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The influence of auger wear on the parameters of the dehydration process of solid waste in the garbage truck

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Abstract

The article is dedicated to the study of the influence of auger wear on the parameters of the dehydration process of municipal solid waste in the garbage truck. An improved mathematical model of the drive operation of dehydration of solid waste in the garbage truck is proposed, which takes into account the wear of the auger and allowed to numerically determine the dynamics of the drive during start-up. It was also established that increasing wear of the auger, the pressure of the working fluid at the inlet of the hydraulic motor rises, and the angular velocity and speed of the auger is significantly reduced. The research of this mathematical model was carried out using the numerical Runge-Kutta-Felberg method of the 4th order with a variable integration step. By means of the method of regression analysis, the power dependencies of the change of nominal values of pressures at the inlet of the hydraulic motor, angular velocity and speed of rotation of the auger from the value of its wear are determined. The last-mentioned dependence defines the detuning from the optimal speed of the auger during 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 dehydration of solid waste by 11.6%, and, therefore, also leads to an increase of the cost of the process of their dehydration in the garbage truck. It was also established the expediency of further research to determine the appropriate material of the auger and the ways to increase its wear resistance.

Key words: wear, auger press, garbage truck, dehydration, solid waste

Introduction

One of the important tasks in machine building is the increasing the wear resistance and reliability of machine parts. Dehydration of municipal solid waste, which is accompanied by their pre-compaction and partial grinding, during loading into the garbage truck is a promising technology for their primary processing, aimed at reducing both the cost of transportation of solid waste and the negative impact on the environment. Dehydration of solid waste in the garbage truck is carried out by means of the conic auger, its surface undergoes an intensive wear due to the friction. This is due to the fact that solid waste contains, in particular, components such as metal, glass, stones, ceramics, bones, polymeric materials, which can be attributed to abrasive materials, because they have different shapes, sizes and hardness. The presence of moisture in the amount of 39-92% in solid waste creates an aggressive corrosive environment. Therefore, the study of the influence of auger wear on the parameters of the process of dehydration of solid waste in the garbage truck is a topical task.

Literary review

The results of experimental studies of wear resistance of different materials of auger with different thermal and chemical-thermal treatment in a corrosive-abrasive environment on special friction machines that simulated the operating conditions of extruders in the processing of fodder grain with saponite mineral impurities are given in the article [2].

Comparative studies have shown that the wear resistance of materials in a corrosive-abrasive environment at elevated temperatures depends not only on the hardness of the friction surface, but also on its

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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 compound feed with impurities of the mineral saponite, it is recommended to use steel X12 strengthen by nitro-hardening technology for the manufacture of parts of the extrusion unit.

A mathematical model for calculating the wear rate of triboelements in a tribosystem which operates in the conditions of corrosion and abrasive wear was developed in the paper [3]. Input factors are active acidity, abrasiveness, roughness, load and sliding speed. Theoretically, the degree of influence of the above factors on the wear rate is established. Abrasiveness is the most important factor, and, by the decrease of influence – the level of active acidity and the load.

In the article [4], it was found that the intensity of abrasive wear of the screw surface of the auger, and hence wear resistance, mainly depends on the hardness, surface roughness, the volume of abrasive particles involved in friction and the area of their contact with the surface.

To restore the auger, it is necessary to process fusing or spraying a layer of a certain thickness on the end part of the auger coil, and the width of the restored layer is usually a few millimeters [5]. An algorithm for selecting the optimal composite powder material for plasma spraying in order to increase the wear resistance of the working surfaces of machine parts, in particular the auger, is described. The authors state that plasma spraying of composite powder materials will increase the durability of the auger by 2-3 times, which will reduce repair costs by tens of times.

The article [6] presents a new design of the auger with a sectional elastic surface, which is designed to reduce the degree of damage to the grain material during transportation. Theoretical calculation of grain interaction with elastic section of auger is carried out. A dynamic model has been developed to determine the influence of structural, kinematic and technological parameters of the elastic auger on the 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 the non-working surface of the auger working body to diminish its damage

The paper [7] is dedicated to the analysis of the process of auger briquetting of plant materials into fuel and feed. Dependencies of this process are the basis for determining the rational parameters of the working bodies. When designing briquette presses, it is necessary to consider the deformation of biomass taking into account the change in physical and rheological properties at the time of interaction with the auger mechanism.

The influence of geometric parameters on the performance and design of the briquetting machine was studied in the paper [8] using a pressure model based on the theory of piston flow. An analytical model that uses a pressure model was also developed based on Archard wear law to study the wear of augers of biomass briquetting machines. The developed model positively 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 to the end of the auger, where the pressure is the highest. Changing the design of the auger to select the optimal geometry and speed with the appropriate choice of material can increase the service life of the auger and the productivity of the machine for briquetting biomass.

The process of pressing wood chips in auger machines is researched in the article [9]. The processes occurring in different parts of the auger are established, also were defined the formulas 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 also defined.

The wear of a twin-auger extruder of rigid PVC resins was researched in the article [10]. The pressures around the cylinder when extruding two rigid PVC resins in a laboratory extruder with a diameter of 55 mm were measured and the forces acting on the screw core were determined. Numerical modeling of the flow was performed using the power parameters of the viscosity of the resins.

In the paper [11] the results of experimental studies of the process of solid dehydration based on the planning of the experiment by the Box-Wilson method are shown. Quadratic regression equations with 1st order interaction effects were obtained using rotatable central composite planning for such objective functions as humidity and density of pre-compacted and dehydrated municipal solid waste, maximum drive motor power, energy consumption of solid waste dehydration. This allowed to determine the optimal parameters of equipment for dehydration by the criterion of minimizing the energy consumption of the process (frequency of auger speed, the ratio of the radial gap between the auger and the housing, and the ratio of the diameter of the auger core to the outer diameter of the auger on the last coil) both for mixed and “wet” solid waste. The obtained experimental dependences allowed to build a mathematical model of the drive of dehydration of solid waste in the garbage truck [12], which allowed to study the dynamics of this drive and the influence of control parameters on the main indicators of the drive. But this mathematical model and experimental dependencies do not take into account the wear of the auger, so, it requires further research.

Purpose

The aim of the article is to research of the influence of auger wear on the parameters of the dehydration process of municipal solid waste in a garbage truck.

Methods

To study the mathematical model of the drive of dehydration of solid waste in a garbage truck taking into account the wear of the auger in the form of a system of ordinary nonlinear differential equations with corresponding boundary conditions, the numerical Runge-Kutta-Felberg method of the 4th order with variable integration step was used [13].

To determine the paired dependencies of change of nominal pressure values at the inlet of the hydraulic motor, angular velocity and speed of rotation of the auger from the values of its wear, the method of regression analysis was used [14]. Regression analysis was performed on the basis of linearizing transformations, which allow to transform the nonlinear dependence to the linear one. The determination of the coefficients of regression equations was carried out by the method of least squares using the developed computer program "RegAnaliz", which is protected by copyright law and appropriate certificate, as described in the paper [15].

Results

In the Fig. 1 a calculation scheme of the drive of dehydration of solid waste in the garbage truck is shown, the following elements and parameters are designated: HM – hydromotor, TR – throttle, P – hydraulic pump, OV – overflow valve, F – filter, T – tank with working liquid, p_1, p_2, p_3 – pressures respectively at the pump outlet, at the inlet of the hydraulic motor, at the outlet of the hydraulic motor; W_1, W_2, W_3 – pipe volumes between pump and throttle, throttle and hydraulic motor, hydraulic motor and filter; Q_H – actual pump feed; S_{TR} - the area of the throttle hole, S_F – the surface area of the filter element; q_M – working volume of the hydraulic motor; J – the moment of inertia on the shaft of the hydraulic motor; M_T – torque of technological loading on a shaft of the hydraulic motor; ω – angular velocity of the hydraulic motor shaft.

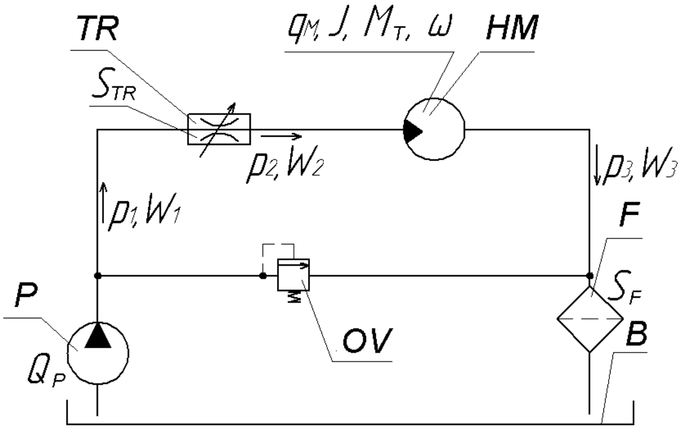


Fig. 1. Calculation scheme of the drive of dehydration of solid waste in garbage truck

The operation of the solid waste dehydration drive in the garbage truck, taking into account the wear of the auger, can be described by the corresponding system of differential equations (1–4) with the boundary conditions (5) and the algebraic equation (6):

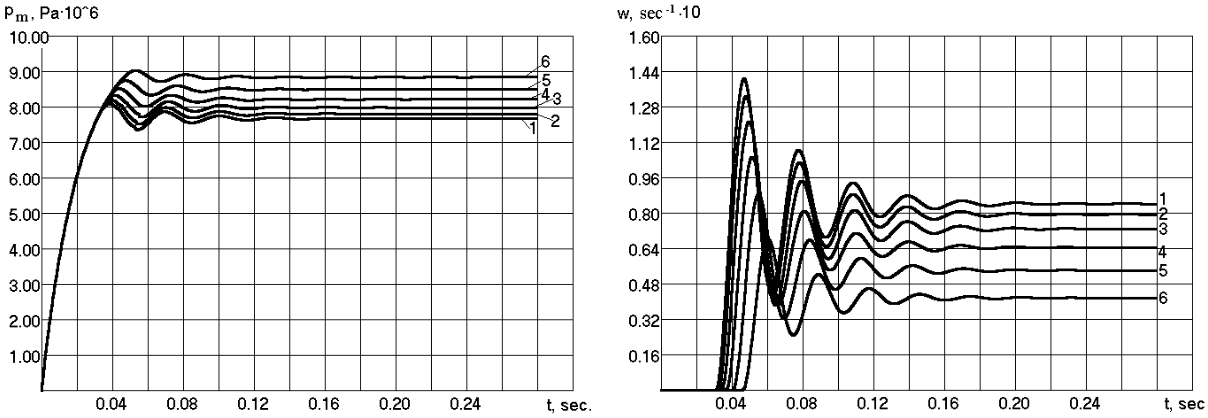
$$
\left\{
\begin{array}{ll}
Q_P = \mu S_{TR}\sqrt{2\left(p_1 - p_2\right)/\rho} + \sigma\left(p_1 - p_2\right) + KW_1\dot{p}_1; & (1) \\
\mu S_{TR}\sqrt{2\left(p_1 - p_2\right)/\rho} = q_{MX}\omega + \sigma\left(p_2 - p_3\right) + KW_2\dot{p}_2; & (2) \\
q_{MX}\omega = k_F S_F p_3/\mu_D + \sigma p_3 + KW_3\dot{p}_3; & (3) \\
q_{MX}\left(p_2 - p_3\right) = \{L_{aug}\rho_0(\overline{T} + 2u)^2[(\overline{D} - 2u)^2 - (\overline{d} - 2u)^2]/(16\pi) + \pi\rho_{aug}[n_c(h - 2u)(\overline{D} - & \\
- \overline{d})[(\overline{D} - 2u)^2 - (\overline{d} - 2u)^2]\sqrt{\pi^2(\overline{D} + \overline{d} - 4u)^2 + 4(\overline{T} + 2u)^2} + L_c(\overline{d} - 2u)^4]/32\}\dot{\omega} + & \\
+ \beta\omega + \alpha q_{MX}\left(p_2 + p_3\right) + 30\{12231 + 109.8w_0 - 0.7676\rho_0 + 27.45n + 91602(\Delta_{aug} + u) \div & \\
\div (D_{\min} - 2u) - 41610(d_{\min} - 2u)/(D_{\min} - 2u) - 0.2475w_0 n + 558.6w_0(\Delta_{ш} + u)/(D_{\min} - & (4) \\
- 2u) - 260.9w_0(d_{\min} - 2u)/(D_{\min} - 2u) - 7.713\rho_0(d_{\min} - 2u)/(D_{\min} - 2u) - 165174\times & \\
\times[(\Delta_{aug} + u)/(D_{\min} - 2u)][(d_{\min} - 2u)/(D_{\min} - 2u)] + 0.7082w_0^2 + 0.009383\rho_0^2 - 0.0726\times & \\
\times n^2 + 40815[(d_{\min} - 2u)/(D_{\min} - 2u)]^2\}/(\pi n); &
\end{array}
\right.
$$

$$0 \le \{p_1, p_2, p_3\} \le p_{ov};\ 0 \le \omega; \quad (5)$$

$$q_{MX} = q_M /(2\pi), \quad (6)$$

where L_{aug} – the length of the auger, m; ρ_0 – the initial density of the solid waste, kg/m^3; $\overline{T}$ – the average pitch of the turns of the conical auger, m; u – wear of the auger, m; $\overline{D}$ – the average outer diameter of the auger; $\overline{d}$ – the average diameter of the screw core, m; ρ_{aug} – the density of the auger material; n_c – the number of coils of the auger; h – coil thickness; L_c – auger core length, m; w_0 – the initial relative humidity, %; n – nominal auger speed, rpm; Δ_{aug} – radial clearance between the auger and the housing, m; D_{min} – outer diameter of the auger on the last turn, m; d_{min} – diameter of the core of the auger on the last turn, m; q_{MX} – radial working volume of the hydraulic motor, m^3.

The results of the numerical study of the mathematical model (1–6) are shown in the Fig. 2, where the numbers 1-6 denote the curves that correspond to such values of screw wear: 0, 150, 300, 450, 600, 750 μm, in accordance. As shown in the Fig. 2, with increasing wear of the auger the pressure of the working fluid at the inlet of the hydraulic motor, but the angular velocity and the speed of the auger are significantly reduced.



a) b)

Fig. 2. Transient processes in the drive of solid waste dehydration during start-up: a) pressure at the inlet of the hydraulic motor; b) angular velocity of the auger

Nominal values of pressures at the inlet of the hydraulic motor, angular velocity and speed of rotation of the auger for different values of its wear are given in Table 1.

Table 1

Nominal values of pressures at the inlet of the hydraulic motor, angular speed and speed of rotation of the auger for different values of its wear

u, μm	0	150	300	450	600	750
$p_м$, MPa	7.763	7.794	7.972	8.202	8.485	8.825
ω, rad/sec	8.396	7.919	7.267	6.430	5.394	4.150
n, rpm	52.75	49.69	45.66	40.40	33.89	26.08

As a result of regression analysis of the data in Table 1, the power dependencies of the change of nominal values of pressures at the inlet of the hydraulic motor, angular velocity and speed of rotation of the auger from the values of its wear are determined:

$$p_m = 7.745 + 1.4 \cdot 10^{-5} u^{1.7}; \quad (7)$$

$$\omega = 8.348 - 2.033 \cdot 10^{-4} u^{1.5}; \quad (8)$$

$$n = 52.43 - 1.276 \cdot 10^{-3} u^{1.5}. \quad (9)$$

The correlation coefficient is 0.99955; 0.99968; 0.99968, correspondently, which indicating the sufficient convergence of the results.

In the Fig. 3 are shown the graphical dependences of the nominal values of the pressure at the inlet of the hydraulic motor, angular velocity and speed of rotation of the auger on the value of its wear, plotted using dependences (7-9), so sufficient convergence of the obtained dependencies in comparison with the data in the Table 1 is confirmed.

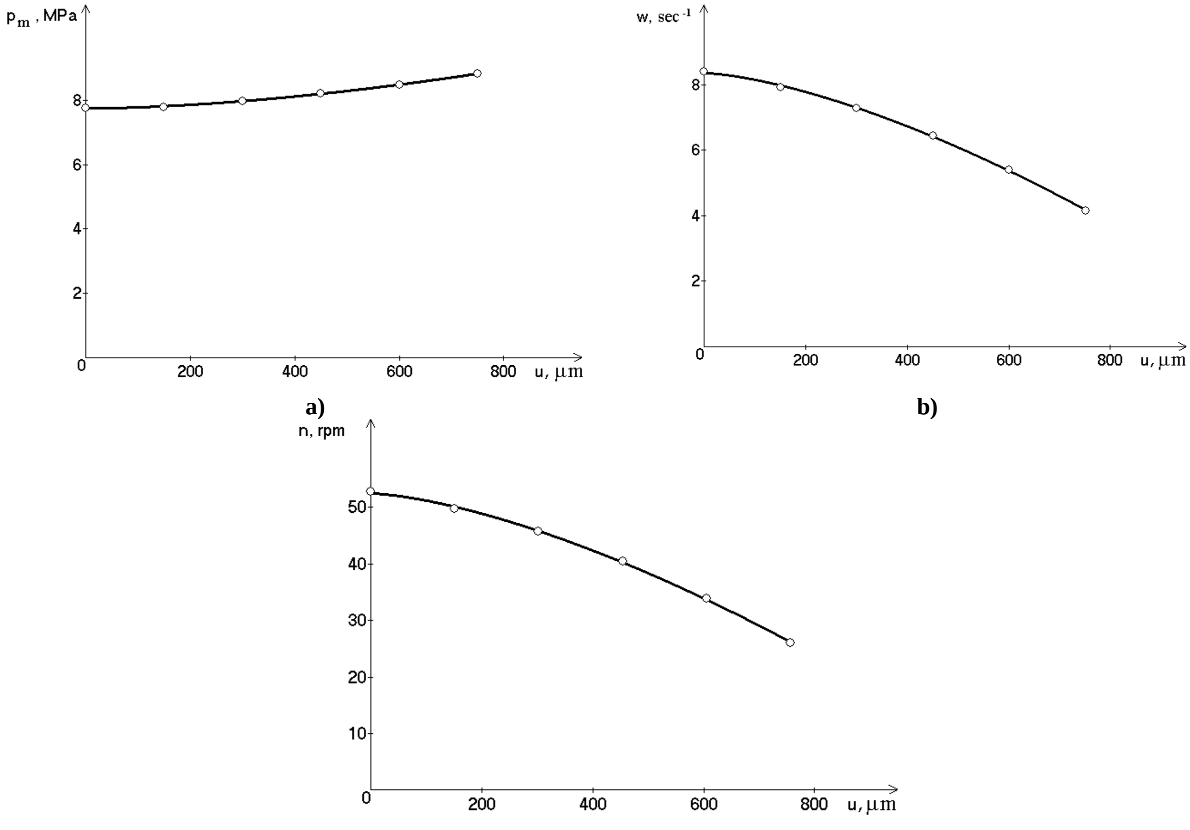


Fig. 3. Dependences of nominal values of pressures at the inlet of the hydraulic motor (a), angular velocity (b) the speed of rotation (c) of the auger from the values of its wear: actual ○, theoretical —

The dependence (9) describes the detune from the optimal speed of the auger in the process of its wear and is used to determine the energy consumption of solid waste dehydration taking into account the wear of the auger

$$\begin{aligned} E = {} & 1504 - 15.92 w_0 + 0.3214 \rho_0 - 1.069 n(u) - 2061 (\Delta_{aug} + u)/(D_{\min} - 2u) - 1947 (d_{\min} - \\ & - 2u)/(D_{\min} - 2u) + 9.118 \cdot 10^{-4} w_0 \rho_0 + 0.002142 w_0 n(u) + 18.12 w_0 (\Delta_{aug} + u)/(D_{\min} - 2u) - \\ & - 2.115 w_0 (d_{\min} - 2u)/(D_{\min} - 2u) + 4.392 \cdot 10^{-4} \rho_0 n(u) - 2.005 \rho_0 (\Delta_{aug} + u)/(D_{\min} - 2u) + \\ & + 0.3361 \rho_0 (d_{\min} - 2u)/(D_{\min} - 2u) + 0.09031 w_0^2 - 7.923 \cdot 10^{-4} \rho_0^2 + 0.008241 n(u)^2 + \\ & + 104172 [(\Delta_{aug} + u)/(D_{\min} - 2u)]^2 + 1318 [(d_{\min} - 2u)/(D_{\min} - 2u)]^2 \; [\mathrm{kW \cdot h/t}]. \end{aligned} \tag{10}$$

In the Fig. 4 is shown a graphical dependence of the increasing of energy consumption of solid waste dehydration due to the auger wear:

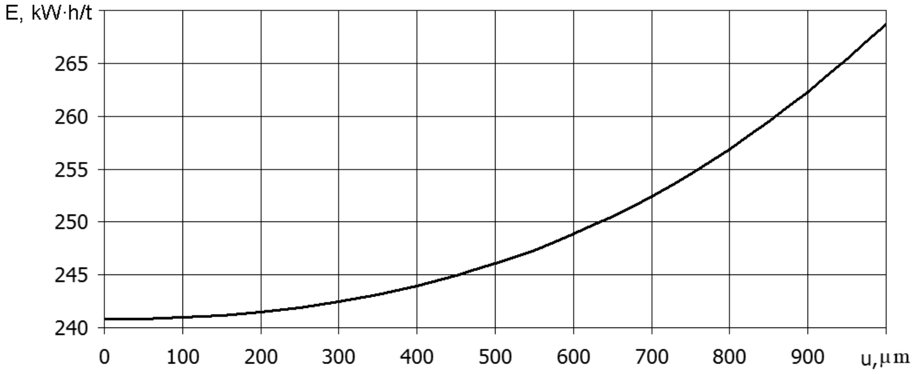


Fig. 4. Increase in energy consumption of solid waste dehydration due to the auger wear

As shown in the Fig. 4, the wear of the auger by 1000 μm leads to an increase in the energy consumption of solid dehydration by 11.6%, and, consequently, to an increase in the cost of the process of dehydration of solid waste in the garbage truck. In addition, it also leads to significant additional heat dissipation in the pressing area. This heat is mainly concentrated at the end of the working zone of pressing. The result is melting and coking of solid components, which converts them into abrasive particles. Consequently, in the auger material under the influence of significant temperatures and mentioned factors, phase transformations occur and catastrophic wear occurs.

Therefore, the definition of the rational material of the friction surfaces of the auger and the ways to increase its wear resistance require further researches.

Conclusions

An improved mathematical model of the operation of the drive of dehydration of solid waste in the garbage truck, taking into account the wear of the auger, which allowed to numerically research the dynamics of this drive during start-up and determine that with increasing wear of the auger, the pressure of the working fluid at the inlet of the hydraulic motor rises, but the angular velocity and speed of rotation of the auger are significantly reduced. The power dependencies of change of nominal values of pressures at the inlet of the hydraulic motor, angular speed and frequency of rotation of the auger from values of its wear are defined, the last of which describes detune from optimum frequency of rotation of the auger during its wear. That 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 dehydration of municipal solid waste by 11.6%, and, consequently, to the increase in the cost of the dehydration process in the garbage truck and accelerate the wear process. Therefore, determining the rational type of material of the auger and the ways to increase its wear resistance require further researches.

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Березюк О.В., Савуляк В.І., Харжевський В.О. Вплив зносу шнека на параметри процесу зневоднення твердих побутових відходів у сміттєвозі

Анотація

Стаття присвячена дослідженню впливу зносу шнека на параметри процесу зневоднення твердих побутових відходів у сміттєвозі. Запропонована удосконалена математична модель роботи приводу зневоднення твердих побутових відходів у сміттєвозі, яка враховує знос шнека і дозволила чисельно дослідити динаміку даного приводу під час пуску та визначити, що зі збільшенням зносу шнека зростає тиск робочої рідини на вході гідромотора, а кутова швидкість і частота обертання шнека суттєво знижується. Дослідження даної математичної моделі проводилось за допомогою чисельного методу Рунге-Кутта-Фельберга 4-го порядку зі змінним кроком інтегрування. За допомогою використання методу регресійного аналізу визначено степеневі закономірності зміни номінальних значень тисків на вході гідромотора, кутової швидкості та частоти обертання шнека від величини його зносу, остання з яких описує відлагодження від оптимальної частоти обертання шнека в процесі його зносу і використана для визначення енергоємності зневоднення твердих побутових відходів із урахуванням зносу шнека. Встановлено, що знос шнека на 1000 мкм призводить до зростання енергоємності зневоднення твердих побутових відходів на 11,6%, а, отже, і до подорожчання процесу їхнього зневоднення у сміттєвозі. Виявлено доцільність проведення подальших досліджень з визначення раціонального матеріалу шнека та шляхів підвищення його зносостійкості.

Ключові слова: знос, шнековий прес, сміттєвоз, зневоднення, тверді побутові відходи.