# RESULTS OF EXPERIMENTAL STUDIES OF THE PROCESS OF SORTING OF ELASTIC COMPONENTS OF MUNICIPAL SOLID WASTE

**T.K. Khankelov**[1]
[1]*Tashkent State Transport University, 100167, Temiryulchilar str., 1, Tashkent, Uzbekistan, Email: karshiev_97@mail.ru*

***ABSTRACT**: The article deals with the theoretical substantiation of the process of sorting of elastic components of waste. The experience of foreign countries shows that the use of waste, their separation into useful components used as secondary raw materials at enterprises, allows not only to gain financial benefits from waste but also to clean up the environment. The aim of the study is to theoretically substantiate the process of sorting of elastic components of waste from the rest of waste mass. The study was conducted using theoretical and empirical methods, in particular, a review and analysis of the literature sources, logical and system analysis, and the basic concepts of the theory of impact. The regulatory legal framework in the field of waste management in the Republic of Uzbekistan has undergone significant changes. There are laws, decrees and resolutions of the President, the projects aimed at solving the problem of separate waste collection. The existing technology for the processing of municipal solid waste (MSW) in the Republic of Uzbekistan, in particular, in the city of Tashkent, does not allow the mechanized separation of valuable components from the MSW composition. In this regard, an analysis of the existing designs of sorting devices was conducted and an analog was chosen for the development of the sorting device design. A significant difference in the values of the lengths of rebound of elastic components of waste from non-"elastic" ones is theoretically determined and experimentally confirmed.*

***KEYWORDS**: municipal solid waste, solid waste sorting device, rebound length, elastic components, theory of impact, metal screen*

## 1 INTRODUCTION

The Population growth, rapid urbanization, rapid economic growth and rising living standards in developing countries, and the pursuit of additional profits for producers through small packaging of goods have significantly accelerated the rate of quantity and quality of municipal solid waste on specialized vehicles intended for transporting waste to landfills will significantly decrease; thirdly, the emission of harmful substances into the atmosphere will be substantially reduced. In addition, it is important to note that by reducing the volume of waste disposal, the service life of landfills increases, thus saving land resources used for filling waste, which, in turn, affects the cost of waste disposal.

The following researchers were engaged in the study of the patterns of sorting of municipal solid waste and the methods of selecting devices: Hongmei Lu [5], A.M. Gonopolsky [6], N. Marashlian [7], D.Bolzonella [8], Scott W Anderson [9], Steven P Hanson [10], Huaxun Ma, Lei Sun [11], T. K. Khankelov [12], Sh.S. Tursunov [13], T.N. Lipatova [14], I.V. Lamzina, V.F. Zheltobryukhov, I.G. Shaikhiev [15], B.S. Kirin, A.N. Klokova [16], A.M. Musaev, R.G. Saifulin [17], Mitsuhiro Oka [18], L.N. Reutovich, M.P. Arlievsky, N.A. Averyanova [19], V.F. Reshitko, G.Yu. Zatsepina, A. A. Shashin, Krelman E.B. [20], F.B. Teshome [21].

The creation of efficient sorting devices with low energy and material consumption rates causes significant difficulties: firstly, waste is a conglomerate of very diverse physical and mechanical properties containing fibrous inclusions (paper, wood, leather, etc.), elastic components (bones, stones, etc.), and food waste; secondly, it is connected with the issues of rational arrangement of the device units relative to each other.

In this regard, the theoretical definition of the length of rebound of the elastic components of waste is relevant, which makes it possible to rationalize the arrangement of units and solve the problems of energy and material consumption. In addition, these sorting devices must be subject to very strict energy, environmental and economic requirements, which are as follows:

-low indicators for energy and material consumption;

-minimum percentage of ballast inclusions;

-minimal emission of harmful substances into the atmosphere;

- simplicity of design and reliability in operation.

.

## 2 MATERIALS AND METHODS

A mathematical model of the process of sorting of elastic components of waste was developed in connection with the aim of theoretically determining the lengths of rebound of the elastic components of waste. The equation of motion of the elastic components of municipal solid waste in the process of collision with a metal plate is described by the following equation

$$y = xtg\varphi_0 - \frac{gx^2}{2\vartheta_0^2 cos^2\varphi_0} - \frac{gkx^3}{3\vartheta_0^2 cos^2\varphi_0} - \cdots \quad (1)$$

The equation of the trajectory of the elastic components of waste without considering the forces of air resistance has the following form

$$y = xtg\varphi_0 - \frac{gx^2}{2\vartheta_0^2 cos^2\varphi_0}, \quad (2)$$

Comparing this equation with (1), we can see that the third term in (1) is a correction that determines the effect of air resistance on the trajectory of MSW. The trajectory, taking into account the air resistance, is located below the trajectory of the projectile in the airless space.

In order to find the flight range of the elastic components of waste, it is necessary to introduce y = 0 into equation (1)

$$x_1 = 0, \; 2gkx^2 + 3gx - 3\vartheta_0^2 sin2\varphi_0 = 0,$$

$$x_2 = \frac{\sqrt{9g^2 + 24gk\vartheta_0^2 sin2\varphi_0} - 3g}{4gk}, \qquad x_3 < 0.$$

If we replace $x_2$ with $d$, we get the formula for determining the rebound length of the elastic components of MSW

$$d = \frac{\sqrt{9g^2 + 24gk\vartheta_0^2 sin2\varphi_0} - 3g}{4gk}, \quad (3)$$

To determine the length of rebound of elastic components of MSW in the process of collision with a metal plate, a program in the Python 3.0 language was developed and numerical values of the lengths of rebound of elastic components were obtained. The rebound lengths range from 0.1 to 0.45 m.

For experimental confirmation of the results obtained, a sorting device was developed; its general view and structural diagram are shown in Figures 1 and 2.

**Fig. 1. General view of the sorting device**

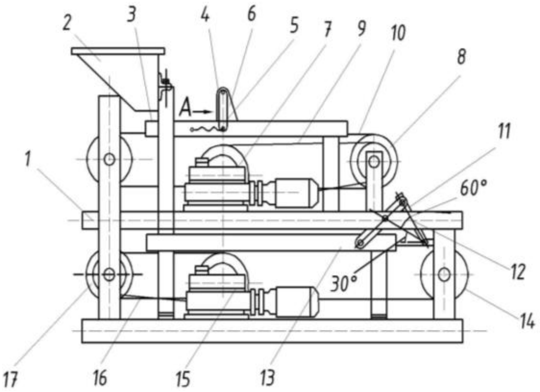


**Fig. 2. Scheme of the device for sorting solid waste.**

**1 - case; 2 - dosing hopper; 3 - top conveyor; 4 - U-shaped frame; 5 - tension spring; 6 - metal bar; 7 - power plant; 8 - driving drum; 9 - V-belt; 10 - upper conveyor belt; 11 - metal plate; 12 - rack; 13 - bottom conveyor; 14 - driven drum; 15 - power plant; 16 - V-belt, 17 - drive drum gearing.**

The device consists of case 1, attached to the racks of the case of loading hopper 2, two conveyors located one below the other. U-shaped frame 4 is attached to the sides of upper conveyor 3 using tension springs 5. Metal bar 6 is rigidly fixed to the U-shaped frame 4. The device contains power plant 7 consisting of an engine and a gearbox, which serves as a drive for driving drum 8 using V-belt 9 of conveyor belt 10. Metal plate 11 is connected to rack 12, which is bolted to the side of lower conveyor 13. Metal plate 11 has the ability to adjust the angle of inclination within the range of 30º-60º relative to the horizontal line. The driven drum 14 is mounted on the racks of case 1. The power plant 15, consisting of an engine and a gearbox, serves by means of V-belt 16 as gear for driving drum 17.

The stand for sorting municipal waste works as follows. Municipal waste through hopper 2 is fed to belt 10 of the upper conveyor using metal bar 6, the waste is leveled, fed in a uniform layer and moved along belt 10 of the conveyor. Having reached the edge of the conveyor, the waste components begin to fall on metal plate 11. When they hit the screen (due to their elasticity, the rebound length of the elastic components is greater than that of organic components), the elastic components bounce off plate 11 and fall into a separate container, and the remaining parts of municipal waste fall onto the lower conveyor belt. Along the bottom conveyor, the waste is fed to the next cycle of technological scheme of waste processing.

## 3 RESULTS AND DISCUSSION

To substantiate the range of variation of the factors influencing the sorting process, a series of one-factor experiments were conducted.

Figure 3 shows the dependence of the percentage of sorting of elastic components of solid waste on the height of the fall of waste (at the speed of the conveyor belt $\vartheta_{\text{тр}} = 0.1$ *m/s*)

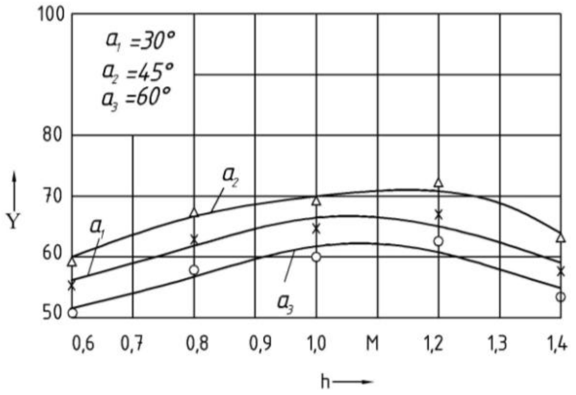


**Fig. 3 Dependence of the percentage of sorting of elastic components of solid waste on the height of the fall of waste (at the speed of the conveyor belt $\vartheta_{\text{тр}} = 0.1$ *m/s*).**

Figure 4 shows the dependence of the percentage of sorting of elastic components of solid waste on the height of the fall of waste (at the speed of the conveyor belt $\vartheta_{\text{тр}} = 0.2$ *m/s*).

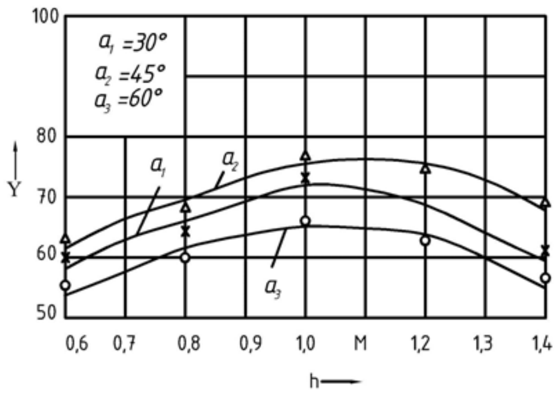


**Fig. 4 Dependence of the percentage of sorting of elastic components of solid waste on the height of the fall of waste (at the speed of the conveyor belt $\vartheta_{\text{тр}}$ = 0.2 *m/s*).**

Figure 5 shows the dependence of the percentage of sorting of elastic components of solid waste on the height of the fall (at the speed of the conveyor belt $\vartheta_{\text{тр}}$= 0.3 *m/s*)

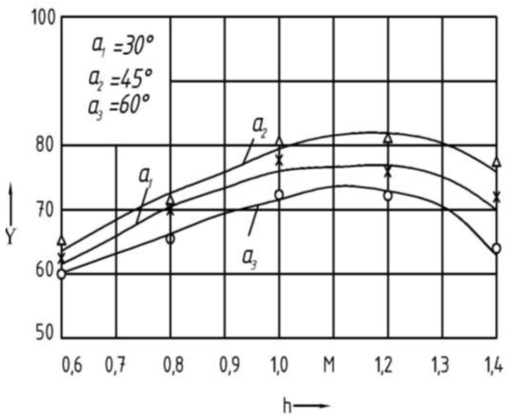


**Fig. 5. Dependence of the percentage of sorting of elastic components of solid waste on the height of the fall (at the speed of the conveyor belt $\vartheta_{\text{тр}}$= 0.3 m/s).**

Analysis of the graphs presented in Figures 3, 4 and 5 shows that the maximum value of the percentage of sorting the elastic components is achieved at values of the height within 1.0 ÷ 1.2 m (the value of the conveyor belt speed is within the limits $\vartheta_{\text{тр}}$= 0.3 *m/s*).

The qualitative difference between the curves indicated by numbers 1, 2, 3 is that when the angle of inclination is α = 30°, the normal component of the impact force is the maximum. This means that the glassware (of various shapes, sizes and thicknesses) begins to break a little earlier than at the angle of α = 45° and α = 60°. Broken glass, mixing with organic components, tends to reduce the percentage of sorting.

The maximum value of the percentage of sorting corresponds to the value of the angle of inclination of the metal plate equal to approximately 35° ÷ 45° (for all three values of speed). To determine the limit of variation (of elastic components) of the inclination angle of the metal plate, a series of one-factor experiments were conducted [22].

Fig. 6 shows a graph of dependence of the percentage of sorting of elastic components of waste on the angle of inclination of the metal plate (at the height of the fall of waste *h = 0.8m*).

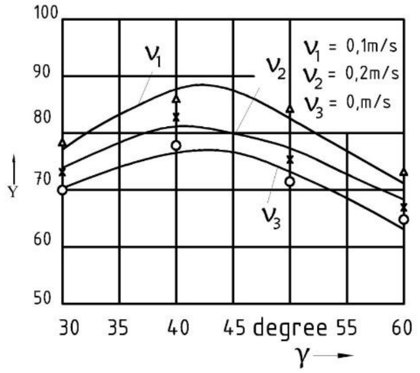


**Fig. 6 Dependences of the percentage of sorting of elastic components of waste on the angle of inclination of the metal plate (at the height of the fall of waste *h = 0.8m*).**

Fig. 7 shows the dependence of the percentage of sorting of elastic components of solid waste on the angle of inclination of the metal plate (at the height of the fall of waste *h = 1.0*).

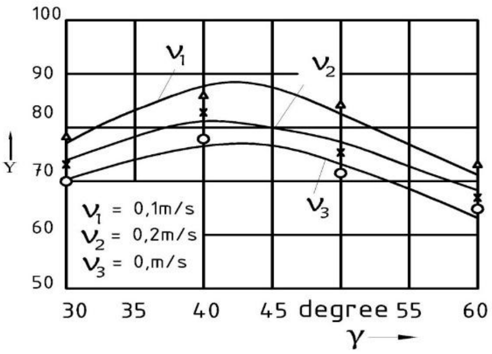


**Fig. 7. Dependence of the percentage of sorting of elastic components of solid waste on the angle of inclination of the metal plate (at the height of the fall of waste h = 1.0 m).**

Fig. 8 shows the dependence of the percentage of sorting of elastic components of solid waste on the angle of inclination of the metal plate (at the height of the fall of waste *h = 1.2 m*).

Analysis of the graphs presented in Figures 6, 7 and 8 shows that the maximum value of the percentage of sorting the elastic components of waste is achieved when the angle of inclination is approximately $\propto \approx 35^0 - 45^0$ (at the height of the fall of waste *h≈1.2 m*, and the speed of conveyor belt $\vartheta_{тр} = 0.1$ *m/s*).

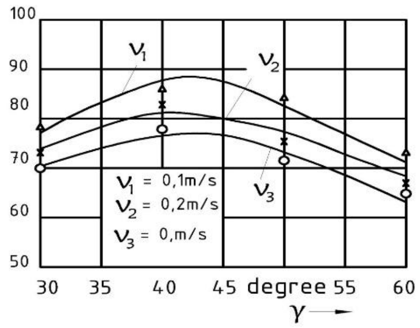


**Fig. 8. Dependence of the percentage of sorting of elastic components of solid waste on the angle of inclination of the metal plate (at the height of the fall of waste h = 1.2 m).**

According to the methodology of mathematical planning of experiments by a priori ranking based on the review and the data obtained from one-factor experiments, the main controllable factors were established that affect the process of sorting the elastic components of solid waste.

This dependence is generally written as follows:

$$Y = f(h; \alpha; \upsilon), \quad (4)$$

where $h$- is the height of the fall of waste, m; α is the angle of inclination of the metal plate, degrees; $\vartheta_{тр}$- is the conveyor belt speed, m/s; $Y$ is the percentage of sorting of elastic components of waste.

The relationship between input and output factors is represented in the form of a regression equation:

$$Y = b_0 + \sum b_i x_i \sum b_{ij} x_{ij} \sum b_i x_i^2 \quad (5)$$

where: $Y$ - is the value of the optimization parameter under study;

$x_i$- are the coded values of factors (i = 1,2,3);

$b_i$- is the estimation of the coefficient of the regression equation of the corresponding *i*-th factor;

$b_{ij}$-is the estimate of the coefficient of the regression equation of the corresponding interaction of factors.

The experiments were conducted by the $B_3$ plan [23], as it is the least laborious in comparison with other plans. Moreover, $B_3$ is the optimal plan that provides the minimum sensitivity of the coefficient estimates and reduces the number of experimental points with varying factors on three equations. The Cochran test was used to check the reproducibility of experiments, i.e. to test the hypothesis about the homogeneity of variances with the same number of repeated experiments, and the significance of the coefficients of the regression equation was determined using the Student's test at a confidence level of 0.05.

The ability to describe the rebound surface well enough, i.e. the adequacy of the process model was checked using the Fisher criterion.

The model is considered adequate provided:

$$F_{расr} < F_{maбл} \quad (6)$$

The optimization of the parameters and operating mode of the sorting device was performed using the method of mathematical design of the experiment. At the same time, a three-factor experiment was conducted according to plan $B_3$. The percentage of sorting of elastic components of solid waste was taken as an evaluation criterion.

**Table 1 shows the levels of factors and the intervals of their variation.**

| Factors | Designation code | Factor levels -1 | 0 | +1 | Interval variation | Dimension |
|---|---|---|---|---|---|---|
| Height of the fall of waste | $x_1$ | 0,8 | 1,0 | 1,2 | 0,2 | M |
| Angle of inclination of the metal plate | $x_2$ | 30 | 45 | 60 | 15 | Degree |
| Conveyor belt speed | $x_3$ | 0,1 | 0,2 | 1,3 | 0,1 | m/s |

After processing the experimental data and assessing the significance of the regression coefficients, a mathematical model of the process of sorting of elastic components of solid waste was obtained.

$$Y=72,66+2,98x_1-2,16x_2-7,6x_3+3,3x_1^2-7,5x_2^2+3,9x_3^2 \quad (7)$$

Checking the adequacy of the model according to Fisher's criterion showed that the mathematical model is adequate with a 95% confidence.

$$F_{расч} = 0.95, \quad F_{табл} = 2.36 \ (8)$$

Analyzing equation (7), it can be noted that an increase in the percentage of sorting of elastic components of waste is achieved by increasing the height of the fall of waste (at the value of h>1.2 m, glassware begins to break and mix with organic components) and by decreasing the speed of the conveyor belt.

To determine the rational values of the factors, Eq. (7) was investigated for an extremum; the results are shown in Table 2.

**Table 2. Rational values of factors**

| Significance of factors | Factors $x_1$,m | $x_2$, *degree* | $x_3$, m/s |
|---|---|---|---|
| Coded | 1 | -0,1447 | -1 |
| Natural | 1,2 | 42,8297 | 0,1 |
| Rounded | 1,2 | 43 | 0,1 |

Thus, the rational values of the parameters of sorting equipment are:

The height of the fall of waste $h = 1.1 - 1.2\ m$;

The angle of inclination of the metal plate $\alpha = 40^0 - 50^0$

The speed of conveyor $\vartheta_0 = 0.1 - 0.2$ *m/s.*

## 4 CONCLUSIONS

1. The values of the lengths of rebound of elastic components of waste are theoretically determined; they vary in the range from 0.1 to 0.45 m. The result obtained will allow the optimization of the size of the sorting device.
2. With an increase in the height of the fall of waste, the percentage of waste sorting increases. When the values of h≥1.2 m are exceeded, glassware begins to break, thereby mixing with the rest of the components.
3. The following rational values of the parameters of the sorting device were received:

- The height of the fall of waste $\boldsymbol{h = 1.1 - 1.2}$ m;
- The angle of inclination of the metal plate $\boldsymbol{\alpha = 40^0 - 50^0}$
- The speed of conveyor $\boldsymbol{\vartheta_0 = 0.1 - 0.2}$ m/s.

## 5 REFERENCES


[1] *Khankelov T., Askarhodzhaev T., Mukhamedova N. 2020 Determination of key parameters of device for sorting municipal solid waste. (Journal of Critical Reviews. Vol.7), Issue:4, pp.27-28.*

[2] *Khankelov T., Tursunov Sh., Maksudov Z. 2020 Domestic Solid Waste Crusher. (International Journal of Psychological Rehabilitation, vol.24, Issue 07), pp.8090-8091.*

[3] *Adylova M. 2006 The problem of primary sorting of waste. (Publishing house "Fan" of the Academy of Sciences of the Republic of Uzbekistan). No. 8. pp. 10-14.*

[4] *Resolution of the President of the Republic of Uzbekistan 2019 PP-4291 On approval of the Strategy for solid waste management in the Republic of Uzbekistan for the period 2019-2028. (Tashkent). 59 p.*

[5] *Hongmei Lu., Roman Sidortsov. 2019 Sorting a problem: A co-production approach to*

*household waste management in Shanghai, China. (Waste Management 95), pp.271-277.*

[6] *Gonopolskiy A.M., Zinyakina E.V., Denisova T.V. 2017 Waste cutter roller. (Bulletin of SUSU. Series "Food and Biotechnology". Vol.5), No. 1, p.45-54.*

[7] *Marashlian N. 2005 Effect of food waste and wastewater management. (Waste Management & Research). №23 (1), pp.20-31.*

[8] *Bolzonella D. 2003 The under-sink garbage grinder: a friendly technology for the environment. (Environmental Technology. Vol. 24), Issue 3, pp.349-359.*

[9] *Scott W Anderson, Steven P Hanson, Joseph G Farmerie, James R Patterson. 2008 Food waste disposer shredder assembly: pat. 7360729. (United States Emerson Electric Co. Appl. No.:10/908,056), 12 p.*

[10] *Steven P Hanson. 2011 Water recycling food waste disposer system: pat. US7963469 (United States Emerson Electric Co. Appl. No.:12/028,855) 15 p.*

[11] *Huaxun Ma, Lei Sun. 2013 Grinding disk for food waste disposer: pat. US20130277475 A1 (United States Zhang Zhou Sunwise Environmental Protection Co. Appl. No.: US 13/880),165 6 p.*

[12] *Khankelov, T.K. 2001 A theory of sorting solid domestic waste. (Stroitelnye Dorozhnye Mashiny) Issue 5, pp.34-36.*

[13] *Tursunov, Sh.S. 2021 Analysis of existing designs of crushers for crushing municipal solid waste. (International Journal for Innovative Engineering and Management Research. Vol 10), Issue 01, pp. 274-276.*

[14] Lipatova T.N. 2013 The culture of sorting solid household waste in large cities. (Annotation of reports of the International scientific-practical conference dedicated to the 100th anniversary of academician P.A. Kirpichnikov). pp. 240-242.

[15] Lamzina I.V., Zheltobryukhov V.F., Shaikhiev I.G. 2015 Analysis of methods for sorting solid household waste. (Bulletin of Kazan Technological University), Issue 5, pp. 244-245.

[16] Kirin B.S., Klokova A.N. 2014 Modern technologies for the separation of plastics waste. (Advances in chemistry and chemical technology. Volume XXVIII). Issue 3. pp.31-33.

[17] Musaev A.M., Saifulin R.G. 2011 Method of vibro-pulsation sorting of solid household waste. (Izvestia KazGASU Ecology in construction). Issue 1, pp. 141-145.

[18] Mitsuhiro Oka. 1993 Sorting apparatus in solid waste sorting system. pat.US0055464100A (United States: Okasan Corparation. Co Appl. №139118) 10 p.

[19] Reutovich L.N., Arlievsky M.P., Averyanova N.A. 2004 Method for cleaning compost from solid domestic waste of ballast fractions: patent application. 2004104371 (Russian Federation: MPKV9/00/:LLC "GIPROKHIM-TECHNOLOG") 11 p.

[20] Reshitko V.F., Zatsepina G.Yu., Shanin A.A., Maslov V.S., Krelman E.B. 2000 Method of cleaning and processing solid household waste and a complex for its implementation: patent application 2000130971/13 (Russian Federation: MPKV09V3/13) 12 p.

[21] Teshome F.B. 2021 Municipal solid waste management in Ethiopia; the gaps and ways for improvement. (Journal of Material Cycles and Waste Management, volume 23), issue1, pp.18-31.

[22] *Augambaev M.A. et al. Fundamentals of planning a research experiment.-T.: Ukituvchi, 1993. -336 p.*

[23] *Gatapova N.Ts., Koliukh A.N., Orlova N.V., Orlova A.Yu. Fundamentals of the theory and technique of physical modeling and experiment. Tambov, 2014.-77 p.*