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INVESTIGATION OF ENERGY CONSUMPTION IN THE COURSE OF PLASTERING MACHINE'S WORK

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Розглянутий процес виконання опоряджувальних робіт за допомогою технологічного комплекту обладнання штукатурної станції. Теоретично досліджені втрати енергії на перемішування та транспортування будівельних розчинів до місця виконання робіт. Отримані дані дослідження дозволять конструювати та створювати ефективні комплекти обладнання для механізованого нанесення штукатурних розчинів на поверхні, що оброблюються, та виконувати підбір силової установки

Ключові слова: технологічний комплект обладнання, гідропривід, будівельний розчин, трубопровід, транспортування, енергетична ефективність

Рассмотрен процесс выполнения отделочных работ с помощью технологического комплекта оборудования штукатурной станции. Теоретически исследованы потери энергии на перемешивание и транспортирование строительных растворов к месту выполнения работ. Полученные данные исследования позволят конструировать и создавать эффективные комплекты оборудования для механизированного нанесения штукатурных растворов на обрабатываемые поверхности и выполнять подбор силовой установки

Ключевые слова: технологический комплект оборудования, гидропривод, строительный раствор, трубопровод, транспортирование, энергетическая эффективность

1. Introduction

Construction efficiency is improved mainly through better labor productivity, shorter construction time, lower volume and cost of manual construction work, as well as better construction quality.

These problems can be solved mainly by using technological equipment sets to prepare, transfer and apply mortar on treated surfaces in finishing operations, whose laboriousness comprises 25–30 % of the total cost of a new construction.

The most labor-intensive among finishing operations is plastering; its cost reaches 18–20 % of the entire cost of construction and installation. Despite the development of industrial finishing, plastering remains one of the most common types of finishing work, particularly in brick house construction.

Although since modern finishing materials appeared dry plaster has been widely used for internal finishing of buildings, the volume of wet plastering has not significantly decreased. However, about 70 % of plastering operations are performed manually, and only 30 % – with the help of mechanization. Mechanized operations mainly include spraying on the wall surface and smoothing with burnishing machines.

It should be noted that a wet plastering technology is almost indispensable in sealing joints of constructions, arranging floors, and waterproofing. These processes require the use of significant amounts of lime-sand and cement-sand mortars of various compositions and liquidity. Along with preparing a mortar and bringing it to the desired condition, much of the energy consumed during plastering is spent on pumping and piping a mortar to the place of its application with the help of mortar pumps.

Peculiarities of the technology and properties of the materials used in finishing, in some cases, impede mechanization of the production processes and, therefore, the latter have to be performed manually. A particularly high proportion of manual labour is observed at geographically disparate construction sites. In manual plastering, a plasterer's average productivity per shift in the construction industry reaches only 8 m^2, which is extremely low. So the issue of mechanical finishing is particularly important since its quality and duration largely depend on a timely launching of facilities in operation.

Creation of technological sets of energy-efficient equipment, such as plaster stations and units, calls for research aimed at the development of a rational design that would meet modern requirements.

It is necessary to apply new approaches to the design features of equipment at each stage of the process, including plastering in specific conditions of a construction site.

The main requirements to mechanization of plastering include:

– efficiency;
– energy conservation;
– reliability;
– an ability to effectively prepare mortars;
– an ability to develop a wide-range working pressure to transfer mortars of various compositions and liquidity over long distances;
– reliability of operation in different modes directly at a construction site.

Units for preparing and pumping mortars as integral parts of technological equipment sets are subject to further

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thorough development with an account of the type of drive. Therefore, the creation of scientifically grounded energy efficient technological equipment sets to perform finishing is a topical problem of modern construction industry.

2. Analysis of previous studies and formulation of the problem

Plastering involves the use of plasters of different compositions – cement or cement-lime ones [1–4].

Depending on the volume of plastering operations, plasters are prepared at permanent centralized mortar nodes or straight at the construction sites, with the use of mechanized mobile mortar mixers [5].

At the construction site, mortar that is delivered in vehicles [6, 7] is received by a technological equipment set that may include plaster stations or units with feeders-reloaders.

The main peculiarity of a plaster station mixer, unlike mortar- and concrete-mixers (that are used for industrial manufacturing of mortars), is that in addition to preparation of ready-mix plasters the mixer as a part of a plaster station provides transfer (feed) of the mixture to the feeder chamber of a mortar pump.

In some cases, it is necessary to provide the most comprehensive and uniform in volume contact of reacting components. The latter is achieved by mixing, i. e. intense movement of individual particles and plots in the total volume of the mixture.

Some mortars are made in concrete mixers according to the principle of "free fall"; however, this is not typical of the technology of mortar production. It is associated with the local conditions of work, including the desire to use one machine to prepare both concrete and mortar.

Mixing mortar components largely involves the use of paddle mixers. There are combined working bodies composed of paddles and belts, which allows uniformity of the mixture components' distribution both in the periphery and in the centre of the hopper.

The technological set must be capable of preparing mortars straight at the site where ready mix mortar is needed. Actuation of the units that form the technological set requires the use of a hydraulic drive allowing a significant reduction of their energy and metal capacities.

A ready mixture is transported to construction sites with the help of mortar pumps. Mortar pumps that are used in plaster stations have a significant drawback – instability of mortar supply pressure, which leads to a decrease in the level of volumetric efficiency and additional energy consumption of mortar transportation via pipelines.

The efficiency of mortar pumps is determined by a number of technical and economic parameters, the main of which are the following: productivity (feed), created pressure, the range of transportation, power consumption, reliability in operation, suction capacity, flow pulsation, and volumetric efficiency.

One of the most efficient in terms of volumetric efficiency is a design of the hydraulic grout pump RNH-4 [8]. Since construction sites are supplied with thick grouts [9], piping of the latter involves the use of pumps with high suction capacity, which is currently provided by RNH-4. This allows using it in a minioperational technology of finishing work [10].

The piston in RNH-4 is subject to the law of motion with constant velocity; thereby, it provides a lower mortar and grout supply pressure fluctuation, which both reduces energy consumption of pumping and provides favorable conditions for compressorless nozzling.

Using a hydraulic drive in the technological set of plastering equipment allows varying the mortar pump performance on the plasterer's demand [11], which extends the scope of its use.

It should be noted that the issue of energy consumption of the working hydraulic part of a mortar pump was not studied earlier.

The complexity of hydraulic processes occurring in the working chamber of the mortar pump makes you determine the power consumption mainly on the basis of experimental data. Prediction of the consumed power requires taking into account the properties of the pumped medium, since the experience of laboratory tests and manufacturing operation of mortar pumps [12] indicates that when liquidity of the pumped grout is lower, the power consumption increases.

At present, construction sites use various sizes and types of mortar pipelines and sleeves that form a hydrotransport highway and are intended for supplying pressurized finishing mortars from mortar pumps to the place of application [13]. Mortar pipelines consist of metal as well as rubber-and-canvas risers, steel pipelines, rubber-and-canvas sleeves, and fittings [14].

The defining characteristics of rubber-and-canvas sleeves is their flexibility and elasticity of the walls. Under the internal pressure, these sleeves can change the cross section by up to 5–7 % and return to the starting position after the load is lifted. This property allows smoothing the mix flow pulsation during its progress from the plaster pump to the injector nozzle.

A wide range of processing equipment that is used in the sets determines the need of generalizing and developing a classification approach to the selection of the technological equipment components in terms of energy efficiency (the effect of each component of the total rate of energy consumption), which allows a more accurate selection of equipment for finishing by the specified design features.

The general classification of the components of the technological equipment set is shown in Fig. 1.

It can be concluded that among the above designs of mortar mixing units the most successful designs are inherent in the following devices:

(1) the hopper (rotary) that allows supplying any mortar in the mixing zone core without any structural complications and waiving any driveway equipment for unloading the tip lorry;

(2) the mixer (belt-paddle) with a mortar discharge off the screw end.

It should be noted that the belt-paddle mixer provides the most active mortar movement [15] to the feeder camera of the mortar pump, which is necessary for the plaster station mixer.

As for the mortar pump, the most promising is the design capable of a small-impulse supply of inert thick mortars under the pressure of 4–6 MPa, with minimal power and volume losses. It is based on the principle of differential performance, equipped with a plunger-type flow-through working body with ball-bearing valves. The pump drive has to provide a smooth motion of the working body for most of the cycle. The pump must be of small size and weight, simple and reliable design.

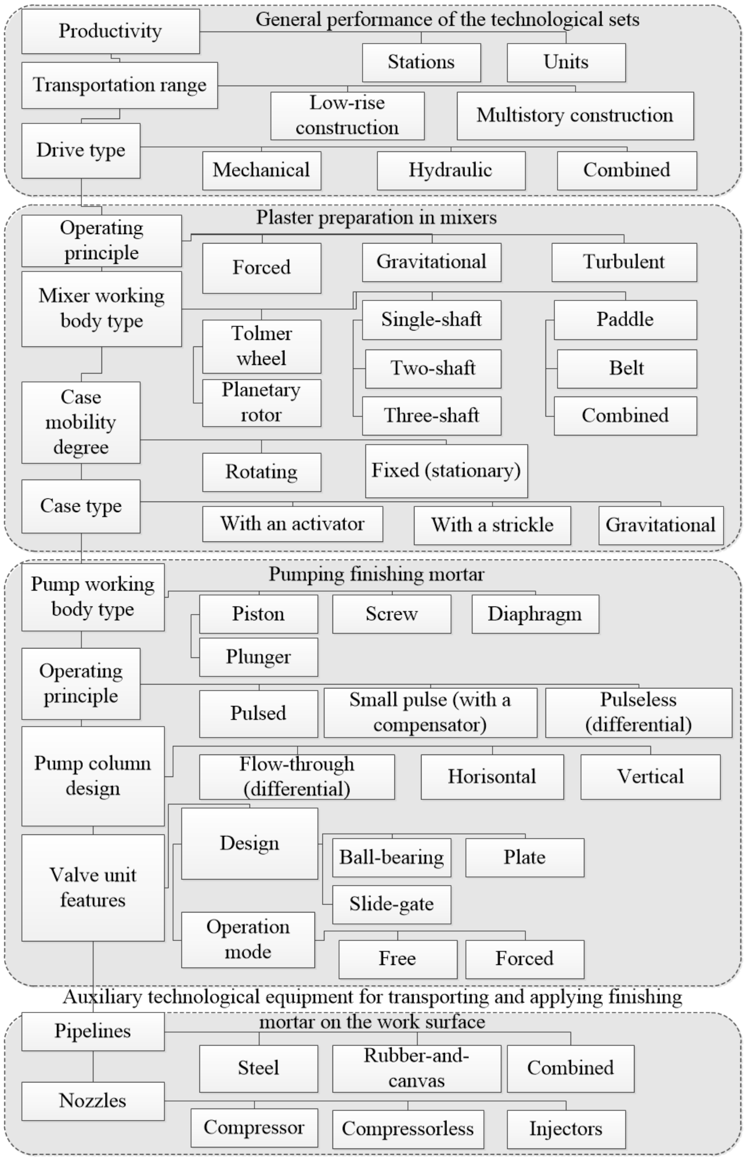


Fig. 1. A general classification of the components of a plasterwork equipment set

Such design can be implemented with the use of a hydraulic drive of a flow-through plunger. The differential property of the plunger allows using only one working body and simplify the design of the hydraulic part. The hydraulic drive provides a mode with minimal fluctuations in supply and pressure, and the increased level of efficiency is likely to reduce the value of power consumption in mortar pumping.

All components of the technological set are important: design features of mixers and the principle of their operation – for preparation of the mortar, design features of mortar pumps – for pumping, and peculiarities of nozzles and injectors – for the mortar application.

3. The purpose and objectives of the study

The aim is to develop a method of calculating energy costs and determine rational values of the parameters and modes of the technological equipment set operation for plasterwork, based on the rheological characteristics of a finishing mortar. To achieve this goal we set the following tasks:

– to choose the rational design of the technological equipment set components, such as a mixer and a mortar pump;

– to determine theoretically the energy loss of the finishing works done with the help of the technological equipment set.

4. Materials and methods of studying energy consumption of the hydraulic equipment set for finishing works

The material of studying the processes of mixing and transporting is a lime-sand mortar of brand S12 according to the DSTU BV.2.7-23-95, with a liquidity of 8 cm and density of ρ=2100 kg/m^3.

The research findings are processed with the use of the methods of physical simulation and mathematical modelling, the theory of similarity, as well as a PC with a package of the free office software "OpenOffice".

5. The research findings on energy consumption of the hydraulic equipment set for finishing works

At present, plaster stations that are used at construction sites have various designs. But the moral obsolescence of technical solutions in most of them can not meet the demands of modern technologies of finishing works in terms of energy efficiency and reduced energy consumption.

The selected rational design of the technological set is as follows: a single-shaft combined forced mixer with a rotatable housing and a belt-paddle shaft, a vertical differential piston mortar pump with ball-bearing valves, combined steel and rubber-and-canvas pipelines, and a compressorless injector. The most common design of a single common-frame set is a plaster station.

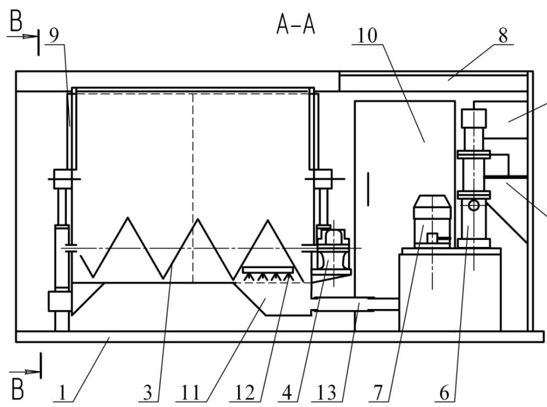
The work of hydraulic cylinders is ensured by means of oil pump units that are present in common designs of plaster stations and activated only several times per shift for short periods of time, i.e. used very inefficiently. Due to the widespread use of plaster stations that are partially equipped with hydraulic drives (actuators), there has been developed and tested a hydraulic mortar pump RNH-4, the advantages of which include a reduced value of the fluctuation in the mortar supply pressure and a possibility of a smooth supply adjustment. A high suction capacity of the above mortar pump ensures a consistent supply of mortar with a liquidity of 9–11 cm at a very low supply fluctuation. The performance control device allows a sustainable mortar supply. Equipping the plaster station SSh-4H [16] with such device results in using only one power unit.

The presence of a rotary hopper effectively differentiates the plaster station SSh-4H because it allows loading a finishing mortar directly from the tip lorry without any additional ramps, and a large tilt angle of the walls in the working position (up to 70°) allows waiving a vibrator, which reduces power consumption and significantly decreses the noise load on the operator. At the same time, the rotary hopper ensures an efficient operation of the mortar pump while pumping high-liquidity finishing mortars (up to 12 cm).

The plaster station SSh-4H (Fig. 2) consists of a frame 1, on which there is a rotary mixing hopper 2 with a mechanical stirrer 3, and its drive 4. Hydrocylinders 5 turn the mixing hopper. A hydraulic mortar pump 6 of brand RNH-4 and an oil pump unit 7 are installed in the frame. On the top of the frame, there is installed a van 8, a gate 9, and a door 10.

The plaster station is equipped with a feeder chamber 11 that has a removable filter grille 12 that is meant for filtering mortar before serving it in the mortar pump. A sludge that results from the work of the technological equipment is removed through a hatch in the bottom of the hopper.

In the mid-cabin there is mounted an electricity box 14 and a hydraulic control valve 15 to operate the hydraulic cylinders of the mixing hopper.



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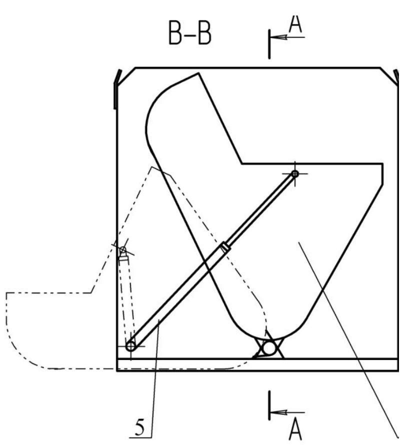

b

Fig. 2. A schematic structure of the station SSh-4H: *a* — section A—A; *b* — section B—B; 1 — the frame; 2 — the screw mixer; 3 — the stirrer; 4 — the mixer drive; 5 — the hydraulic cylinder; 6 — the mortar pump; 7 — the oil unit; 8 — the van; 9 — the gate; 10 — the door; 11 — the feeder chamber; 12 — the filter grille; 13 — the rubber-and-canvas sleeve; 14 — the electricity box; 15 — the hydraulic control valve

The above model of the plaster station is the most conformist with the modern requirements of a complex mechanization of construction works that are associated with the use of mortars.

Energy consumed by the equipment set comprises energy that is spent on mixing the finishing mortar, creating pressure for its supply via pipelines, losses during the pipeline transportation, and applying it on the surfaces by means of compressorless nozzling (Fig. 3).

It is rather difficult to determine the energy consumed by the electrical drive of the forced mortar mixing equipment during preparation of the mix. Mortars that are coarse dispersions belong to visco-plastic media, whose properties and motion conditions differ significantly from those of viscous liquids. It is important that the changeability of physical and mechanical properties of mortars depends on the time and velocity. This fact considerably complicates the picture of the finishing mortar motion during mixing. There is a great amount of resistance forces, the most important being the forces of internal and external friction, resistance caused by moving the mix masses, as well resistance arising from the inertia efforts and wave formation. Much of this resistance, as noted above, does not remain constant over the mixing cycle. Moreover, there is used a wide range of mortars in terms of their composition and characteristics of their components. All this further complicates determining the components of resistances that arise from mixing.

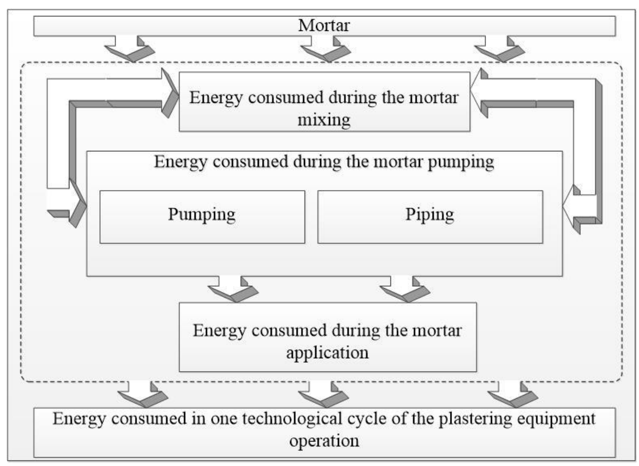

Fig. 3. A scheme of energy consumption of the operating equipment set

It is expedient to consider the complex of phenomena occurring during mixing mortars with the help of the shear stress magnitude τ, Pa, that is quite predestinate for the operational modes, the working body size, and the mortar composition. Its physical essence is that it determines the effective stress in Pa required to create irreversible deformation (mixing) of the mortar. Given this, we propose the following method to determine the power of the mortar mixing equipment engine, which reflects a generalized picture of a screw mixer.

During the rotation, the screw mixer drive experiences resistance from the mixed medium. Let us isolate an elementary surface with dimensions of $db \times dr$ (Fig. 4) on the working body. The elementary section area dS, in this case, is calculated as follows:

$$dS = db \cdot dr. \quad (1)$$

The resistance that is generated by the medium under the relative displacement (shear stress) is described by the Shvedov-Bingham equation [4]:

$$\tau = \tau_0 + \eta \frac{d\upsilon}{dx}, \tag{2}$$

where τ_0 is the limit shear stress of the medium, Pa; η is the coefficient of structured viscosity, Pa s.

The resistance dF, kN, acting on the elementary section is calculated as follows:

$$dF = \tau \cdot dS, \tag{3}$$

where τ is the mortar shear stress, Pa.

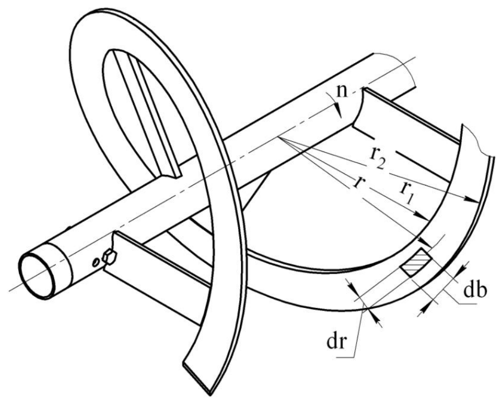

Fig. 4. A design scheme for determining the resistance dF acting on the elementary section of the screw mixer

The elementary moment of resistance dM, N·m, is calculated as:

$$dM = dF \cdot r = \tau \cdot dS \cdot r. \tag{4}$$

If we assume that the angular velocity is constant: $d\upsilon = \omega \cdot dr$, $dx = dr$, equation (2) takes the following form:

$$\tau = \tau_0 + \eta \cdot \omega. \tag{5}$$

The moment of the belt resistance is calculated as:

$$M_b = \int_{r_1}^{r_2} \tau \cdot dS \cdot r = \int_{r_1}^{r_2} \tau \cdot r \cdot dr \cdot db_b = \frac{t \cdot b_b}{2} \cdot \left(r_2^2 - r_1^2\right), \tag{6}$$

where r_1 and r_2 are inner and outer radii of the mixer belt, respectively, m; b_b is an unfolded belt length, m.

The moment of resistance forces of the brackets is calculated as:

$$M_{br} = n_{к} \cdot \int_{r_s}^{r_1} \tau \cdot r \cdot dr \cdot db_{br} = n_{br} \cdot \frac{\tau \cdot b_{br}}{2} \cdot \left(r_1^2 - r_s^2\right), \tag{7}$$

where r_s is the shaft radius, m; b_{br} is the bracket width, m; n_{br} is the number of brackets.

The moment of resistance of the paddles is found as:

$$M_{bd} = n_{bd} \cdot \int_{r_1}^{r_2} \tau \cdot dS \cdot r = n_{bd} \cdot \frac{\tau \cdot b_{bd}}{2} \cdot \left(r_2^2 - r_1^2\right), \tag{8}$$

where b_{bd} is the paddle width, m; n_{bd} is the number of paddles.

The full time M, N m, of all elementary resistance forces is calculated as:

$$M = \frac{t \cdot b_b}{2} \cdot \left(r_2^2 - r_1^2\right) + n_{br} \cdot \frac{\tau \cdot b_{br}}{2} \cdot \left(r_1^2 - r_s^2\right) + n_{bd} \cdot \frac{\tau \cdot b_{bd}}{2} \cdot \left(r_2^2 - r_1^2\right). \tag{9}$$

Power P, W, that is spent on mixing mortar in a belt-paddle mixer with a helix angle of α, deg., is found as follows:

$$\begin{aligned} P &= M \cdot \omega = \frac{M \cdot \pi \cdot n}{30} = \\ &= \frac{\pi \cdot n}{30} \cdot \left[\frac{\tau \cdot b_b}{2} \cdot \left(r_2^2 - r_1^2\right) + n_{br} \cdot \frac{\tau \cdot b_{br}}{2} \cdot \left(r_1^2 - r_{в}^2\right) + \right. \\ &\left. + n_{bd} \cdot \frac{\tau \cdot b_{bd}}{2} \cdot \left(r_2^2 - r_1^2\right) \right] \cdot \cos\alpha, \end{aligned} \tag{10}$$

where ω is the angular velocity of the shaft rotation, rad/s; n is the frequency of the shaft rotation, rev/min; α is a helix angle of the mixer, deg.

In formula (10) that is proposed to determine the net power of the forced cyclic mortar mixing equipment with a screw mixer, all the values are calculated by the geometry of the working body and the angular velocity.

After stirring, the mortar must be pumped into the traffic artery. The power consumed by the mortar pump is found as follows:

$$P = p\left(\frac{\pi d^2}{4} \cdot r\right) \cdot \frac{n}{60} \cdot \frac{1}{\eta}, \tag{11}$$

where p is the pressure; d is the piston diameter; r is the stroke; n is the crank velocity; η is the efficiency.

The total inlet pressure is calculated as:

$$p = p_h + p_n = \rho g\left(l_1 \sin\alpha_1 + l_2 \sin\alpha_2\right) + 8\tau\left(\frac{l_1}{2d_1} + \frac{l_2}{2d_2}\right). \tag{12}$$

This pressure is substituted in the power formula:

$$P = p\left(\frac{\pi d^2}{4} \cdot r \cdot \frac{n}{60}\right) \frac{1}{\eta_{eff}}, \tag{13}$$

where n is the stroke; d is the piston diameter.

The specific energy consumed during mortar pumping is:

$$E_{pump} = \frac{P \cdot t_n}{\rho \cdot V}, \tag{14}$$

where t_n is the time of pumping that is calculated on the basis of the known volume of the mixing hopper and the pump efficiency.

The general formula takes the following form:

$$\begin{aligned} E_{pump} &= \left(\rho g\left(l_1 \sin\alpha_1 + l_2 \sin\alpha_2\right) + 8\tau\left(\frac{l_1}{2d_1} + \frac{l_2}{2d_2}\right)\right) \times \\ &\times \left(\frac{\pi d^2}{4} \cdot r \cdot \frac{n}{60}\right) \frac{1}{\eta_{eff}} \cdot \frac{t_n}{\rho \cdot V}. \end{aligned} \tag{15}$$

The graphical dependence of equation (15) is shown in Fig. 5.

It is necessary to take into account energy losses during mortar piping.

Longitudinal energy losses are calculated as follows:

$$E_h = \rho \cdot g \cdot V \cdot l, \tag{16}$$

where ρ is the mortar density, kg/m^3; g is the acceleration of free fall, m/s^2; V is the volume of the transported mortar, m^3; l is the length of the highway section, m.

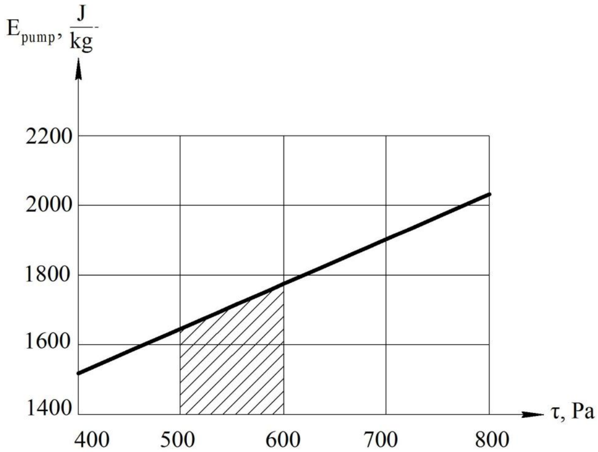

Fig. 5. The dependence of the specific energy of mortar pumping E_{pump} on the value τ of the critical shear stress of the ready mix

The energy consumption depends on the mortar rheology and the pipe material properties:

$$E_{\tau,\eta,n} = \left(\frac{4\cdot\tau}{d_0} + \frac{2\cdot\eta\cdot n}{r_0^2}\right)\cdot V\cdot l, \tag{17}$$

where τ is the critical shear stress of the mixture, Pa; d_0 is the pipeline diameter, m; η is the coefficient of the structured viscosity, Pa s; n is the roughness of the pipeline material; r_0 is the pipeline radius, m.

If there is more than one section V_i with a length of l_i, the total energy losses are calculated as:

$$E_o = \sum_{i=1}^{K}\left(\rho\cdot g + \frac{4\cdot\tau}{d_0} + \frac{2\cdot\eta\cdot n}{r_0^2}\right)\cdot V_i\cdot l_i, \tag{18}$$

$$V_i = \frac{\pi\cdot d_0^2}{4}\cdot l_i. \tag{19}$$

At the construction site, the penstock consists of two different parts of the pipeline:

(1) horizontal, where the losses result from the mortar characteristics τ and the pipes' characteristics: d is diameter, l is length, and n is the roughness. If the pipeline is plastic, n is 4, rubber-and-canvas – 8, and steel – 11;

(2) vertical, where losses are added because of the gravity.

For the horizontal section (i=1, 2, 3 – plastic, rubber-and-canvas and steel pipelines, respectively)

$$E_h = \sum_{i=1}^{3}\left(\frac{4\cdot\tau}{d} + \frac{2\cdot\eta\cdot n_i}{r^2}\right)\cdot\left(\frac{\pi\cdot d^2}{4}\cdot l_{hi}\right)\cdot l_{hi}. \tag{20}$$

For the vertical section:

$$E_v = \sum_{i=1}^{3}\left(\frac{4\cdot\tau}{d} + \frac{2\cdot\eta\cdot n_i}{r^2}\right)\cdot\frac{\pi\cdot d^2}{4}\cdot l_{hi}^2 + \sum_{i=1}^{3}\rho\cdot g\cdot\frac{\pi\cdot d^2}{8}\cdot l_{hi}^2. \tag{21}$$

The initial data for the plastic pipeline are as follows:

$\alpha_1 = 30°$; $l_1 = 4$ m; $d_1 = 0.08$ m; $\rho = 2000$;

$\tau = 600$ Pa; $\eta = 40$ Pa·s; $n_1 = 4$.

The initial data for the rubber-and-canvas pipeline are:

$\alpha_2 = 45°$; $l_2 = 6$ m; $d_2 = 0.06$ m; $\rho = 2000$;

$\tau = 600$ Pa; $\eta = 40$ Pa·s; $n_2 = 8$;

$\rho = 2000$ kg/m^3; $V = 3.2$ m^3,

where n_1, n_2 are characteristics of the pipeline material.

A graphical representation of the specific energy consumption during pumping is shown in Fig. 6.

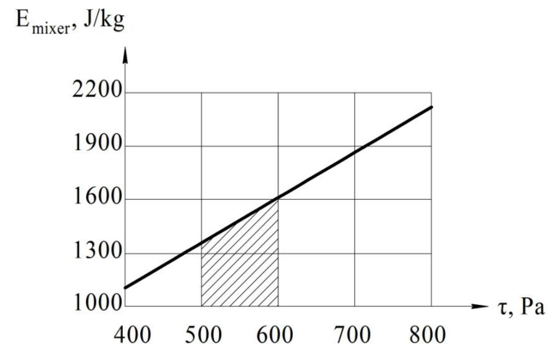

Fig. 6. The dependence of specific energy of mortar pumping E_{mixer} on τ of the critical shear stress of the ready mix

The research findings show that the growing value of the critical shear stress of the ready mix results in higher power inputs, and the process of mixing involves a higher rate of growth than the process of supply.

6. Discussion of the research findings on energy consumption of the hydraulic equipment set for finishing works

The dependence presented in Fig. 5 shows that the higher value of the critical shear stress of the ready mix (which corresponds to a thicker mixture), the higher the specific energy of pumping mortar. A range of practical values of the critical shear stress is between 500 and 600 Pa, thus, the value of the consumed specific energy amounts to 1650–1750 J kg or 3.3–3.5 MJ/m^3 of the mortar.

The graph in Fig. 6 shows that the higher value of the critical shear stress of the ready mix (which corresponds to a thicker mixture), the higher the specific energy of mortar pumping. A range of practical values of the shear stress is between 500 and 600 Pa, thus, the value of the consumed specific energy amounts to 1400–1600 J/kg or 2.8–3.2 MJ/m^3 of the mix.

The general principle of calculating the specific energy consumption is shown in Fig. 7.

The principle of calculating the specific energy consumption consists in its account at each stage of the mortar passage from loading into the mixer to application on the surface, namely: mixing, creating the supply pressure, pipeline transportation, and an injector application.

The proposed method allows calculating and predicting the energy performance of the selected components of the equipment set to enhance the efficiency of finishing works.

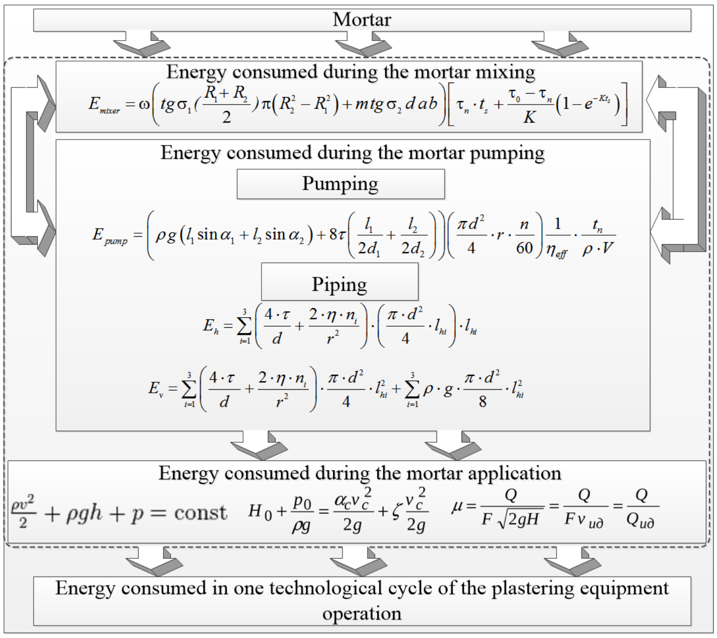

Fig. 7. A scheme of calculating the specific energy consumption of the equipment set

7. Conclusions

1. The use of the selected components of the technological equipment set, namely, a hydraulic plaster station equipped with a belt-paddle mixer and a hydraulic mortar pump in construction operations that are related to the use of mortars allows organizing a sustainable and energy efficient mechanized process of applying the latter on the workpiece surface. This choice of components also helps reduce the energy and material capacity of the equipment by using a single power and oil pump unit for driving all the major working bodies (rotary mixing hopper and mortar pump) of the hydraulic plaster station.

2. The suggested method allows to study the value of the specific energy consumption of the equipment set that (in the considered case) is in the range of 1700–1900 J/kg at the value of the critical shear stress of the ready mix varying between 500 and 600 Pa (which is the range of the most commonly used mortars). This allows selecting an appropriate power of the powerplant.

3. The study of the dependence of energy consumption during mortar piping on the geometric characteristics of the pipeline and rheological characteristics of the mixture allows predicting the energy consumption based on the configuration of the penstock and mixture that is planned for use. These data allow providing rational energy consumption during operation of a plaster station as part of the technological equipment set and finding ways to reduce the value of energy consumption for on-site construction work processes, in particular, at the stage of construction arrangement.

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AN ALGORITHM OF REGULATING AN ENERGY-EFFICIENT HOT WATER SYSTEM WITH THE OBJECT MODEL IN THE CONTROLLER

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Наведені результати розробки аналітичної моделі контуру гарячого водопостачання з котлом, сонячним колектором та баком-акумулятором тепла. Розглянуто варіанти структур та алгоритмів автоматичних регуляторів температури гарячої води на подачі до користувача. Описано процедуру налаштування регулятора з внутрішньою моделлю за допомогою отриманої аналітичної моделі. Показано умови ефективного застосування запропонованого рішення

Ключові слова: система гарячого водопостачання, алгоритм керування, регулятор з внутрішньою моделлю, енергоефективність

Приведены результаты разработки аналитической модели контура горячего водоснабжения с котлом, солнечным коллектором и баком-аккумулятором тепла. Рассмотрены варианты структур и алгоритмов автоматических регуляторов температуры горячей воды на подаче к потребителю. Описана процедура настройки регулятора с внутренней моделью с помощью полученной аналитической модели. Показаны условия эффективного применения предлагаемого решения

Ключевые слова: система горячего водоснабжения, алгоритм управления, регулятор с внутренней моделью, энергоэффективность

1. Introduction

Energy conservation is a priority of the state policy. Economic growth in Ukraine largely depends on the rate of power supply, the potential of energy efficiency and its use in industry. The main requirements of energy conservation in Ukraine are set out in the Comprehensive state program “Energy conservation in Ukraine of 2005–2020” [1–3].

Ukraine increases energy efficiency and provides comprehensive industry development by taking measures aimed at technical upgrading of production, the use of scientific and technological potential of the country, and high-tech manufacturing.

An extensive use of automated engineering equipment helps save energy sources, improve the quality and increase reliability of production, which can be more efficient if we integrate automation means in network structures.

By 2020, according to the International Energy Agency (IEA), up to 75 % of heating units in developed countries will be based on energy-saving technologies [4].

In modern conditions of insufficient fuel resources and problematic heat production, it is important to create an alternative system of autonomous heating and hot water supply through innovations in energy efficiency. Therefore, there is a need to develop a special methodological and methodical apparatus. New conditions of fair competition in the sector are likely to improve the quality of services and lower the tariffs [5].

2. Analysis of the previous studies and formulation of the problem

Improving the energy efficiency of units that use renewable energy sources is quite an urgent problem to be solved in different ways that upgrade the technical and economic characteristics of the power equipment and optimize its energy balances and modes depending on a variable load and the power of a renewable source. Ways to solve these problems are sought in many countries, such as China, Japan, France, and the Philippines [6], and include, in particular, the creation of new materials and technologies, the integration of alternative sources in systems of existing power plants, and algorithms to optimize the interaction of multiple sources.

Heating supply units based on alternative energy sources have prospects in terms of saving fuel resources [7]. Involvement of automation in this type of systems allows subsequent increase in the lifetime of units and quite a precise control of heat and fuel efficiency.

According to the International Energy Agency (IEA) [8], given the urgent environmental issues and the existing need of energy conservation, more attention is paid to the use of renewable energy worldwide. The ABB company (Switzerland) has studied and considered possible areas of the application of renewable energy [9]. According to the statistics summary, it is proved that significant opportunities of power supply to buildings are offered by installation of solar collectors for hot water

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