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[1]**Олексій Васильєв,**
кандидат технічних наук, доцент кафедри галузевого машинобудування та мехатроніки, https://orcid.org/0000-0002-9914-5482, e-mail: a.s.vasiliev.76@gmail.com

[2]**Андрій Яковенко,**
викладач, полтавський фаховий коледж нафти і газу, https://orcid.org/0000-0003-0818-6332, e-mail: andrii.yakovenko95@gmail.com

[1]**Андрій Число,**
аспірант кафедри галузевого машинобудування та мехатроніки, https://orcid.org/0009-0008-8604-9134, e-mail: a.chyslo@ford.pl.ua

[1]*National University «Yuri Kondratyuk Poltava Polytechnic»Vitaliia Hrytsaienka, 24 Poltava, 36011, Ukraine*
[2]*National University «Yuri Kondratyuk Poltava Polytechnic» Mykhailo Hrushevskoho, 2A Poltava, 36021, Ukraine*

ВИВЧЕННЯ ВПЛИВУ КОНСТРУКТИВНИХ ТА РЕЖИМНИХ ПАРАМЕТРІВ РОЗЧИНОНАСОСА НА ВЕЛИЧИНУ ОБ'ЄМНОГО ТА ЗАГАЛЬНОГО КОЕФІЦІЄНТА КОРИСНОЇ ДІЇ

АНОТАЦІЯ. *Зазначено, що ефективність роботи розчинонасосів традиційно оцінюється за значенням коефіцієнта корисної дії, який визначається сукупністю трьох складових: об'ємного, гідравлічного та механічного ККД. Величина загального ККД також впливає на ефективність використання потужності привода машини. В роботі представлені результати експериментальних досліджень по встановленню впливу конструктивних та режимних параметрів вертикального диференціального розчинонасосу з тарілчастими клапанами, при перекачуванні вапняно-піщаного розчину. Проаналізовано та виділено основні фактори впливу та їх інтервали зміни, до яких слід віднести: діаметр отвору сідла клапана, висоту підйому клапана, масу клапана, частоту та довжину руху робочого органу при визначеній рухливості розчину. Наведені графічні залежності, які дозволяють провести аналіз та встановити раціональні значення зазначених параметрів на величину об'ємного коефіцієнта корисної дії. Отримані раціональні числові значення встановлених конструктивних та режимних параметрів розчинонасоса мають практичне значення при проєктуванні нових конструкцій обладнання та експлуатації вже існуючих.*

Ключові слова: *розчинонасос, загальний коефіцієнт корисної дії, об'ємний коефіцієнт корисної дії, оптимізація параметрів, будівельні розчинні суміші*

STUDY OF THE INFLUENCE OF THE DESIGN AND MODE PARAMETERS OF THE NON-PUMP SOLUTION ON THE VOLUME AND TOTAL CO-FIGURE COEFFICIENT OF ACTION

ABSTRACT. *It is noted that the efficiency of solution pumps is traditionally evaluated by the value of the coether-useful effect value, which is determined by a set of three components: volumetric, hydraulic and mechanical efficiency. The value of the total efficiency also affects the efficiency of using the power of the machine drive. The paper presents the results of experimental studies on establishing the influence of structural and mode parameters of a vertical differential solution pump with poppet valves when pumping lime-sand solution. The main influencing factors and their intervals of change, which should include: the diameter of the valve seat opening, the height of the valve lift, the mass of the valve, the frequency and length of movement of the working body with the determined mobility of the solution, were analyzed and highlighted. Graphical dependencies are given, which make it possible to conduct an analysis and establish the rational values of the specified parameters on the value of the volumetric efficiency. The obtained rational numerical values of the established design and mode parameters of the solution pump have practical significance in the design of new equipment structures and the operation of existing ones.*

Keywords: *solution pump, total efficiency, volumetric efficiency, parameter optimization, mortar construction mixtures.*

1. Problem statement. Analysis of existing designs of solution pumps shows that the most common are pumps with ball valves, for which a significant amount of research and optimization has been carried out. At the same time, the issues of determining the volumetric efficiency of dish valve solution pumps remain poorly understood [1, 2].

The design features of such pumps, in particular the ramjet operating chamber and the reduced volume of the harmful space, create the prerequisites for increased volumetric efficiency, improved valve operating conditions and reduced hydraulic losses. Additionally, the application of a differentiated plunger contributes to the reduction of uneven supply and expands the possibilities of performance regulation [3].

Insufficient studies on the influence of these factors on the volumetric efficiency factor make it necessary to carry out an appropriate theoretical analysis.

2. Analysis of recent research and publications. The efficiency of solution pumps is traditionally evaluated by the value of the efficiency coefficient, which is determined by a set of three components: volumetric, hydraulic and mechanical efficiency [4]. The value of the total efficiency also affects the efficiency of using the power of the machine drive and consists of three components:

$$\eta_{заг} = \eta_{об} \cdot \eta_{Г} \cdot \eta_{мех}\,, \tag{1}$$

where $\eta_{об}$ – volumetric efficiency; $\eta_{Г}$ – hydraulic efficiency; $\eta_{мех}$ – mechanical efficiency.

At the same time, the mechanical efficiency is determined by the design features of the kinematical scheme of the pump and has a practically constant value for a specific design, in connection with which, in most studies, the main attention is paid to the volumetric and hydraulic components.

The analysis of scientific papers [5, 6, 7] shows that the volumetric and hydraulic efficiency of the mortar-suckers depend on a complex of structural and regime factors. The main ones include the frequency of movement of the working body, the parameters of the valve units, the method of regulating the supply, as well as the geometry and hydrodynamic characteristics of the flow part of the pump. Considerable attention in the literature is paid to the study of the influence of valve systems on the processes of suction and injection, since they determine the conditions of filling the working chamber.

It was established that the increased hydraulic resistance of the valve units leads to a decrease in hydraulic efficiency, deterioration of the filling of the working chamber and a decrease in the pump supply. In addition, disruption of flow continuity in the valve zone can cause the occurrence of hydroimpact phenomena, which negatively affects the stability of the pump and reduces its volumetric efficiency [4, 5, 8].

However, in the available research, insufficient attention is paid to the comprehensive analysis of the influence of the design of valve assemblies and the flow part on the volumetric efficiency factor, which necessitates further research in this direction.

3. Purpose and objectives of the study. The purpose of this article is to analyze the working conditions and establish the influence of the design parameters of the solution pump with poppet valves on the value of the volume efficiency.

4. Discussion of research results. To study the influence of the design parameters of a mortar pump with poppet valves on the volumetric efficiency, the laboratory experiment method was used [9, 10]. The design and operating parameters that most affect the volumetric efficiency of the mortar pump were selected as determining factors, in particular, the valve lift height, the diameter of its seat, the mass of the suction valve, as well as the stroke length and the frequency of movement of the working element.

Experimental studies were performed on a specialized test stage (Fig. 1), using a solution pump equipped with poppet valves.

In the first stage of the experiments, when studying the volumetric efficiency of the solution pump, a study was conducted aimed at determining the influence of various constructive pas. In particular, the dependence of the value of the volume efficiency coefficient on design parameters, such as the diameter of the valve seat opening d_c, the height of the valve lift h, the weight of the valve m_k, was studied. Other parameters for this stage of the experiment were fixed: the mobility of the solution OK = 10 cm, the frequency of movement of the working body n = 120 min^{-1} and the length of its stroke L = 65 mm.

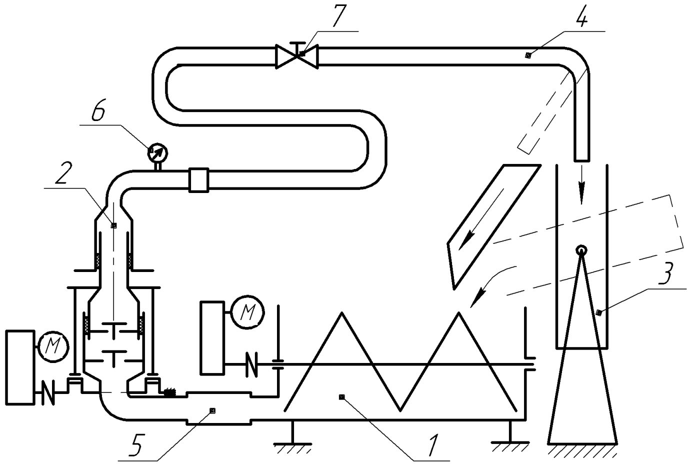

Fig. 1. Test bench layout:
1 – hopper mixer; 2 – test solution pump; 3 – measuring capacity; 4 – solution pipe; 5 – connecting vacuum hose; 6 – manometer; 7 – loading device.

In order to determine the volumetric efficiency of the solution pump, which is used as a criterion for the effectiveness of constructive decisions, we adopt the following functional dependence:

$$\eta = \frac{Q_Д}{Q_T} \cdot 100\% = \frac{24 \cdot 10^9 \cdot V}{\pi \cdot n \cdot D^2 \cdot L \cdot t}, \% \quad (2)$$

where $Q_д$ – is the actual pump supply, l/s; Q_m – theoretical pump supply, l/s; V – volume of measuring capacity, 60 l; n – frequency of movement of the working body, min^{-1}; D – plunger diameter, 127 mm; L – plunger stroke length, mm; t – time of filling with a solution of a measuring container, s.

At the initial stage of determining the interval of values of the design parameters of the valve, the diameter of the seat opening d_c, the lifting height h and the mass m_k, the gradient movement method was used. As the starting point (zero level), the following values of the studied parameters were chosen: h = 15 mm, d_c = 50 mm, m_k = 0.5 kg with intervals of variation of 5 mm, 10 mm and 100 g, respectively. In the region of this "point" the response surface was approximated using a plane, which was constructed using a linear three-factor design [11, 12]. The matrix of this plan is shown in Table 1.

$$\eta = f\,(d_c, h, m_k). \quad (3)$$

In this matrix, the values of the changing factors are marked with the sign "+", at the top level, at the bottom - "–", and "0" - at the middle (zero).

Table 1. Matrix of a linear three-factor plan for conducting an experiment when moving along a gradient

№	X_1(h, mm)	X_2 (d_C, mm)	X_3 ($m_к$, g)	Y (efficiency, %)
1	+ (20)	+ (60)	+ (600)	70,5
2	- (10)	+ (60)	+ (600)	74
3	+ (20)	- (40)	+ (600)	78
4	- (10)	- (40)	+ (600)	81
5	+ (20)	+ (60)	- (400)	66
6	- (10)	+ (60)	- (400)	69
7	+ (20)	- (40)	- (400)	70,5
8	- (10)	- (40)	- (400)	72,5
9	0 (15)	0 (50)	0 (500)	72,5

As a result of statistical data processing, the equation was obtained:

$$\eta = -106,26 + 5,45 \cdot h + 6.73 \cdot d_c - 0,14 \cdot h^2 - 0,063 \cdot d_c - 0,06 \cdot h \cdot d_c, \% \quad (4)$$

Based on this equation, the plot is shown in Figure 1.

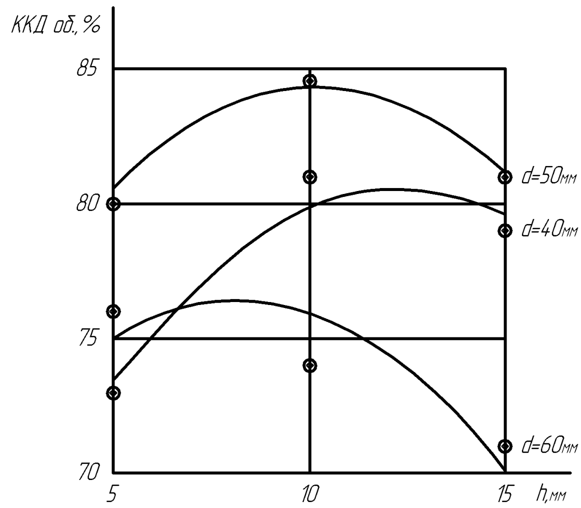

Figure 1. Graph of the dependence of the volumetric efficiency of the solution pump on the seat diameter *d* and the lifting height *h* of the suction valve at m_k=0.6 kg; *n*=120 rpm; *OK*=10 cm

In carrying out the present plan, the following sequence of execution of its lines 1,2,3,9,4,5,6,7,8 was used. As a result of statistical data processing, the equation:

$$\eta = -135,9 + 34,04 \cdot OK - 0,24 \cdot n - 1,44 \cdot OK^2 - 0,002 \cdot n^2 + 0,02 \cdot OK \cdot n, \% \quad (5)$$

Based on equation 5, the plot is shown in Figure 2.

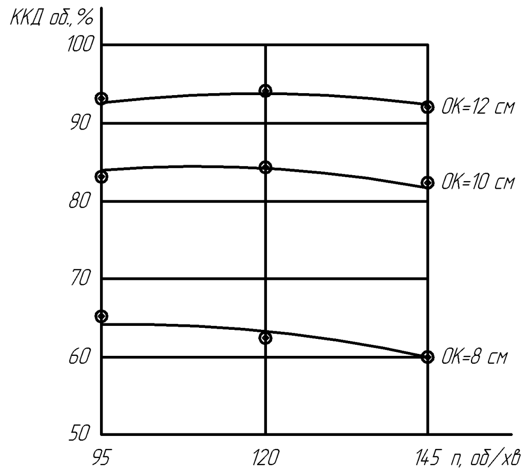

Figure 2. Graph of the dependence of the volumetric efficiency of the solution pump on the frequency *n* of the movement of the working body and the mobility *OK* of the pumped solution at *d*=50 mm *h*=10 mm; m_k=0.6 kg.

A study of the influence of the stroke length *L* of the plunger on the volume efficiency of the investigated solution pump was carried out. This is due to the fact that the possibility of adjusting the feed is built into the structure and is very convenient to operate. The study was carried out according to fixed parameters that had previously been determined to achieve the maximum volume efficiency of the solution pump in the previous series of experiments. Only the upper 80% of the plunger travel adjustment range was used to conduct the experiment, since at small values there is a significant increase in the error of the experiment, which can lead to inaccurate results.

The results of the experiment were processed using the method of least squares [11] and the following equation was obtained as a result:

$$\eta = -0,186 \cdot L^2 + 2,36 \cdot L + 9,064, \% \qquad (6)$$

Based on equation 6, a plot of the volumetric efficiency of the solution pump versus the stroke length L of its working body is depicted in Figure 3.

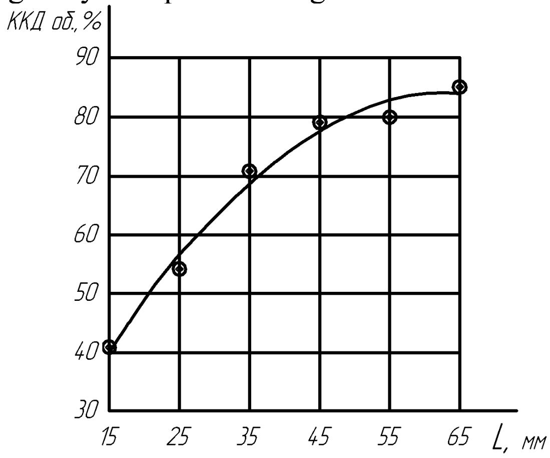

Figure 3. Graph of the dependence of the volumetric efficiency of the solution pump on the stroke length L of its working body at d=50 mm h=10 mm; m_k=0.6 kg; n=120 rpm; OK=10 cm

After that, a study of the influence of the mass of the suction valve on the volume efficiency of the solution pump was carried out. The parameters according to which the maximum result was achieved in the previous series of experiments were fixed: valve lifting height h – 10 mm, mobility of the solution OK – 10 cm, frequency of movement of the plunger n – 120 min^{-1}. The mass of the valve was changed with the help of lead loads, which were put on the valve stem and fixed with a nut. The efficiency was determined for different valve seat opening diameters: d_C = 40 mm, d_C = 50 mm, d_C = 60 mm. The results of this series of experiments are presented in Table 2 and in the graph of Figure 4.

Table 2. Results of the determination of the maximum values of the volumetric efficiency of the solution pump for a valve with different masses

d_C=40 mm		d_C=50 mm		d_C=60 mm	
m_K, kg	η, %	m_K, kg	η, %	m_K, kg	η, %
0,5	80,5	0,5	81	0,5	68
0,6	81	0,6	85	0,6	74
0,7	76	0,7	83	0,7	75

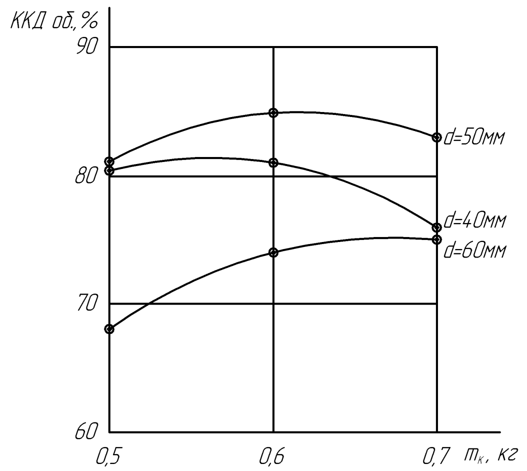

Figure 4. Graph of the volume efficiency of the solution pump versus the mass and diameter of the valve seat at: h=10 mm; n=120 rpm; OK=10 cm

5. Conclusions. As a result of experimental studies of a vertical differential solution pump with poppet valves, when pumping a lime-sand solution with a mobility of 10 cm and a fraction size of up to 5 mm, it was established that the maximum volume efficiency is achieved with the following design parameters: valve seat opening diameter d_c = 50 mm, valve lifting height h = 10 mm, valve weight m_k = 0.6 kg, frequency of movement of the working body n = 105 min^{-1}. However, due to the strong pulsation of the solution jet at a given frequency, which can be seen in Figure 2, a rational frequency range from 100 to 125 min^{-1} was chosen and the frequency of movement was set at a value of n = 120 min^{-1}, which better meets the technological requirements.

From the graph shown in Figure 1, it can be deduced that regardless of the diameter of the valve seat opening, with an increase in the height of the valve lift above the seat, the volume efficiency of the solution pump first increases to the maximum value, and then decreases again. With a constant height of valve lifting and an increase in the diameter of the seat opening, there is also an increase in the volume efficiency to the maximum value at d_c = 50 mm, and then a decrease again. The pattern clearly expressed on the graph is that the maximum volumetric efficiency of the solution pump, which is 81% with a smaller diameter of the seat opening, is achieved with a higher valve lifting height of 12 mm, and with a larger diameter, the efficiency of 76% is the opposite with a lower height of 8 mm.

A decrease in the stroke length of the working body leads to an increase in the volume of the "dead" space of the working chamber, that is, it reduces the coefficient of its filling. This is reflected in the graph shown in Figure 3, based on experimental data, where there is a drop in the volume efficiency of the solution pump. This dependence is the regulating characteristic of the designed solution pump. In the ranges of increasing the speed of movement of the working body shown in Figure 3 and reducing the length of its stroke shown in Figure 2 by 40%, the volume efficiency of the solution pump is practically equally reduced, namely by 2–6%.

When the mass of the valve increases, there is also a decrease in the rational volume efficiency, which is explained by the increase in the time of delay in opening the valve due to the high force required to separate the valve from the seat. Thus, the graph shows that when the load on the valve increases, the volumetric efficiency increases, but this load must remain within a certain rational value to ensure minimal lateness during valve operation. In addition, each diameter of the seat opening has its own optimal valve weight as shown in the graph in Figure 4.

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