**Determination of Rational Values of Key Parameters of a Device for Sorting Elastic Components of Municipal Solid Waste**

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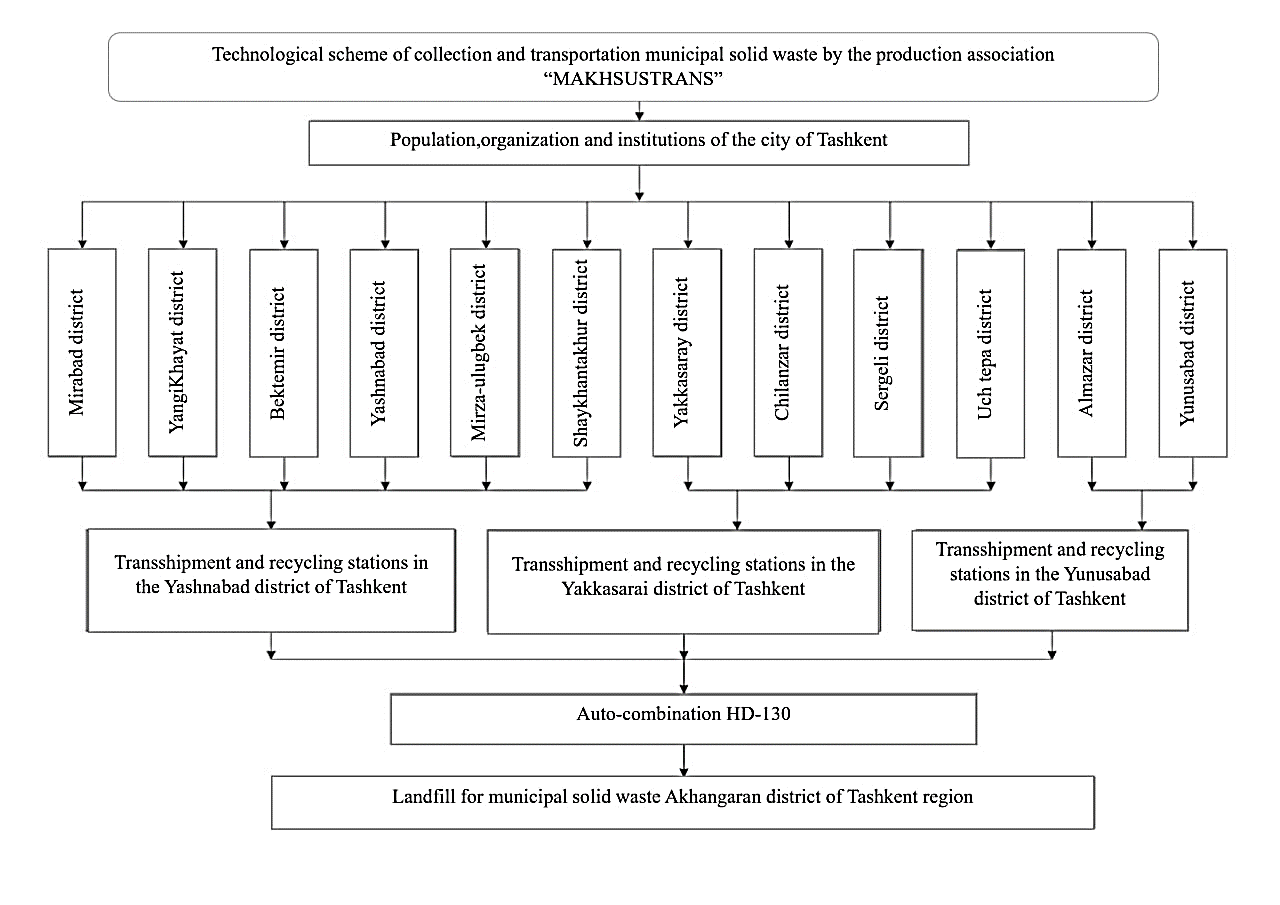
**Abstract.** This article focuses on establishing the fundamental parameters for a sorting device designed to separate elastic components from municipal solid waste. An analysis of existing sorting device designs was conducted, leading to the selection of a prototype for the development of a laboratory sample of the machine. Utilizing modeling principles, a physical model of the device was created, and a series of experiments was performed to determine its key parameters. The processing of experimental data collected from the physical model enabled the development of a mathematical model for the sorting process of elastic components in municipal solid waste. This mathematical model will facilitate the determination of optimal values for the sorting percentage of waste elastic components across significant variations in similarity criteria.

**Keywords**: municipal solid waste, sorting device, mathematical model, experiment

**INTRODUCTION**

The rapid growth of the urban population in developing countries, including the Republic of Uzbekistan, has led to significant challenges in solid waste management in recent years (from 2018 to the present). According to the Ministry of Ecology, Environmental Protection, and Climate Change of the Republic of Uzbekistan, approximately 14.5 million tons of household waste were generated in the country in 2022. Of this total, only about 10% was recycled, while the remaining 90% was disposed of in landfills [1].

To implement innovative projects in the field of solid waste management, it is essential to examine the current state of municipal solid waste (MSW) management in Tashkent. The city has a population of over 3.5 million people, generating more than 2,000 tons of solid waste each day. The existing solid waste management system is structured as follows: household waste is collected in a mixed form and placed in designated garbage bins. Specialized vehicles are responsible for collecting and transporting this mixed waste from all 12 districts of Tashkent to three waste transshipment stations. At these stations, large bulky items are separated from the waste, and the remaining mass is compacted using powerful hydraulic presses into capsules with a volume of 27 m³. This compacted waste is then transported to solid waste landfills for disposal. The technological scheme for solid waste management in Tashkent, developed by the production association "MAKHSUSTRANS," is illustrated in **Figure 1**.



**FIGURE 1.** Technological scheme of MSW management in Tashkent

An analysis of the current waste processing technology reveals that a significant amount of valuable secondary raw materials, such as paper, plastic, metal, and food waste, is being lost. Currently, waste processing is conducted in a very basic manner, lacking essential steps like sorting, crushing, or drying. Instead, waste is simply collected, compacted, and sent to a landfill for disposal. To assess the volume of raw material losses, we can refer to studies conducted by several authors [2, 3], which detail the morphological composition of waste (see Table 1) and the mass fraction of various components of municipal solid waste. Table 2 presents the purchase prices calculated by various private organizations, which are relevant for 2025.

**TABLE 1.** Morphological composition of municipal solid waste generated in the city of Tashkent

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Waste composition | 2022 year | 2023 year | 2024 year | Average value |
| Paper, cardboard | 23.5 | 26.0 | 26.3 | 25.2 |
| Food waste | 35.1 | 34.9 | 33.6 | 34.5 |
| Metal | 2.1 | 2.0 | 1.2 | 1.8 |
| Bones | 2.7 | 2.5 | 2.3 | 2.5 |
| Leather, rubber | 3.3 | 3.5 | 3.5 | 3.4 |
| Plastic | 5.8 | 4.9 | 6.2 | 5.6 |
| Textile | 3.6 | 3.7 | 2.4 | 3.2 |
| Glass | 3.1 | 3.5 | 4.9 | 3.9 |
| Other | 20.8 | 19.0 | 19.6 | 19.9 |
| Total | 100 | 100 | 100 | 100 |

The analysis of the data in Table 1 reveals that highly valuable components of household waste, such as paper, cardboard, plastic, glass, and metal, comprise approximately 36% of the total. This indicates a significant volume of potential secondary resources. While the percentage of textiles, metals (ferrous and non-ferrous), and bones is declining, the absolute quantities of these components are increasing. The morphological composition data collected over the past three years will serve as a probabilistic model for determining the physical properties of waste. This includes aspects such as fractional composition and morphological composition, which vary depending on the size of the waste fraction. Furthermore, this information will provide the foundational data needed to assess the value of municipal solid waste.

**TABLE 2.** Mass fraction and the cost value of highly valuable components of MSW generated in the city of Tashkent

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Waste composition | Average value | Mass fraction of waste per year (thousand tons) | Average purchase price of waste per ton (US dollars) | Possible revenue from the sale of MSW generated in the city of Tashkent in one year (million dollars) |
| Paper, cardboard | 25.4 | 182.5 | 160 | 29.20 |
| Metal | 1.8 | 13.1 | 240 | 3.14 |
| Plastic | 5.6 | 40.9 | 400 | 16.30 |
| Glass | 3.9 | 28.5 | 100 | 2.85 |
| Total | 36.5 | - | - | 51.49 |

The analysis of the data in Table 2 indicates that the current waste management method is inefficient and incurs significant costs. This further highlights the importance of the study focused on extracting valuable components from municipal solid waste.

A significant number of publications focus on studying the sorting processes of various components of municipal solid waste to determine and justify the optimal values for the fundamental parameters of sorting devices. The research conducted by authors such as Kui [4], Anich [5], Hongmei [6], Gonopolskiy [7], Marashian [8], Bolzonella [9], Khankelov [10, 11, 12], Hussein [13], Lamzina [14], Kirin [15], Musaev [16], Teshome [17] deserves considerable attention. These studies primarily analyze waste processing methods, the state of MSW management in specific countries, and the issues surrounding sustainable household waste management. However, the challenges associated with the theoretical analysis of the waste sorting process remain unresolved, making this topic highly relevant.

Analyzing existing designs of sorting devices has enabled authors to identify an analog for the machine design. To develop a laboratory setup for sorting elastic components of municipal solid waste, it is essential to employ physical modeling techniques, which are more effective than traditional machine-building methods. The benefits of physical modeling include significant savings in materials and time, as well as the ability to quickly assess the effectiveness of the chosen theoretical model. This approach also allows for rapid reconfiguration of the equipment when necessary. The overall view and design scheme of the proposed device are illustrated in **Figure 2**.

|  |  |
| --- | --- |
|  |  |
| *a)* | *b)* |

**FIGURE 2.** Device for sorting MSW: a) overall view of the device; b) design scheme of the device:  
1 - frame; 2 - feeder; 3 - upper conveyor; 4 - spring bar; 5 - lever; 6 - pin; 7 - drive; 8 - main drum; 9 - trapezoidal belt; 10 - conveyor belt; 11 - inclined metal plate; 12 - rod; 13 - lower conveyor; 14 - auxiliary drum of the lower conveyor; 15 - drive; 16 - trapezoidal belt, 17 - main drum of the lower conveyor

The sorting machine operates as follows: The components of MSW, crushed to a size of 15 mm, are fed onto the surface of the conveyor by feeder 2. The waste is then spread uniformly with a leveler and transported at a consistent thickness along the working element of the upper conveyor. Upon reaching the end of the conveyor, the solid waste collides with inclined fence 1, resulting in an elastic-plastic impact. Waste components with elastic properties bounce back during the impact, leading them to travel a greater distance and fall into the container located beneath the lower conveyor. In contrast, softer components slide down the inclined plate and fall onto the surface of the lower conveyor, which transports them in the opposite direction. The lower conveyor directs the waste into a ballistic sorting machine for the final extraction of the elastic components from the remaining mass.

The rational value of the coordinate for the center of gravity of the inclined metal bar facilitates the process known as "double sorting." This process unfolds as follows: solid household waste, after bouncing off the inclined metal plate, falls onto the rim of the drum of the lower conveyor. Due to the drum's shape, the second rebound occurs.

The primary factors influencing the sorting of municipal solid waste were identified using mathematical statistics. This was achieved through preliminary distribution analysis, taking into account observations and results obtained from single-factor experiments [18, 19]. The relationship between the percentage of organic components sorted from the MSW and the key parameters of the process is implicitly represented as follows:

(1)

The regression relationship between the percentage of sorted organic components in municipal solid waste (MSW) and the key parameters influencing the sorting process is represented by Equation (1).

To carry out the experimental plan for sorting organic components of waste, the Box-Behnken design (*B3*) was utilized. This design is advantageous compared to others as it accounts for the complex interactions among factors while minimizing the influence of coefficient variability.

By employing mathematical planning methods for the experiment, specifically fractional replicas, we were able to optimize the parameter values and operational settings of the sorting machine during the series of experiments on sorting elastic components. A multifactorial experiment was conducted according to the *B3* plan. Table 3 outlines the factors involved and the upper and lower boundaries of the parameters.

**TABLE 3.** Levels of factors and intervals of their variation

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| No. | Factors | Code Designation | Levels of factors | | | Intervals of variation | Dimension |
| -1 | 0 | +1 |
| 1 | Waste fall height | X1 | 0.8 | 1.0 | 1.2 | 0.2 | m |
| 2 | Angle of metal plate inclination | X2 | 30 | 45 | 60 | 15 | degree |
| 3 | Conveyor speed | X3 | 0.15 | 0.20 | 0.25 | 0.05 | m/s |

To minimize random and systematic errors of experiments and the unnecessary number of experiments, a special technique was used.

The planning matrix and the results of multifactorial experiments are presented in Table 4.

**TABLE 4**. Experimental planning matrix for sorting elastic components of waste

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| № |  |  |  |  |  |
| 1 | + | - | - | - | 90.4 |
| 2 | + | + | - | - | 86.8 |
| 3 | + | - | + | - | 86.0 |
| 4 | + | + | + | - | 92.0 |
| 5 | + | - | - | + | 87.1 |
| 6 | + | + | - | + | 96.3 |
| 7 | + | - | + | + | 82.8 |
| 8 | + | + | + | + | 98.8 |
| 9 | + | - | 0 | 0 | 86.6 |
| 10 | + | + | 0 | 0 | 91.7 |
| 11 | + | + | - | 0 | 97.2 |
| 12 | + | 0 | - | 0 | 91.4 |
| 13 | + | 0 | 0 | - | 91.2 |
| 14 | + | 0 | 0 | + | 85.2 |

The analysis of the data presented indicates that the highest percentage of sorting for elastic components corresponds to the following values of parameters: waste fall height, ; metal plate inclination angle, ; conveyor speed, .

An evaluation of the adequacy of the adopted model compared to standard models demonstrated that this model describes the process with 95% accuracy.

(2)

From the study of this data, it can be concluded that increasing the waste fall height significantly enlarges the machine's dimensions and leads to higher energy and material consumption.

Experiments conducted using the Box-Behnken method (*B3*) enabled a systematic analysis of the key parameters that determine the efficiency of sorting elastic components of waste. By varying the height of the waste fall () between 0.8 and 1.2 m, adjusting the plate inclination () from 30 to 60 degrees, and changing the conveyor belt speed (*X3*) within the range of 0.15 to 0.25 m/sec, a data matrix was obtained that provides a reliable estimate of the coefficients for the regression equation.

The mathematical model developed from the analysis of the statistical data demonstrated a strong correlation between the expected and actual values of waste sorting. Additionally, the chosen model exhibited a 95% level of adequacy compared to existing models. The excellent agreement between theoretical predictions and practical results underscores the relevance of the selected factors and the reliability of the experimental outcomes.

The results of the experiments presented in the table indicate that the highest sorting efficiency, reaching 98.8%, is achieved when the waste components are dropped from a height of approximately 1.2 meters. This optimal performance occurs with a plane inclination of 43 degrees and a conveyor belt speed of 0.2 m/s.

It was also observed that increasing the fall height of the waste beyond this point significantly enlarges the dimensions of the device, which negatively affects the energy efficiency of the process. Additionally, if the conveyor belt speed exceeds 0.25 m/s, waste components tend to collide with the inclined plate, leading to mixing and a subsequent decrease in the waste separation percentage. If the conveyor belt speed falls below 0.15 m/s, the productivity of the sorting station is substantially reduced.

In summary, it can be concluded that the sorting device, designed with efficient parameters, not only enhances separation productivity but also ensures minimal energy costs during operation. With minor adjustments, the results achieved can be scaled effectively for use in the industrial sector of the Republic of Uzbekistan.

By analyzing and synthesizing experimental data and determining the coefficients for the factors of the regression equation, a mathematical model of the process of sorting elastic components of MSW was developed.

(3)

Table 5 shows the rational values of the factors obtained by research on the maximum value of the percentage of sorting organic components of MSW.

**TABLE 5.** Rational values of factors

|  |  |  |  |
| --- | --- | --- | --- |
| Value of factors | Factors | | |
| х1, *m* | х2, *deg* | х3, *m/s* |
| Coded | 1 | -0.1447 | 0 |
| Natural | 1,2 | 42.8297 | 0.2 |
| Rounded | 1,2 | 43 | 0.2 |

The following rational values for the key parameters of the impact sorting machine were obtained:

height of fall for municipal solid waste components – ;

angle of installation of the metal plate - ;

conveyor speed – .

**CONCLUSIONS**

The analysis of household waste volumes in the city of Tashkent revealed that approximately 36.5% of the total municipal solid waste consists of valuable materials, including paper, cardboard, plastic, glass, and metal. This represents a potential annual financial resource of $51.49 million. The current methods of waste processing, collection, compaction, and landfill disposal lead to a significant loss of these secondary resources. This highlights the need for the development of effective technologies and equipment for waste management.

Developing a physical model of the sorting machine and conducting a series of experiments enabled us to perform a comprehensive analysis of the sorting process, in contrast to existing methods that rely on trial and error. By utilizing dimensional analysis during the machine development and experimentation, we significantly reduced both material and time costs, while allowing for prompt modifications to the machine's design. A quantitative analysis of the results confirmed the accuracy of the regression model, with a confidence level of 95%.

The mathematical model developed will serve as a reliable tool for predicting productivity and optimizing the machine across various applications.

The results of the experiments identified the optimal parameters for the device:

- waste fall height - 1.2 m;

- metal plate inclination angle - 43 degrees;

- conveyor speed - 0.2 m/s.

The stated values ensure high efficiency in waste separation without incurring additional costs. Utilizing the developed device can greatly enhance waste processing effectiveness in Uzbekistan. By enabling the recovery of elastic waist fractions, the device contributes to reducing landfill volumes, lowering environmental pollution, and supporting the circular economy. Furthermore, the adoption of such technologies aligns with the national strategy for sustainable waste management and provides a scalable solution for urban centers facing rising waste generation. The experimental findings open avenues for further research, particularly in integrating the proposed device with other waste management technologies such as ballistic sorting machines, vibratory separators, and automated conveyor networks. In addition, scaling up the prototype to industrial-level operations will require studies on durability, maintenance requirements, and long-term economic feasibility.

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