УДК 622.242.6

M. M. Liakh[1], Cand. Sc. (Tech.), Prof.,
V. M. Savyk[2], Cand. Sc. (Tech.), Assoc. Prof.,
P. O. Molchanov[2], Cand. Sc. (Tech.), Assoc. Prof.

1 – Ivano-Frankivsk National Technical University of Oil and Gas, m. Ivano-Frankivsk, Ukraine, e-mail: karimat@rambler.ru
2 – Poltava National Technical University, m. Poltava, Ukraine, e-mail: savicppntu@rambler.ru; petja_men@ukr.net

IMPROVING THE EFFICIENCY OF FOAMGENERATING DEVICES OF PUMP-CIRCULATIVE SYSTEMS OF DRILLING SETS

М. М. Лях[1], канд. техн. наук, проф.,
В. М. Савик[2], канд. техн. наук, доц.,
П. О. Молчанов[2], канд. техн. наук, доц.

1 – Івано-Франківський національний технічний університет нафти і газу, м. Івано-Франківськ, Україна, e-mail: karimat@rambler.ru
2 – Полтавський національний технічний університет імені Юрія Кондратюка, м. Полтава, Україна, e-mail: savicppntu@rambler.ru; petja_men@ukr.net

ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ ПІНОГЕНЕРУЮЧИХ ПРИСТРОЇВ НАСОСНО-ЦИРКУЛЯЦІЙНИХ СИСТЕМ БУРОВИХ УСТАНОВОК

Purpose. Increasing efficiency of foamgenerating devices of pump-circulating systems of drilling sets. The purpose is achieved through implementation of the following tasks:

- the carrying-out of the analysis and selective choice of theoretical and experimental results, geometrical parameters, work modes of foamgenerating devices;
- the development and explanation of rational schemes of equipment strip and devices for cleaning oil and gas wells with foam.

Methodology includes:

- the analysis of conditions and experience of exploitation of different constructive peculiarities of devices and equipment of pump-circulating systems for cleaning wells with foam;
- the mathematical modelling of foam formation in ejection foamgenerating device using the laws of energy balance, flow continuity, conservation of momentum, Laplace criterion, Weber and Mach's figures and Lishevskiy's equation;
- the computing modelling of foamgenerating device was performed with the purpose of optimizing its internal constructive elements;
- the experimental definition of main parameters and work modes, considering the construction change of foamgenerating device.

Findings. Theoretical research studies has been carried out to reveal and define the influence of the most important factors and optimal geometrical parameters and work modes of foamgenerating devices have been selected which provided the highest efficiency of well cleaning with foams. Experimental research studies have been carried out to define the connection between the geometrical shapes, parameters, work modes of foamgenerating devices and the efficiency of foam formation.

Originality. The theoretical and experimental research studies of fluid streaming, air and their mixture through constructive elements of the equipment allow revealing the regularities of connection of the efficiency of foam formation and parameters and work modes of foamgenerating devices.

During the research:

- connection between the quality of foam formation and constructive peculiarities of detached elements of foamgenerating device was defined;
- there were advanced mathematical models of motion streams of fluid, air and foam through constructive elements of foamgenerating device and detached elements of equipment of pump-circulating system ;
- analytic dependences of motion of fluid, air and foam streams and the work efficiency of foamgenerating devices on their constructive peculiarities were explained theoretically and experimentally;
- the method of choosing the optimal constructive shapes of elements in foamgenerating devices that influence the formation of fluid, air and foam streams has been explained scientifically.

Practical value. Due to the performed theoretical and experimental research studies, we have defined the rational geometrical shapes and parameters, set the optimal work modes of foamgenerating devices, which are the basic for creating new high efficient foamgenerating devices. We have suggested a row of methods and instrumentalities of constructive and technological character for booming the efficiency of well cleaning with foam solution. The results have been used during the development of pump-circulating system for well cleaning with foam solution.

Keywords: *the foamgenerating device, the pump-circulating system, the aerative fluid, foam, the fluid stream*

Introduction. The drilling of oil and gas wells in dispersed and unstable rocks is connected with certain difficulties, namely:

- high, even catastrophic, absorption of drilling solution and connected with it significant expenditure on providing chemical agents, preparation of cleaning fluid, lowering of intermediate columns, plugging works etc.;
- the washing of unstable rocks with drilling solution that does not allow getting a qualitative core for geological research;
- appearing of complications in the process of drilling, connected with washing of well walls, core creation deposits on the bottom of sludge, catching and wedging of a drilling pump and others;
- during the revealing of oil and gas horizons, a producing reservoir can be plugged with drilling solution lacking the predicted effect.

The situations can be prevented by using gas and liquid mixtures as drilling solution; compared with washing fluids, they have a number of advantages and give the possibility to remove all mentioned facts.

Gas and fluid mixtures are dispersed systems that consist of two elements – gas and liquid ones (the mixture of water and various chemicals: surfactants, inhibitors, stabilizers, etc.).

The aerative fluids and foam are the most widespread in Ukraine. In our case we consider foam and equipment connected with them. During the drilling process by washing a face with foam there is mechanical speed of drilling in solid rocks increases (approximately by 4 times), compared with drilling solution, and makes it possible to avoid the absorption in porous and fractured rocks and mudding permeable layers. While revealing and reclaiming productive horizons, the productivity of wells increases by 1.5–2 times along with the reduction of reclaiming terms by 4–5 times [1, 2].

The process of foam formation is difficult since it is influenced by physical and chemical, physical and technical and other factors. As a rule, to get foam we have to use foamgenerating devices of different types and work principles [3–5]. All existing devices can be recommended for drilling of shallow exploration, geophysical and other wells.

According to the information from available resources, at present there is lack of equipment for drilling of oil and gas wells with foam, which allows forming foam with given parameters and dispersion.

Everything mentioned above confirms the topicality of the work and necessity of further scientific and research works, aimed at increasing the foam system efficiency while drilling with foam solution.

Analysis of the recent research and publications. The article analyses theoretical and experimental works, considering modern level of machines for foam solution preparation: Amiyan A.V., Amiyan V.A., Vassiliev V.H., Izzatdust E.S., Kovalenko V.I., Kuzmenko N.N., Mezhlumov A.A., Tyhomirov V.K., Yakovlev A.M., Anderson G., Garavini O., Radenti G., Sala A. and other scientists. It has been established that there is not enough information regarding the influence of construction, parameters and work modes of foamgenerating devices on efficiency of foam formation.

Unsolved aspects of the problem. The article considered the following issues: the topicality of the problem of well washing with foam solution and work conditions of the equipment during it; the work efficiency of foamgenerating devices and assess methods of their exploitation parameters; works devoted to the research of the main exploitative parameters of foamgenerating devices; peculiarities of constructions of existing foamgenerating devices for preparation of foam solution.

Objectives of the article include the following: the advancement and choice of characteristics of ejection foamgenerating devices of pump-circulating systems of drilling sets; processes of aeration and foam formation that occur in foamgenerating devices of pump-circulating system; methods of assessing and defining the limits of technical characteristics of foamgenerating devices for getting maximal efficiency of foamgenerating; definition of parameters of constructive elements of foamgenerating device which will allow the creation of high qualitative foam; providing reliability and work quality of the pump-circulating system during well washing with foam solution by improving devices and the scheme of pump-circulating system.

Representation of the main resarch. Based on the conducted theoretical research of the processes which cause the motion of fluid, air and foam mixture in elements of foamgenerating devices, we offer the method of choosing flow parameters of work fluid and ejection air, which would allow achieving the highest efficiency in the process of foam formation and explaining the choice of rational constructive variant of foamgenerating device. We have studied the processes which occur on at every stage of foam formation in foamgenerating devices.

There are certain methods of calculating foamgenerating devices, according to which we carry on the calculation of pressure loss in devices in the process of foam solution production, through which the geometrical sizes are chosen [6]. The disadvantage of these methods is the fact that the qualitative characteristics of produced foam are not considered; in particular, meeting the requirement of the energy to create small dispersed air and drop, fluid and bubbles mixtures, and its value is inverse to the average radius of a drop or bubble. Notably, the energy to create a bubble stream with large values of volume gas content can be bigger than the energy required to create a drop flow.

In this regard, during theoretical research of foamgenerating devices with usage of famous equations of energy balance, continuity of stream and conservation of momentum we propose the method of choosing parameters of fluid and air streams, using which we would be able to achieve the highest efficiency in the process of foam formation.

We have explored the working process of foam formation which occurs in one of the channels of the foamgenerating device. The analysis was carried out, based on a simplified scheme of ejection device and calculation model of static pressure distribution along the length of the device (Fig. 1).

In the initial section with the length l_1, the separate flows of fluid and gas phase occurs. However, gradually, due to the turbulent transverse pulses of speed which cause liquid dispersion in the transverse direction and aeration of air squirt, the gas capacity reduces near wall, while increasing on axis and in the end of the section they reach the equality between each other, which proves formation of homogeneous air and drop stream.

Here, the section with the length l_2 begins. The formation of homogeneous air and drop stream occurs along this field.

The third section with the length l_3 begins with completion of formation of homogeneous air-drop mixture. At the end of the section a skip of consolidation is observed while the air-drop mixture turns into fluid-bubbled mixture with the air bubbles having approximately the same diameters and being divided by fluid layers. The skip of consolidation is characterized by sharp increase in pressure.

In the fourth section which begins after the skip of consolidation, the mixture moves as a two-phase homogeneous bubbles-foam stream (foam solution).

In order to initiate the skip of consolidation the speed of air- drop stream is to be higher than the sound speed in it. The lower Mach's figures are, the higher the energy of the work stream to produce foam solution will be; that is when the speed of stream movement approximates the sound speed of the stream before the skip of consolidation. The sound speed is calculated according to known formulas or using graphic of the dependence of the sound speed in water and air solution on the content of gas in it (Fig. 2).

The relative length of the initial section is determined according to Lishevskyi's equation

$$\frac{l_1}{d} = 50{,}3 \cdot We^{-0{,}83} \cdot \left(\frac{\rho_г}{\rho_p}\right)^{0{,}5} \cdot Lp^{-0{,}096}, \qquad (1)$$

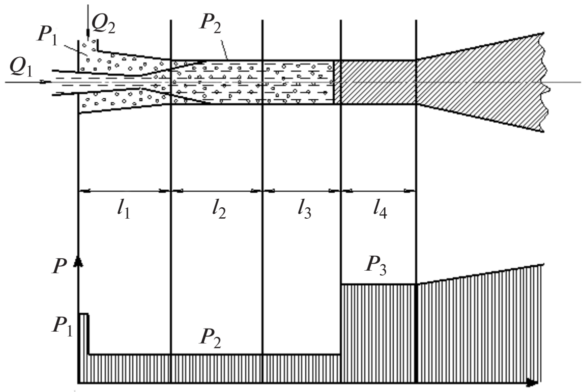

Fig. 1. The schemes of ejection device and static pressure distribution along its length:

Q_1 and Q_2 are the volume loss of fluid and air correspondingly; p_1, p_2 and p_3 are the static pressures near the nozzle before and after shock wave correspondingly; l_1, l_2, l_3, i l_4 are the sections of the ejection device

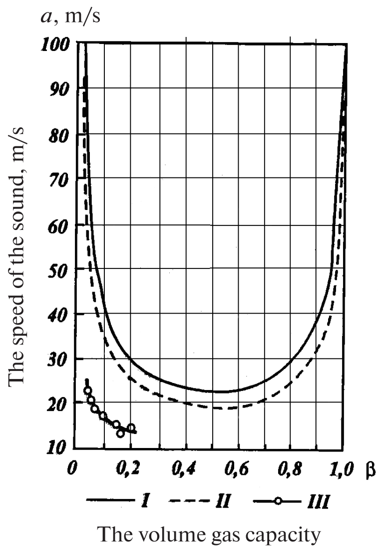

Fig. 2. The sound speed in water and air solution:

I — calculated values during the adiabatic process; II — calculated values during isothermal process; III — experimental values on small dispersed solutions

where $We = \frac{\rho_г \cdot d \cdot (\upsilon_p - \upsilon_г)^2}{\sigma}$ is Weber's number; $Lp = \frac{\rho_p \cdot d \cdot \sigma}{\mu_p^2}$ is Laplace criterion; d is the diameter of an ejection camera; ρ_p, $\rho_г$ *are* the density of fluid and air correspondingly; σ, μ_p are surface tension and liquid viscosity; υ_p, $\upsilon_г$ are the speeds of fluid and gas correspondingly; p is the pressure of mixed fluid and gas stream.

The relative length of the main section we can calculate according to Miguel's dependence

$$\frac{l_2}{D} = 18{,}36 \cdot M_R^{-0.181}, \qquad (2)$$

where D is the diameter of mixing camera.

According to the well-known expression for sound speed in a two-phase environment provided the absence of phase changes, the formula for Mach's number of overtaking drop stream before the skip of consolidation

$$M_1 = \upsilon_2 \cdot \left(\frac{n \cdot p_2}{\alpha_1 \cdot (1-\alpha_1) \cdot \rho_p}\right)^{-0.5}, \qquad (3)$$

where υ_2, p_2 are the speed and pressure of mixture before the skip of consolidation correspondingly; n is the polytrope value; α_1 is the volume gas capacity before the skip of consolidation.

In the process of calculations a dimensionless system of equations for determining the relative changes of parameters of mixture movement is obtained

$$\frac{p_3}{p_2} = 1 + \frac{M_1^2 \cdot n}{\alpha_1} \cdot \left(1 - \frac{\xi^{-1} + (1-\alpha_1) \cdot \left(\frac{2 \cdot \gamma \cdot \alpha_1}{\gamma - 1} - 1\right)}{\alpha_1 \cdot \left(\frac{2 \cdot \gamma}{\gamma - 1} - 1\right)}\right); \qquad (4)$$

$$\frac{\upsilon_3}{\upsilon_2} = \frac{\xi^{-1} + (1-\alpha_1)\cdot\left(\frac{2\cdot\gamma\cdot\alpha_1}{\gamma-1} - 1\right)}{\alpha_1\cdot\left(\frac{2\cdot\gamma}{\gamma-1} - 1\right)}; \qquad (5)$$

$$\frac{\alpha_2}{\alpha_1} = \frac{1-\xi\cdot(1-\alpha_1)^2}{\alpha_1 + \xi\cdot\alpha_1\cdot(1-\alpha_1)\cdot\left(\frac{2\cdot\gamma\cdot\alpha_1}{\gamma-1} - 1\right)}; \qquad (6)$$

$$\xi = \left(1 + \frac{2\cdot\gamma}{\gamma-1}\cdot\frac{\alpha_1^2}{n\cdot M_1^2}\right)^{-1}, \qquad (7)$$

where n is the value of polytrope; γ is the value of adiabatic exponent.

From equations 4–7 we can see that relative parameters of mixture stream after the skip of consolidation depend on Mach's number M_1 of overtaking flow and volume gas capacity α_1 before the skip, which, in its term, is defined by the degree of aeration u. Based on theoretical research the values of energy expenditure to produce drops from a unit of volume of fluid in main section ΔE_2 are calculated, as well as those of the energy expenditure which is spent on producing free surface of fluid during creation of bubbles ΔE_3

$$\Delta E_2 = \frac{\rho_p\cdot\upsilon_p^2}{2} - \frac{\rho_1\cdot\upsilon_2^2}{2} + p_1 - p_2 - \Delta P_{mp1} - \Delta P_{mp3}; \qquad (8)$$

$$\Delta E_3 = \frac{\rho_1\cdot\upsilon_2^2}{2} - \frac{\rho_2\cdot\upsilon_3^2}{2} + p_2 - p_3 - \\ - \Delta P_{mp4} - u\cdot p_1\cdot\tau\cdot\ln\frac{p_3}{p_2}, \qquad (9)$$

where p_0, p_1, p_2 *and* p_3 are the atmospheric pressure, static pressures near the nozzle before and after the skip of consolidation correspondingly; υ_3 is the speed of mixture after the skip of consolidation; u is the degree of aeration; ΔP_{mp1}, ΔP_{mp3} i $DP_{mp}4$ is the loss of pressure on rubbing in the initial field l_1 and l_3 before the skip and in section l_4 after the skip of consolidation; ρ_1 and ρ_2 are the density of drop mixture before the skip of consolidation and the bubble mixture after the skip of consolidation correspondingly; τ is the ratio of absolute temperature of gas in the zone of skip to the temperature in accepted camera, that characterizes isobaric change of gas temperature before the skip of consolidation.

Besides these equations, to determine feasible modes of movement of gas and fluid stream, the equation for calculating the change (loss) of power of fluid ΔN in the section from the nozzle to the overcut of the flow of gas and fluid mixture after the skip of consolidation looks as follows

$$\Delta N = Q_1\cdot\left(\frac{\rho_p\cdot\upsilon_p^2}{2} + p_1 + \frac{\gamma}{\gamma-1}\cdot u\cdot p_0\right) - \\ - W\cdot\left(\frac{\upsilon_3^2}{2} + \frac{p_3}{\rho_2} + \frac{\Delta P_{mp1} + \Delta\ P_{mp3}}{\rho_1} + \frac{\Delta \quad_{mp4}}{\rho_2}\right) - \qquad (10) \\ - Q_1\cdot p_0\cdot u\cdot\tau\cdot\ln\frac{p_3}{p_2},$$

where $W = \rho_1\upsilon_2 F_3 = \rho_2\upsilon_3 F_3$ is the mass expenditure of gas and fluid mixture.

The movement of gas and fluid stream is feasible only with those values of parameters, during which the power loss ΔN acquires positive values.

Thus, considering the given information, we can infer, that with parameters of movement of gas and fluid stream for which $M_1 > 1$ a skip of consolidation occurs in the mixing camera, which could be characterized by step-like increase in pressure and reduction of stream speed and volume gas capacity, whereas with parameters of gas and fluid stream movement for which $M_1 < 1$, a skip of rarefaction occurs in the mixing camera, which is characterized by skipping reduction of pressure and increase in stream speed and volume gas capacity.

Since the energetic characteristics of gas and fluid stream are defined not only by parameters of its motion but also by properties of fluid and gas, to perform the following calculations let's take water as a liquid while adding surfactants with such parameters: the density is $\rho_p = 10^3$ кg/m^3; the coefficient of surface tension is $\sigma = 0.05$ N/m; the coefficient of dynamic viscosity is $\mu_p = 10^{-3}$ Pa · s; the temperature is $T = 300$ K. The air is taken as a gas, which is given by the compressor to the accepted camera from environment with $p_0 = 10^5$ Pa and $T = 300$ K. The coefficient of dynamic viscosity of the air does not depend on the pressure and is equal $\mu_p = 1.88\cdot 10^{-5}$ Pa · s with the temperature $T = 300$ K. The graphic dependences (Fig. 3–5) are drawn for the following geometrical sizes of the ejection device: the diameter of the ejection camera is $d = 0.006$ m; the diameter of the mixing camera is $D = 0.012$ m; the expenditure of fluid is $Q_1 = 10^{-3}$ m^3/s; the fluid pressure is $P_1 = 1.4$ MPa.

The dependences of power losses of stream on producing gas and fluid mixture ΔN on the aerative degrees with different values of pressure in accepted camera p_1 are shown in Fig. 3, which shows that with height p_1 general expenditure of power ΔN on production of free water surface increases. All three curves of dependence ΔN on u have maximums with those values u, when Mach's number M_1 (Fig. 4) is bigger than 1, that corresponds to the skip of sonsolidation.

Fig. 5 provides information on dependences of losses of volume density of energy on production of air and drop stream ΔE_2 as well as that of fluid and bubble stream ΔE_3 on the aerative degree with pressure $p_1 = 7.5\cdot 10^5$ Pa in accepted camera. From the graphic dependence we can see that with increasing u values ΔE_2 and ΔE_3 decrease, and with value of u, for which M_1 becomes bigger than 1, $\Delta E_3 < 0$. It signifies that all the energy of stream is spent on work of the solution cramping in the skip of consolidation ($A = Q_1 u p_0 \tau \ln(p_3/p_2)$) and bubbles are not created during the skip or after it.

In Fig. 6 we observe the dependences of energy expenditure of the stream to produce air and fluid mixture ΔN on the aerative degree with two different diameters of nozzle and the same values of fluid losses $Q_1 = 10^{-3}$ m^3/s and pressure in receiving camera $p_1 =$

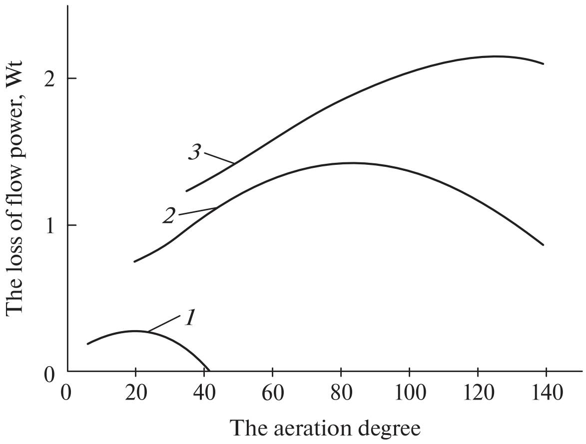

Fig. 3. The dependence of power losses of stream on aerative degrees with different values of pressure in accepted camera:

1 – 0.3 MPa; 2 – 0.75 MPa; 3 – 1 MPa

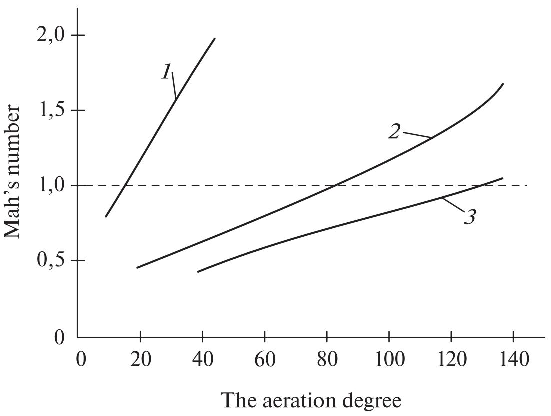

Fig. 4. The dependence of Mah's number of gas and liquid stream on aerative degree with different pressure values in accepted camera:

1– 0,3 MPa; 2 – 0,75 MPa; 3 – 1 MPa

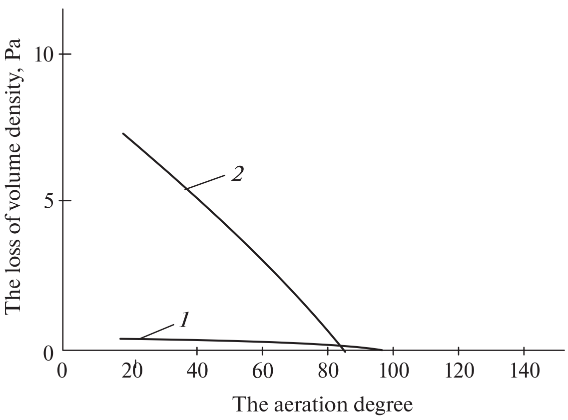

Fig. 5. The dependences of expenditure of volume density of energy on production of air and drop stream ΔE_2 (curve 1) and fluid and bubble stream ΔE_3 (curve 2) on aerative degree with pressure $p_1 = 7.5 \cdot 10^5$ Pa

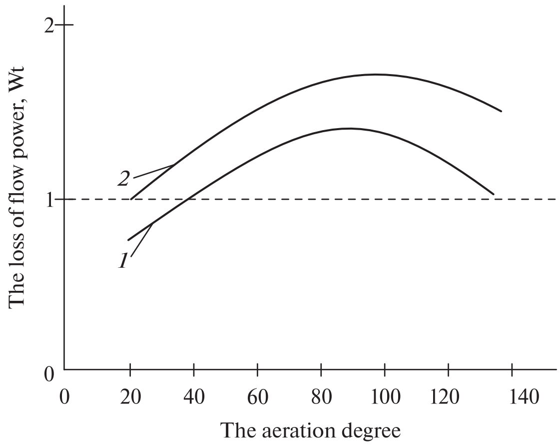

Fig. 6. The dependences of energy expenditure of stream ΔN on aerative degrees during the change of the nozzle diameter:

1 – 0,006 m; 2 – 0,004 m

= 0.75 MPa, according to which the reduction of nozzle leads to increasing energy expenditure to produce free surface and shifting of maximum ΔN in direction to bigger values of u. It is explained by increasing speed of fluid outcoming from nozzle, which occurs with bigger initial pressure in exit branch pipe.

Thus, according to the data described above we can conclude that the most effective mode of gas and liquid stream movement for homogeneous saturation of fluid with gas with further formation of small dispersed foam stream occurs with the following values: aerative degrees and other movement parameters, during which the value of Mach's number M_1 of gas and liquid stream is bigger than one, but is closer to it. In this case general energy expenditure of stream ΔN on production of free surface are maximal, whereas in the mixing camera a skip of consolidation occurs which is required for conversion of the air and liquid mixture into a liquid and bubble one, although the energy of the stream in the skip is consumed on mixture cramping and bubbles are not created neither during the skip and after it. They will appear only in those places of the device, where the fast reduction of static pressure occurs, compared to pressure p_3 in the mixing camera after the skip of consolidation, considering the work of gas expending phase.

To continue the process of foamgenerating we chose the computer application software FlowSimulation, which is an applicative module of SolidWorks that provides an opportunity to carry on the change of internal parameters of fluid and air in wide range and gives objective information on the necessary parameter in any point of foamgenerating device. In this program there a three-calculative model of one-nozzle device of ejection type was produced. The choice of a one-nozzle device was made with the purpose of work with this program and methods of research to a greater extent. Apart from this, the graphs show the trajectory of movement of fluid, air and their mixture streams, from which we can see that under some conditions self-absorption of air through incoming pipe occurs.

In the process of computer research while using the one-nozzle device we applied different variants of geometrical parameters of composing parts of the device during different modes of work.

A one-nozzle foamgenerating device was probed: with the change of distance between the nozzle and mixing camera; change of nozzle diameter; with the change of length of its cylindrical part; with the lengthening of mixing camera with help of extra diffuser discs. The research was executed applying a receiving part of the mixing camera of cylindrical or conical shape. The results obtained were taken as a basis of producing foamgenerating device of optimal construction, where the length of the cylindrical part of the nozzle is equal to 2 of its diameters, there is no distance between the nozzle and mixing camera, the receiving part of the mixing camera of conical shape with the length of the cylindrical part of the mixing camera is equal to 1.5 of its diameter with extra diffuser discs. This device does not feature any skips of speed over a period of mixture moving whereas distinctive increasing pressure is observed in the place of the skip of consolidation, where the process of producing free surface of liquid during bubble formation occurs (Fig. 7).

Research conclusions and recommendations for further research. As a result of the research, we have resolved the main scientific task which aims to set regularities of foam solution preparation for washing oil and gas wells in the process of drilling and reclaiming of wells, and it permitted producing the highly effective foamgenerating device and recommendations for its application while introducing it into production field, namely:

1. Based on analysis of a foam formation mechanism and exploitive characteristics of ejection foamgenerating device, we have established that actions of turbulent transverse pulsations call for the dispersion of liquid stream transversely and its aeration by the air, as a result, formation of homogenous air and drop stream occurs followed by its movement to the shock wave, which is characterized by fast pressure increase and accompanied by conversion of the air and drop mixture into emulsion one. At the same time the air bubbles are small and have almost the same diameter and are divided by the liquid films. To obtain a skip of consolidation the speed of air and drop stream is to be higher than sound speed in it. Considering this, we can suppose that geometrical shapes and sizes of composing parts of the foamgenerating device, as well as its modes and parameters are determining in its work efficiency.

2. The mathematical models of stream movement of fluid, air, their mixture and foam through the constructive elements of foamgenerating device have been advanced. We have established that the necessary condition for forming stable highly dispersed foam is increasing movement speed in gas and fluid mixture before the skip of consolidation in the mixing camera; the speed should be higher than that of the sound. With 60–80 % of the air content in the gas and liquid mixture, the exceeding of sound speed will make 25–40 m/s, whereas with 80–95 % of the air content in the gas and fluid mixture, the exceeding of sound speed will make 35–60 m/s. However, exceeding the set speed limits for mixture stream results in decreasing foam formation efficiency, which is conditioned by significant increase in Mach's figure. In addition, the boundaries of the highest values of the efficient coefficient are defined for different factors including: pressure, fluid and gas (air) expenditure, degrees of foam aeration etc.

3. Analytic dependences of movement of fluid, air and their mixture streams, including foam, and efficiency of work of foamgenerating devices on their geometrical parameters have been theoretically and experimentally explained; this gave the possibility to define the optimal constructive executing of elements of foamgenerating device. The positive factors are reduction of surfactant usage by 15–25 % and saving necessary properties of the foam during well washing of deep (more than 4000 m) drilling sets.

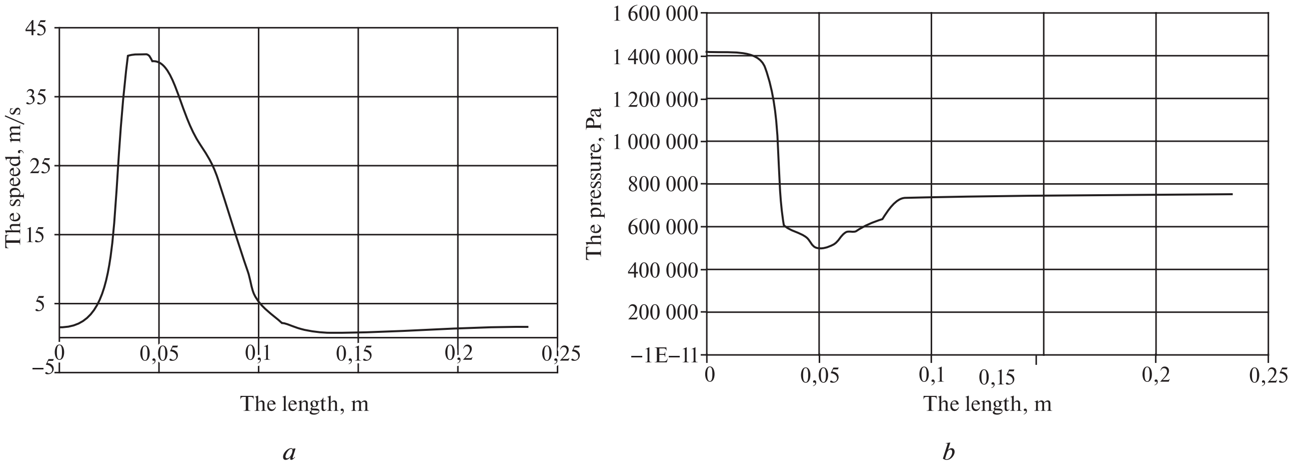

Fig. 7. The graphical dependences of parameter distribution in foamgenerating device of the most rational construction:

a – the speed distribution in transverse cutting of device; b – the pressure distribution in transverse cutting of device

References / Список літератури

1. Luzhanitsa, O.V., Pedenko, Yu.O., Dolyuk, I.P., Nazarenko, S.O., and Luzhanitsa, M.V., 2005. On the issue of technology advancement of primary revealing of productive horizons with anomaly low reservoir pressures. *Rozvidka ta rozrobka naftovich I gazovich rodovisch*, No. 3(16), pp. 9–14.

До питання удосконалення технології первинного розкриття продуктивних горизонтів з аномально низькими пластовими тисками / О.В.Лужаниця, Ю.О.Педенко, І.П.Долюк [та ін.] // Розвідка та розробка нафтових і газових родовищ. – 2005. – №3 (16). – С. 9 –14.

2. Marukhnyak, V.M., Fik, Z.V., Datsishin, M.Y., Kuzmich, B.V., Luzhanitsa, O.V., Pereiaslov, A.M., and Vlasov, P.A., 2005. Explorative and technological problems of horizons revealing with anomaly low reservoir pressures and granular collectors in West Ukraine, *Mineralni Resursy Ukrainy*, No. 1, pp. 35–37.

Геолого-технічні проблеми розкриття горизонтів з аномально низькими пластовими тисками та гранулярними колекторами в Західному регіоні України / В.М.Марухняк, З.В.Фик, М.Й.Дацишин [та ін.] // Мінеральні ресурси України. – 2005. – № 1. – С. 35–37.

3. Pedenko, Yu.O., 2005. Topical questions of advancement of circulating system of drilling sets, *Mineralni Resursy Ukrainy*, No. 1, pp. 43–44.

Педенко Ю.О. Актуальні питання вдосконалення циркуляційної системи бурових установок / Ю.О.Педенко // Мінеральні ресурси України. – 2005. – № 1. – С. 43–44.

4. Isaiev, Yu.M., 2008. The probation of stream in the SOLIDWORKS / FLOWORKS system, *Uspekhi Sovremenogo Yestestvoznaniia: Nauchnyi zhurnal,* No. 4, pp. 36–39.

Исаев Ю.М. Исследование течений в системе SOLIDWORKS / FLOWORKS / Ю.М.Исаев // Успехи современного естествознания. – 2008. – №4. – С. 36–39.

5. Mocherniuk, D.Yu., 2001. The modelling of physical processes, based on definitive equations, *Naftohazova Promyslovist*, No. 3, pp. 12–14.

Мочернюк Д.Ю. Моделювання фізичних процесів на основі визначальних рівнянь / Д.Ю.Мочернюк // Нафтова і газова промисловість – 2001. – №3. – С. 12–14.

6. Mysliuk, M.A., and Petruniak V.Yu., 2011. The assessment of parameters of productive reservoir according to curves of pressure recovering, *Problemy Naftohazovoi Promyslovosti*, No. 9, pp. 178–188.

Мислюк М.А. Оцінка параметрів продуктивних пластів за кривими відновлювання тиску / М.А.Мислюк, В.Я.Петруняк // Проблеми нафтогазової промисловості: Зб. наук. праць. – К., 2011. – Вип. 9. – С. 178–188.

7. Liakh, M.M., Savyk, V.N., Vakaliuk, V.M., Fedoliuk, N.V., and Solonichnyi, Ya.V., 2013. The peculiarities of foamformation gear in ejection foamgenerating device, *Naukovyi Visnic IFNTUNG*, No. 1, pp. 98–104.

Особливості механізму піноутворення в піногенеруючих пристроях ежекторного типу / М.М.Лях, В.М.Савик, В.М.Вакалюк [та ін.] // Науковий вісник ІФНТУНГ. – 2013. – № 1. – С. 98–104.

Мета. Підвищення ефективності піногенеруючих пристроїв насосно-циркуляційних систем бурових установок. Поставлена мета досягається через реалізацію наступних задач:

- проведення аналізу й селективного відбору теоретичних та експериментальних результатів, геометричних параметрів, режимів роботи піногенеруючих пристроїв;
- розроблення та обґрунтування раціональної схеми обв'язки обладнання й пристроїв для промивання нафтогазових свердловин пінами.

Методика. Включає:

- аналіз умов та досвіду експлуатації різних конструктивних особливостей пристроїв та обладнання насосно-циркуляційних систем для промивання свердловини пінами;
- математичне моделювання піноутворення в піногенеруючому пристрої ежекційного типу з використанням законів балансу енергії, неперервності потоку, збереження кількості руху, а також використання критерію Лапласа, чисел Вебера та Маха, рівняння Лишевського;
- комп'ютерне моделювання піногенеруючого пристрою проводилось з метою оптимізації його внутрішніх конструктивних елементів;
- експериментальне визначення основних параметрів та режимів роботи з урахуванням зміни конструкції піногенеруючого пристрою;

Результати. Виконані теоретичні дослідження з виявлення та визначення впливу найбільш суттєвих факторів і вибрані оптимальні геометричні параметри та режими роботи піногенеруючих пристроїв, що забезпечили найвищу ефективність промивання свердловини пінами. Проведені експериментальні дослідження для встановлення взаємозв'язку між геометричними формами, параметрами, режимами роботи піногенеруючих пристроїв та ефективністю піноутворення.

Наукова новизна. Теоретичні та експериментальні дослідження протікання рідини, повітря та їх суміші через конструктивні елементи обладнання дозволяють встановлювати закономірності взаємозв'язку ефективності піноутворення від параметрів і режимів роботи піногенеруючих пристроїв.

При цьому:

- визначено взаємозв'язок між якістю піноутворення та конструктивними особливостями окремих елементів піногенеруючого пристрою;
- удосконалені математичні моделі руху потоків рідини, повітря й піни через конструктивні елементи піногенеруючого пристрою та окремі елементи обладнання насосно-циркуляційної системи;
- теоретично та експериментально обґрунтовані аналітичні залежності руху потоків рідини,

повітря й піни та ефективності роботи піногенеруючих пристроїв від їх конструктивних особливостей;

- науково обґрунтовано метод вибору оптимальних конструктивних форм елементів піногенеруючих пристроїв, що впливають на формування потоків рідини, повітря й піни.

Практична значимість. На основі проведених теоретичних і експериментальних досліджень визначені раціональні геометричні форми та параметри, встановлені оптимальні режими роботи піногенеруючих пристроїв, що є основою для створення нових високоефективних піногенеруючих пристроїв. Запропонована низка методів та засобів конструктивного й технологічного характеру для підвищення ефективності промивання свердловин пінистими розчинами. Результати використані при вдосконаленні насосно-циркуляційної системи для промивання свердловин пінистими розчинами.

Ключові слова: *піногенеруючий пристрій, насосно-циркуляційна система, аерована рідина, піна, потік рідини*

Цель. Повышение эффективности пеногенерирующих устройств насосно-циркуляционных систем буровых установок. Поставленная цель достигается через реализацию следующих задач:

- проведение анализа и селективного отбора теоретических и экспериментальных результатов, геометрических параметров, режимов работы пеногенерирующих устройств;

- разработка и обоснование рациональной схемы обвязки оборудования и устройств для промывки нефтегазовых скважин пенами.

Методика. Включает:

- анализ условий и опыта эксплуатации различных конструктивных особенностей устройств и оборудования насосно-циркуляционных систем для промывки скважины пенами;

- математическое моделирование пенообразования в пеногенерирующем устройстве эжекционного типа с использованием законов баланса энергии, непрерывности потока, сохранения количества движения, а также использование критерия Лапласа, чисел Вебера и Маха, уравнения Лышевского;

- компьютерное моделирование пеногенерирующего устройства проводилось с целью оптимизации его внутренних конструктивных элементов;

- экспериментальное определение основных параметров и режимов работы с учетом изменения конструкции пеногенерирующего устройства.

Результаты. Выполнены теоретические исследования по выявлению и определению влияния наиболее существенных факторов и выбраны оптимальные геометрические параметры и режимы работы пеногенерирующих устройств, которые обеспечили высокую эффективность промывки скважины пенами. Проведены экспериментальные исследования для установления взаимосвязи между геометрическими формами, параметрами, режимами работы пеногенерирующих устройств и эффективностью пенообразования.

Научная новизна. Теоретические и экспериментальные исследования протекания жидкости, воздуха и их смеси через конструктивные элементы оборудования позволяют устанавливать закономерности взаимосвязи эффективности пенообразования от параметров и режимов работы пеногенерирующих устройств.

При этом:

- определена взаимосвязь между качеством пены и конструктивными особенностями отдельных элементов пеногенерирующего устройства;

- усовершенствованы математические модели движения потоков жидкости, воздуха и пены через конструктивные элементы пеногенерирующего устройства и отдельные элементы оборудования насосно-циркуляционной системы;

- теоретически и экспериментально обоснованы аналитические зависимости движения потоков жидкости, воздуха и пены и эффективности работы пеногенерирующих устройств от их конструктивных особенностей;

- научно обоснован метод выбора оптимальных конструктивных форм элементов пеногенерирующих устройств, которые влияют на формирование потоков жидкости, воздуха и пены.

Практическая значимость. На основе проведенных теоретических и экспериментальных исследований определены оптимальные геометрические формы и параметры, установлены оптимальные режимы работы пеногенерирующих устройств, которые являются основой для создания новых высокоэффективных пеногенерирующих устройств. Предложен ряд методов и средств конструктивного и технологического характера для повышения эффективности промывки скважин пенистыми растворами. Результаты использованы при совершенствовании насосно-циркуляционной системы для промывки скважин пенистыми растворами.

Ключевые слова: *пеногенерирующее устройство, насосно-циркуляционная система, аэрированная жидкость, пена, поток жидкости*

Рекомендовано до публікації докт. техн. наук В. С. Білецьким. Дата надходження рукопису 02.06.15.