 0.1 ton of ferrous metals, and 0.01 ton of non-ferrous metals. A significant share of processed waste consists of polyethylene and plastic bottles, which, after sorting and recycling, serve as raw chemical feedstock for further industrial applications [8-10].

Figure 1 presents the sorting process of municipal solid waste at the landfill.

Figure 1 - Aktas solid waste landfill

A measuring reference point has been installed on the territory of the landfill, designed to monitor the degree of compaction of solid household waste (MSW). During the summer period, characterized by increased fire danger, regular humidification of the stored masses is carried out at the solid waste landfill. This measure is aimed at preventing spontaneous combustion, reducing dust and minimizing the risk of fire spread. At the same time, water consumption averages about 10 liters per 1 m3 of solid waste, which allows maintaining a safe humidity level. In order to monitor the operational condition of the landfill, the degree of compaction of waste is monitored twice a year. This is necessary to assess the density of the stored masses, prevent uneven precipitation, and ensure the stability of the landfill body. The intermediate and final insulation of the compacted layers is carried out using soil. This insulation helps to reduce the negative impact on the environment, limits the spread of odors and prevents the separation of light waste fractions. After the completion of the technical stage of the work, the territory is subject to landscaping, which is part of the measures for reclamation and restoration of the landscape. The outer slope of the landfill is formed with a slope in the ratio of 1:4, which ensures its stability and operational safety. The slope condition and compliance with the established parameters are monitored quarterly as part of routine monitoring. There is a strict ban on the incineration of waste and the collection of scrap materials on the territory of the landfill. Mandatory radiation dosimetric monitoring is organized to prevent the disposal of waste containing radionuclides.

During the operation of the landfill, a biothermal anaerobic decomposition process of the organic part of the waste develops in the thickness of the buried solid waste under the influence of natural microflora. The technology of composting of organic waste fraction has been introduced at the Aktas landfill, located near the city of Shymkent. The technological scheme for the production of man-made soil provides for the sequential processing of mixed solid household waste. At the first stage, the waste is separated on a circular sieve with the release of a fine fraction of 0-80 mm in size. Further, ferrous metals are extracted from this fraction by magnetic separation. The resulting organomineral mass is sent to the composting site, where it undergoes a stage of coarse composting and biostabilization for 90 days. As a result, man-made soil is formed, which is subsequently subject to burial. The morphological composition of the mixed solid waste and the isolated fine fraction (0-80 mm) entering the Aktas landfill is shown in Table 1.

Table 1–Morphological composition of MSW and separated fraction 0-80 mm

| № | Name | MSW | 0-80mm |
|---|---|---|---|
| | | % of mass | % of mass |
| 1 | Paperboard | 12,6 | 4,2 |
| 2 | Polymers | 12,7 | 2,7 |
| 3 | Tree | 4,1 | 0,6 |
| 4 | Black metal scrap | 1,3 | 0,5 |
| 5 | Aluminum can | 0,2 | - |
| 6 | Glass | 11,1 | 9,4 |
| 7 | Food waste and plant components | 31,6 | 30,5 |
| 8 | Footwear | 0,7 | - |
| 9 | Rubber | 0,1 | - |
| 10 | Diapers | 2,5 | - |
| 11 | Textile | 6,1 | - |
| 12 | Tetra Pack | 0,5 | - |
| 13 | Stone | 3,7 | 2,8 |
| 14 | Other | 13,0 | 0,03 |
| 15 | Packaging | 0,7 | - |
| | TOTAL | 100 | 50,7 |

Also this analysis shows, that morphological composition of municipal solid waste and the separated 0–80 mm fraction. The comparison of the morphological composition of municipal solid waste (MSW) with the separated 0–80 mm fraction reveals significant differences in the distribution of material categories, which are directly related to their physical properties, density, and behavior during mechanical separation. Cardboard and polymer content decreases notably in the 0–80 mm fraction—from 12.6% to 4.2% and from 12.7% to 2.7%, respectively—indicating that lightweight, voluminous materials predominantly remain in the coarse fraction during screening processes. A similar trend is observed for wood (4.1% to 0.6%), black metal scrap (1.3% to 0.5%), and several minor fractions such as footwear, rubber, diapers, textile, and Tetra Pak packaging, which are absent in the fine fraction.

Glass demonstrates a relatively high retention in the 0–80 mm fraction, decreasing only slightly from 11.1% to 9.4%. This is attributed to the brittleness of glass, which causes it to fragment into smaller particles during waste compaction and handling, making it more likely to fall into finer size classes. Food waste and plant-based components remain the dominant category in both MSW and the fine fraction, accounting for 31.6% and 30.5% respectively. Their high proportional stability is due to the typically moist, dense, and deformable nature of organic materials, which allows them to pass through screening meshes. The share of stones also remains relatively high (3.7% to 2.8%), reflecting their natural density and resistance to fragmentation.

The "Other" category shows a substantial reduction from 13.0% in MSW to 0.03% in the fine fraction, suggesting that most heterogeneous materials either remain in the coarse fraction or are effectively separated during the sorting process. Overall, the total share of materials in the 0–80 mm fraction constitutes 50.7% of the initial waste mass, demonstrating that approximately half of the MSW stream consists of fine materials suitable for further biological or mechanical-biological treatment. These findings underscore the importance of granulometric separation in optimizing downstream recycling and processing operations.

As part of the present study, a modernized technological scheme for producing technogenic soil was developed, incorporating an additional mechanized treatment stage for the fine fraction of municipal solid waste (MSW). The proposed improvement involves equipping the existing fine-fraction sorting line with an air separator for the removal of lightweight components and an optical separator designed for the extraction of waste glass. In order to assess the technological feasibility of extracting cullet from a fine fraction of solid household waste, experimental studies were conducted using equipment from the Austrian company Binder+Co AG. During the tests, stable and reproducible separation indicators were obtained, which confirmed the high efficiency of the technology used. The results obtained indicate the expediency and practical applicability of this solution in industrial operation.

The mineral (non-combustible) component of MSW consists mainly of metals, ceramics, and glass. The glass portion entering the MSW stream is primarily represented by glass cullet, the average share of which is approximately 7 %. The majority of this material originates from discarded glass containers. Currently, national standards are in force that regulate the requirements for container glass cullet.

In accordance with the established regulatory requirements, cullet is subject to classification by color characteristics (Table 2) and is divided into two grades — the first and the second. The criterion for classifying a material to a certain grade is the quantitative ratio of impurities of green and brown glass in the total mass of processed raw materials. Thus, the grade is determined by the degree of color uniformity and the level of permissible inclusions of glass of other shades. [11–13].

Table 2 — Color-based classification of glass cullet

| № | Cullet brand | Cullet color |
|---|---|---|
| 1 | BS | Colorless |
| 2 | PST | Semi-white container |
| 3 | PSL | Semi-white sheet |
| 4 | ZS | Green |
| 5 | KS | Brown |

In order to determine the prospects for the involvement of glass waste in the production of building materials, an analysis of the main sources of their formation was carried out, on the basis of which a conceptual scheme reflecting the key areas of processing was developed (Fig. 1). The results of the study showed that the largest volumes of glass waste are formed as part of solid household waste, as well as in the process of food and pharmaceutical industry enterprises. Waste generated during the dismantling of window structures and other special glass products also makes up a significant proportion. The main areas of secondary glass consumption are the glass industry, the production of building and thermal insulation materials, road construction, as well as a number of related industries focused on the use of mineral secondary raw materials.Despite this, only approximately 3% of the generated waste glass is reintroduced into the production cycle in the form of new products [14,15]. Although the share of glass directed to recycling reaches around 20%, the total amount collected in 2009 was 3,277.2 thousand tons, of which 655.4 thousand tons were processed [15].

Among the various components of municipal solid waste, the recycling of waste glass is considered one of the most economically viable. The key challenge limiting the reuse of glass packaging is its timely and efficient separation from other household and industrial waste streams. Many countries have accumulated significant expertise in the organization of waste glass collection and recycling. In large metropolitan areas, this activity is commonly performed by specialized enterprises. For instance, in the United States, the collection and processing of waste glass are carried out predominantly by glass manufacturers, who establish collection points and provide initial preparation of the material. Sorting and recycling facilities are frequently located directly at glass production plants.

The disposal of used glass containers is carried out, as a rule, in three main directions. Firstly, it can be used as a secondary raw material in the production of new glass products, which reduces the consumption of primary mineral resources and energy costs. Secondly, cullet is included in the composition of raw materials in the manufacture of various building materials and products, thereby expanding the scope of its industrial application. Thirdly, in the absence of separate collection and processing, glass containers are removed as part of solid household waste, followed by landfill and burial. Globally, the most common application of waste glass remains the production of new glass containers (bottles and jars). This direction is technologically adaptable, as it allows the use of secondary raw materials differing in color and chemical composition.

However, recycling waste glass is not limited to container production. A particularly important technological application is the synthesis of foam glass materials. Foam glass is widely used in the construction industry as an effective thermal insulation material. It is used in the insulation of walls, roofs and floor slabs, is part of sandwich panels, is used for thermal insulation of pipelines and industrial equipment, and also serves as a lightweight filler in the production of concrete mixtures. Depending on the technological features and purpose, foam glass can be produced in various forms: in the form of blocks or panels, in a granular state (in terms of fractional composition comparable to building sand or gravel), as well as in the form of fragments of irregular configuration.

Waste glass and residues from glass production may also serve as raw materials in the manufacture of a broad spectrum of building and finishing products, such as mosaic glass tiles, staple glass fibers, glass containers, façade and roofing materials, floor coverings, artificial slate, artificial stone composites, and various types of concrete, drainage, and engineering system fillers.

Another important application of waste glass includes its use as a subgrade or drainage layer, for instance, in pavement structures or in the construction of water management and runoff control systems. [16].

In such applications, glass cullet can serve as a substitute for traditional inert materials of similar particle size, such as granite gravel. This technical solution is justified by the comparable cost of materials, the high load-bearing resistance of glass cullet, and its favorable drainage properties. However, the use of glass cullet in this context is subject to certain limitations associated with the variability of its mechanical strength, which is determined by the heterogeneity of its composition, as well as the availability of less expensive materials on the market with similar performance characteristics.

In addition to its use in drainage systems, glass cullet that meets the particle-size requirements of road construction can serve as aggregate in asphalt concrete mixtures, enabling the production of so-called “glass asphalt.” By replacing traditional mineral aggregate with glass cullet, the overall cost of the final asphalt mixture can be reduced. Additional benefits of such material include increased surface reflectivity and reduced weight, owing to the lower density of glass compared with granite gravel.

Shymkent has an organized glass container collection system, focused on ensuring its subsequent processing and reducing the environmental impact on the environment. Within the framework of this system, specialized reception points have been created that provide the public with the opportunity to deposit used glass bottles and other containers. The implementation of these measures contributes to the involvement of secondary raw materials in economic turnover and the reduction of waste volumes sent for burial.The analysis indicated that the degree of cleaning of the recovered glass cullet depends on the number of processing cycles performed by the optical separator. Based on these findings, an air separator was acquired to conduct pilot tests for the first stage of the technological modernization at the production site of *EuroCrystal LLP*.

EuroCrystall LLP is a manufacturing company specializing in the production of glass containers for the food and pharmaceutical industries. The product range covers products ranging from 150 ml to 2 liters, available in both transparent and color versions. Based on the company's production facilities, a technological scheme for the processing of mixed solid household waste was implemented, including the separation of fine fractions, the removal of ferrous metals, the separation of light components suitable for use as alternative fuels, as well as the subsequent processing of heavy fractions.

The heavy fraction was sent to a specialized cullet processing plant of EuroCrystall LLP, where the second stage of experimental research was carried out, aimed at extracting secondary material resources from the 0-80 mm fraction. The company is equipped with a cascade of optical separators manufactured by Binder+Co AG, which ensure the production of pure color-separated fractions of cullet. The results of the tests showed that in order to achieve the required commercial purity level, the fine fraction of solid household waste must be subjected to double optical sorting. (Fig. 4).

During the pilot testing, a modernized technological scheme for processing small fractions of solid household waste was formed, focused on increasing the degree of recovery of secondary material resources. The developed scheme provides for the sequential execution of the following operations:

(1) using a disk screen to extract a fraction of 0-80 mm in size;
(2) the use of a magnetic separator for the removal of ferrous metals;
(3) air separation to separate light components;
(4) optical sorting for cullet extraction;
(5) additional magnetic separation for the final removal of residual metal inclusions.

The pilot 0-80 mm fraction sorting line has demonstrated high efficiency in extracting valuable components from the fine-grained waste with their subsequent transfer to recycling. The implementation of this technology contributes to an increase in the proportion of organomineral raw mix (OMRM) enriched with food waste, which is further used in the composting process [20].

*Results and Discussion*

The composting site at the "Aktas" landfill represents an open technological area with a compacted solid base, over which a waterproof film liner has been installed. Along the perimeter of the site, embankments and a leachate collection system, as well as a stormwater drainage system, have been arranged to manage the liquids generated during the composting process.

On the prepared surface, trapezoid-shaped windrows of organo-mineral feedstock are formed in parallel using a loader. Aeration of compost rolls is carried out using a specialized chopper-flipper, the design features of which ensure effective loosening and mixing of the compostable mass. During operation, the rotating working shaft sequentially processes the material along the entire length of the roll as the equipment moves, contributing to the saturation of the mass with oxygen and the intensification of biothermal processes. At the same time, the geometric shape and stability of the formed roll are preserved, which ensures uniformity of composting and stability of the technological regime.

At the composting site, aerobic decomposition occurs within the prepared windrows, primarily targeting the fine fraction of municipal solid waste that has undergone preliminary preparation. The initial organic raw materials are characterized by the presence of natural microflora, the quantitative and qualitative composition of which is sufficient to start the biodegradation processes without introducing additional biological preparations. The intensification of the metabolic activity of microorganisms is ensured by systematic aeration of the compostable mass, which helps to saturate it with oxygen, as well as maintaining the optimal moisture level necessary for the course of microbiological and enzymatic processes. [21]. During the activity of saprophytic aerobic microorganisms, intensive decomposition reactions of organic components take place, accompanied by heat release due to ongoing biochemical metabolic processes.

Continuous oxygen supply is necessary to maintain microbial community activity. This is ensured by regular irrigation of the windrows: twice a week when the air temperature is above 10 °C and once a week when it is below 10 °C. Moistening of the composting material, necessary for maintaining optimal humidity, is performed using the collected leachate.

Throughout the composting process, the volume and mass of the material decrease due to $CO_2$ emission and water evaporation, which accompany the decomposition of organic matter. Biodegradation of the components results in a reduction of organic matter content by 30–40 %, associated with the formation of carbon dioxide and water. After approximately 60 days, the intensity of the active decomposition phase decreases, giving way to the stabilization stage, which lasts about 30 days and is characterized by changes in the pH level and temperature regime of the composting mass.

Upon completion of the composting process, a technogenic soil is formed, the appearance of which is shown in Figure 2.

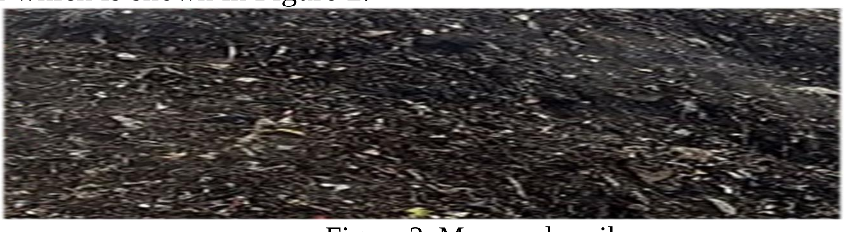

Figure 2–Man-made soil

As a result of mechanized processing of a small fraction of solid household waste with subsequent composting, a technogenic soil containing stabilized biodegradable components was formed. To determine its agronomic value, an assessment of agrochemical parameters was carried out. At the same time, an analysis of the heavy metal content was performed in order to confirm the environmental safety of the obtained material.The results of these investigations are presented in figure 3.

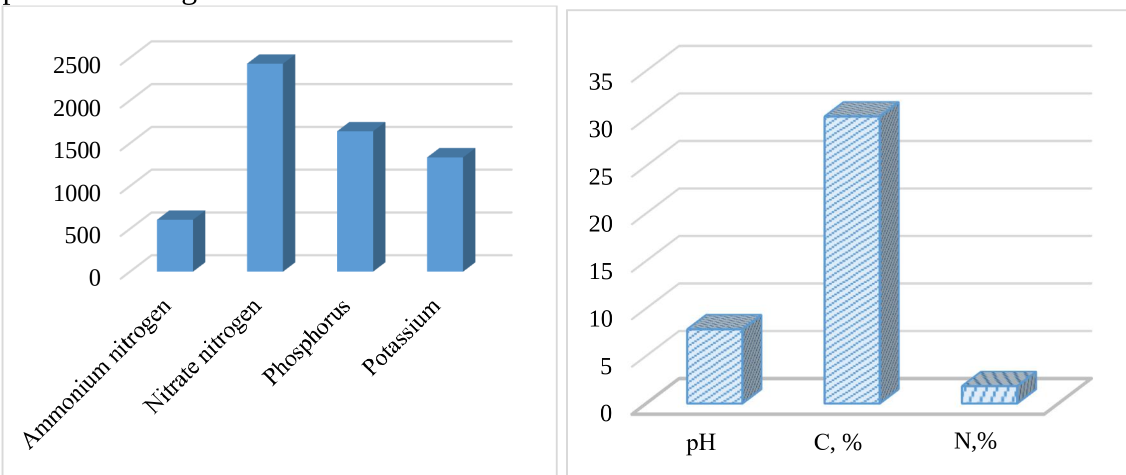

Figure 3 – Agrochemical parameters of technogenic soil

Analysis of the data presented in Figure 3 (diagrams) indicates that the produced technogenic soil is characterized by elevated levels of key plant nutrient elements—nitrogen, phosphorus, and potassium. These components support plant development, allowing the resulting material to be classified as a substrate with high biological potential. The calculated C/N ratio is 16.6, which falls within the optimal range. It is known that when the C/N ratio exceeds 20, a deficiency of available nitrogen forms occurs, leading to reduced microbial activity and potential nitrogen limitation for plants. An optimal C/N ratio promotes intensive mineralization and transformation of organic matter, during which nitrogen is released in forms accessible to plants. Conversely, excessively high C/N ratios result in nitrogen immobilization by microorganisms, reducing its availability to roots, while excessively low ratios may accelerate mineralization and lead to nitrogen loss from the system.

The presented data characterize the chemical and agrochemical properties of the analyzed substrate. The pH value of 7.80 indicates a slightly alkaline reaction of the medium. This level of acidity is favorable for most microbiological processes involved in the decomposition of organic matter and enhances the availability of several macronutrients.

The organic carbon content reaches 30.2%, indicating a high level of organic matter and potentially intensive biological activity within the substrate. Total nitrogen is 1.82%, also reflecting the material's richness in nitrogen-containing compounds. The content of mineral forms of nitrogen is characterized by high values: the concentration of ammonium nitrogen is 606 mg/kg, while nitrate nitrogen reaches 2430 mg/kg. The predominance of the nitrate form indicates the dominance of oxidized nitrogen compounds, which is typical for well-aerated substrates with intensive nitrification processes.

The level of mobile forms of phosphorus (1,640 mg/kg) and potassium (1,335 mg/kg) significantly exceeds the average values of natural soils, which indicates a high availability of basic macronutrients and its potential agrochemical value.Such levels are characteristic of organo-mineral mixtures, composts, or technogenic substrates enriched with nutrients.

Overall, the results demonstrate that the substrate contains high levels of organic matter and available nutrients, as well as optimal acidity conditions. This allows it to be characterized as a potentially fertile material suitable for use as a component of soil mixtures or as a soil amendment.

Thus, a balanced content of organic carbon and total nitrogen is critically important for maintaining a favorable environment that supports healthy plant growth and development.

The concentration of ammonium nitrogen serves as an indicator of the intensity of ammonification, one of the main stages of the mineralization of organic nitrogen compounds. This process is a universal microbiological reaction carried out by a wide range of microorganisms, including bacteria, fungi and actinomycetes, and proceeds under both aerobic and anaerobic conditions.

The presence of nitrate forms of nitrogen is due to the development of nitrification processes, which are the next stage of the biochemical transformation of nitrogen-containing compounds in the soil environment and indicate a high biological activity of the substrate. [23-25].

The predominance of nitrate forms of nitrogen in the technogenic soil indicates a high degree of stabilization and maturity, confirming that optimal aeration conditions were maintained during composting, thereby promoting the oxidative transformation of nitrogen-containing organic compounds.

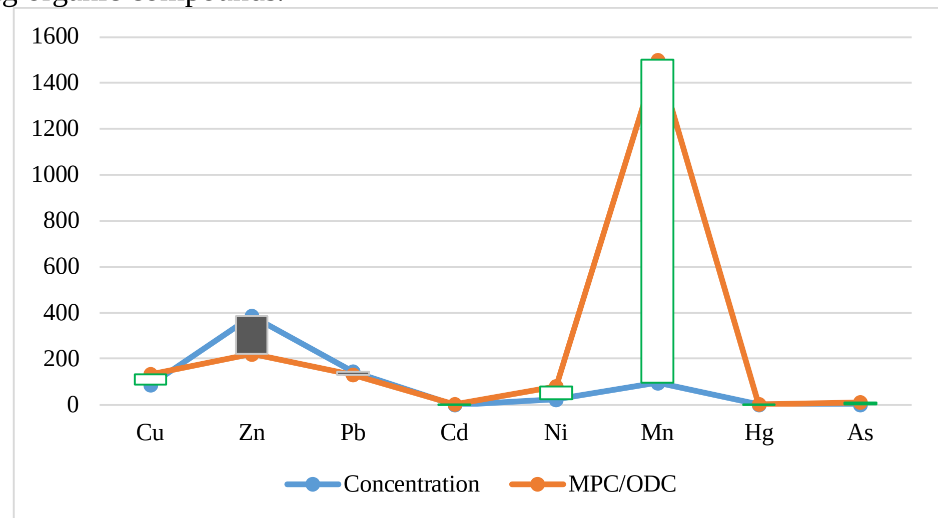


Figure 4 – The content of gross forms of heavy metals (mg/kg) in technogenic soil

The analysis of the results presented graphically in Figure 4 showed an excess of the content of certain heavy metals in the studied technogenic soil compared with the standards for residential soils. In particular, the zinc concentration exceeds the maximum permissible level by 1.8 times, and the lead content by 1.1 times, which indicates the presence of environmental risks and the need for additional material safety assessment. The obtained data reflect the levels of heavy metal accumulation in the analyzed substrate and allow for an assessment of their compliance with sanitary and environmental standards. The concentrations of copper (86 mg/kg), zinc (385 mg/kg), and lead (143 mg/kg) do not exceed their respective maximum permissible concentrations (132, 220, and 130 mg/kg). However, the lead concentration is close to the upper permissible limit, which may indicate a potential risk of its accumulation under continued anthropogenic influence.

The cadmium content is 0.37 mg/kg, compared to the permissible level of 2 mg/kg, indicating a minimal degree of contamination with this highly toxic element. Nickel concentrations (22 mg/kg) also remain well below the established threshold (80 mg/kg), confirming the absence of excessive accumulation. Manganese is present at 95 mg/kg, which is far below its high permissible limit (1500 mg/kg), suggesting a natural background level.

Special attention should be given to elements of hazard classes I and II—mercury and arsenic. Mercury concentration is 0.46 mg/kg (MPC: 2.1 mg/kg), while arsenic is present at 0.7 mg/kg (MPC: 10 mg/kg). Although no exceedances are observed, the presence of these elements requires continuous monitoring due to their pronounced toxicity, bioaccumulative potential, and ability to affect ecosystems.

Overall, the results demonstrate that the concentrations of all studied heavy metals do not exceed the established MPC/ODC values, indicating a satisfactory environmental condition of the substrate. However, the values approaching permissible limits (particularly Pb and Zn) highlight the need for regular monitoring and assessment of potential anthropogenic sources contributing metals to the environment.

Concentrations of copper, cadmium, nickel, manganese, mercury and arsenic meet the established regulatory requirements. At the same time, the variability of the heavy metal content is largely due to the composition of the feedstock supplied to the sorting complex. In this regard, the present study did not consider the use of the resulting product outside the landfill of solid household waste. Incoming waste is processed with the release of a fine fraction (0-80 mm), from which cullet, scrap metal and materials suitable for use as alternative fuels are extracted. The residual organomineral mixture is sent for composting, resulting in the formation of man-made soil used to form and strengthen slopes during landfill operation. Excess volumes of this material are disposed of as stabilized waste, which helps to reduce greenhouse gas emissions and reduce the toxicity of the filtrate.

The filtrate formed at the landfill is discharged through a drainage system and fed to a lithification plant, where, as a result of interaction with aluminum sulfate and shale ash, lithification is formed, an environmentally safe solid product. It is used for daily covering of waste during the operation of the landfill, as well as during the formation of leveling layers and gas disposal systems at the reclamation stage. The combined use of technogenic soil and lithification ensures full coverage of the landfill's needs for soil materials.

The implementation of this system ensures the rational use of the resource potential of solid household waste and helps to reduce the environmental burden of landfills. The effect is achieved by:

1. conservation of natural soil resources;
2. reducing greenhouse gas emissions;
3. reducing the toxicity of the filtrate;
4. complex processing of filtrate and individual industrial waste.

The proposed model of waste and secondary resources management has been implemented at the Aktas landfill (Shymkent). As part of the project, technologies for the production and use of man-made soil were applied. As a result of processing of the fine fraction of solid waste, 1,400 tons of man-made soil, 470 tons of cullet, 260 tons of alternative fuels and 22 tons of scrap metal were obtained. Subsequently, the vegetation cover diversified through colonization by local flora, primarily weed and ruderal species such as nettle (Urtica), field sow thistle (Sonchus arvensis), curly thistle (Carduus crispus), common dandelion (Taraxacum officinale), common yarrow (Achillea millefolium), tansy (Tanacetum vulgare), and wormwood (Artemisia vulgaris).

*Conclusion*

Glass waste is increasingly viewed as a promising resource for use as a primary component in the production of construction materials and the formation of technogenic soils. An efficient glass management system contributes to reducing anthropogenic pressure on the environment, while the reuse of glass containers remains the most rational recycling option.

At the same time, the inherent brittleness of glass leads to the generation of substantial amounts of cullet, necessitating the development of timely and technologically sound disposal methods.

The improved technology for processing the fine fraction of municipal solid waste (MSW) is aimed at maximizing the resource potential of waste and producing technogenic soil.

Treatment of the 0–80 mm MSW fraction enables the recovery of 27.4% of valuable materials, including 17.1% cullet, 9.5% alternative fuel components, and 0.8% metallic inclusions.

As a result of mechanized preparation, the fine MSW fraction is converted into an organo-mineral mixture with a biodegradable component content of up to 90%, making it suitable for further composting.

The resulting technogenic soil was used to cover a section of the landfill slope, reducing the demand for natural soils and thus contributing to the conservation of natural resources.

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**Байбатырова Б.У., Алтынбаев Ж.М., Аскербекова А.М., Абдуова А.А.,Шапалов Ш.К.**

**ИННОВАЦИОННЫЕ РЕШЕНИЯ ДЛЯ МИНИМИЗАЦИИ ВОЗДЕЙСТВИЯ ТВЕРДЫХ БЫТОВЫХ ОТХОДОВ НА ОКРУЖАЮЩУЮ СРЕДУ**

**Аннотация.** В Казахстане проводится активная модернизация системы управления твердыми бытовыми отходами, приоритетное внимание уделяется сокращению свалок и расширению процессов переработки. Переход к принципам экономики замкнутого цикла предполагает внедрение инновационных, экологически безопасных и ресурсосберегающих технологий, направленных на повторное использование отходов и смягчение негативного воздействия на окружающую среду. Развитие сектора переработки отходов способствует снижению геоэкологической нагрузки, связанной с деятельностью свалок; однако дальнейшее использование существующих свалок и последующая необходимость в их рекультивации представляют собой постоянные проблемы, требующие значительных природных ресурсов. В этом контексте использование переработанных отходов в качестве вторичного сырья становится важным стратегическим направлением, особенно для производства материалов, используемых при рекультивации свалок. Такой подход способствует более рациональному управлению ресурсами, снижает техногенную нагрузку на окружающую среду и согласуется с более широкими целями устойчивого экологического развития.

**Ключевые слова:** отходы, переработка, стеклобой, техногенный грунт, свалки, вторичное сырье.

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**ТҰРМЫСТЫҚ ҚАТТЫ ҚАЛДЫҚТАРДЫҢ ҚОРШАҒАН ОРТАҒА ӘСЕРІН АЗАЙТУҒА АРНАЛҒАН ИННОВАЦИЯЛЫҚ ШЕШІМДЕР**

**Аңдатпа.** Қазақстанда қатты тұрмыстық қалдықтарды басқару жүйесін белсенді жаңғырту жүргізілуде, полигондарды қысқартуға және қайта өңдеу процестерін кеңейтуге басымдық беріледі. Айналмалы экономика қағидаттарына көшу қалдықтарды қайта пайдалануға және қоршаған ортаға теріс әсерді азайтуға бағытталған инновациялық, экологиялық қауіпсіз және ресурстарды үнемдейтін технологияларды енгізуді көздейді. Қалдықтарды қайта өңдеу секторын дамыту полигондардың қызметіне байланысты геоэкологиялық жүктемені төмендетуге ықпал етеді. Алайда, қолданыстағы полигондарды одан әрі пайдалану және оларды қалпына келтіру қажеттілігі айтарлықтай табиғи ресурстарды қажет ететін тұрақты проблемалар болып табылады. Бұл тұрғыда қайта өңделген қалдықтарды қайталама шикізат ретінде пайдалану, әсіресе полигондарды қалпына келтіруде қолданылатын материалдарды өндіру үшін маңызды стратегиялық бағытқа айналады. Бұл тәсіл ресурстарды ұтымды басқаруға ықпал етеді, қоршаған ортаға техногендік жүктемені азайтады және тұрақты экологиялық дамудың кең мақсаттарына сәйкес келеді.

**Кілт сөздер:** қалдықтар, қайта өңдеу, шыны, техногендік топырақ, полигондар, қайталама шикізат.