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EXPERIMENTAL SUBSTANTIATION OF MANURE FRACTIONATION ON PIG FARMS USING A SPIRAL-SCREW MECHANISM

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ABSTRACT

The main vector of mechanization and automation of livestock farming at the present stage of technological development of producers is the improvement of resource-saving technologies and technical devices that enables agricultural producers to produce relatively expensive and high-quality equipment to improve conditions for the animals. This article was considered a method for effective fractionation of manure on pig farms to further obtain humus for soil fertilization. The optimal conditions for the performance of the presented gadget were identified, namely: the time spent by the manure mass in the rotor is 0.1, with a separation factor of 170 to 180, the partition for the filter is made of metal sheet with holes whose diameter varies from 0.8 to 1.5 mm and a thickness of no more than 1 mm. The device presented in the manuscript has several advantages in the form of automation, low energy consumption and cost, novelty, and high efficiency.

Keywords: *Humus, pig farming, fractionation, manure, centrifuge, spiral*.

1. INTRODUCTION

At the moment, there are a large number of machines and devices for processing and using manure mass in the world. The concept of processing of lint-free liquid material (manure) it consists of the following main stages: separation, decontamination, and purification of liquid material from light particles.

A spiral-screw manure-dewatering device (Isaev Yu. M., Gubaidullin Kh. Kh., Shigapov I. I. 2016) has been developed, which is designed to separate manure with a moisture content of more than 97 %. The device for manure dewatering consists of supporting struts and a housing (Figures 1 and 2), inside which there is a pipe fixed in the bearing unit on both sides and a pulley that drives the helical mechanism utilizing an electric motor through a V-belt drive. A bushing with a cup is rigidly attached to the pipe by a cotter pin connection, on the outside of which a transporting spiral-screw working body is attached with a bracket. There is a hopper for loading and a branch pipe for unloading the dehydrated product in the upper and lower parts of the housing, a tightly pressed spiral with a gap, and in the lower part in the center a drain pipe.

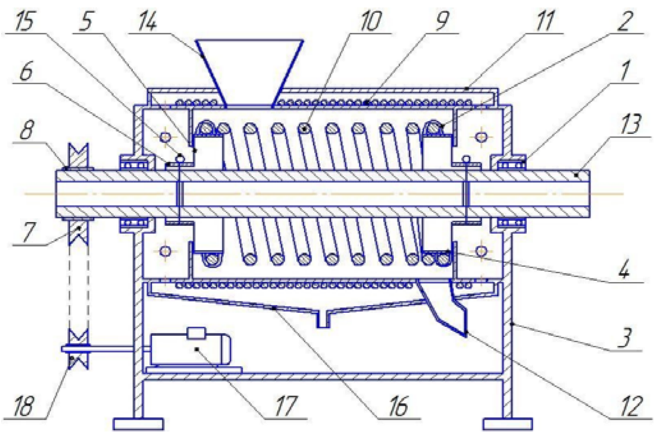

***Figure 1.** Diagram of a helical-screw manure dewatering device where 1 – bearing; 2 – bracket; 3 – bearing; 4 – cup; 5 – disk; 6 – sleeve; 7 – driven pulley; 8 – fastening of a pulley; 9 – spring; 10 – working on; 11 – casing; 12 – the discharge outlet for the dewatered*

manure; 13 – pipe; 14 – the hopper; 15 – pin; 16 – discharge pipe for the liquid; 17 – motor; 18 – drive pulley.

The main working body of the technical means in the device recommended by us for removing water from liquid and semi-liquid manure (cattle, pig) and other contaminated liquids of organic origin is a spiral screw (Zuev V. A., Kovalev V. A. 1976.), (Kapustin V. P. 1997) (Figure 1). The helical screw is driven in rotational movement of the shaft–pipe (7) through a pulley (8), the shaft tube rests on two the bearing unit (1), the bearing device is mounted on a common frame (3) on the shaft are two cups (4) by disks (5), and bushing (6) mounted on the shaft by cotter pins (11). The glasses are inserted inside the spring (10), and the coils are tightened rigidly to the glasses with brackets (2), two fasteners for each glass at an angle of 180 degrees. Overall dimensions and dimensions of parts are selected based on the parameters of the technological process (volume of work, the percentage reduction in manure moisture, degree of clarification of the resulting liquid). Figure 3 shows the following layout dimensions: shaft-pipe length (1650 mm), spring length (1200 mm), outer spring diameter (300 mm), device height in the center of the spring– (750 mm). A general view of the layout of the spring attachment to the stakan is shown in Figure 3.

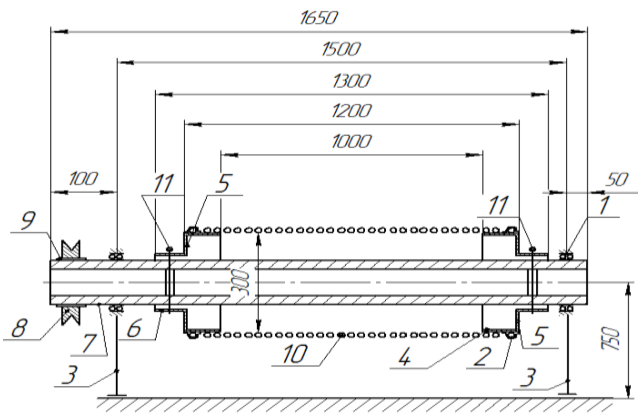

Figure 2. *The general arrangement of the helical screw where 1-bearing; 2 – bracket for pressing the wire to the cup; 3 – support; 4 - cup; 5-disk; 6 - bushing; 7-pipe (shaft); 8 – pulley; 9-fixing the pulley; 10-spring; 11-cotter pin.*

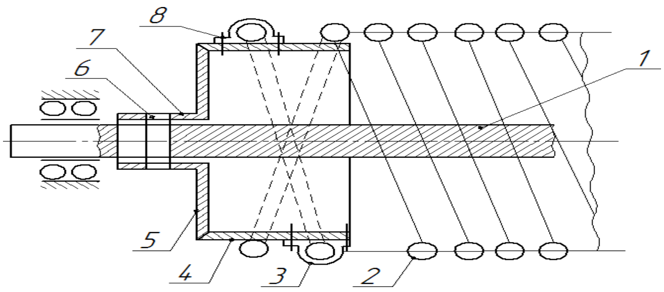

Figure 3. *Arrangement of node A: 1-shaft; 2-spring; 3-bracket; 4-cup; 5-disk; 6-pin; 7-bushing; 8-bolts tightening the wire bracket to the cup.*

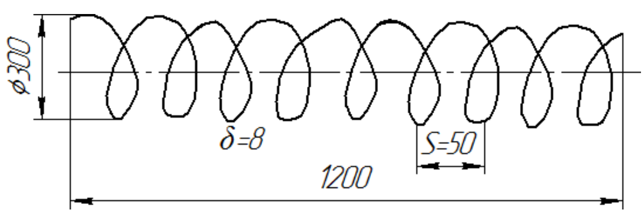

Figure 4. *Spring: art. 65 g, i = 24, length of dense winding a)нн =192 mm + 24 = 216 mm.*

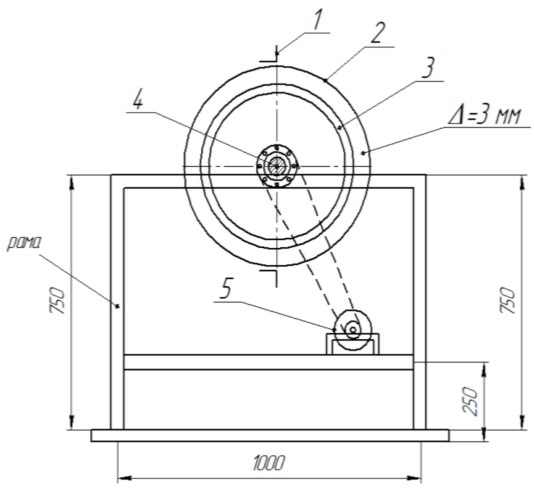

Figure 5. *Layout scheme of the spiral drum: 1–corners; 2-drum; 3-spring; 4-pulley; 5 – electric motor.*

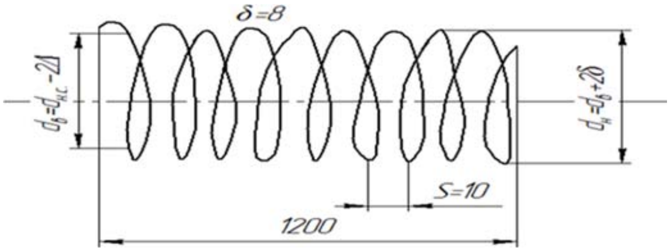

Figure 6. *Spiral drum (art. 3): i = L/S = 1200/10 =120; ℓ1в=πdn=3,14·30=94,2 cm; the total length of the wire p= ℓ1в ·l = 0,942·120 = 113м; G = 0,4·113 = 45,2 kg; length thick coiling PL = 0,8·120= 96 cm (δ = 6).*

The above data follows that only this centrifuge is capable of separating the initial manure mass without initial preparation into liquid and solid material that meets agrotechnical and veterinary requirements.

The technological process of separating liquid manure mass allows reducing transport and handling operations by 70% by using pipelines, reducing losses of manure mass, nutrients, and eliminating contamination of the territory (Yu. A. Kirov, F. G. Zabirov, D. N. Kotov 2012). This technology allows reducing the volume of expensive concrete manure storage facilities, simplifying working conditions by using mechanized and automated equipment at all stages, as well as the final technological processes for applying manure to the soil. (Shigapov I. I., Artemyev V. G., Kadyrova A.M. 2012)

2. MATERIALS AND METHODS

When developing the working body, it is necessary to identify its main design and operating parameters and their impact on the flow and uniformity of the filtration process. In this case, it is necessary to identify the relationship between physical and mechanical properties and manure mass supply.

Based on the analysis of the patent review and scientific and technical literature (Yu. a. Kirov, D. R. Costa-Rin, T. Yu., Kozlov, D. N. Kotov, S. V. Eremin), the results of initial experimental studies, the factors that mainly affect the uniformity of filtration by the working body of the filter device are determined.

In the scientific and technical literature, data on the impact of parameters such as the rotation speed of the screw working body n and the pitch of the spiral s on the supply of manure mass by the working body is insufficient. This was the basis for the use of first-order orthogonal planning and applying a full-factor experiment of type 2^2, the purpose of which is to vary two variable factors at two main levels.

The mathematical model uses an algebraic polynomial of 1 degree:

$$y = b_0 + \sum_{i=1}^{k} b_i x_i \qquad \text{(Eq. 1)}$$

where *x* is the factor affecting the process;

k – number of factors;

i - factor number;

b_i – coefficient of the regression equation of the corresponding *i*-th factor;

b_0 – free term equal to the response at $x_i = 0$;

y – output parameter of the process.

The calculated coefficients of the mathematical model are entered in a table called the planning matrix, which is shown in Table 1.

When conducting experiments, certain conditions were observed since the planning of a multi-factor experiment is carried out when all factors change simultaneously. In the course of the conducted experimental studies, the results were obtained, which are summarized in Table 2, which are necessary for screening out insignificant factors with the help of an experimental setup.

In the experiment, were adopted on the following variables: *α* – the angle of inclination of the casing to the horizon; *s* – pitch propeller; *n* – frequency of rotation of the working body; d_{in} – inner diameter of the working body; d_h – internal diameter of the casing. These factors have a significant impact on the process of moving manure mass by the screw working body.

3. RESULTS AND DISCUSSION

The density of liquid biological waste from pig farming varies, depending on the moisture content percentage in them. The different speed of movement of liquid and solid particles (dispersion medium and dispersed phase) in the process of separating pig biological waste is due to the different densities of these particles. Thus, light particles, because of centrifugal separation, quite quickly fall on the filter surface, clogging it, which creates an additional obstacle to the passage of the dispersion medium.

Experimentally, it was found that the temperature and percentage of moisture content in the initial biological waste of pig farming directly affect the dynamic viscosity of the clarified liquid fraction.

With increasing humidity of the filtrate (w), its viscosity (μ) decreases significantly; this dependence is shown in Figure 7.

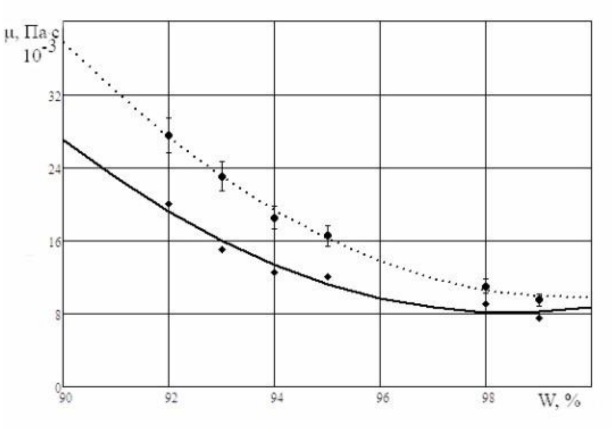

Figure 7. *Change in filtrate viscosity μ depending on the percentage of moisture content in it. W.*

From this dependence (Fig. 7), it can be seen that the range of changes in viscosity is extensive. This is due to the presence of colloidal particles and salts in the clarified fraction of liquid manure, and when the liquid fraction of manure is diluted with water, the percentage of suspended particles per unit volume will decrease. This leads to a decrease in viscosity.

Analyzing the dependence presented in figure 8, it can be said that when the temperature of the clarified manure liquid increases, the viscosity decreases, which leads to an increase in filtration units.

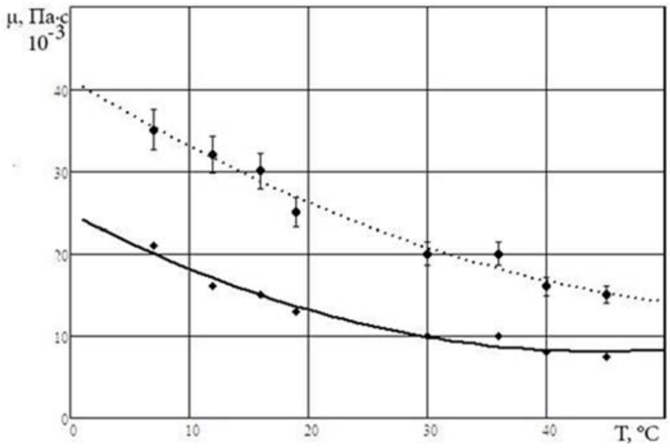

Figure 8. *Graph of changes in the viscosity (μ) of clarified liquid manure from its temperature (T) °C (humidity of biological pig waste is 1-W= 97.2%, 2-W = 92.7%)*

Pig manure is not uniform in its fractional composition. Thus, experimental studies suggest that the dispersed phase has the form of fibers, the length, and diameter of which, respectively, are in the ranges of 0.25 to 10 mm and 0.1 to 0.5 mm (Figure 9).

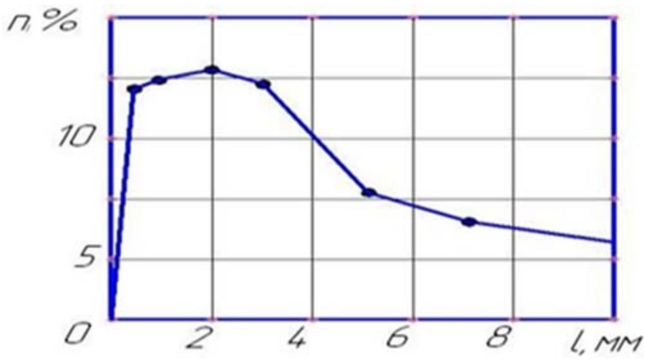

Figure 9. *Distribution of fractional sizes of the dispersed phase of pig manure.*

Having analyzed the dependence shown in Figure 9, it can be said that there is a clogging of the pores between the dispersion medium and the fibers in the liquid waste of pig life. As a result, the pig manure contains a lot of liquid.

Summing up the above, it can be said that due to the fibrous structure of the biological waste of pigs, there is a "soiling" of the filter surface, which in turn significantly reduces the productivity of the installation. This, in turn, leads to the need to extract fibers from its surface.

The graph of the dependence (Fig. 10) shows that if the percentage of moisture increases to 72% to 87%, the coefficient of friction of the dispersed phase on the inner surface of the housing decreases in biological waste from pig farming. This is due to the occurrence of liquid friction. Figure 10 also shows that the coefficient of friction of the dispersed phase on the steel surface of the casing is higher (here, the manure fibers cling to the roughness of the steel casing, and in some places, there is friction between the fibers) than the coefficient of friction on a smooth polyethylene surface.

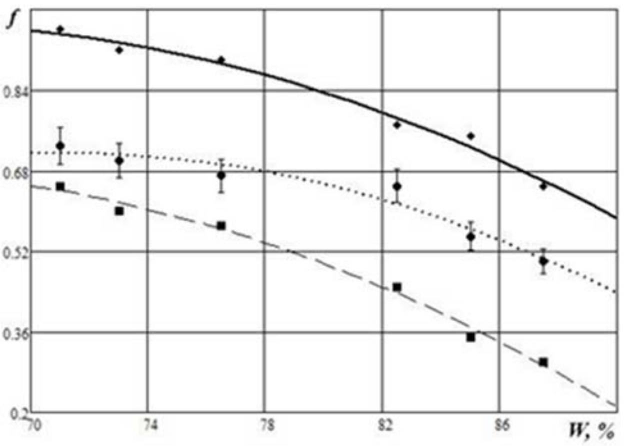

Figure 10. *Change in the friction coefficient f of the solid phase from humidity W at a specific pressure N = 600 PA: 1 – on the filter spiral; 2 – on steel; 3 - on polyethylene.*

As a result of laboratory and experimental studies, a regression equation was obtained that allows describing the change in the friction coefficient (f) of the solid phase of pig manure depending on the percentage of moisture content and the forces of adhesion on the friction surface (F):

$f = 9.89\cdot10^{-6}WF - 9.18\cdot10^{-4}W^2 + 0.132W - 2.58\cdot10^{-7}F^2 + 6.85\cdot10^{-4}F - 3.842$ (insert equation according template)

The optimum coordinates are also obtained, and the response surfaces of the change in the friction coefficient (f) of the solid phase of pig manure depending on the percentage of moisture content and the adhesion forces on the friction surface (F) are constructed, as shown in Figure 11 (Put “Figure 11A and 11B” the figures need to be identified).

Analyzing the surface cross-sections (Figure 11), it can be said that with the humidity of biological pig waste W = 72.3% and the coupling forces on the friction surface F = 57.913 N, the highest value of the coefficient of friction is achieved.

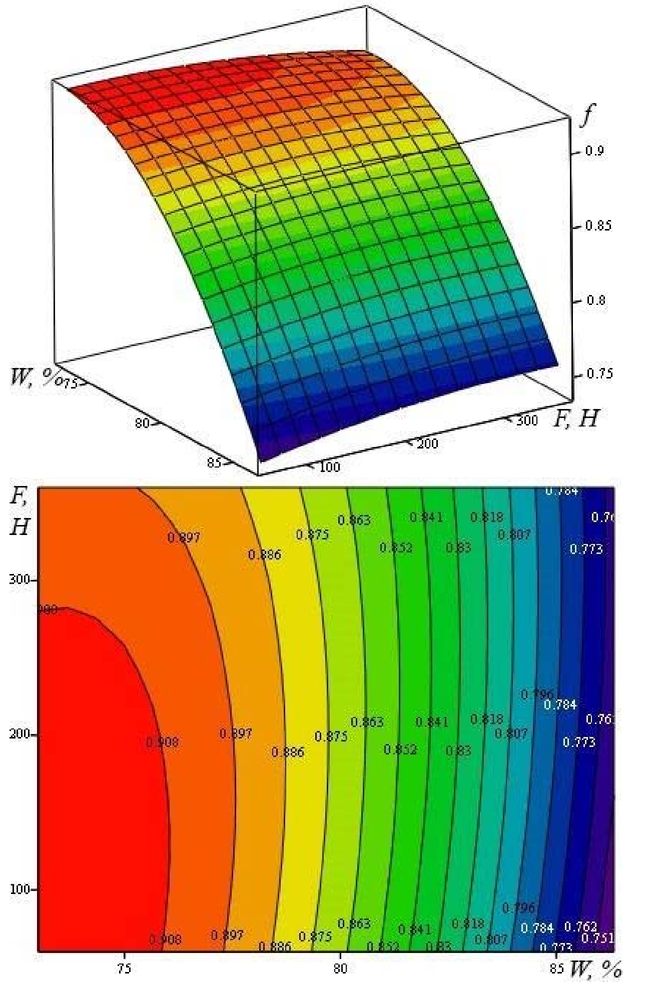

Figure 11. *Cross-section of the surface of changes in the friction (f) coefficient of the solid phase of pig manure depends on the percentage of moisture content and adhesion forces on the friction surface (F).*

Because of the analysis of the dependence of the sliding coefficient f of the solid fraction on the speed of movement *v* (Figure 12), it can be said that with an increase in the speed of movement of the manure mass, the friction coefficient is also increased. This is explained by the fact that, with an increase in the speed of movement of the solid fraction of manure over 0.5 m/s, liquid friction practically ceases (since the speed of liquid intake is lower than the speed of solid fraction intake), intermolecular forces of coupling increase.

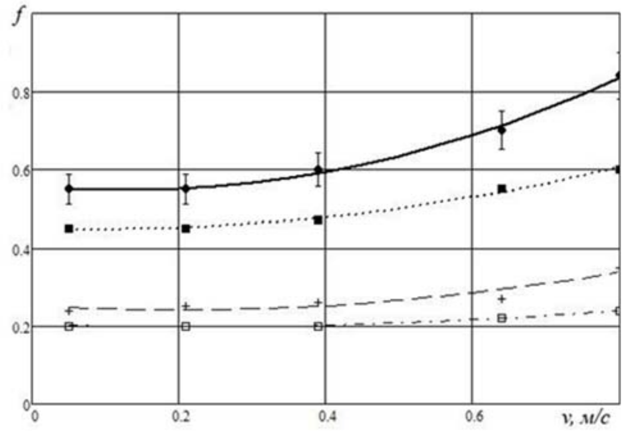

Figure 12. *Dependence of the sliding coefficient f of the solid fraction on the speed of movement v: 1, 3 – on the filter partition; 2, 4-on the steel.*

Based on the obtained experimental data, dependencies of the change in the stickiness of the dispersed phase of pig and fresh pig manure on the percentage of moisture contained in them are constructed (Figure 13). From which it can be seen that the stickiness of fresh pig manure is 660 N/m^2, which in turn is twice as much as the stickiness of the dispersed phase of pig manure (1250 N/m^2) with a humidity of 82%. This phenomenon is explained by a decrease in the total number of colloidal particles in the dispersed phase, which have a high degree of stickiness.

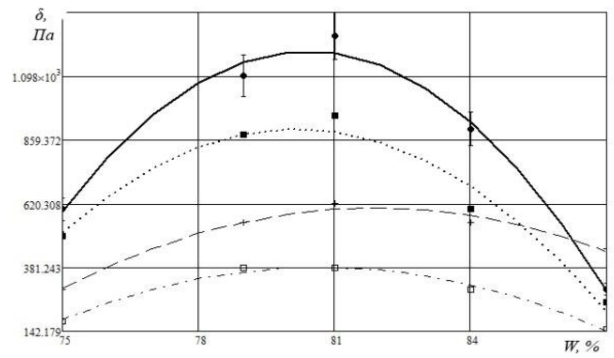

Figure 13. *Dependences of changes in the stickiness of the dispersed phase of pig and fresh pig manure on the percentage of moisture contained in them: 1, 2 –manure mass; 3, 4 – filtered sediment; 1, 3–for steel; 2, 4 – for plastic.*

Experimental studies have shown that with the humidity of biological waste from pig farming in the range of 78 to 83%, the highest degree of stickiness is observed, which in turn is the main factor in reducing the productivity of the centrifuge for separating biological waste from pigs.

Based on the experimental studies described above, the design of the spiral screw was selected, which reduces the degree of stickiness and theoretically calculating its performance, taking into account the speed of movement of the manure material and the amount of pressure from the casing. Also, it was found that the pitch (S) and angle (a) of the helix lift have a significant influence on the movement of the manure mass. So the angle (a) of the lifting of the helical line, in order to coordinate with the friction forces of the dispersed phase (where the coefficient of friction on the steel is f = 0.7 to 0.6, then φ =30 to 35°) must be equal to ≤ 30°. Also, to increase the ability of the spiral screw to capture biological waste from pig farming, it is necessary to increase the roughness of the working surface of the screw.

To coordinate the obtained theoretical and experimental data on the velocity *V,* taking into account *n* the rotation frequency n of the helical working body for different travel speeds.

For a spiral with a diameter $d_n = 90$ mm and a wire diameter δ = 8 mm, we obtain the dependence υ (*n*) (Figure 14).

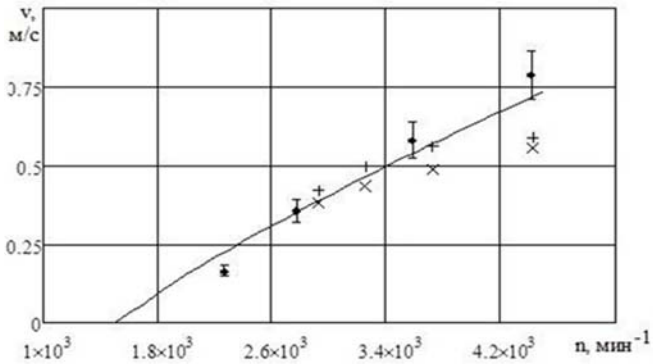

Figure 14. *Dependence of the axial velocity Ʊ of the material on n the rotation frequency n of the helical device at s = 80 mm (solid line– theoretical dependence).*

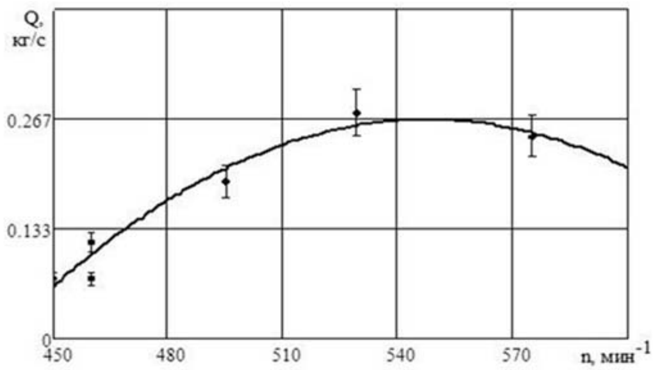

Figure 15. *Dependence of feed Q(n) of the helical device on the rotation speed of the working body on the horizontal plane.*

Figure 15 shows the dependence of the feed *Q(n)* of the helical device on the speed of rotation of the helix along the horizontal plane with parameters: *p* = 512 kg/m^3; *v* V = 0.39 PA·C; *δ* = 8 mm; *s* = 80 mm; d_n = 90 mm. The solid line represents the theoretical dependence, and the dots represent the experimental values.

The conducted studies show that for a liquid fraction with a viscosity *v* of V = 0, 39 PA·s, and a density of *p* = 512 kg/m^3, the coincidence of the results of the theoretical dependence *U* (*n*) with the experiment is observed throughout the test site. For manure mass with higher viscosity and density, the results are well consistent with the theoretical dependence until the set speed of rotation 500 min^{-1}, and then there is a discrepancy. This is explained by the fact that at the maximum rotation speeds of the helical working body, the coefficient of resistance must be specified, considering the specific conditions of the research being conducted.

This graph shows that the experimental data are consistent with the theoretical dependence, which confirms the movement of the manure mass in the complex process of rotation of the helicoidal working organ in the channel.

According to the results of the experiment, a regression equation was obtained, which makes it possible to show the changes in the dependence of the feed Q of the helicoidal working body on its rotational speed and the linear speed of movement υ of the device itself on a flat floor surface accurately:

Q = 8.17x10^{-4} *nυ* – 1.7x10^{-5}n^2 + 0.02 *n* – 9.82 $υ^2$ + 3.16 *υ* – 5.43 (insert equation according template)

Because of the model calculation, sections of the presented response surface are made to figure 4.10 (Figure 4? Or 10? or 14? it is not clear). The maximum feed *Q* = 0.288 kg/s when moving, obtained by the traditional optimization method applied at a rotation *speed of n* = 562 min^{-1}, the linear speed of movement *W* = 0.184 m /s.

Investigating the dependence of the specific energy consumption *N* (kW·s/kg) of the transported manure mass on the rotation speed of the helical screw *p* (min^{-1}) and linear travel speed *υ* (m/c), we have built a regression equation showing the model changes:

N = 0.118 *nυ* – 3.1x10^{-5} n^2 + 3.5x10^{-3} *n* + 79.6 $υ^2$ – 110 *υ* + 16.9.(insert equation according template)

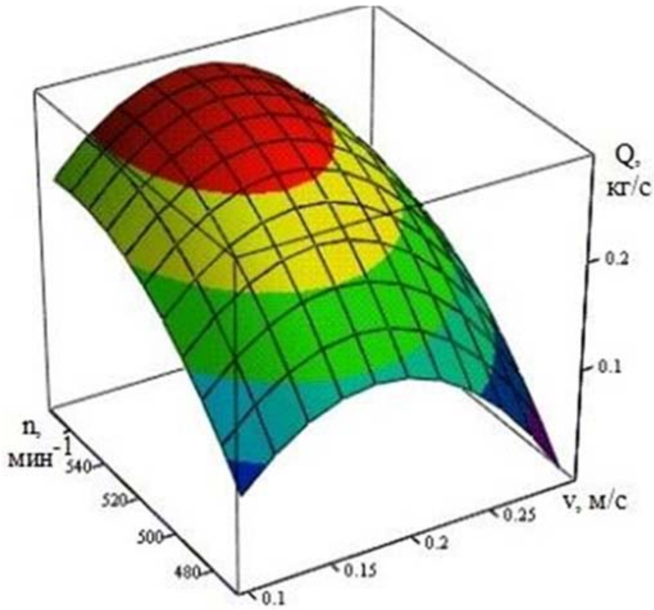

Figure 16. *Response surface of the regression dependence of the feed of the helicoid device Q (kg/s) on the speed p(min^{-1}) and linear displacement υ velocity (m/s) ρ = 512 kg/m^3.*

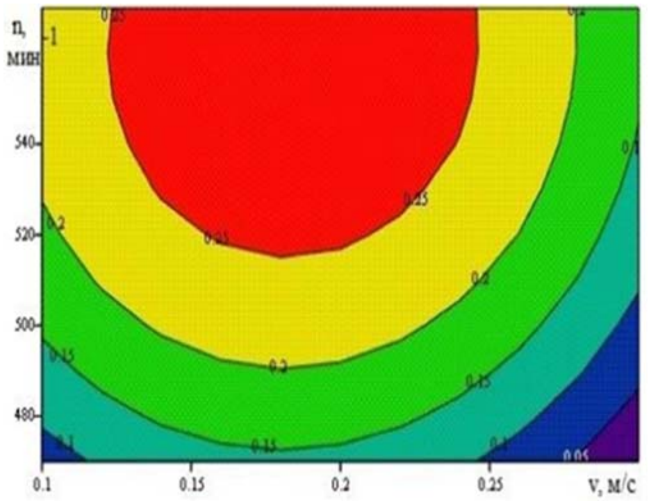

Figure 17. *Experimental dependence of the feed of the helicoid device Q (kg/s) on the rotation speed p (min^{-1}) and the linear velocity of movement υ (m /s) ρ = 512 kg/m^3.*

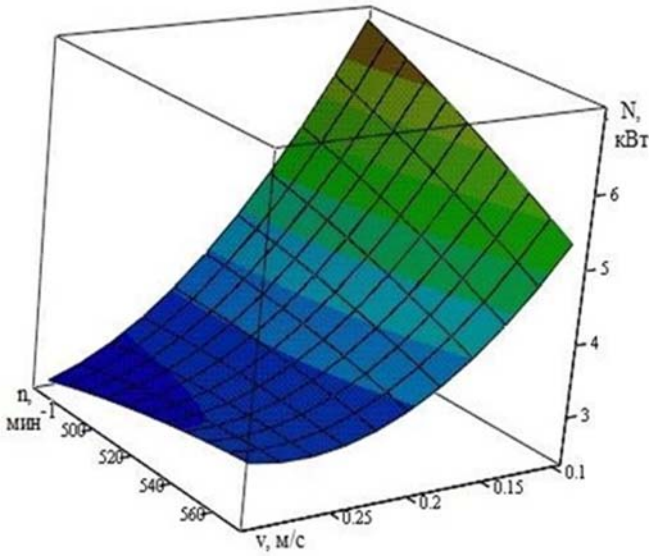

Figure 18. *The response surface of the dependence of the specific energy consumption of the device N (kW. s/kg) on the rotational speed p (min^{-1}) and the linear displacement velocity υ h (m/s) p = 512 kg/m^3.*

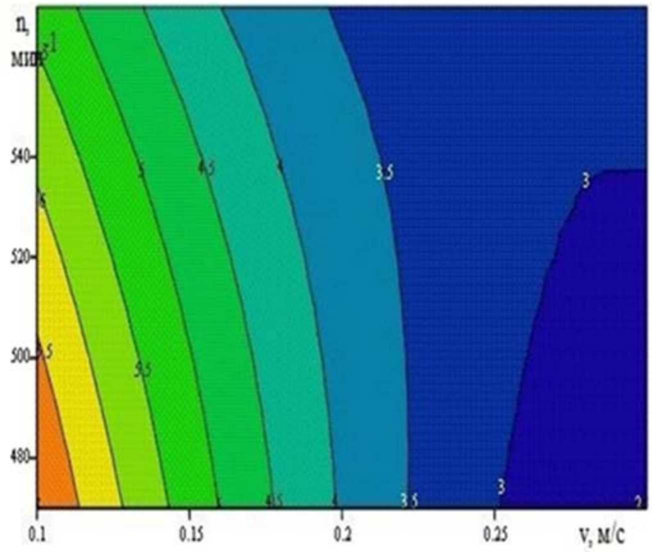

Figure 19. *Experimental dependence of the specific energy consumption of the n-helical device (W.s/kg) to the rotational speed n (min^{-1}) and the linear velocity of movement υ (m/s) ρ = 512 kg/m^3.*

The specific energy consumption at minimum values calculated by the traditional optimization method is achieved at a rotational speed *of n* = 570 min^{-1}, and a linear displacement speed *υ* = of h = 0.27 m/s. Combining the results for specific energy consumption and feed, we will obtain optimal performance indicators of a vertical helicaldevice. For a material with a viscosity of V = 2.36·PA·s and a density *of p* = 916 kg/m^3 at *n* = 563 to 570 min^1 and a linear displacement velocity *of V* = 0.184 to 0.27 m/s. *Q* = 0.288 kg/s; *N* = 3.1 kW.s/kg.

Based on this, the optimal design and operating parameters of the working body are found, which has the necessary supply of liquid material, taking into account the minimum value of specific energy consumption.

In experimental studies, we obtained regression equations, showing the nature of the change accurately based on the flow *Q* of the working body to the rotational speed of spiral *n* and the linear travel speed *υ* of the device on a flat floor surface:

$$Q = 8.17x10^{-4}\, n\upsilon - 1.7\cdot 10^{-5}\, п^2 + 0.02\, n - 9.82\, \upsilon^2 + 3.16\, \upsilon - 5.43.$$

Based on the regression equation, the response surface shown in figure 20 was constructed. The graph shows that the maximum feed *Q* = 0.373 kg/spri movement, obtained by the traditional optimization method, with optimal values such as: rotation *speed n* = 536 min^{-1}, linear velocity of movement *υ* = h = 0.141 m/s.

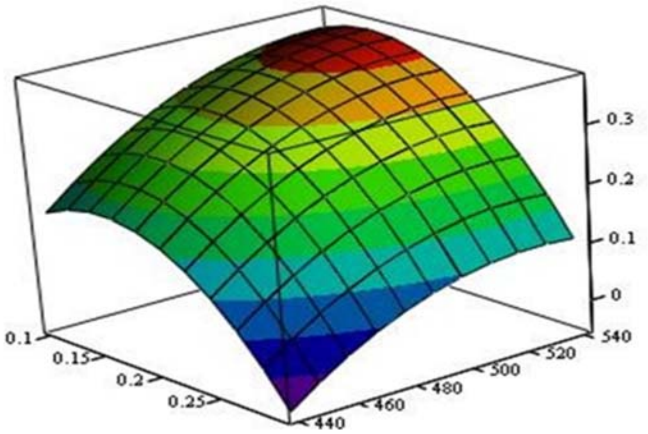

Figure 20. *Surface response regression curves of the helical feed device (kg/s) speed n (min^{-1}) and linear carotidartery υ(m/c)ρ = 916 kg/m^3.*

The evaluation of the efficiency of the helical device for feeding will not fully reflect the characteristics.

Following the obtained values, we calculated a regression equation that characterizes the changes in the dependence of the specific energy consumption *N* (kW.s/kg) of the material being moved on the speed of rotation of the helical screw *n* (min^{-1}) and linear velocity of movement *of the object* (m/s):

$$N = 0.039\, n\upsilon + 3.6x10^{-5}\, п^2 - 0.05\, n - 11.7\, \upsilon^2 - 18.9\, \upsilon + 20.1.$$

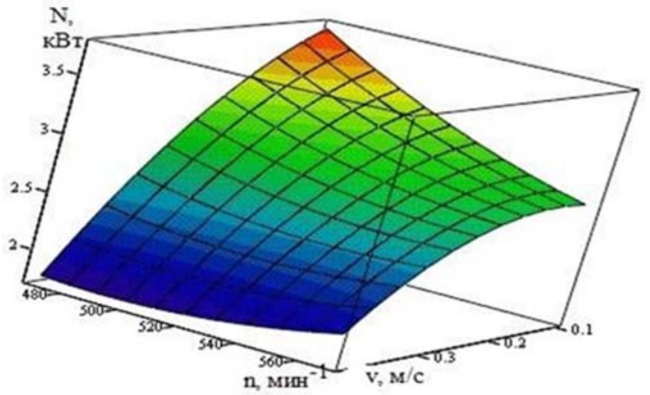

Figure 21. *Response surface of the dependence of the specific energy consumption of the device under development N (kW.s/kg) on the rotational speed n (min*$^{-1}$*) and the linear velocity of movement υ(m/s)ρ = 916 kg/m*^{3}*.*

The minimization of specific energy consumption values revealed by the traditional optimization method is found at a rotation frequency *of n* = 570 min^{-1}. A linear displacement velocity *υ* = of h = 0.27 m/s. Combining the data on specific energy consumption and on the supply, we get the permissible values for the operation of the helicoidal device along the plane. For a material with a viscosity vof V = 2.76 * 10^{-} 6м^{6m2}/ s (confused, please improve expression) at *n* = 536 min^{-1} and a linear displacement velocity *υ* = of h = 0.141 m/s, *Q* = 0.373 kg/s; *N* = 0.754 W.h/kg. Based on the results, the design operating parameters of the installation were calculated using a helical working body along the plane, which performs the highest supply of liquid fraction at low values of specific energy consumption.

Figure 22 shows the productivity dependence on the separation factor of the centrifuge, which is very difficult to analyze since an increase in the rotor speed gives, on the one hand, an increase in the specific filtration surface and an increase in the filtration pressure affecting the unit volume of treated manure, and on the other hand, a decrease in the duration of suspensions in the rotor (Text which has no punctuation and long sentence). From the obtained figures, it can be seen that the separation factor of the filter centrifuge increases sharply with its performance [31, 33].

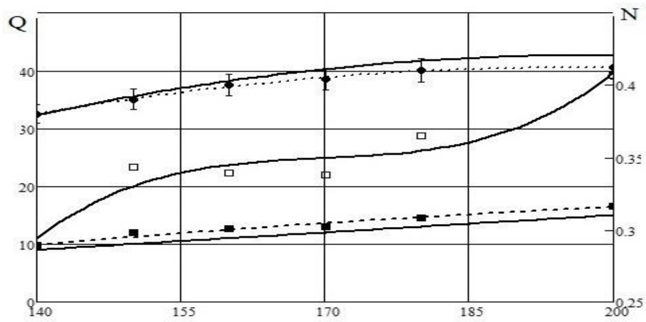

Figure 22. *Dependence of productivity Q and power* N_C *on the factor of separation of the centrifuge: calculated theoretically.*

The optimum for the separation factor can be considered from 160 to 190. With its subsequent increase, the productivity growth process decreases, and according to the observations made, removing sediment significantly worsens. Experimental studies have allowed us to determine the filter centrifuge performance in theoretical terms; however, its real performance is much lower than the theoretical one. The actions of factors can be taken into account by the coefficient K. The value of K obtained experimentally is in the range of 1.2 to 1.3. The experimental results Found agree well with the data calculated theoretically. This reflects the reality of technological parameters calculation of the filter centrifuge according to the theoretical expressions (Shigapov I. I., Gubaidullin Kh., 2012.),(Shigapov I. I., Kadyrova A. M. 2012.).

To calculate engineering parameters, it was necessary to know the values R of the AF, n, t, RK, and L due to the design feature of the centrifuge and the values that depend on the properties of the manure mass. The following two tasks must be performed: calculate the performance of a filtering centrifuge with known values when processing any material, or find design values based on a given performance and characteristic of the initial suspension.

Production studies on finding the filter centrifuge energy indicators have found confirmation of mathematical equations for calculating the required energy. It is established that a significant part of the necessary energy (up to 40%) is spent on removing sediment.

4. CONCLUSIONS:

1. The obtained results of experimental studies of the filter centrifuge found their confirmation of the theoretical assumptions about 2 filtration zones, which are carried out only with thin-layer filtration. During the second stage, all the free moisture leaves. In this case, the specific resistance of the sediment remains almost unchanged.
2. In the developed filter centrifuge, humidity W_{0C} = 80 to 82% was achieved due to centrifugal forces. In the dung mass of cattle, the solid fraction was practically absent of free moisture, resulting in a dried consistency and had a flowability at the slope angle of 70-80 degrees.
3. To calculate the parameters of the filter centrifuge, use the values of the physical and mechanical properties of liquid manure mass in liquid form from cattle in the following ranges: the density of dry matter from 1250 to 1300 kg/m^3; the density and viscosity of the filtered liquid, respectively, 1005...1020 kg/m^3 and 0.008 to 0.025 PA·s. The value of the coefficient of friction of the sediment on the filter surface is 0.9 to 1.2, the stickiness of the sediment is 300 to 600 PA.
4. The main parameters that affect the filtration process due to centrifugal forces are the moisture content of the initial suspension, centrifugation, the thickness of the filtered sediment layer on the filter, and the separation factor.
5. Studies have shown that during the operation of the centrifuge, optimal values were identified that have an impact on productivity: the time of manure mass in the rotor is 0.1, with a separation factor of 170 to 180, the partition for filtering is made of a metal sheet with holes whose diameter varies from 0.8 to 1.5 mm and a thickness of no more than 1 mm.

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6. OPEN ACCESS

Table 1- matrix of experiment planning 2^2 (Build the table. It is not acceptable to table this way)

Number of experiment	Variable factors			Results of experiments			
	x_0	x_1	x_2	y_1	y_2	…	y_i
1	+1	-1	-1	y_{11}	y_{21}	…	y_{i1}
2	+1	-1	+1	y_{12}	y_{22}	…	y_{i2}
3	+1	+1	-1	y_{13}	y_{23}	…	y_{i3}
4	+1	+1	+1	y_{14}	y_{24}	…	y_{i4}

Table 2 - levels of variables

Variable factor, *x*	Upper level Level (+1)	Lower level Level (-1)
Rotation speed of the working body *n*, min^{-1}	35	15
Inner diameter of the outer casing *Dk*, mm	36	28
Outer diameter of the helical working body *dh*, mm	26	20
Wire diameter *dp*, mm	18	15
Length of the helical working body *L*, mm	400	100
helix Pitch of the working body *s*, mm	24	6
The angle of inclination of the casing to the horizon *α*, deg.	45	0