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Research of the impact of carbon content in the auger material on its wear during dehydration in the solid waste garbage truck through regression analysis

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Abstract

The article is devoted to the study of the influence of carbon content in the auger material on its wear during dehydration of municipal solid waste in the garbage truck. Using the method of regression analysis, the hyperbolic regularities of screw wear depending on the carbon content in its material for different values of the friction path were determined. Graphical dependences of auger wear were constructed, depending on the carbon content in its material for different values of the friction path, which confirms the sufficient convergence of the obtained patterns. Carrying out additional regression analysis allowed to obtain the pattern of wear of the auger, depending on the carbon content in its material and the friction path, which established the following. After two weeks of operation and wear of the auger during the dewatering of solid waste in the garbage truck, increasing the carbon content in the auger material from 0.2% to 2.1% leads to a decrease in the energy intensity of dehydration of solid waste from 19.6% to 4.4 %, which makes the process of dehydration in the garbage truck cheaper. The graphical dependence of the reduction of energy consumption of dehydration of solid household waste due to increased carbon content in the auger material during its two-week wear is presented. The practicality of further research is to determine the rational material of the auger and ways to increase its wear resistance.

Key words: wear, carbon content, auger press, garbage truck, dehydration, municipal solid waste, regression analysis.

Introduction

In municipal engineering, an important task is to increase the wear resistance and reliability of machine parts [1, 2]. One of the promising technologies for primary processing of municipal solid waste (MSW), aimed at reducing both the cost of solid waste transportation MSW and the negative impact on the environment is their dehydration with accompanying processes of pre-compaction and partial grinding during loading into the garbage truck. In the garbage truck dehydration of MSW is performed by a conical screw, the surface of which is intensively worn out due to the available friction. This is due to the fact that MSW contains, in particular, components such as metal, glass, ceramics, stones, bones, polymeric materials, which can be attributed to abrasive materials, because they have different shapes, sizes and hardness, and available in MSW moisture 39-92% by weight creates an aggressive corrosive environment. Therefore, the study of the impact of carbon content in the auger material on its wear during dehydration of municipal solid waste in the garbage truck is a pending task

Literary review

The work [3] contains the results of experimental studies of wear resistance of different auger materials with different thermal and chemical-thermal treatment in corrosive-abrasive medium on special friction machines that simulated the operating conditions of extruders in the processing of feed grain with saponite impurities. The authors found that the wear resistance of materials in corrosive and abrasive environments at elevated temperatures depends not only on the hardness of the friction surface, but also on its structure and phase composition and changes in the hardness gradient along the depth of the hardened layer. To ensure high wear resistance of extruders in the manufacture of animal feed with admixtures of the mineral saponite, it is recommended to use for the manufacture of parts of the extruder unit steel KH12, reinforced by nitro hardening technology.

The authors of [4] investigated the effect on the properties of steel of its main elements (carbon and manganese), as well as alloying and modification of active carbide-forming and stabilizing austenite elements (chromium, titanium, boron). It is noted that the high carbon content contributes to the formation of carbides such as Me_xC_y, increase the wear resistance of steel and improve the casting properties.

In work [5], a mathematical model for calculating the rate of wear of triboelements in the tribosystem under conditions of corrosion and abrasive wear is proposed. The authors considered: active acidity, abrasiveness, roughness, load and sliding speed as input factors. Theoretically, the degree of influence of the above factors on the wear rate is established. It was found that abrasiveness is the most important factor, followed by the degree of decline – the level of active acidity and load.

The new design of the auger with a sectional elastic surface to reduce the degree of damage to the grain material during its transportation is presented in the article [6]. Concluded theoretical calculation of the interaction of the gran with the elastic section of the auger. A dynamic model has been developed to determine the influence of structural, kinematic and technological parameters of elastic auger on time and path of free movement of bulk material particles during their movement between sections, as well as to exclude the possibility of grain material interaction with non-working surface of auger working body.

The authors of [7] determined that to restore the screw requires surfacing or spraying a layer of a certain thickness on the end part of the screw coil, while the width of the restored layer is usually a few millimeters. An algorithm for selecting the optimal composite powder material for plasma spraying is described to increase the wear resistance of the working surfaces of machine parts, particularly the auger. Plasma spraying of composite powder materials, according to the authors, will increase the durability of the auger by 2-3 times, which will reduce the cost of repairs tenfold.

The influence of geometric parameters on the performance and design of a briquetting machine using a pressure model based on the theory of piston flow was studied in [8]. An analytical model using the pressure model was also developed based on Archard's wear law to study the wear of augers of biomass briquetting machines. The developed model satisfactorily predicted the wear of the auger and showed that the greatest influence on it are the speed of rotation and the choice of material. The amount of wear increases exponentially until the end of the auger, where the pressure is highest. Changing the auger design to select the optimal geometry and speed with the appropriate choice of material can increase the life of the auger and the productivity of the biomass briquetting machine.

Work [9] contains an analysis of the process of screw briquetting of plant materials into fuel and feed. Regularities of this process are necessary to determine the rational parameters of the working bodies. When designing briquette presses, it is necessary to consider the deformation of biomass, taking into account changes in physical and rheological properties at the time of interaction with the screw mechanism.

The article [10] investigated the wear of a twin-screw extruder of rigid PVC resins. The pressures around the cylinder were measured by extrusion of two rigid PVC resins. In a laboratory extruder with a diameter of 55 mm, the forces acting on the screw core are determined. Numerical simulation of the flow was performed using the degree parameters of the viscosity of the resins.

The process of pressing wood chips in screw machines was studied in [11]. The processes occurring in different parts of the auger are established, formulas are determined that allow to calculate the loads acting on the auger turns, as well as to determine the power required for pressing. The specific energy consumption and the degree of heating of raw materials during pressing are set.

In work [12], the results of experimental studies of the MSW dehydration process based on the planning of an experiment by the Box-Wilson method are presented. Rotary central regression planning was used to obtain quadratic regression equations with 1st order interaction effects for such objective functions as humidity and density of pre-compacted and dehydrated MSW, maximum drive motor power, MSW dehydration energy consumption. This allowed to determine the optimal parameters of dewatering equipment by minimizing the energy consumption of the process (screw speed, the ratio of the radial gap between the auger and the housing, as well as the ratio of the auger core diameter to the outer diameter of the screw on the last turn) for both mixed and "wet" MSW.

The materials of the article [13] proposed an improved mathematical model of solid wastewater dewatering in the garbage truck, taking into account the wear of the auger, which allowed to numerically study the dynamics of this drive during start-up, and determine that increasing auger wear increases the pressure of the speed and speed of the auger are significantly reduced. The degree regularities of the change of nominal values of pressures at the inlet of the hydraulic motor, angular velocity and frequency of rotation of the auger from the values of its wear are determined, the last of which describes the debugging from the optimal speed of the auger in the process of its wear and is used to determine the energy consumption of dehydration of solid waste, taking into account the wear of the auger. It is established that the wear of the auger by 1000 μm leads to an increase in the energy consumption of solids dehydration by 11.6%, and, consequently, to the rise in the cost of their dehydration in the garbage truck and speed up the wear process.

In [14], the influence of surface hardness of the auger on its wear during dehydration of MSW in a garbage truck was investigated by regression analysis, and also found that during two weeks of operation and wear of the auger during dehydration of solid waste in the garbage truck increase in the hardness of the auger surface from 2310 MPa to 10050 MPa leads to a decrease in energy consumption of solid waste dehydration from 16.7% to 1.5%, and, hence, to reduce the cost of the process of dehydration in the garbage truck

Purpose

Investigation of the influence of carbon content in the auger material on its wear during dehydration of solid household waste in the garbage truck.

Methods

Determination of paired regularities of screw wear from carbon content in its material was performed by regression analysis [15]. Regressions were determined on the basis of linearizing transformations, which allow to reduce nonlinear dependence to linear one. The coefficients of regression equations were determined by the method of least squares with the help of the developed computer program "RegAnaliz", which is protected by a copyright registration certificate for the work.

The following regularities were used to determine the energy consumption of MSW dehydration taking into account the wear of the auger [13]:

$$E = 1504 - 15.92w_0 + 0.3214\rho_0 - 1.069n(u) - 2061(\Delta_{aug} + u)/(D_{\min} - 2u) - 1947(d_{\min} - 2u)/(D_{\min} - 2u) + 9.118\cdot10^{-4} w_0\rho_0 + 0.002142 w_0 n(u) + 18.12 w_0(\Delta_{aug} + u)/(D_{\min} - 2u) - 2.115 w_0(d_{\min} - 2u)/(D_{\min} - 2u) + 4.392\cdot10^{-4}\rho_0 n(u) - 2.005\rho_0(\Delta_{aug} + u)/(D_{\min} - 2u) + 0.3361\rho_0(d_{\min} - 2u)/(D_{\min} - 2u) + 0.09031 w_0^2 - 7.923\cdot10^{-4}\rho_0^2 + 0.,008241 n(u)^2 + 104172[(\Delta_{aug} + u)/(D_{\min} - 2u)]^2 + 1318[(d_{\min} - 2u)/(D_{\min} - 2u)]^2 \left[\text{kWh/tons}\right]; \quad (1)$$

$$n = 52.43 - 1.276\cdot10^{-3}u^{1.5} \text{ [rpm]}, \quad (2)$$

where E – is the energy consumption of solid waste dehydration, kW·h/tons; ρ_0 – initial density of solid waste, kg/m^3; w_0 – initial relative humidity of solid waste, %; n – the nominal speed of the auger, rpm; u – auger wear, m; Δ_{aug} – radial clearance between auger and housing, m; d_{min} – outer diameter of the auger on the last coil, m; D_{min} is the diameter of the auger core on the last coil, m.

Results

The values of auger wear for different values of carbon content in its material and the friction path are given in table. 1 [3].

Table 1

Auger wear values for different values of carbon content in its material and friction path [3]

No	Steel grade and heat treatment	The carbon content in the auger material, %	Wear, μm for friction path, m			
			3000	6000	9000	12000
1	steel 20 without heat treatment	0.2	68	132	195	258
2	steel 45 hardening	0.45	53	103	153	203
3	steel U8 hardening	0.8	48	91	134	177
4	steel SHKH15 hardening	1	43	80	116	152
5	steel KH12 hardening	2.1	39	72	105	138

As a result of regression analysis of the data in table 1 determined the hyperbolic patterns of wear of the auger depending on the carbon content in its material for different values of the friction path:

$$u_{s=3000} = 37.9 + \frac{6.181}{C_C}; \quad (3)$$

$$u_{s=6000} = 70.08 + \frac{12.82}{C_C}; \quad (4)$$

$$u_{s=9000} = 102.2 + \frac{19.31}{C_C}; \quad (5)$$

$$u_{s=12000} = 134.3 + \frac{25.8}{C_C}, \quad (6)$$

where u – wear, μm; C_C – carbon content in the auger material, %; s – path of friction, m.

Figure 1 shows the graphical dependences of auger wear depending on the carbon content in its material for different values of the friction path, constructed using dependences (3 – 6), confirming the sufficient convergence of the obtained patterns compared to the data in table 1.

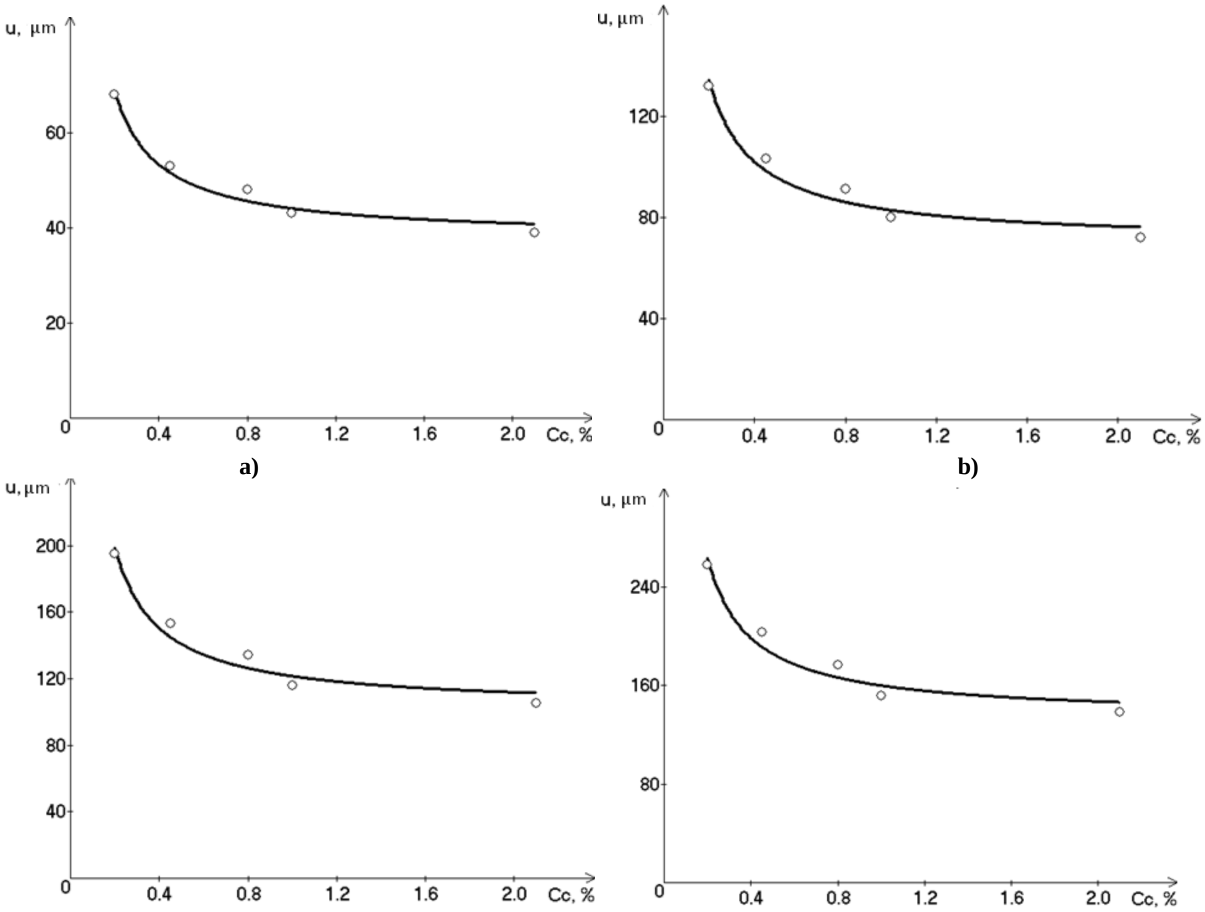


Fig. 1. The wear of the auger depending on the carbon content in its material for different values of the friction path (a) – *s* = 3000 m, (b) – *s* = 6000 m, (c) – *s* = 9000 m, (d) – *s* = 12000 m: actual ○, theoretical —

Regularities (3 - 6) for different values of the friction path can be written in general as follows

$$u = A(s) + \frac{B(s)}{C_C}, \quad (7)$$

where A (s), B (s) are the regression coefficients that depend on the friction path.

After additional regression analysis, the regression coefficients that depend on the friction path can be described by linear laws:

$$A(s) = 5.79 + 0.01071s; \quad (8)$$

$$B(s) = 0.002178s - 0.309. \quad (9)$$

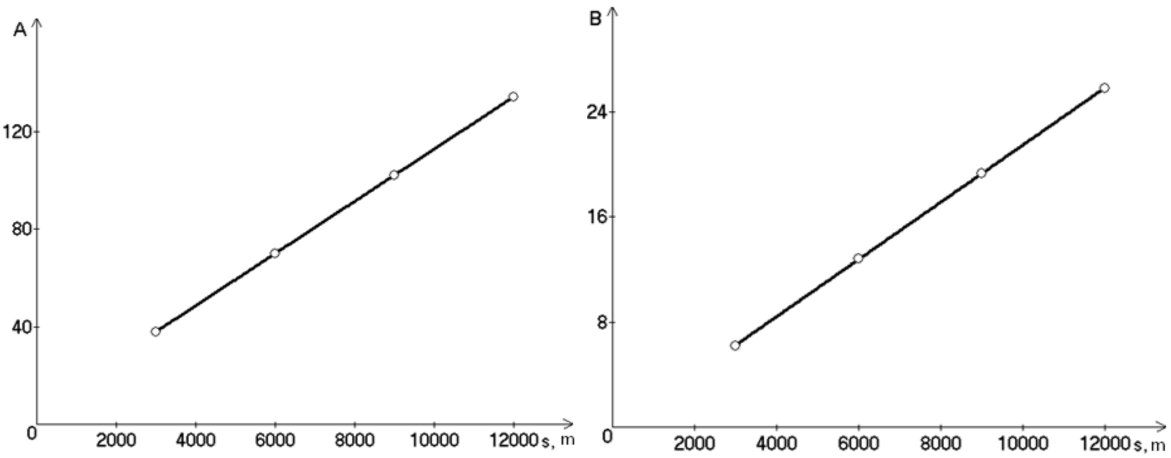
The results of the regression analysis are shown in Table 2, where the cells with the maximum values of the correlation coefficient R for each of the paired regressions are marked in gray.

Figure 2 shows the graphical dependences of the regression coefficients on the friction path, constructed using the dependences (8, 9), which confirm the sufficient convergence of the obtained regularities.

Table 2

The results of regression analysis of the dependence of the wear of the auger depending on the carbon content in its material for different values of the friction path

No	Type of regression	Correlation coefficient R for paired regressions					
		$u_{s=3000}=f(C_C)$	$u_{s=6000}=f(C_C)$	$u_{s=9000}=f(C_C)$	$u_{s=12000}=f(C_C)$	$A=f(s)$	$B=f(s)$
1	$y = a + bx$	0.83755	0.84605	0.84762	0.84820	0.9999998	0.99998
2	$y = 1 / (a + bx)$	0.91045	0.91891	0.91715	0.91595	0.9385673	0.92340
3	$y = a + b / x$	0.98738	0.98299	0.97928	0.97723	0.9289544	0.93077
4	$y = x / (a + bx)$	0.96886	0.96886	0.96839	0.96839	0.9407220	0.84683
5	$y = ab^x$	0.87626	0.88527	0.88527	0.88501	0.9831751	0.97792
6	$y = ae^{bx}$	0.87626	0.88527	0.88527	0.88501	0.9831751	0.97792
7	$y = a \cdot 10^{bx}$	0.87626	0.88527	0.88527	0.88501	0.9831751	0.97792
8	$y = 1 / (a + be^{-x})$	0.96524	0.97832	0.97832	0.96832	0.9883223	0.98832
9	$y = ax^b$	0.96652	0.97839	0.97839	0.96839	0.9998737	0.99993
10	$y = a + b \cdot \lg x$	0.97417	0.97800	0.97798	0.96775	0.9802967	0.98124
11	$y = a + b \cdot \ln x$	0.97417	0.97800	0.97798	0.96775	0.9802967	0.98124
12	$y = a / (b + x)$	0.91045	0.91891	0.91715	0.91595	0.9385673	0.92340
13	$y = ax / (b + x)$	0.94810	0.93476	0.92777	0.92406	0.9996063	0.99989
14	$y = ae^{b / x}$	0.97160	0.96307	0.95757	0.95460	0.9805651	0.98556
15	$y = a \cdot 10^{b / x}$	0.97160	0.96307	0.95757	0.95460	0.9805651	0.98556
16	$y = a + bx^n$	0.69931	0.70792	0.70891	0.70924	0.9842758	0.98346



a) b)

Fig. 2. Dependences of regression coefficients on the path of friction (a) - A = f (s), (b) - B = f (s): actual ○, theoretical —

After substituting the laws (8, 9) into the dependence (7), we obtain the law of wear of the auger depending on the carbon content in its material and the friction path

$$u = 5.79 + 0.01071s + \frac{0.002178s - 0.309}{C_C}. \quad (10)$$

Figure 3 shows the graphical dependence of auger wear in the plane of the impact parameters: the carbon content in its material and the friction path.

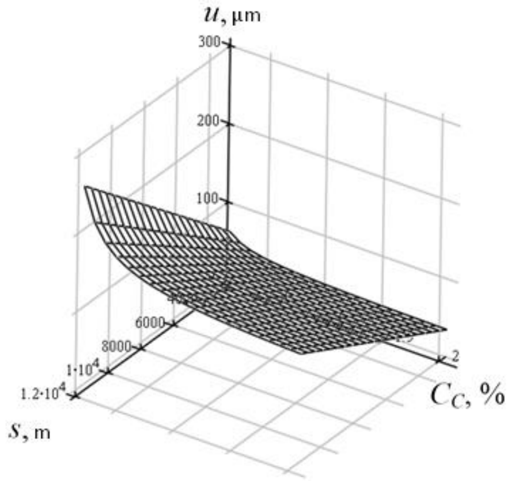


Fig. 3. Dependence of screw wear *u* in the plane of impact parameters: carbon content in its material C_C and friction path *s*

Figure 4 shows the graphical dependence of the carbon content in the auger material of the solid waste management device on the energy intensity of the process (with its two-week wear *s* = 56850 m [14]), constructed using regularities (1, 2, 10).

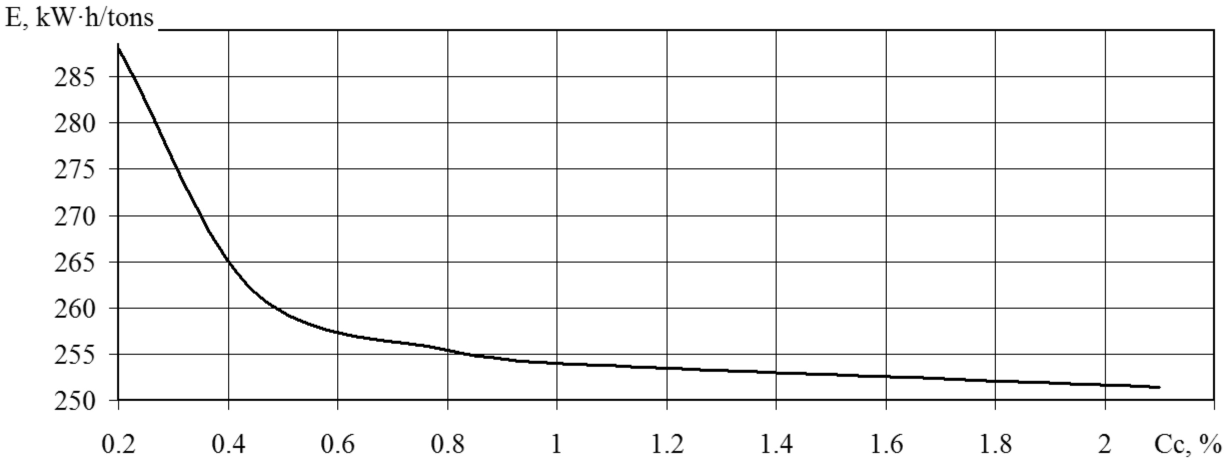


Fig. 4. The effect of increasing the carbon content in the auger material on reducing the growth rate of energy consumption of the dehydration process MSW after its two-week operation and wear (*s* = 56850 m)

Figure 4 shows that after two weeks of operation and wear of the auger during MSW dehydration in the garbage truck, the increase in carbon content in the auger material from 0.2% to 2.1% leads to a decrease in the energy intensity of MSW dehydration from 19.6% to 4.4% , and, consequently, to reduce the cost of dehydration MSW in the garbage truck. Due to carburizing surfacing, it is possible to increase the carbon content in the surface layers up to 6%, forming a composite metal-carbide surface. Therefore, the determination of the rational composition and structural state of the material of the friction surfaces of the auger and ways to increase its wear resistance require further research.

Conclusion

The hyperbolic regularities of auger wear depending on the carbon content in its material for different values of the friction path were determined. Carrying out additional regression analysis allowed to obtain the pattern of wear of the auger depending on the carbon content in its material and the friction path, which showed that during two weeks of operation and wear of the auger during dehydration of solid waste, in the garbage increase carbon content in the auger material from 0, 2% to 2.1% leads to a decrease in the growth rate of energy consumption of solid waste dehydration from 19.6% to 4.4%, and, consequently, to a reduction in the cost of the process of dehydration in the garbage truck. Due to carburizing surfacing, it is possible to increase the carbon content in the working layers to the formation of supereutectic iron-carbon alloys with the formation of a composite metal-carbide surface. Therefore, the definition of rational auger material and ways to increase its wear resistance requires further research.

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Березюк О.В Савуляк., В.І., Харжевський В.О., Осадчук А.А. Дослідження за допомогою регресійного аналізу впливу вмісту вуглецю в матеріалі шнека на його знос під час зневоднення у сміттєвозі твердих побутових відходів

Стаття присвячена дослідженню впливу вмісту вуглецю в матеріалі шнека на його знос під час зневоднення твердих побутових відходів у сміттєвозі. За допомогою використання методу регресійного аналізу визначено гіперболічні закономірності зносу шнека залежно від вмісту вуглецю в його матеріалі для різних значень шляху тертя. Побудовано графічні залежності зносу шнека залежно від вмісту вуглецю в його матеріалі для різних значень шляху тертя, що підтверджують достатню збіжність отриманих закономірностей. Проведення додаткового регресійного аналізу дозволило отримати закономірність зносу шнека залежно від вмісту вуглецю в його матеріалі та шляху тертя, за допомогою якої встановлено, що при двотижневій експлуатації та зношуванні шнека під час зневоднення твердих побутових відходів у сміттєвозі збільшення вмісту вуглецю в матеріалі шнека з 0,2% до 2,1% призводить до зниження темпів зростання енергоємності зневоднення твердих побутових відходів з 19,6% до 4,4%, а, отже, і до здешевлення процесу їхнього зневоднення у сміттєвозі. Представлена графічна залежність зниження енергоємності зневоднення твердих побутових відходів внаслідок збільшення вмісту вуглецю в матеріалі шнека при його двотижневому зношуванні. Виявлено доцільність проведення подальших досліджень з визначення раціонального матеріалу шнека та шляхів підвищення його зносостійкості.

Ключові слова: знос, вміст вуглецю, шнековий прес, сміттєвоз, зневоднення, тверді побутові відходи, регресійний аналіз