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Study of factors affecting the energy consumption of the mixing plant for the preparation of aerated concrete

Abstract. The current stage of development of the construction industry is characterized by increased requirements for the energy efficiency of technological processes and the quality of building materials. The preparation of aerated concrete is a complex technological process and its efficiency is largely determined by the mixer's operating parameters. One of the key indicators that affects both the quality of the finished mixture and the cost-effectiveness of the process is the energy consumption of the mixing plant. The article presents the results of a study of the influence of the main technological and design parameters on the energy consumption of the mixing plant for preparing aerated concrete. The purpose of these measurements was to determine the patterns of changes in the mixer's electricity consumption depending on the frequency of rotation of the working body, the duration of mixing and the mobility of the concrete mixture. To achieve this goal, mathematical planning methods were used, namely a three-factor experiment of the second order, thanks to which a mathematical model of the electricity consumption of the plant for preparing aerated concrete was obtained in the form of a regression equation. The developed model allows us to estimate the magnitude of the individual impact of each factor on energy consumption and determine their optimal range. Based on the data, graphical dependencies were constructed that reflect the change in the energy consumption of the plant. The results of the study show that the decisive influence on the energy efficiency of the process is the frequency of rotation of the working body and the fluidity of the mixture, while the rational duration of mixing is about 40 seconds. The study creates the prerequisites for optimizing the energy consumption of mixing equipment and improving the quality of the preparation of aerated concrete in mobile forced-action plants.

Keywords: mixing, forced action concrete mixer, drive power, mathematical analysis, energy efficiency.

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Introduction.

The modern stage of development of the construction industry is characterized by increased requirements for energy efficiency of technological processes and quality of building materials. The process of preparing aerated concrete belongs to energy-intensive technological operations and its efficiency is largely determined by the design of the mixing equipment and its operating parameters. An important component of these installations is the working body, which ensures intensive mixing of the components, affecting the degree of homogeneity of the mixture, the stability of its structure and the overall quality of the final material.

Special attention in modern research is paid to mobile forced action installations, which ensure compactness, versatility and high energy efficiency. Inconsistency of drive power with actual technological needs can lead to excessive energy losses or, conversely, to deterioration of the mixing quality due to insufficient intensity of action [1, 2].

The study of patterns of changes in energy consumption in the process of preparing aerated concrete depending on the main technological parameters, such as the frequency of rotation of the working body, mixing time, mobility of the mixture, is of particular scientific and practical importance. The establishment of these interconnections makes it possible to justify rational modes of operation of the mixer, reduce energy consumption and ensure high quality of the finished product [3].

Thus, the relevance of the study is due to the need to increase the energy efficiency of mobile forced-action mixers through analytical and experimental study of the factors that determine the power of the drive and the general energy characteristics of the process of mixing aerated concrete.

Review of Research Resources and Publications

At the current stage of technology development in the field of production of dry construction mixtures, one of the most urgent tasks is the creation of highly efficient mixers of improved design. The main requirements for such installations are a reduction in energy consumption while simultaneously expanding the range of products obtained and ensuring high quality mixing [4, 5].

A review of scientific and technical sources indicates the increased attention of researchers to the problem of reducing energy consumption in the processes of preparing concrete and soluble mixtures, in particular aerated concrete. In most modern works, it is emphasized that the energy consumption of mixing plants largely depends on the design parameters of the working body, the physical and mechanical properties of the mixture and the kinematic modes of its mixing [3,6,7].

Particular attention is paid to mixers with a vertical shaft arrangement, in which intensive interaction of the working elements with the material is ensured by creating zones of reduced resistance to the movement of particles. In such zones, the effect of fluidization of the powder mass occurs, which contributes to the activation of the mixing process. Due to this, increased homogeneity of multicomponent mixtures is achieved, in particular those with a complex formulation or low fluidity [8, 9].

Special attention is paid to the improvement of methods for assessing the energy efficiency of mixers [5, 6, 10]. The proposed approaches are based on a combination of experimental measurements of power consumption with analytical modeling of the force interaction between the working bodies and the particles of the mixture. This approach allows you to form generalized dependencies describing the influence of design and technological parameters on electricity consumption.

Definition of unsolved aspects of the problem

The preparation of aerated concrete is a complex technological process and its efficiency is largely determined by the parameters of the mixer. One of the key indicators affecting both the quality of the finished mixture and the economy of the process is the energy consumption of the mixing plant.

Special attention needs to be paid to the analysis of the relationship between the design parameters of the mixer's working bodies (shape, dimensions, and location of the blades) and electricity consumption during installation operation.

The study of patterns of changes in energy consumption depending on the characteristics of the mixture will allow to determine the optimal modes of operation of the mixer, which ensure minimal energy consumption while maintaining high quality of the final product.

This article deals with the issue of analyzing the parameters that affect the energy consumption of the mixing plant. The interrelationship of mixture flow, working organ rotation frequency and mixing time will help to understand better the process of preparing aerated concrete and to develop optimal conditions for achieving high quality concrete products.

Problem statement

The purpose of this article is to highlight the results of a study of the change in energy consumption of a unit for preparing aerated concrete depending on the influence of factors such as: the frequency of rotation of the working body, mixing time and mobility of the mixture, in order to increase the efficiency of the process and improve the quality of the finished material.

Basic material and results

The working process in forced action mixers is based on intensive mixing of the components of the mixture due to the rotational movement of the blades around the vertical shaft.

Based on theoretical research and design developments, a plant for preparing aerated concrete with a vertically positioned shaft was created, which is presented in Fig. 1. The main feature of the created plant is its ability to easily change the working elements and the speed of rotation of the mixer blades.

In order to carry out a comprehensive analysis of the energy consumption of a mobile concrete mixer of forced action, designed for the preparation of components during the production of aerated concrete, it is necessary to take into account the design features of the working body and the conditions of its interaction with the material being mixed. The principle of operation of such a mixer is based on the rotation of the blades fixed on the vertical drive shaft in the lower part of the mixing chamber. During rotation, the blades exert an intense mechanical effect on the mixture, ensuring uniform distribution of components throughout the volume of the working area.

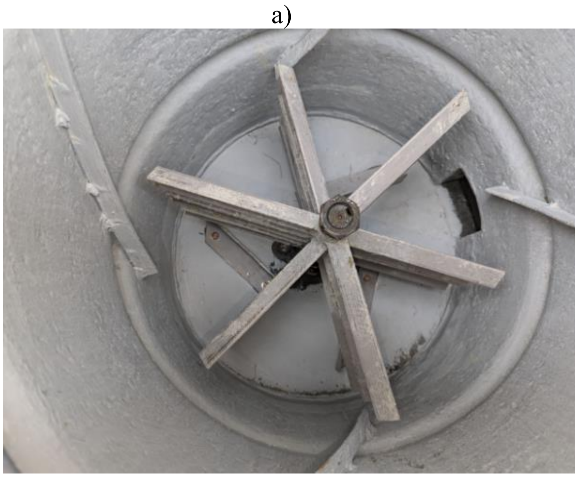
Figure 1 – Installations for the preparation of aerated concrete

In order to study the energy consumption of the installation for the preparation of aerated concrete, experimental measurements of energy consumption were carried out when mixing the mixture in a working container (Fig. 2).

At the same time, the amount of energy consumption is determined by the conditions of interaction of the blades with the stirred medium.

In order to obtain a reliable mathematical model of the effect of the working body on the material during experimental research, the methods of mathematical planning and mathematical statistics are applied [11, 12].

a)



b)

Figure 2 – Mixing container with working body
a) – the working body of the mixing plant
b) – mixing container (bunker)

In order to find the degree of influence of the mobility of the mixture *П*, the mixing time of the mixture *t* and the rotation frequency of the vertical drive shaft *n* on the energy consumption of the experimental equipment, the goal was to find the functional dependence of the influence of the above parameters on the electricity consumption *P* of the investigated installation for the preparation of aerated concrete.

$$P = f\left(t, n, \Pi \right). \quad (1)$$

Measurements of electricity consumption were made in the ranges of change of the output factors described above, the numerical values of which are given in table 1.

To perform the experiment, based on the results of previous studies, a three-factor experiment of the second order was chosen. This approach makes it possible to develop an adequate mathematical model of the concrete mix preparation process, reflecting the relationship between the main input parameters — exposure time, rotation frequency and mixture mobility — and the energy expenditure of the plant. The experiment planning matrix and the obtained measurement results are shown in table 2.

Figure 3 shows the placement of pulleys on the engine and working body, which varied in the diameter range of 90 mm., 145 mm., 290 mm.

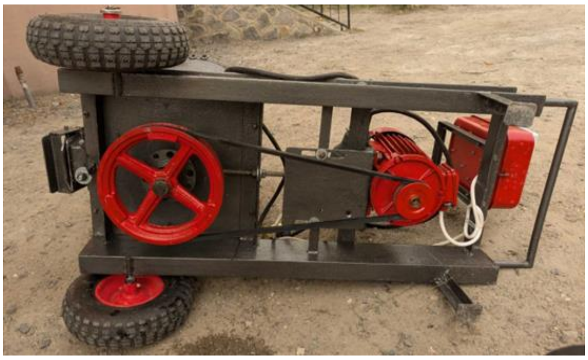


Figure 3 – Placement of pulleys on the engine and working body

The implementation of the experiment and the processing of the obtained data make it possible to obtain a mathematical model of the electricity consumption of the installation for the preparation of aerated concrete in the form of a regression equation:

$$y_i = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{11} x_1^2 + b_{22} x_2^2 + b_{33} x_3^2 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 \quad (2)$$

where *y* – is the consumption of electricity;
b_0, b_1, b_2, b_3 – coefficients of the regression equation.

Table 1 - Ranges of change in output factors

№	Name	Dimensionality	Designation	Upper level (+)	The main level (0)	Lower level (-)	ariation interval
X_1	Exposure time	s	*t*	50	40	30	10
X_2	Rotation frequency	rpm	*n*	620	465	310	155
X_3	Mixture mobility	cm	П	12	10	8	2

Table 2 − Implementation of the experimental plan

№ experiment		Planning matrix (x_i)			Squares parameters (x_i^2)			Interaction (x_ix_j)			Electricity consumption, W
		x_1	x_2	x_3	x_1^2	x_2^2	x_3^2	x_1x_2	x_1x_3	x_2x_3	y_i
N_1	1	+	+	+	+	+	+	+	+	+	70
	2	—	+	+	+	+	+	—	—	+	56
	3	+	—	+	+	+	+	—	+	—	64
	4	—	—	+	+	+	+	+	—	—	42
	5	+	+	—	+	+	+	+	—	—	78
	6	—	+	—	+	+	+	—	+	—	64
	7	+	—	—	+	+	+	—	—	+	61
	8	—	—	—	+	+	+	+	+	+	54
N_α	9	+	0	0	+	0	0	0	0	0	65
	10	—	0	0	+	0	0	0	0	0	55
	11	0	+	0	0	+	0	0	0	0	59
	12	0	—	0	0	+	0	0	0	0	57
	13	0	0	+	0	0	+	0	0	0	50
	14	0	0	—	0	0	+	0	0	0	58
n_0	15	0	0	0	0	0	0	0	0	0	55
	16	0	0	0	0	0	0	0	0	0	56
	17	0	0	0	0	0	0	0	0	0	54

The calculated values of the regression coefficients were tested for significance using the Student's test and found to be all significant.

Therefore, the sought regression equation has the form:

$$y_i = 55.239 + 6.7x_1 + 4.9x_2 - 3.3x_3 + 4.606x_1^2 + \\ +2.6.6x_2^2 - 1.394x_3^2 - 0.125x_1x_2 + \\ +1.875x_1x_3 - 0.875x_2x_3 \quad (3)$$

The obtained equation establishes the dependence of electricity consumption on the values of the determined factors.

This equation was tested for adequacy according to Fisher's criterion:

$$F_p \le F_{ma6}, \\ 16,64 \le 19,3. \quad (4)$$

It was established that the difference between the corresponding values of the experimental data and those calculated according to the regression equation does not exceed the permissible limits, and the regression equation reflects the real work process of the working body with sufficient accuracy.

Using special software, graphs were constructed showing the influence of three main factors – exposure time, mixture mobility and rotation frequency on electricity consumption.

Graphs of the dependence of the amount of electricity consumption of the mixer at a fixed one parameter and variable by two others in the defined ranges are shown in Fig. 4 – 6.

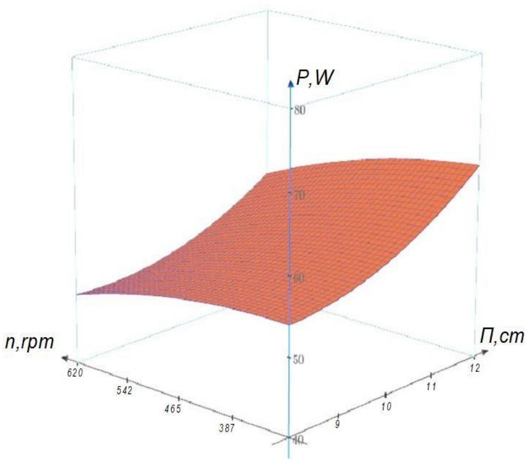


Figure 4 – Graph of the dependence of the electricity consumption *P* of the mixer at a fixed exposure time *t* in the range of rotation frequency n = 310...620 rpm and mobility of the mixture П = 8...12 cm

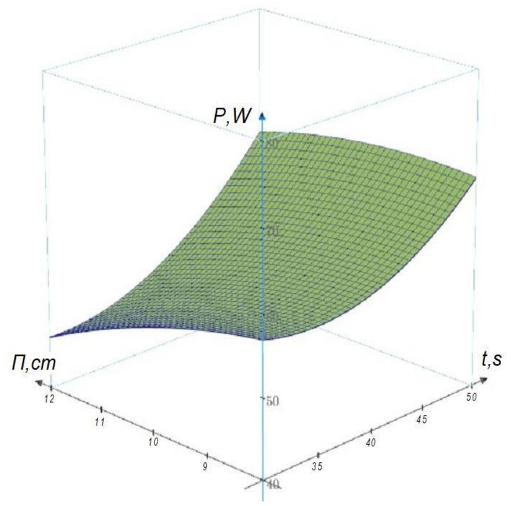


Figure 5 – Graph of the dependence of the electricity consumption *P* of the mixer at a fixed rotation frequency *n* in the range of mobility of the mixture П = 8...12 cm and the exposure time t = 30...50 s.

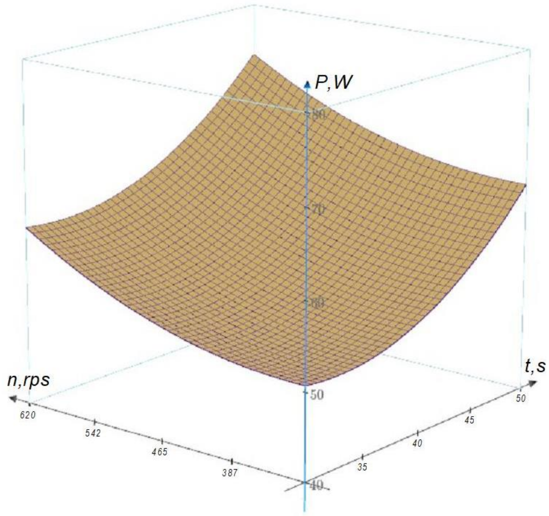


Figure 6 – Graph of the dependence of the electricity consumption *P* of the mixer at a fixed mobility of the mixture *П* in the range of rotation frequency n = 310...620 rpm and exposure time t = 30...50 s

The given graphs (Fig. 4–6) make it possible to trace in detail the influence of the change of each of the studied factors on the amount of electricity consumption, which is important for the further optimization of this process in the conditions of real production.

Conclusions

As a result of the conducted research, a mathematical relationship was established that describes the change in electricity consumption *P* of the mixer for the preparation of aerated concrete depending on the main influential factors — of the frequency of rotation of the working body, mixing time and mobility of the mixture.

The analysis of the dependence graphs showed that the key factors affecting the consumption of electricity in the process of mixing the mixture are the mobility *П* and the rotation frequency *n* of the working body.

There is a direct proportional relationship between the duration of mixing and electricity consumption. The optimal duration of mixing of aerated concrete is 40 s, which ensures the maximum quality of the mixture, the mobility of the mixture also plays a decisive role, its optimal value is 12 cm.

This study can be used to increase the efficiency of the process and improve the quality of the finished material in the preparation of aerated concrete

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Дослідження факторів, що впливають на енерговитрати установки для приготування ніздрюватих бетонів

Аннотація. Сучасний етап розвитку будівельної галузі характеризується підвищеними вимогами до енергоефективності технологічних процесів та якості будівельних матеріалів. Приготування ніздрюватих бетонів є складним технологічним процесом, ефективність якого значною мірою визначається параметрами роботи змішувача. Одним із ключових показників, що впливає як на якість готової суміші так і на економічність процесу, є енергоспоживання змішувальної установки. У статті наведено результати дослідження впливу основних технологічних та конструктивних параметрів на енерговитрати установки для приготування ніздрюватих бетонів. Метою цих вимірів було визначення закономірностей зміни споживання електроенергії змішувача залежно від частоти обертання робочого органу, тривалості змішування та рухливості бетонної суміші. Для досягнення поставленої мети було використано методи математичного планування, а саме трифакторний експеримент другого порядку, завдяки якому було отримано математичну модель витрати електроенергії установки для приготування ніздрюватих бетонів у вигляді рівняння регресії. Розроблена модель дозволяє оцінити величину індивідуального впливу кожного фактору на енерговитрати та визначити їх оптимальний діапазон. На основі даних побудовано графічні залежності, які відображають зміну енергоспоживання установки. Результати дослідження показують, що вирішальний вплив на енергоефективність процесу має частота обертання робочого органу та текучість суміші, тоді як раціональна тривалість перемішування становить близько 40 секунд. Проведене дослідження створює передумови для оптимізації енергоспоживання змішувального обладнання та підвищення якості приготування ніздрюватих бетонів у мобільних установках примусової дії.

Ключові слова: змішування, бетонозмішувач примусової дії, потужність приводу, математичний аналіз, енергоефективність.

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