

Evaluation Of The Energy Parameters Of The High-Speed Spiral Blade Mixer For Dry Materials

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ABSTRACT

In article the branch of production of construction materials most actual today and its modern processing equipment is considered. The analysis of new designs of the mixing equipment and processes of mixture in rotor mixers of compulsory action is

submitted. The perspective directions of improvement of mixers of the considered type are given. The new design of the rotor spiral and bladed mixer of compulsory action with a vertical arrangement of a mesilny shaft is presented, the description of this design and the principle of action is given. The constructive knots of the car allowing to increase overall performance of the mixer and to reduce mixing time are considered. The analytical dependences establishing connection between design data of the mixer and quality of the bulk which is in it are removed. The dependence allowing to determine power parameters of the considered mixer is received. The analysis of pilot studies allowing to estimate influence of design data of the mixer on a specific expense of the electric power is given. The presented results of researches allow to draw a conclusion on efficiency of the offered design of the high-speed spiral and bladed rotor mixer and receiving qualitative mixes.

Key words: dry mortar, spiral blade mixer, specific energy consumption.

INTRODUCTION.

Today, the extensive private housing construction has led to a significant demand for modern construction materials, made with dry mortars. Most of them, both in Russia and abroad, are produced with the application of mixing equipment.

The mixing of bulk materials is a complex mechanical process and it depends mainly on mixer design [1, 2, 3]. It consists of the following basic processes: convective mixing, diffusion mixing and segregation. Therefore, it is preferable to consider the mixing equipment in terms of mixing modes, characterized by the speed and the lead time of the abovementioned processes [4].

Disadvantages of the mixers with medium-speed mixing mode are significant energy consumption per volume unit of the final mixture, high wear of the blades, etc. [5].

The most promising for study are mixers with high-level effect on the mixed material which are characterized by a high rate of the movable unit

In such mixers the principle of transition of bulk material into a fluidized state [6] using the spinning rotor is investigated.

Considering the modern requirements for the quality of dry mortars rotary spiral blade batch mixer [7, 8, 9] for obtaining different bulk materials with high-speed mixing mode is designed. The idea of counter-current convective flows (Nesmeyanov et al., 2013) of the mixed material both in horizontal and vertical direction was embodied in the design. Generation of these flows is provided by the helices installed on the inner surface of the mixing tank.

The mixer (Fig. 1) consists of a cylindrical drum 2, inside which the rotor 3 fixed in bearings is cantilevered. Several rows of blades are fixed on this shaft and turned by 120° relative to each other. Besides they are installed in such a way as to throw mixed components on the helix 5 fixed on the inner wall of the drum.

Triple-threaded helix consisting of changeable perforated blades (Fig. 2) has discontinuities in the planes of rotor blades rotation. The mixer drum is installed in bearings, which in turn are fixed at the housing 1. In the upper part of the mixer drum

the cover is rigidly fixed which prevents the escape of the mixing components from the mixer drum.

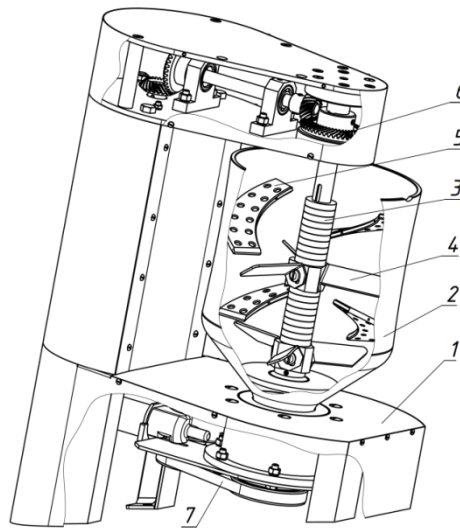


Figure 1. Rotor spiral blade mixer for bulk materials production

The mixer operates as follows:

mixing components are loaded through the top hatch and get inside the mixer drum 2. Simultaneously the drive 6 is thrown into action, which results in rotation of the vertical shaft via a gear and drive 7, which results in rotation of the mixing drum 2 via a V-belt transmission.

Simultaneously the rotor 3 rotates in the opposite direction to the drum 2 rotation and the rotation direction of the mixer drum is selected according to the direction of helix 5 turns. The rotation of the shaft makes blades 4 to raise mixing components and throw them into the helix 5, thereby moving the material in different directions, and discontinuities in it creates additional turbulent flows of the mixture.

Moving along the surface of the screw conveyor, the mixture reaches the second row of blades and, having moved both vertically and horizontally, reaches the middle part of the helix and moves upward.

Thus the mixture reaches the upper part of the mixing drum, and is directed downwards towards the main flow of the mixture. After the mixture was stirred, it is discharged through the bottom hatch by opening the cover. After mixer unloading the process is repeated.



Figure 2. A set of changeable blades of the triple-threaded helix.

Therefore the proposed mixer design allows increasing the degree of homogeneity of the final product by creating a circulation of the starting mixture components both horizontally and vertically inside the mixer drum.

THE MAIN PART.

In case of ratio distortion of the geometric parameters of the conveyor blade and the level of material loading in the mixer the dead zones near the housing may appear, which impairs the mixing process.

We shall consider the motion of material particles along the spiral conveyor blade surface fixed inside the mixer drum [10, 11, 13]. The conveyor blade surface is approximated according to the calculation scheme (Fig. 3) by the inclined plane with a length l , which forms an angle α with the horizon. Thus, it is necessary to consider the movement of material particles with a mass m on the inclined plane.

If at the beginning of the screw conveyor blade the material particles mass has a kinetic energy:

(1)

and at the end of the path with a length l , the kinetic energy of the yielded mass has energy:

$$\frac{mv^2}{2}, \quad (2)$$

then on the basis of the kinetic energy conservation law the following expression can be written :

$$\frac{mv^2}{2} = mgh_2, \quad (3)$$

where mgh_2 is the potential energy, which is necessary to impart to the yielded mass of the material to lift it to a height h_2 .

The expression for this energy value is:

$$A = mgh_2, \quad (4)$$

is a work against frictional force of material mass during its motion along the inclined plane. The expression for this work is determined by:

$$A = \mu mg l, \quad (5)$$

Here μ is a coefficient of friction of the mixture particles on conveyor blade.

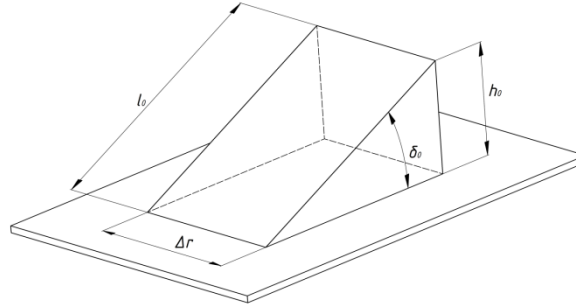


Figure 3. Design scheme for describing the motion of the material along the inclined surface

According to the design scheme (Fig. 3), it can be found that:

$$h_2 = l_0 \cdot \sin \delta_0, \quad (6)$$

Substituting (1) and (2), (4) – (6) into the expression (3) results in the following expression:

$$\frac{w^2 - v_{1z}^2}{2} = g \cdot l_0 \cdot (\sin \delta_0 + f \cdot \cos \delta_0). \quad (7)$$

According to the relation (7) we can find the expression estimating the value of the material particles climb speed at the end of the conveyor blade:

$$v_{1z} = \sqrt{w^2 - 2 \cdot g \cdot l_0 \cdot (\sin \delta_0 + f \cdot \cos \delta_0)}. \quad (8)$$

The obtained expression is converted to:

$$\begin{aligned} \sin \delta_0 + f \cdot \cos \delta_0 &= \sqrt{1 + f^2} \cdot \left(\frac{1}{\sqrt{1 + f^2}} \cdot \sin \delta_0 + \frac{f}{\sqrt{1 + f^2}} \cdot \cos \delta_0 \right) = \\ &= \sqrt{1 + f^2} \cdot (\cos \varphi_0 \cdot \sin \delta_0 + \sin \varphi_0 \cdot \cos \delta_0) = \sqrt{1 + f^2} \cdot \sin(\delta_0 + \varphi_0) \end{aligned} \quad (9)$$

Where

$$\cos \varphi_0 = \frac{1}{\sqrt{1 + f^2}} \quad (10)$$

$$\sin \varphi_0 = \frac{f}{\sqrt{1 + f^2}}. \quad (11)$$

On account of expressions (10) and (11) it can be found that:

$$\operatorname{tg} \varphi_0 = f. \quad (12)$$

On account of (12) it can be found that:

$$\varphi_0 = \operatorname{arctg} f. \quad (13)$$

Consideration of (9) allows writing the expression (8) as:

$$v_{1z} = \sqrt{w^2 - 2 \cdot \sqrt{1 + f^2} \cdot g \cdot l_0 \cdot \sin(\delta_0 + \varphi_0)} \quad (14)$$

If in (14) we take $v_{1z} = 0$, then we can find the maximum permissible relationship between the parameters characterizing the material particles motion and the design parameters of the screw conveyor blade of the spiral blade mixer. On account of the abovementioned considering the expression (14) we find that:

$$w^2 = 2 \cdot \sqrt{1 + f^2} \cdot g \cdot l_0 \cdot \sin(\delta_0 + \varphi_0). \quad (15)$$

The resulting relation (15) can be regarded as a trigonometric equation for the unknown variable δ_0 . Therefore, the solution of equation (15) is represented as follows:

$$\delta_0 = -\varphi_0 + \arcsin \frac{w^2}{2\sqrt{1+f^2} \cdot g \cdot l_0}. \quad (16)$$

If we introduce the following notation:

$$\delta_* = -\varphi_0 + \arcsin \frac{w^2}{2\sqrt{1+f^2} \cdot g \cdot l_0}, \quad (17)$$

and take into account that

$$w = v_z \cdot \left(r = \frac{(R-l)}{2} \right) = \frac{(\sqrt{\lambda^2+1}) \cdot w \cdot (R-l)}{4}, \quad (18)$$

which considering (13) and (18) results in:

$$\delta_* = -\arctg f + \arcsin \frac{(\sqrt{1+\lambda^2}-\lambda)^2 \cdot w^2 \cdot (R-l)^2}{32\sqrt{1+f^2} \cdot g \cdot l_0}, \quad (19)$$

Thus, the movement of the particles of bulk material along the surface of the screw conveyor blade will occur at the installation angles determined by the relation $[\delta] \leq [\delta_*]$ and when the installation angle of the screw conveyor blade $[\delta] \leq [\delta_*]$ the movement of the material particles along the surface of the screw conveyor blade will not occur, resulting in the formation of “dead” zones and impairment of the mixing process near the mixer housing.

To evaluate the length l_0 of the screw conveyor blade we use the following results of the study.

On one hand, according to the relation (19) the following inequality must be fulfilled:

$$(\sqrt{1+\lambda^2}-\lambda)^2 \cdot w^2 \cdot (R-l)^2 \leq 32 \cdot \sqrt{1+f^2} \cdot g \cdot l_0 \quad (20)$$

On account of (20) the frequency of material particles rotation in the mixer must satisfy the relation:

$$w \leq \frac{4\sqrt{2 \cdot \sqrt{1+f^2} \cdot g \cdot l_0}}{(\sqrt{1+\lambda^2}-\lambda) \cdot (R-l)}, \quad (21)$$

On the other hand for bulk material transition into a fluidized state the condition $w \geq w_*$ must be satisfied or:

$$w \geq \frac{2\sqrt{2gH_0}}{(\sqrt{1+\lambda^2}-\lambda)(R-l)}, \quad (22)$$

It is easy to verify that the joint consideration of the inequalities (21) and (22) leads to the following relationship:

$$H_0 \leq 4 \cdot \sqrt{1+f^2} \cdot l_0. \quad (23)$$

Thus, the obtained inequality (23) establishes a relationship between the design parameter l_0 – the length of the screw conveyor blade plane and H_0 – the level of the initial loading of material. If ratio distortion of (23) occurs the dead zones near the mixer housing may appear, which in turn will provide an impairment of the mixing process in the spiral blade mixer.

In order to calculate the energy consumption during the preparation of dry mortars in this mixer, we use the existing method of calculation of power of mixers with a vertical shaft proposed by N.P. Popov for machines with multiple blades and smooth walls of a mixing drum [13].

On account of helices position on the internal surface of the drum the power consumption will increase on account of energy consumption necessary for lifting the

material along the surface of the helix and rotation of the mixing drum with a material.

The power for lifting the material along the surface of one helix is calculated by the following equation:

$$N_{\text{wi}} = \frac{\Delta U + A_T}{t} . \quad (24)$$

where N_{wi} is a power consumed for lifting the material along the surface of one helix;

ΔU is a difference of kinetic energies of the material at the beginning and at the end of the surface of one helix;

A_T is a work against frictional force of material mass during its motion along the helix;

t – time of material passing along the helix.

On account of the expressions (4) and (5), the equation (24) will become as follows:

$$N_{\text{wi}} = \frac{1}{t} \cdot g \cdot l_0 \cdot (\sin \delta_0 + f \cos \delta_0) \cdot \Delta m_i , \quad (25)$$

where Δm_i is the mass of the material column which is above the I helix.

As is well known:

$$\Delta m_i = \gamma_t \cdot V_i . \quad (26)$$

Where $[\gamma_t]$ is the density of the material in a fluidized state;

V_i is the amount of the material above the helix in a fluidized state.

$$V_i = l_0 \cdot \Delta r \cdot (H_i - h_0) \quad (27)$$

where Δr is the width of the helix.

Then on account of (26) and (27) the power for lifting the material along the helical surface will be calculated as:

$$N_{\text{wi}} = \frac{\gamma_t \cdot g \cdot l_0^2}{2 \cdot \pi} \cdot w \cdot (\sin \delta_0 + f \cos \delta_0) \cdot \Delta r \cdot \sum_{i=1}^n (H_i - h_0) . \quad (28)$$

On account of the data [12] the power consumed by the vertical shaft in the mixer with multiple blades and cylindrically smooth drum is calculated by the equation:

$$N_{\text{ji}} = k_1 \cdot k_2 \cdot \sum N_{\text{ni}} . \quad (29)$$

where N_{ji} is the power on a vertical shaft of a mixer with multiple blades (kW)

k_1, k_2 are trial coefficients which consider how the number of mixer blades in a row and the number of rows impact on the power [12];

N_{ni} is the power of single-row two-blade mixer (kW).

Power of a single-row two-blade mixer is calculated as [4]:

$$N_{\text{ni}} = C_2 \cdot w^{2,56} \cdot L^{3,5} \cdot (b \cdot \sin \alpha)^{0,68} \cdot H^{0,74} \cdot S^{0,39} \cdot \rho_H \quad (30)$$

where N_{ni} is the power of single-row two-blade mixer (kW).

C_2 is a coefficient of resistance in the fluidized regime [12];

w is a blade rotation speed, (c^{-1});

L is a blade length, (m);

b is a projection of the blade to a vertical plane (m);

$[\alpha]$ is the blade angle to the horizon, ($^\circ$);

H is a height of the material layer above the blade (m);

S is a gap between the edge of the blade and the inner wall of the drum (m);

$[\rho_H]$ is a bulk material density (kg / m^3).

To determine the power required to rotate the mixing drum with rotation speed w_6 , we assume that it is affected by inertia, the value of which is determined by:

$$I = \frac{M_0}{2} \cdot R^2, \quad (31)$$

where M_0 is a total mass of the mixer drum, which includes the mixed material mass and the drum housing mass.

The work that must be imparted to the mixer housing to make it rotate with a frequency w_6 is equal to the change of the rotation kinetic energy and is calculated as follows:

$$A_B = \frac{M_0 \cdot R^2 \cdot w_6^2}{4}. \quad (32)$$

On account of (32) the power needed to perform this work, will be equal to:

$$N_B = \frac{A_B}{t_n}, \quad (33)$$

where t_n - is a time of complete turn of the drum housing, equal to:

$$t_n = \frac{2\pi}{w_6}. \quad (34)$$

Substituting (32) and (34), into (33) results in the following:

$$N_B = \frac{M_0 \cdot R^2 \cdot w_6}{8\pi}. \quad (35)$$

Also when calculating the power required for the rotation of the mixing drum, it is necessary to consider lifting of the material along a helical surface disposed on the inner surface of the mixer housing. Then, on account of the additivity the value of power consumed to lift the material to the height h_0 (Fig. 3) should be found and the obtained result should be multiplied by k_{π} which is the number of blades, forming a helical surface. Resulting from the abovementioned, it can be written:

$$N_{\pi} = \frac{k_{\pi} \cdot A_{\pi}}{t} = \frac{k_{\pi} \cdot w_6 \cdot A_{\pi}}{t \cdot w_6} = \frac{k_{\pi} \cdot w_6 \cdot A_{\pi}}{\Delta\varphi}, \quad (36)$$

where $\Delta[\text{pfi}]$ is the angular size of the screw conveyor helix;

A_{π} is the work for lifting mixture mass along the helical surface to a height h_0 , which equals to:

$$A_{\pi} = g \cdot \gamma_t \cdot l_0 \cdot c \cdot \int_0^{h_0} z dz = \frac{g \cdot \gamma_t}{2} \cdot l_0 \cdot c \cdot h_0^2. \quad (37)$$

Then, the power required to lift the material to the height h_0 :

$$N_{\pi} = \frac{k_{\pi} \cdot w_6}{2 \cdot \Delta\varphi} \cdot g \cdot \gamma_t \cdot l_0 \cdot c \cdot h_0^2. \quad (38)$$

The total power consumed for the rotation of the mixing drum, will be equal to:

$$N_6 = \frac{M_0 \cdot R^2 \cdot w_6^3}{8\pi} + \frac{k_{\pi} \cdot w_6 \cdot g \cdot \gamma_t \cdot l_0 \cdot c \cdot h_0^2}{2 \cdot \Delta\varphi}. \quad (39)$$

Thus the obtained relation (39) determines the power necessary for drum rotation in the established mixer operating mode.

Then the full power required for the rotor spiral blade mixer will be estimated as follows:

$$N = \left[\frac{\gamma_t \cdot g \cdot l_0^2}{2 \cdot \pi} \cdot w \cdot (\sin\delta_0 + f \cdot \cos\delta_0) \cdot \sum_{i=1}^n (H_i - h_0) \right] + [C_2 \cdot w^{2,56} \cdot L^{3,5} \cdot (b \cdot \sin\alpha)^{0,68} \cdot H^{0,74} \cdot S^{0,19} \cdot \rho_H] +$$

$$+ \left[\frac{M_0 \cdot R^2 \cdot \omega_0^3}{8\pi} + \frac{k_{\pi} \cdot \omega_0 \cdot g \cdot \gamma_t \cdot l_0 \cdot c \cdot h_0^2}{2 \cdot \Delta \varphi} \right]. \quad (40)$$

DISCUSSION.

For the analysis of changes in the specific energy consumption of the mixer on the basis of statistical processing of the experimental study results [14] the natural regression equation is obtained:

$$q = 17,36 - 0,003 \cdot \delta_0 \cdot \Delta r + 0,004 \cdot \delta_0 \cdot n_{\text{III}} - 0,025 \cdot \delta_0 + 0,009 \cdot \Delta r^2 - 0,002 \cdot \Delta r \cdot n_{\text{III}} - \\ - 0,329 \cdot \Delta r + + 0,002 \cdot n_{\text{III}}^2 - 0,341 \cdot n_{\text{III}} - 0,028 \cdot n_p$$

Figure 4 shows the dependence of the specific energy consumption of the mixer on the helix lead angle at the average values of helix width and screw conveyor rotary speed.

The diagram shows that the dependence $q = f([\delta]_0)$ is growing, i.e. with helix lead angle increasing the specific energy consumption increases. This can be explained by the fact that under the kinetic energy law, the increase in the helix lead angle provides the increase of potential energy, which should be imparted to the material for its motion along the angled surface. The diagrams show the same nature of the change at different values of the rotary speed of the rotor: 450 min^{-1} , 550 min^{-1} and 650 min^{-1} .

The highest value of the specific energy consumption $q = 5,5 \text{ kW} \cdot \text{h} / \text{t}$ is observed when the helix lead angle is $[\delta]_0 = 32^\circ$ and maximum rotary speed $n_p = 650 \text{ min}^{-1}$.

The smallest value of the mixer specific energy consumption $q = 2 \text{ kW} \cdot \text{h} / \text{t}$ will be at the helix lead angle of $[\delta]_0 = 18^\circ$ and rotary speed $n_p = 450 \text{ min}^{-1}$.

It should be noted that for all values of the rotary speed of the mixer the difference in specific power consumption at the minimum and the maximum helix lead angle has a double value.

Figure 5 shows the dependence of the specific energy consumption on the width of the screw conveyor helix width with the average rotary speed of screw conveyor and the rotor. The diagrams show that this is extreme dependence with the inflection point in the bottom of the diagram.

On the span of the conveyor width from 26 mm to 32 mm the specific energy consumption decreases at all values of the helix lead angle. Such specific consumption change can be explained as follows. Most of the power consumed by the rotor is expended on overcoming friction of the material against the mixing blades, and the value of this force, under constant conditions, depends on the pressure (mass) value of the material located above the blade. Installation of helical blades and change of their width decreases the frictional forces of the material against the mixing blade as the part of the material pressure is transmitted directly to the helical surface. In this connection the energy required to overcome the friction of the material against the helical surface is less important than the energy required to overcome the friction of the material against the mixing blade.

The increase of the screw conveyor helix width alters the values of the forces of material friction against the mixing blade and screw surface. The frictions forces on the helical surface acquire greater values than the friction of the material against the mixing blade that causes an increase in the power consumption of the mixer rotor.

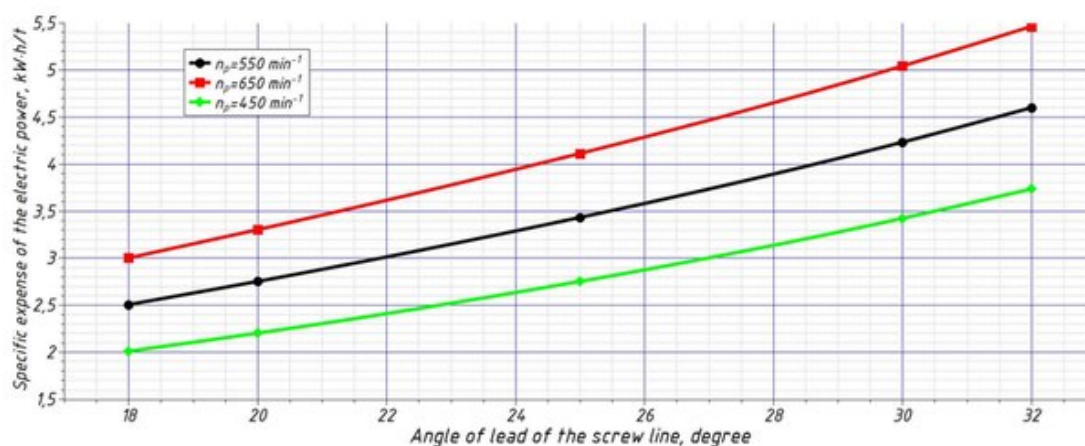


Figure 4. Diagrams of dependence $q = f(\delta_0)$ at $\Delta r = 40 \text{ mm}$ and $n_m = 40 \text{ min}^{-1}$

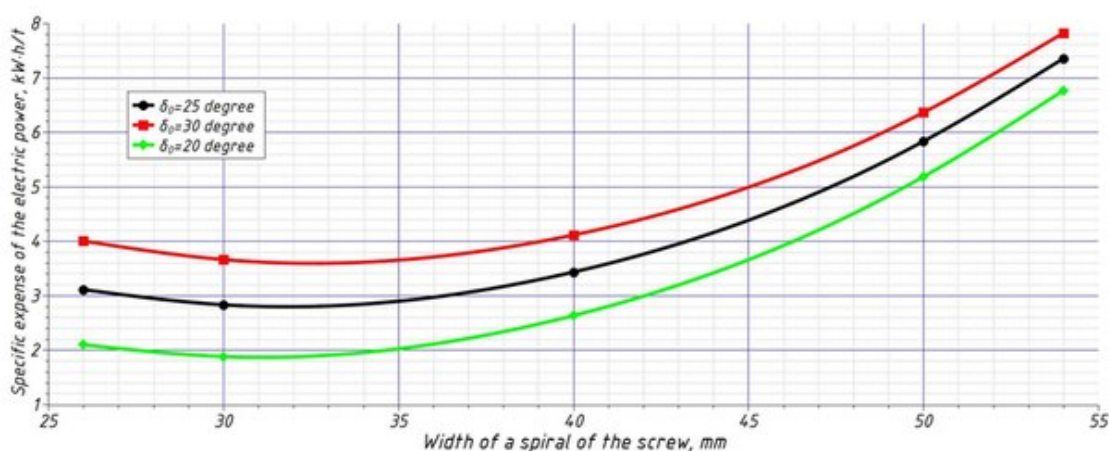


Figure 5. Diagrams of dependence $q = f(\Delta r)$ at $n_m = 40 \text{ min}^{-1}$ and $n_p = 550 \text{ min}^{-1}$

The highest value of the specific energy consumption of the mixer $q = 8 \text{ kW} \cdot \text{h} / \text{t}$ will be at a screw conveyor helix width of 54 mm and the helix lead angle of 30 degrees.

The smallest value of the specific energy consumption $q = 1,9 \text{ kW} \cdot \text{h} / \text{t}$ will be at a screw conveyor helix width of 32 mm and the helix lead angle of 20 degrees.

It is worth noting that the change of mixer specific energy consumption at any value of the helix lead angle between the minimum and maximum width of the screw conveyor helix will also have the double value.

CONCLUSION.

The analysis of the regression equations, obtained in the research, showed that the width of the helical surface (of a screw conveyor helix) has the greatest impact on the coefficient of mixture heterogeneity V_c and specific energy consumption q .

The discrepancy between theoretical calculations and experimental studies in the evaluation of the speed parameters of material motion along the surface of the screw conveyor and the energy parameters of the mixer does not exceed 10%.

The calculation methods offered above allow determining the rational design and technological parameters of the developed high-speed rotary spiral blade mixer for various dry mortars with a heterogeneity coefficient not more than 4% and minimum power consumption.

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