Review Article

DETERMINATION OF KEY PARAMETERS OF A DEVICE FOR SORTING MUNICIPAL SOLID WASTE

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Abstract
The article is devoted to the determination of rational values of the key parameters of a device for sorting municipal solid waste (MSW). The basic physical and mechanical properties of MSW (morphological and fractional compositions, morphological composition depending on fraction values) that affect the design of a device are determined. The basic principles of the impact theory and the mathematical theory of experimental design are used in defining the key parameters. A mathematical model of the process of municipal solid waste sorting has been developed.

Keywords: solid waste, impact theory, sorting device, rebound length, metal strip.

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INTRODUCTION

An increase in population, rapid urbanization, booming economic growth and the improvement of living standards in developing countries have significantly accelerated the pace, quantity and quality of solid waste formation [1, pp 1275-1276].

Solid waste includes the waste generated in residential and public buildings, trade, sports and industrial enterprises, fallen leaves, swept trash, bulky refuse [2, pp 6-9;3, pp11-12; 4, pp16-17; 5, pp76-77].

Recently, there has been a decrease in MSW density due to the increased content of paper and plastics (mainly due to the packaging materials). The solid waste composition in different countries does not fundamentally differ, and therefore the problems of its storage, disposal, neutralization or processing are largely identical.

MATERIALS AND METHODS

However, this does not mean that in solving these problems it is possible to use some universal method of MSW management, since each country and each region has its own specifics [6, pp1-2 In our opinion, these specifics are as follows:

- the system for solid waste collection and transport (separate or mixed one);
- climatic zones (northern, temperate, southern ones);
- the level and the lifestyle of people (average annual income per capita).

One of the fundamental types of waste collection and transport system is a separate type, to which, most EU countries have moved [7, pp.41-42;8]. Separate type of waste collection has a number of undeniable advantages. At a separate collection and transportation method, the components of solid waste are pre-sorted, which eliminates the need for preliminary sorting. In addition, at a separate method of collecting and transporting, the waste components retain their original form, which favorably affects the quality of secondary raw materials.

In the case of a mixed type of collection and transportation, waste components mixed with food waste become unusable and thereby increase the waste negative impact on the environment. In this regard, the experience of Israel is indicative and interesting. Under the auspices of the Ministry of Ecology, a garbage separation program has been adopted. So, garbage is divided into two parts: the so-called "wet" garbage (organic waste) - food residues, and "dry" garbage (inorganic waste) - package, bottles, plastic, paper, etc. [9, pp240-241] The Chinese government's pilot program is also interesting. In 2000, the government selected eight pilot cities, including Shanghai, to study the mechanisms for sorting solid waste. To advance this pilot program, a series of administrative regulations and policies have been developed at national and local levels. Selected as a pilot city, the Shanghai government included the management into municipal practical tasks. In addition, incentive and education programs have been introduced. The local government, together with the Bank of China, began introducing a "Green Account" program for the households. Waste sorting brought the points to the account which could be exchanged for everyday goods, such as milk, shampoo, etc. or pay the utility bills. [10, pp271-277] Sorted food waste, for example, can serve as a livestock feed, and the waste from another container can serve as the secondary raw materials to be used in industry [11, pp74-75.] With such separate processing, the damage caused by landfills to the environment is reduced, as well as the amount of stored waste at landfills and the number of vehicles involved in waste transportation to landfills.

Realizing the versatile benefits of separate collection and transportation of waste, Uzbekistan is also taking practical steps to switch

from mixed to separate collection. A Decree of the President of the Republic of Uzbekistan adopted on April 17, 2019, PP-4291 "On approval of the Strategy for the management of municipal solid waste in the Republic of Uzbekistan for the period 2019-2028" [12, pp19-20] clearly indicates the terms for a staged percentage increase in processing solid waste in the republic, as well as the time to transfer to separate collection. Unfortunately, despite the adopted resolution, it is rather difficult at this stage to organize separate waste collection everywhere. The reason for this is not only the unpreparedness of the population, but the lack of appropriate living conditions and technical support, the absence of garbage chutes [13, pp3-4]. Based on the above statements, the sorting of solid waste, in particular, food components, the development of a sorting device with rational values of the key parameters is an urgent and relevant task.

Many prominent scientists, such as R.T. Chernolutsky [14, pp 3-7], L. Ya. Schubov [15, pp94-358], I.V. Lamzina [16, pp244-247], A.M. Musaev, R.G. Saifulin [17, pp141-145], B.S. Kirin, A.N. Klokova [18, pp31-33], Mitsuhiro Oka [19, pp2-8], L.N. Reutovich, M.P. Arlievsky, N.A. Averyanova [20, pp2-10], V.F. Reshitko, G.Yu. Zatsepina, A.A. Shashnin, V.S. Maslov, E.B. Krelman [21, pp2-11] and others have studied the issues of sorting regularities, as well as the methods and selection of solid waste sorting devices. The existing technology for processing solid waste at collection and transportation sites in Uzbekistan, in particular, in Tashkent, is as follows: the waste that is brought to the waste transfer station is sorted manually, then, it is disposed via a conveyor line to a tank where it is pressed and taken to a landfill for waste burial. In the process of manual sorting, only large (clearly distinguishable) waste is separated, besides, the bulk of the waste is in plastic bags; to tear the bags and sort out the waste manually is a labor-intensive and low-profitable process. So, an analysis of existing devices for sorting solid waste has been conducted and the main disadvantages of these structures identified. Based on the analysis of literary sources and existing designs of sorting devices, a prototype of a sorting device design was selected.

EXPERIMENTAL RESULTS

Materials and research methods

In accordance with the task to create a rational design of a sorting device, to check the theoretical conclusions and substantiate the key parameters and operating modes, the following issues are included into the program:

1. Definition of morphological and fractional composition of solid waste in places of waste collection and transportation.
2. The study of the quality indices of sorting process, depending on:
- the height of the waste fall;
- angle of inclination of metal strip;
- conveyor belt speed.
3. Optimization of the parameters and operating modes of a sorting device.
4. Development of an experimental sorting device with rational parameters and an assessment of its economic efficiency.

The criterion for assessing the quality of a sorting device is the percentage of sorting the food components of the waste, to lessen the secondary pollution of the environment.

Physical properties of solid waste were determined at places of waste collection and transportation.

To study the morphological composition of municipal solid waste, 10 waste collecting points were selected. The weight of each sample was 30 kg.

The definition of morphological composition of solid waste was carried out as follows: the waste was leveled on a tarpaulin (2000 × 2000 mm), after leveling, the tarpaulin area was divided into four parts, the waste from ¾ was thrown away, and ¼ part of the waste was used for analysis (the quartering method) [7, pp222-223]. After that, the analyzed part of the waste was leveled on a tarpaulin and each component of the waste was separated from each other.

The percentage of waste constituents was determined by formula:

$$Y = \frac{A_1}{B_1} \cdot 100\%, \qquad (1)$$

where Y_1 – is the percentage of constituent waste, %;
A_1 - the weight of the constituent waste, kg;
B_1 - total weight of waste, kg.

The value of the constituent components of municipal waste was determined by successive sieving of samples weighing 30 kg on sieves with mesh sizes of 250 × 250, 150 × 150, 100 × 100, 50 × 50 and 15 × 15 mm.
The criterion for assessing the quality of a sorting device (food components) was the percentage of waste sorting with less secondary pollution of the environment. Each option of experiments was repeated for three times. To conduct a series of experiments, 10 medium samples weighing 30 kg were prepared.

The percentage of sorted food waste was determined using the formula:

$$Y_2 = \frac{A_2}{B_2} \cdot 100\%, \qquad (2)$$

where Y_2 – is the sorting percentage of food waste,%
A_2 – the weight of sorted food waste, kg;
B_2 - the weight of food components of the waste, kg.

To conduct experimental studies on the sorting process of food components of MSW, a stand was designed and manufactured. The general view of the stand is shown in Fig. 1, and the device scheme - in Fig. 2.

The stand consists of a housing 1, attached to the racks of the housing of the loading hopper 2, two conveyors located one below the other. A U-shaped frame 4 is attached to the sides of the upper conveyor 3 using tension springs 5. A metal strip 6 is rigidly fixed to the U-shaped frame 4. The device comprises a power unit 7 consisting of an engine and a gearbox serving as a drive of the driving drum 8 with a V-belt 9, a conveyor belt 10. The metal strip 11 is connected to the rack 12, bolted to the side of the lower conveyor 13. A metal strip 11 is mounted so as to adjust the angle of inclination within $30^0 - 60^0$ in horizontal direction. The driven drum 14 is mounted on the racks of the housing 1.

The power plant 15, consisting of an engine and a gearbox, serves as a drive of the driving drum 17 with a V-belt 16.

Fig. 1. General view of a device for sorting food waste.

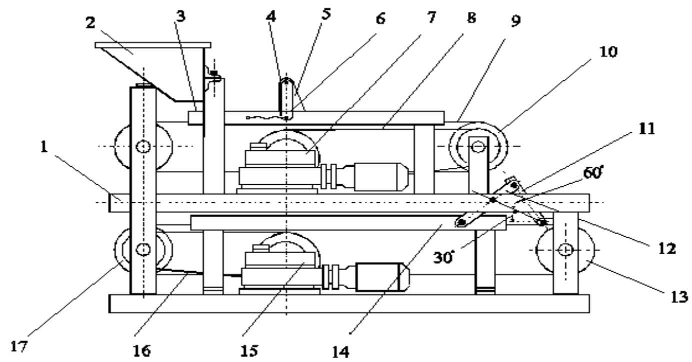

Fig. 2. Scheme of a device for sorting food waste.

1 - case; 2 - measuring hopper; 3 - upper conveyor; 4 - U-shaped frame; 5 - tension spring; 6 - metal strip; 7 - power plant; 8 - drive drum; 9 - V-belt; 10 - belt of the upper conveyor; 11 - metal strip; 12 - rack; 13 - lower conveyor; 14 - driven drum; 15 - power plant; 16 - V-belt; 17 – drive (gear) of the driving drum.

A device for sorting food waste works as follows.

Shredded and dried waste of sizes less than 50 mm is fed through the feed hopper 2 to the belt 10 of the upper conveyor; using a metal strip 6 the waste is leveled, fed in a uniform layer and moved along the conveyor belt 10. When they reach the edge of the conveyor, the waste components begin to fall on metal strip 11. Hitting the screen (due to its elasticity, the length of the rebound of elastic components is longer than that of organic components), the elastic components bounce off the strip 11 and fall into a separate container, and the remaining part of waste falls on the belt of the lower conveyor. In addition, the location of metal screen is set in such a way that the non-bouncing (for some reasons) waste components sliding along the metal strip fall on the lower conveyor drum rim.

Elastic components due to their elasticity bounce off the drum and fall into the container, and food (organic) components are transported by the lower conveyor.

Using the lower conveyor, the waste is fed into the next cycle of technological scheme of waste processing.

The results of preliminary experiments made it possible to determine a list of main factors affecting the process of food waste sorting, as well as their variation intervals.

Figures 3 - 8 show the dependences of the percentage of food waste sorting on the height of the waste fall and the angle of inclination of metal strip for various values of conveyor belt speed.

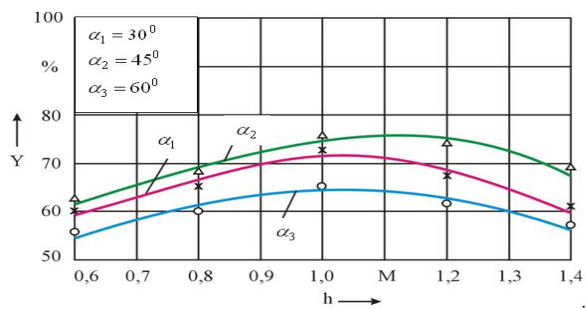

Fig. 3. Dependence of the percentage of food waste sorting on the height of the waste fall at various values of the angle of inclination of metal strip (at conveyor belt speed *v* = 0.1 *m/s*).

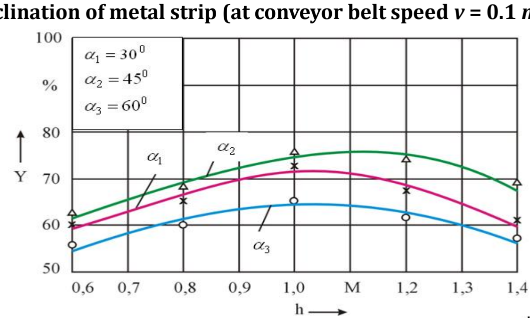

Fig. 4. Dependence of the percentage of food waste sorting on the height of the waste fall at various values of the angle of inclination of metal strip (at conveyor belt speed *v* = 0.2 *m/s)*

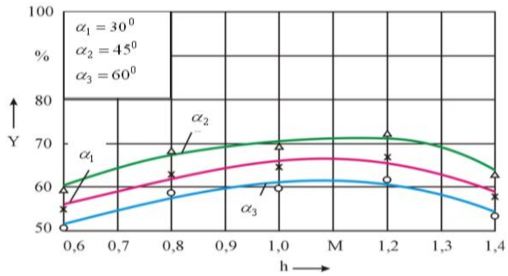

Fig. 5. Dependence of the percentage of food waste sorting on the height of the waste fall at various values of the angle of inclination of metal strip (at conveyor belt speed *v* = 0.3 *m/s*)

An analysis of the dependencies (Figures 3, 4 and 5) shows that the maximum value of the percentage of food components sorting is reached at a fall height of 1.0 ÷ 1.2 *m* (at conveyor belt speed v = 0.2 *m/s).*

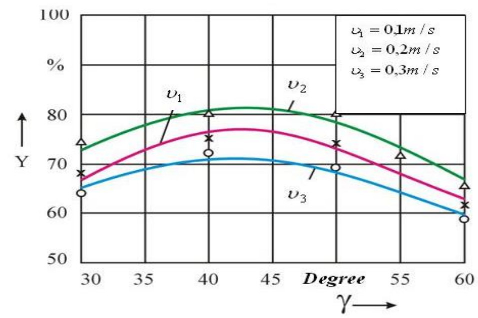

Fig. 6. Dependence of the percentage of food waste sorting on the height of waste fall at various values of the angle of inclination of metal strip (at a fall height of *h* = 0.8 *m*).

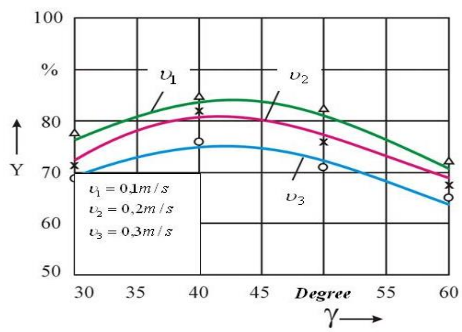

Fig. 7. Dependence of the percentage of food waste sorting on the height of waste fall at various values of the angle of inclination of metal strip (at a fall height of *h=1,0 m).*

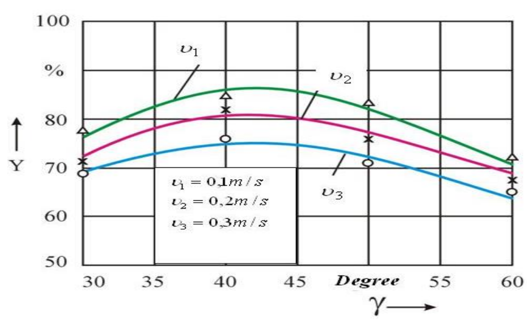

Fig. 8. Dependence of the percentage of food waste sorting on the height of waste fall at various values of the angle of inclination of metal strip (at a fall height of *h=1,2 m).*

An analysis of the graphs presented in Figures 6, 7 and 8 shows that the maximum value of the percentage of food waste sorting is reached at the angle of inclination $\alpha \approx 35^0$-45^0 (at the height of the waste fall *h≈1,2m,* the speed of the conveyor belt *v≈ 0,1m/s*).

According to the methods of mathematical planning of experiments by eliminating non-essential factors and obtained one-factor experiment data, the main controlled factors were established [22, pp69-93] that affect the process of food waste sorting. This dependence is generally written as follows:

$$Y=f(h, \alpha, v), \quad (3)$$

where *h* – is the height of waste fall, m;

α – is the angle of inclination of metal strip, degrees;
v - is the speed of the conveyor belt, m/s;
Y - is the percentage of food waste sorting, %.

The relationship between input and output factors is represented as a regression equation:

$$ó = \hat{a}_{\hat{\imath}} + \sum \hat{a}_i õ_i + \sum \hat{a}_{ij} õ_{ij} + \sum \hat{a}_i õ_i^2 \quad (4)$$

where y - is the value of the studied optimization parameter;
x_i – are the coded values of factors (i = 1,2,3);

$\hat{a}_i$ - is the estimation of the coefficient of regression equation of corresponding i-th factor;

$в_{ij}$ - is the estimation of the coefficient of regression equation corresponding to the interaction of factors.

The experiments were carried out on plan B_3 [23, pp227-230], since it is the least labor-intensive one in comparison with other plans. Besides, B_3 – is an optimal plan, providing minimum sensitivity of coefficient estimates, and reducing the number of experimental points with varying factors in three equations. To test the reproducibility of experiments, i.e. to test the hypothesis of dispersions homogeneity at the same number of experiment repetitions, the Cochrane criterion was used, and the coefficient significance of regression equation was determined using the Student criterion at a confidence level of 0.05.

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

The model is considered adequate provided:

$$F_{calc} = 0.95 \qquad F_{tab} = 2.36$$

$$F_{calc} \langle F_{tab} \quad (5)$$

Optimization of the parameters and operation mode of the sorting device was carried out using the method of mathematical planning of an experiment. A three-factor experiment was implemented according to plan B_3.

The percentage of food waste sorting was selected as an estimation criterion.

Table 1 shows the factor levels and their variation intervals.

Table 1. Factor levels and their variation intervals

No.	Factors	Notation code	Factor Levels			Variation intervals	Dimensions
			-1	0	+1		
1	Height of waste fall	x_1	0,8	1,0	1,2	0,2	m
2	The angle of inclination of metal strip	x_2	30	45	60	15	degree
3	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 sorting process of MSW food components is obtained.

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

The planning matrix and the experimental results are shown in table 2.

Table 2. Planning matrix with experiment results

Experiment No.	x_0	x_1	x_2	x_3	$\bar{y}$
1	+	-	-	-	79,4
2	+	+	-	-	85,4
3	+	-	+	-	74,4
4	+	+	+	-	80,3
5	+	-	-	+	63,9
6	+	+	-	+	69,8
7	+	-	+	+	60,4
8	+	+	+	+	65,4
9	+	-	0	0	72,4
10	+	+	0	0	79,5

11	+	0	-	0	67,0
12	+	0	-	0	63,4
13	+	0	0	-	84,6
14	+	0	0	+	68,5

Checking the model adequacy by the Fisher criterion showed that with a 95% reliability, the mathematical model is adequate

$$F_{calc} = 0.95 \qquad F_{tab} = 2.36 \qquad (7)$$

in order to determine the rational values of the above factors, equation (6) was investigated to an extreme. Results are presented in the table 3.

Table 3. Rational values of factors

Values 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
Round	1,2	43	0,1

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

- the height of waste fall - *h=1,1-1,2 m*;
- the angle of inclination of metal strip - α*=40-50*^{0};
- conveyor belt speed - *v =0,1-0,2 m*/s.

CONCLUSION

1. The developed methods for conducting experimental studies allowed us to determine the morphological and fractional composition of solid waste, and the morphological composition depending on the fraction size of solid waste components and the percentage of food waste sorting.
2. The developed design of a sorting device provides an efficient sorting of food waste by double sorting. This is achieved by the fact that non-bounced (for some reason) waste from the metal screen falls on the rim of the lower conveyor, the elastic components (due to their elastic properties) bounce off the drum and fall into the container, and food (organic) components are carried away by the lower conveyor.
3. An increase in the angle of inclination of metal strip to ≈ leads to an increase in sorting percentage, but its further increase leads to a decrease in sorting percentage.
4. The rational parameters of the sorting device are established:
- the height of the waste fall, h≈1,1-1,2m;
- the angle of inclination of metal strip α≈400-500;
- conveyor belt speed v =0,1-0,2 m/s.
5. The developed design of a sorting device easily fits into existing technological scheme of waste processing in Tashkent and significantly increases its efficiency.

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