RESEARCH ON THE IMPACT OF THE OPERATING MODES AND MAIN DESIGN PARAMETERS ON THE EFFICIENCY OF THE MACHINE FOR PREPARING AND PACKING SLAKED LIME

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ДОСЛІДЖЕННЯ ВПЛИВУ РЕЖИМІВ РОБОТИ ТА ОСНОВНИХ КОНСТРУКТИВНИХ ПАРАМЕТРІВ НА ПРОДУКТИВНІСТЬ МАШИНИ ДЛЯ ПІДГОТОВКИ І РОЗФАСУВАННЯ ГАШЕНОГО ВАПНА

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ABSTRACT

Slaked lime finds wide application in agriculture. For convenient use lime is often packed in plastic bags. The common equipment for these purposes has a number of disadvantages. The article presents the design of an experimental machine for packing slaked lime in polyethylene containers, which ensures high efficiency and has a wide range and accuracy of packing by weight. As a result of experiments, regression dependence was obtained and an assessment was made of the rotational frequency impact of the machine working body, depending on the design parameters of the mechanism. It has been established that the dominant factor affecting the efficiency value is the rotation frequency of the working body n and the lowest factor of impact is the machine outlet pipe diameter.

АНОТАЦІЯ

Гашене вапно має широке застосування у сільському господарстві. Для зручного транспортування та застосування часто використовуються упаковки вапна в поліетиленових мішках. Поширене існуюче обладнання цих цілей має ряд недоліків. В статті представлена нова конструкція експериментальної машини для розфасовки гашеного вапна в поліетиленову тару, що забезпечує високу продуктивність і має великий діапазон та точність розфасовки за вагою. В результаті експериментів отримано регресійна залежність та проведена оцінка впливу частоти обертання робочого органу машини для фасування гашеного вапна в поліетиленову тару, в залежності від конструктивних параметрів механізму. Встановлено, що домінуючим фактором, що впливає на величину продуктивності, є частота обертання робочого органу, а найменш впливовим є діаметр вихідного патрубка машини.

INTRODUCTION

Slaked lime (*calcium hydroxide*- ($Ca(OH)_2$) is widely used in agricultural production as a raw material for the preparation of safe fertilisers that reduce its acidity, ensuring efficient and safe control of various pests and fungal plant diseases, insects and small rodents, as well as for other purposes *(Horn et al., 2021; Frank et al., 2019; Conesa et al., 2012; Scanlan et al., 2017; Kolesnikov, 1999).*

In the production of slaked lime (the technological process of its quenching) efficient methods of mechanisation have been studied and worked out. However, the operations of batch dosing and packing of slaked lime in polyethylene containers of a preset capacity and weight still require significant improvement and optimization of parameters.

A number of modern investigations have been devoted to the subject of preparing and applying lime in agricultural production *(Stark and Wicht, 1999; Koshy, 2002; Qates, 2008).*

However, the analysis of modern technologies' state, literature and patent examination of the designs of the machines and mechanisms for transporting viscous materials showed that they, to a greater or lesser extent, satisfy a significant part of the requirements for them. However, most designs of the working bodies of conveyors perform not only forward axial movement of the material but also rotational movement, which leads to decreased efficiency of such mechanisms (*Podevyn, 2008; Hevko et al., 2016; Hevko et al., 2014).* When packing slaked lime in polyethylene containers, it is necessary to take into account to a considerable extent its physical and mechanical properties.

For instance, using a screw mixer with a closed mixing cycle does not make it possible to obtain sufficient mixing quality; it also has limited technological capabilities and low labour productivity *(Hevko, 2008).* Application of a carousel-type machine for packing liquid and viscous products in containers creates high energy costs and metal consumption due to the rotary layout of this device. In addition, a disadvantage of such a device is the sequence of dosing operations in time, which limits the possibility of raising its efficiency productivity.

Therefore, it is an urgent task to create such a design of a machine for packing slaked lime in polyethylene containers which would allow mixing the entire volume of the material, and would have a large range and accuracy of packing by weight, ensuring high labour efficiency.

For this purpose, we have developed an experimental design of a machine for packing slaked lime in polyethylene containers, containing of an auger shaft, made of two parts, with a left and a right winding, which allows keeping the lime mass in the desired consistency of an appropriate density, and moving to it the lime mass from the central part of the container *(Klendii et al., 2019).*

The purpose of the research is to determine the impact on the machine efficiency of the working body rotation frequency, the diameter of the machine outlet pipe and the width of the screw working body belt.

MATERIALS AND METHODS

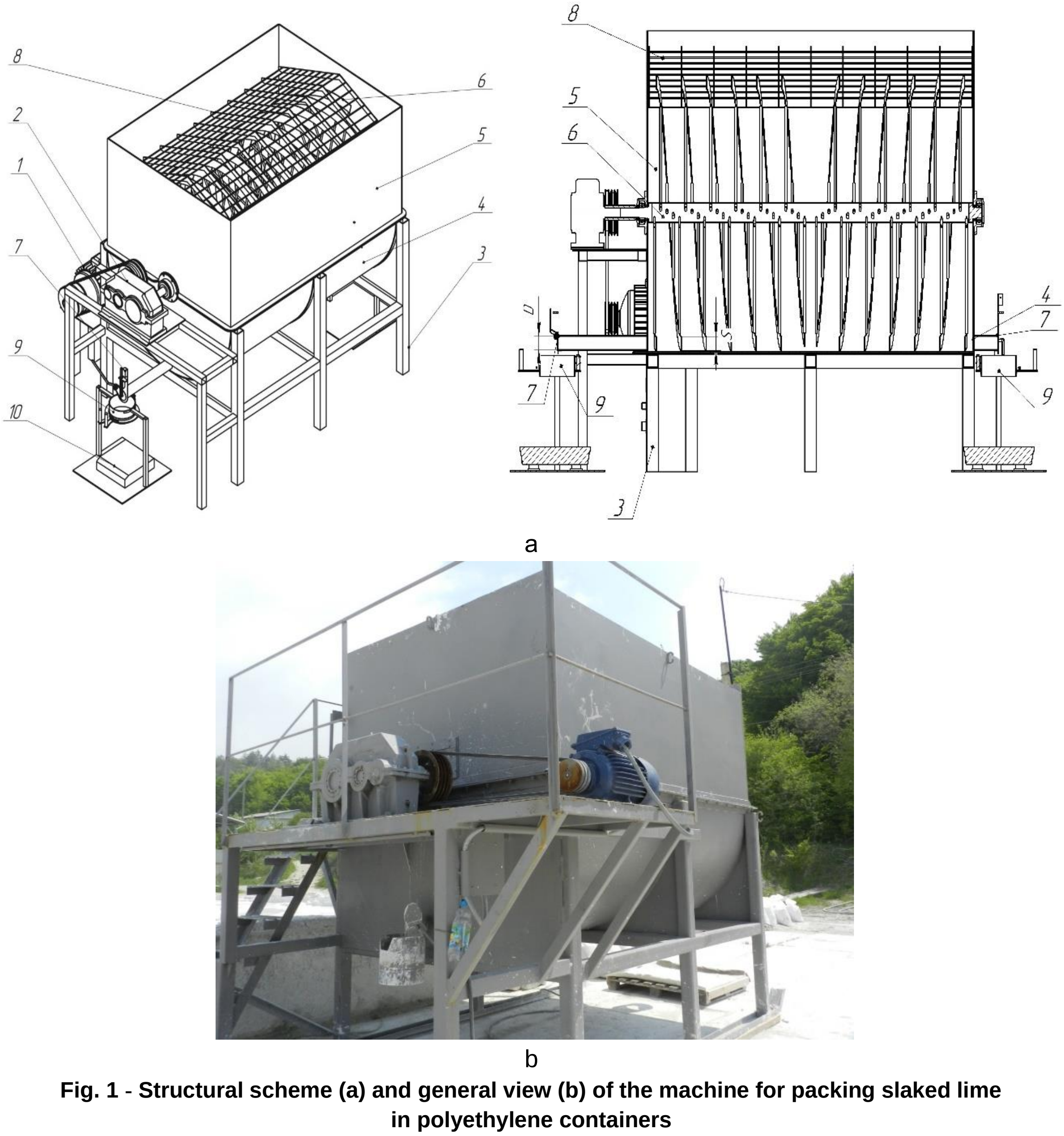
In the research, a new experimental machine was used for packing slaked lime in polyethylene containers (Fig. 1).

It consists of the electric motor *1* and a gearbox (reducer) *2*, a welded frame structure *3*, on which a container is installed in the form of a semi-cylinder *4* (the lower body) to the upper open part of which a rectangular box *5* (the upper body) is fixed, through which lime is loaded. An auger shaft *6* is installed on the axis of the semi-cylinder, which is made of two parts with a left and a right winding, which allows keeping the lime mass in the desired consistency of the appropriate density and moving the lime mass from the central part of the tank to its ends. At the lower points of these ends, there are holes with sleeves for feeding the lime in the container. For dosage of the lime mass the end of the hole is equipped with a locking mechanism *7*. From above, the auger shaft is protected by a grid *8*, to prevent stones or other solid particles from getting inside. The polyethylene container is fixed in the clamping mechanism *9*. The locking mechanism *7* is actuated by a command from the technical weight sensor *10*, set to a certain mass of the lime mixture. The auger shaft *6* is driven by the electric motor *1* through a belt drive and a gearbox *2* (*Hevko R.B., 2008*).

Fig.1b shows a general view of the machine for packing slaked lime in polyethylene containers. We carried out experimental studies on this machine to determine the magnitude of efficiency, the quality of mixing and transportation of the slaked lime.

To carry out packing of slaked lime in polyethylene bags of various capacities, an electric motor is first switched on, which is connected through a belt drive and a gearbox to the auger shaft, installed inside the cylindrical body. Lime is loaded through the open top of the container using an excavator or other loading device. The auger shaft is executed of two parts - with a left and a right winding; by rotating it mixes the lime mixture and does not allow the lime to settle and, at the same time, pushes it to the ends of the cylindrical body. At the ends of the body there are openings executed through which, along the sleeve, the lime passes in the polyethylene container. The openings are equipped with locking mechanisms that can automatically, completely or partially, block them for dosage or adjustment of the lime supply. The container (polyethylene bag) is installed on scales, and the mouth of the bag is fixed in the clamping mechanism. When the necessary filling of the plastic bag with lime is reached, the weight processor of the technical scale sends a signal to the solenoid of the locking mechanism to close the bag, that is, to stop the supply of the slaked lime. After this, the plastic bag is removed from the weighing platform and hermetically closed.

The lime supply to the container is regulated by means of locking mechanisms on the openings for the lime supply from the hopper into the container. Scales of the type TV1 perform weighing of the polyethylene bag, filled with lime, using an IP65 load cell; and then the signal from the IP40 weight processor is transmitted to the LED display for visualisation of the weighing results. Likewise, when the required weight of the bag with lime is reached, the signal passes from the relay output of the weight processor to the solenoid that retracts the rod of the blocking mechanism and unblocks the rod which, under the action of the spring, moves down, shutting off the supply of the lime from the sleeve to the bag. The value of the weight of the lime bag, required to operate the locking mechanism, is set using the buttons on the LED display.



a

b

Fig. 1 - **Structural scheme (a) and general view (b) of the machine for packing slaked lime in polyethylene containers**

1 - electric motor; 2 – gearbox (reducer); 3 - welded frame structure; 4 - lower body; 5 - upper body; 6 - auger shaft; 7 - locking mechanism; 8 - grid; 9 - clamping mechanism; 10 – technical weight sensor

To obtain a regression model of the optimization parameter, taken as a functional $Q = (x_1; x_2; ...; x_i)$, where Q is the efficiency from 1 to the *i*-th case; $x_1; x_2; ...; x_i$ are natural independent variable factors, we chose an appropriate conditional plan of a multifactor experiment, the implementation of which was executed in such a sequence.

The main variables that influenced the mixing and transport process were:

- the outlet pipe diameter of the machine D = 0.05 – 0.15 m (x_1);
- the frequency of rotation of the auger working body n = 9 – 27 rpm (x_2);
- the width of the auger working body belt S = 0.1 – 0.2 m (x_3).

The change in the diameter D of the machine outlet pipe and the width of the belt S of the auger working body was implemented by the design of the machine; the rotational speed n of the working body was changed using the Altivar 71 converter.

The results of the factor coding and the levels of their variation are presented in Table 1. After coding the input factors, the design matrices of a full-factor experiment of type 3^3 were compiled.

Table 1

Results of the factor coding and levels of their efficiency variation of the machine for packing slaked lime in polyethylene containers

Factors	Name		Interval variation	Levels of variation, Physical parameter / coded		
	Physical parameter	Code				
Diameter of the outlet pipe of the machine D, m	X_1	x_1	0.05	0.05/-1	0.1/0	0.15/+1
Frequency of rotation of the auger working body n, rpm	X_2	x_2	9	9/-1	18/0	27/+1
Width of the belt of the auger working body S, m	X_3	x_3	0.05	0.1/-1	0.15/0	0.2/+1

For the operation of the experimental equipment the Power Suite program was used to configure the frequency converters of the Altivar series, in which the selection of those characteristics that were necessary during the experiments according to the developed test procedure was made. In the process of testing they are displayed on the PC monitor in the form of tabular data and graphical dependencies as a percentage of the rated power with the preset frequency. Due to the Power Suite program, there were also selected the required rotation frequency of the motor shaft and the direction of its rotation. The rotation frequency was set on the PC oscilloscope window in the form of multiples.

The processing of experimental data, obtained after the implementation of the planned experiments, took place in the following order.

The response function (the optimization parameter) was taken as an approximating mathematical model of a full square polynomial, describing the real experimental process *(Peherstorfer and Willcox, 2016; Lekavicius et al., 2015)*:

$$Q = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 \quad (1)$$

where:

Q – the experimental value;

$b_0, b_1, b_2, b_3, b_{12}, b_{13}, b_{23}, b_{11}, b_{22}, b_{33}$ – regression coefficients of the corresponding values of the input factors x_i;

x_1, x_2, x_3 – the coded input factors.

The coefficients of the approximating polynomial, represented as a complete quadratic equation, under the condition of orthogonality and symmetry, were determined by the corresponding general formulas:

- the free term b_0 and coefficients b_i of the i-th factor:

$$b_i = \frac{\sum_{u=1}^{N} x_{iu}\bar{y}_u}{\sum_{u=1}^{N} x_{iu}^2} = \frac{\sum_{u=1}^{N} x_{iu}\bar{y}_u}{N} \quad (2)$$

- the interaction coefficients b_{ij}:

$$b_{ij} = \frac{\sum_{u=1}^{N} x_{iu}x_{ju}\bar{y}_u}{N}, \quad (3)$$

where:

x_{iu} - the value of the coded variable in the corresponding column of the plan of the experiment;

$\bar{y}_u$ – the average result of the u-th experiment; u – the serial number of the experiment;

i – the number of the factor; j, k – the number of the factor other than the i-th;

N – the number of the conducted experiments.

Checking the reproducibility of the obtained values of the experimental array with an identical number of repetitions for each experiment was carried out according to the Cochran criterion *(Conover, 1999; Fahmy and Bellétoile, 2017)*. After checking the adequacy of the distribution of random variables to the real process the statistical significance of the regression coefficients was assessed, using Student's criterion *(Guo and Yuan, 2017; Fau and Proschan, 2010).*

The general form of the regression equation for the efficiency of a machine for packing slaked lime in polyethylene containers, based on the results of the conducted full-factor experiments 3^3, is:

$$Q = 3642.5 - 51.45n + 4567S + 2.06n^2 + 1781D^2 \tag{4}$$

So the obtained regression dependence (4) of the performance of the filling machine in the form of a functional $Q = f(D; S; n)$ characterises the impact of single factors (diameter D of the machine outlet pipe, the belt width S of the auger working body and the rotation frequency of n of the working body), and their interaction upon the optimization parameter.

To obtain graphical dependencies, the Statistica-6.0 for the Windows software was used, by means of which a graphical reproduction of the regression models in the form of quadratic responses and their two-dimensional sections was built.

RESULTS

The graphical values of the dependence to determine the efficiency of the machine for packing the slaked lime in polyethylene containers are shown in Figs. 2-4, which present the response surfaces and their two-dimensional cross-section of the change in efficiency from the diameter of the machine outlet pipe D, the frequency of rotation of the working body n and the width of the belt S of the auger working body.

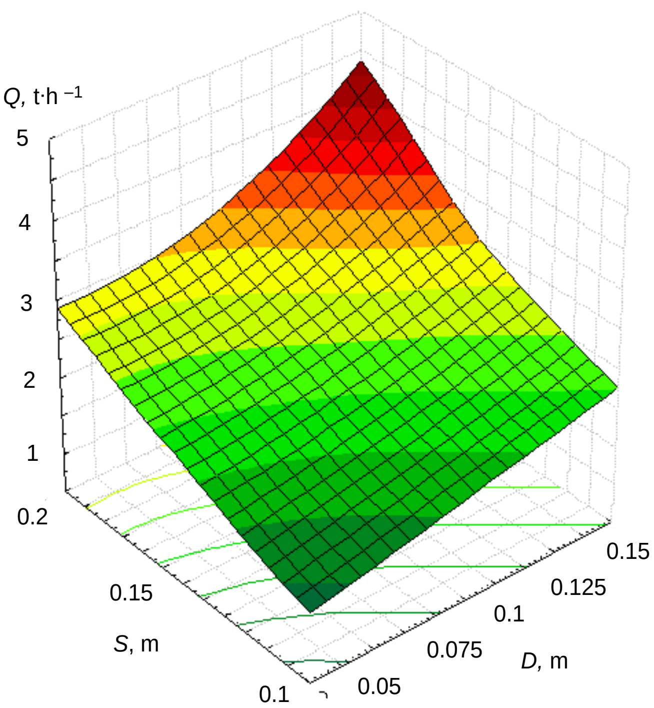


Fig. 2 - Response surface of the change in efficiency *Q* from the diameter of the machine outlet pipe *D* and the width *S* of the auger working body

From their analysis it can be established that the dominant factor affecting the efficiency value is the rotation frequency of the working body n, but the least affecting factor is the diameter D of the machine outlet pipe. However, the width of the belt S of the auger working body also has a significant impact on the efficiency of the transportation process of slaked lime.

When diameter D of the machine outlet pipe changes from 0.05 m to 0.15 m, the efficiency changes from 1.5 t/h to 2 t/h with the width of the auger working body belt S = 0.1 m and from 3 t/h to 4.5 t/h at a width equal to S = 0.2 m. When diameter D of the machine outlet pipe changes from 0.05 m to 0.15 m, the efficiency changes from 1.2 t/h to 3.5 t/h at the rotation frequency of the working body n = 9 rpm, and from 2.5 t/h to 3.7 t/h at n = 27 rpm. When the width of the auger working body belt S is changed from 0.1 m to 0.2 m, the efficiency changes from 1 t/h to 2.3 t/h at a rotation frequency of the working body n = 9 rpm and from 2 t/h to 4 t/h at n = 27 rpm.

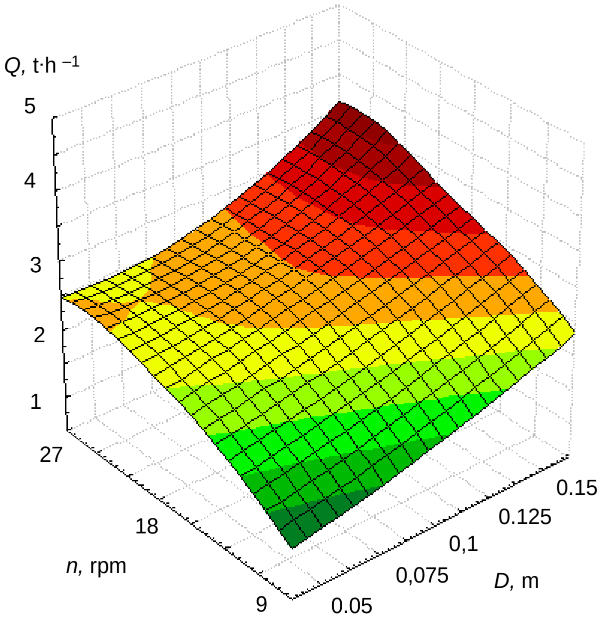


Fig. 3 - Response surface of the change in efficiency *Q* from the diameter *D* of the machine outlet pipe and the rotation frequency *n* of the auger working body

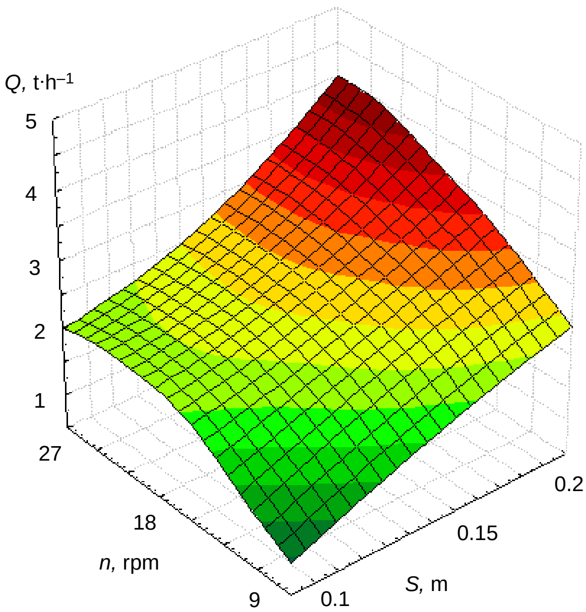


Fig. 4 - Response surface of the change in efficiency *Q* from the width of the belt of the auger working body *S*, and the rotation frequency of the auger working body *n*

So, when the width of belt *S* of the auger working body changes within 0.1 ... 0.2 m, the efficiency increases by 12%; when the rotation frequency of the auger working body changes within 9 ... 27 rpm, the productivity increases by 10%, and within the range of change of diameter *D* of the machine outlet pipe from 0.05 m to 0.15 m, the efficiency increases only by 0.9%.

CONCLUSIONS

On an experimental machine that ensures mixing of the entire volume of the material and which has a high labour efficiency, the process of continuous mixing, transportation and packing of slaked lime in plastic bags was studied. On the basis of full-factorial experiments, a regression dependence of efficiency on three optimization parameters was obtained.

An assessment of the impact of the operating modes and the design parameters on the characteristics of the process of mixing and transporting slaked lime was made. When the width of belt *S* of the auger working body changes within 0.1 ... 0.2 m, the efficiency increases by 12%; when the rotation frequency of the auger working body changes within 9 ... 27 rpm, the productivity increases by 10%, and within the range of change of diameter *D* of the machine outlet pipe from 0.05 m to 0.15 m, the efficiency increases only by 0.9%.

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