Научная новизна. Впервые систематизированы нерудные месторождения магматического и метаморфического генезиса скальных строительных материалов Украины по пространственным размерам карьерных полей и мощности вскрышных пород, вследствие чего выделены базовые карьеры в качестве основных объектов дальнейших исследований.

Практическая значимость. Результаты исследования и полученная систематизация нерудных карьеров позволит усовершенствовать существующие эколого- и ресурсосберегающие технологии разработки, учитывая их конкретные пространственные параметры, что обеспечит рациональное природопользование при разработке месторождений. Внедрение полученных результатов позволит повысить эффективность и экологическую безопасность ведения горных работ. Данная классификация позволит разработать методику расчета предельной экономически эффективной глубины отработки гранитных карьеров с внутренним расположением вскрышных пород и отходов горного производства, отличающуюся учетом горно-геологических параметров, в наибольшей степени влияющих на эффективность горных работ, и экономических показателей, которые ограничивают достижение максимального эффекта.

Ключевые слова: *эколого- и ресурсосберегающие технологии, нерудные месторождения, карьер, параметры карьерного поля, систематизация, мощность вскрышных пород*

Рекомендовано до публікації докт. техн. наук А. Ю. Дриженком. Дата надходження рукопису 28.07.16.

UDC 622.242.6

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

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

EXPERIMENTAL AND INDUSTRIAL RESEARCH ON FOAMGENERATING DEVICES

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

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

ЕКСПЕРИМЕНТАЛЬНІ ТА ПРОМИСЛОВІ ДОСЛІДЖЕННЯ ПІНОГЕНЕРУЮЧИХ ПРИСТРОЇВ

Purpose. Finding out and researching rational constructive parameters of foamgenerating devices. The purpose is achieved through implementation of the following tasks:

- carrying out computer research on multi-nozzle foamgenerating devices and choosing rational geometric parameters and modes of their work that would provide high efficiency of washing wells with foam;
- finding out relation between geometrical shapes, parameters, work modes of foamgenerating devices and the efficiency of foam creation while performing experimental and industrial research;
- developing and explaining the rational scheme of strap in equipment and devices for washing oil and gas wells with foam in the process of industrial studies.

Methodology. It includes:

- experimental definition of the main parameters and work modes, considering the construction change of foamgenerating device;
- computer modelling of foam generating was performed with the purpose of optimizing its internal constructive elements.

Findings. Relations between geometrical shapes, parameters, work modes of foamgenerating devices and the efficiency of foam generating have been established.

Originality. Experimental studies on streaming of liquid, air and foam and their mixture through constructive elements of the equipment allow establishing regularities of the relation of the efficiency of foam generating with parameters and work modes of foamgenerating devices.

In addition to the above:

- relation between quality of foam generating and constructive peculiarities of single elements in the foamgenerating device has been defined;
- analytic dependences of movement of streaming of liquid, air and foam and the efficiency of foamgenerating device work from their constructive peculiarities have been experimentally explained;
- a method for choosing optimal constructive shapes of elements of foamgenerating devices that influence the formation of streams of liquid, air and foam have been scientifically explained.

Practical value. Rational geometrical shapes and parameters have been defined, optimal work modes of foamgenerating devices have been set, which are the basis for creating new high efficient 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: *a five-nozzle foamgenerating device, drilling with foam, gas and liquid mixture, aerative fluid, foam solutions*

Introduction. There have been shown laboratorial, experimental and industrial studies and trials of suggested optimal construction of the foamgenerating device, and offered the scheme of the strap of the circulating system while drilling with foam.

Based on the laboratory research, we can define the dependence of pressure in foam solution at the output and productivity of the foamgenerating device on parameters of liquid and air at the input for the main constructive elements of the foamgenerating device.

Based on industrial trials and research, we have found out that the usage of the foamgenerating device FGD-100x25-5 gives the possibility to reduce the usage of surfactants by 15...25 %; the foam produced with foamgenerating device FGD-100x25-5 saves necessary properties on the way from the foamgenerating device to the output of the well with the depth of 4700 m.

Analysis of the recent research and publications. The article analyses theoretical and experimental works, considering modern level of machines for foam solution preparation, namely, by Amiian A. V., Amiian V. A., Vasyliev V. Kh., Izzatdust E. S., Kovalenko V. I., Kuzmenko M. M., Mezhlumov A. A., Tykhomirov 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. We have researched the problems of laboratorial, experimental and industrial studies and trials, suggested the optimal construction of the foamgenerating device, and offered the scheme of the strap of the circulating system while drilling with foam. There has been determined the Dependence of pressure in foam solution at the output and productivity of the foamgenerating device on parameters and liquid and air supply at the input for the main constructive elements of the foamgenerating device.

Objectives of the article include the following: carrying out experimental and industrial studies to set the relation between geometrical shapes and parameters, work modes of foamgenerating devices and the efficiency of foam generation; experimental definition of the main parameters and work modes with accounting the construction change of the foamgenerating device; computer modelling of the foamgenerating device was performed with the purpose of optimizing its internal constructive elements.

Presentation of the main research and explanation of scientific results. Gas and liquid mixtures are dispersed systems that consist of two components – gas and liquid (a mixture of water and various chemicals: surfactants, inhibitors, stabilizers, and others).

The most widespread ones in the oil and gas industry are aerated liquid and foam. In our case we deal with foam and equipment which are associated with them and affect their quality. When drilling with foam compared to the drilling solution there is an increase in the mechanical speed of drilling in hard rock (by 4 times), you can prevent the absorption in porous and fractured rocks and mudding of permeable layers. When revealing and exploring productive horizons wells productivity increases by 1.5–2 times while shortening exploring time by 4–5 times [1].

While exploring productive horizons with anomalous ratio below 1.0 for washing there should be used mineralized aerated fluid with impurities of surface-active agents (surfactants) or petroleum-based liquid, and with a low coefficient of anomality we need foam and gas agents.

Aerated fluid and foam solutions are among the biggest polluters of the environment, because before re-injecting a mixture to drilling pipes gases are drained out which is accompanied by a large amount of gases and vapours from the liquid chemicals [2]. Any aeration allows adjusting the drilling fluid density in any extent and, thus, reducing or increasing hydrostatic pressure on the face. If foaming surfactant is added to the aerated liquid, it contributes to formation of very small air globules in the aerated fluid and turns the latter into foam.

Preparation of aerated (foam) drilling fluid there can be performed in three ways:

- using a clay-mixer;
- using an ultrasonic generator;
- via a mixer of fluid and air in the pump discharge line.

Let us consider in detail the way of making foam using mixer of liquid and air (the foamgenerating device) in the pump discharge line since the process of foam production in the clay-mixer is too long and low-efficient whereas while using hydrodynamic radiator foam has no necessary parameters for usage in the oil and gas industry. Foam pressure is low as fluid is given to the radiator under pressure of 0.6–0.8 MPa.

Getting foam in a production environment is carried out in special foamgenerating devices through intensive co-dispersion of foamgenerating solution and air. The effect of dispersion is achieved:

- during the movement of the gas flow through the foam solution;
- with action of moving devices on fluid in the air atmosphere or effect of moving fluid on any obstacle;
- exhaustion of the air with moving flow.

The process of foam generating is complex due to joint influence of numerous physical and chemical, physical and technical and other factors. Nowadays, foam used in drilling as a cleaning agent is produced only in a dispersed way in foamgenerating devices, which according to the design can be divided into the following main types:

- with foam generation because of multi-hits by the air and solution of a foamgenerator [3];
- with foam generation while bubbling the air and solution of a foamgenerator [4];
- with foam generation under the pressure through sprayer on the net [5];
- devices in which the flows of the air and solution of a foam generator are mixed by reverting spatulas-turbines that are triggered with automatic drive or cramped air coming in the device.

Currently there have been developed many different designs of foamgenerating devices. The analysis of constructions of various types of foamgenerating devices makes it possible to classify them. In all types of foamgenerating devices liquid is given with higher pressure compared to the air. The air is usually sucked into the mixing space. The air can be supplied at the atmospheric pressure or, more frequently used, the compressor pressure. The working fluid in foamgenerating devices is mainly used with surfactants additives. The liquid is fed into a one- or multi-nozzle insert. Mixing of the two phases may be due to saturation of liquid air (gas) or by centrifugal forces. Foaming can be performed in the mixing chamber; on the net (mesh bag); in a perforated tube; in a mixing chamber and grids; in the vortex chamber. The foamgenerating device can be directly set on the manifold mud pump or making a “bypass” which will allow turning it on during the transition to drilling with foam while revealing productive layers.

Along with the positive aspects of each design attention should be paid to their disadvantages:

- mandatory use of additional pumping units and compressor stations for producing foam of required parameters;
- failure of the device under the high liquid pressure;
- inability to saturate liquid with gas qualitatively under the high fluid supply due to limited contact area of the liquid with the air;
- inability to regulate the input parameters of liquid and gas;
- one-nozzle devices do not provide sufficient saturation efficiency of liquid with gas because of only one mixing chamber;
- low efficiency of devices for use with viscous drilling fluids.

Thus, the main factors affecting the performance of foamgenerating devices are: composition and properties of liquid and gas; properties of surfactants; the pressure of liquid, gas or foam in different parts of their movement; change in pressure at the outlet of the foamgenerating device and others.

However, most works do not widely consider the impact of the design and parameters of liquid and gas environments on work of foamgenerating devices. Therefore, it is appropriate to conduct theoretical, experimental and computer studies to determine the optimal parameters and modes of equipment for washing of wells with foam solutions (foam). It is necessary to define the relationship between quality foam and design of the individual parts in the foamgenerating device.

Therefore there have been conducted theoretical studies to identify and determine the impact of the most significant factors as well as select the optimal geometric parameters and modes of foamgenerating devices that provide the highest efficiency of well washing with foam. There have been carried out computer studies of one-nozzle foamgenerating devices to establish the relationship between geometric forms, parameters, modes of operation and efficiency of foam generation [6].

To provide multi-staged fluid mixing with air, which helps create a stable small-dispersed foam, it is recommended to use multi-nozzle foamgenerating devices, the geometric parameters of which are selected taking into account the conducted computer research on the one-nozzle device [7]. Foamgenerating devices were compared during the change of fluid supply at the input, the air pressure at the input in the inlet pipe and the foam pressure at the output of the device.

We observe a three-calculative model of the five-nozzle foamgenerating device of optimal construction and geometrical parameters [8] that have been defined while studying one- and five-nozzle devices.

While conducting computer research on one- and five-nozzle foamgenerating devices, having counted different modes of their exploitation, we obtained the graphic dependences of necessary pressures of fluid at the inlet to the device, depending on the value of foam pressure at the outlet.

The results of computer modelling of the five-nozzle foamgenerating device which worked at the gas-liquid mixture allowed setting regularities of foam parameter change due to geometrical sizes of the device as well as supply and pressure of liquid and air at the input in the device.

With the purpose of checking the authenticity of results of theoretical and computer studies it is expedient to carry out experimental probations. For it, having considered the results of the computer research, we produced the five-nozzle device that has been granted a patent [9].

The closest to the developed device is the foamgenerating device [3]. The disadvantages of the device include constant geometric dimensions of nozzle diameters and lengths of the mixing chamber that prevent obtaining foam mixture with a wide range of properties that are required in drilling oil and gas wells.

The design of the developed device allows changing the length of the mixing chamber by installing a different number of diffuser discs and spacer rings of the general diffuser in its shell. There are also used variable nozzles of changeable diameters.

For research in the laboratory a scheme of the experimental setup was developed (Fig. 1).

This scheme works in the following way: for washing of a well with foam we need to open locking elements *8*, *9* and *17*. Then we need to launch the pump *2* and compressor *3* and after it we carry on the observation for displays of gauges *10*, *11* and *15*. Doing so, *12*, *13* and *16* are to be opened.

The fluid and air go through the foamgenerating device *1*, creating the foam, which is given to the bowl of its hoarding, after this we execute the probation of foam. In the process of experimental studies it is allowed to change the pressure and volume giving of fluid and gas (air).

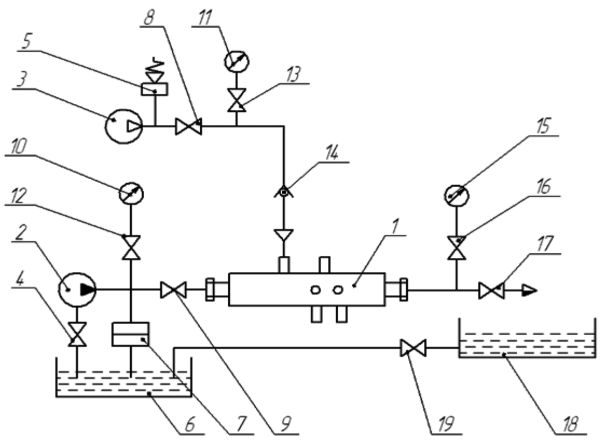
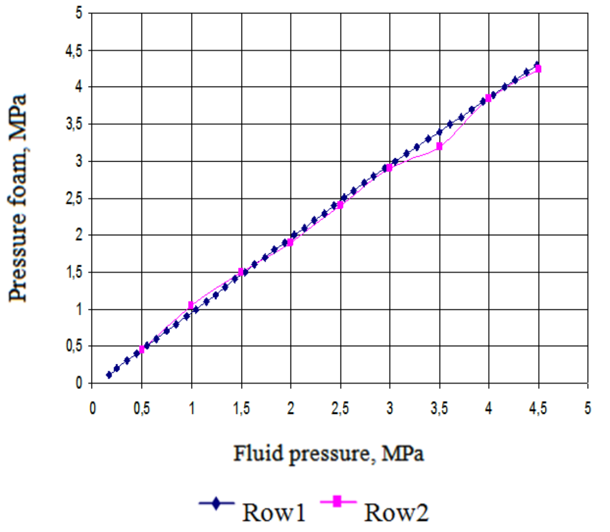


Fig. 1. The scheme of experimental set for researching the foamgenerating device in laboratory conditions:
1 – the foamgenerating device; 2 – the pump; 3 – the compressor; 4 – the locking element of the suction line*; 5 – the safety* valve *of the* air line*; 6 – the bowl with liquid; 7 – the safety* valve *of the heating line; 8 – the locking element of the air line; 9, 17, 19 – valves; 10, 11, 15 – gauges; 12, 13, 16 – the locking armature; 14 – the inverse valve; 18 – the bowl of foam hoarding*

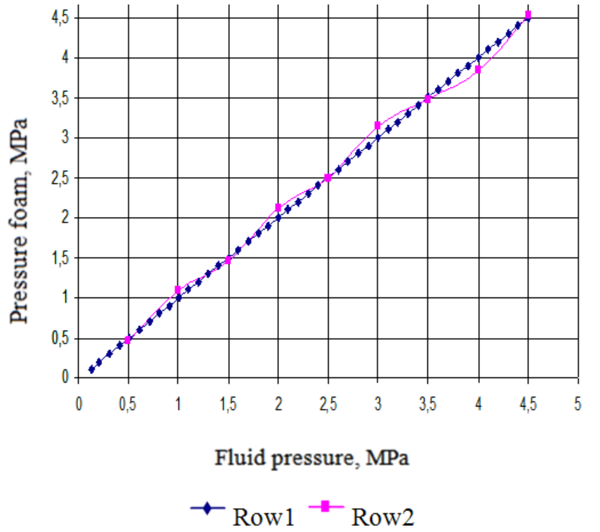
If it is necessary to change parameters in the foamgenerating device after stop of pump *2* and compressor *3*, we need to reduce the pressure in the system (the control is executed over displays of gauges *10*, *11*, *15*). After the absence of pressure in the system has been confirmed, we need to mount the foamgenerating device *1*. Having taken apart the device, we can alter the nozzle inserts and set nozzles of other diameters and change the length of mixing camera and diffuser along the axis.

While performing the research the most important parameters for measuring were the pressure and supply of gas and fluid at the input of the foamgenerating device and the pressure and supply of foam at the output of the device. The results are the following.

On the basis of the laboratory and experimental studies the dependence of the pressure of foam solution at the output and productivity of the foamgenerating device on the pressure and supply of fluid and air at the input for the main structural elements of the foamgenerating device has been defined, graphic dependences of correlation of experimental data with theoretical curves have been developed (Fig. 2). While exploring the foamgenerating device with fluid supply at the input being 0.0011 m^3/s, we obtained the resulting regression equation $y = 0.9x + 0.0222$ and reliability factor of approximation $R^2 = 0.9978$, whereas with fluid supply at the input 0.00056 m^3 / s we obtained the following regression equation $y = 0.9003x + 0.0575$ and reliability factor of approximation $R^2 = 0.9986$.



a



b

Fig. 2. The dependence of forecast foam pressure on the outlet from the foamgenerating device on fluid pressure on the inlet with air pressure 0.2 MPa on the inlet and fluid giving:
a – 0.00056 m^3/s; b – 0.0011 m^3/s; Row 1 – the theoretical research; Row 2 – the experimental research

The analysis of the experimental studies was conducted in comparison with the theoretical research whose methods are presented in [6]. Good agreement of theoretical and experimental research points to the possibility of using the foamgenerating device design for production of stable small-dispersed foam.

The main purpose of field tests was to validate the effectiveness of the foamgenerating device FGD-100x25-5 for preparation of foam solution.

To enable the most efficient use of the foamgenerating equipment there is provided a scheme of the strap of the circulating system while drilling with foam developed on the basis of Patent No. 42464 of Ukraine.

The implementation of well washing by foam is provided using the foamgenerating devices which are to be mounted in the field of bypass with valves. If it is necessary to implement the circulation by fluid, we have to close by-pass valves and open common line valve. For aeration of circulating solution we have to open by-pass valves and close common line valves. The air is given to foamgenerating devices with the help of the compressor. The adjusting of air flow is carried on with the help of valves.

During the industrial research we measured supply and pressure of the fluid and air at the inlet and foam supply and pressure at the outlet of the foamgenerating device. Reduction to 25 % of surfactants content (sulfanol) did not influence the quality of created foam. To expand work modes of the foamgenerating device it is possible to change the nozzle diameter, length of mixing camera, including the diffusor length, and, if it is necessary, to put out of action one or several nozzles. The foam, produced using the foamgenerating device, saves the necessary properties on its way from the device to the outlet of the well with depth nearly 4700 m. The results of the industrial research on the foamgenerating device FGD-100x25-5 are presented in industrial research reports at wells No. 201 of Hadiach area and No. 172 of Kotelevska area.

During the industrial research, high efficiency of work of the foamgenerating device FGD-100x25-5 has been confirmed. The results of the research were recorded at a scientific and production meeting in CLR "Techcomplectservice", where it was recommended to develop technical documentation for producing foamgenerating devices FGD-100x25-5 and introduce them at enterprises of oil and gas field.

In further studies it is appropriate to consider means of generating three-phase foams, in formation of which one of the dominant factors is hard seed that can change the structure of water films [10].

Research conclusions and recommendations for further research. As a result of computer, industrial and experimental studies we resolved an important scientific and practical task, which was to establish regularities of foam solution production for washing oil and gas wells while drilling and revealing wells which allowed developing a highly effective foamgenerating device and recommendations for its implementation at the workplace, including.

The conducted laboratory and experimental studies of the proposed design of the foamgenerating device revealed the impact of configuration of basic structural elements on the effectiveness of foam generation. On the basis of the laboratory and experimental studies the dependence of the pressure of foam solution at the output and productivity of the foamgenerating device on the pressure and supply of fluid and air at the input for the main structural elements of the foamgenerating device has been defined.

While performing the industrial research and trials of the foamgenerating device we have established the following:

- the proposed schemes of straps of the circulation while drilling with well washing with foam are practical and rational;
- the designed foamgenerating device is convenient when installing it into the existing pump and circulating system or additional strap for well washing with units, by using rapidly collapsible threaded connection;
- the designed multi-nozzle foamgenerating device makes it possible to change the degree of foam aeration by allowing the regulation of liquid and air supply;
- the trialled foamgenerating device makes it possible to change the nozzle diameter, the length of the mixing chamber and, if necessary, suspend the work (suppression) of one or more nozzles;
- the usage of foamgenerating device FGD-100x25-5 makes it possible to reduce the use of surfactants by 15...25 %;
- the mechanical drilling speed has increased by 1.5 times, the absorption of drilling fluid (foam solution) was not observed;
- foam produced with the foamgenerating device FGD-100x25-5 saves the necessary properties on the way from the foamgenerating device to the outlet from the well with a depth of 4700 m;
- the designed multi-nozzle foamgenerating device is highly effective and safe in operation in industrial environments;
- after testing and research in foamgenerating device no defects and damages occurred and it can be used at wells that are washed with foam.

References.

1. Luzhanytsia, O.V., Pedenko, Yu.O., Doliuk, I.P., Nazarenko, S.O. and Luzhanytsia, 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, Ivano-Frankivsk: IFNTUNG*, 3(16), pp. 9–14 [online]. Available at: <http://library.nung.edu.ua/sites/default/files/articles/213p.pdf> [Accessed 4 December 2016].

2. Shkitsa, L.E., Yatsyshyn, T.M., Popov, A.A. and Artemchuk, V.A., 2013. The prediction of contaminators distribution in the atmosphere on the territory of the drilling unit. *Neftyanoe hazyaystvo*, 11, pp. 136–140.

3. Ponomarenko, V.V., Pushanko, M.M. and Kopylenko, A.V., 2016. *The liquid and gas ejector*. Ukraine. Pat. 107169.

4. Kolesnik, Yu.V., Meshengisser, Yu.M., Shulikov, O.S. and Zhurba, M.S., 2014. *The aerator*. Ukraine. Pat. 104775.

5. Kabanov, A. I., Miller, V. A. and Chernov, A. N. *The aerator*. The Russian Federation. Pat. 2214915 [online]. Available at: <http://penzavod.ru/penogenerator-patent-rf-2214915> [Accessed 17 December 2016].

6. Lyakh, M. M., Savyk, V. M. and Molchanov, P. O., 2016. Improving the efficiency of foamgenerating devices of pump-circulative systems of drilling sets. *Naykovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, 3, pp. 23–30.

7. Dzyiuban, A. V., 2013. The computer modelling of hydrodynamic effects appearing in the shrinking device. *Naukovi praci. DonNTU; Seria: Himiya I himicha tehnologiya,* 2(21), pp. 169–179.

8. Sergiyenko, A. M., Valery, P., Simonenko, V. P. and Simonenko, A. V., 2016. Improved algorithm for appointment scheduler in a heterogeneous distributed computing systems. *System Research and Information Technologies* [e-journal]. 2, http://dx.doi.org/10.20535/SRIT.2308-8893.2016.2.03.

9. Savyk, V. M., Lyakh, M. M. and Myhayliuk, V. V., 2013. *The multi-nozzle foamgenerating device*. Ukraine. Pat. 77955.

10. Biletskyi, V. S., Shendrik, T. and Sergeev, P., 2012. Derivatography as the method of water structure studying on solid mineral surface. In: *Geomechanical Processes During Underground Mining*. London: CRC Press Taylor & Francis Group, pp. 181–184. http://www.crcnetbase.com/doi/pdfplus/10.1201/b13157-31.

Мета. Встановлення й дослідження раціональних конструктивних параметрів піногенеруючих пристроїв. Поставлена мета досягається через реалізацію наступних задач:

- виконання комп’ютерних досліджень багатосоплових піногенеруючих пристроїв і вибір оптимальних геометричних параметрів і режимів їх роботи, які би забезпечили найвищу ефективність промивання свердловини пінами;
- встановлення взаємозв’язку між геометричними формами, параметрами, режимами роботи піногенеруючих пристроїв та ефективністю піноутворення в результаті проведення експериментальних і промислових досліджень;
- розроблення та обґрунтування раціональної схеми обв’язки обладнання й пристроїв для промивання нафтогазових свердловин пінами у процесі промислових досліджень.

Методика. Включає:

- експериментальне визначення основних параметрів і режимів роботи з урахуванням зміни конструкції піногенеруючого пристрою;
- комп’ютерне моделювання піногенеруючого пристрою проводилося з метою оптимізації його внутрішніх конструктивних елементів.

Результати. Встановлено взаємозв’язок між геометричними формами, параметрами, режимами роботи піногенеруючих пристроїв та ефективністю піноутворення.

Наукова новизна. 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 й конструктивними особливостями окремих елементів піногенеруючого пристрою;
- 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. Визначені раціональні геометричні форми й параметри, встановлені оптимальні режими роботи піногенеруючих пристроїв, що є основою для створення нових високоефективних пристроїв. Запропонована низка методів і 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: *п’ятисопловий піногенеруючий пристрій, буріння пінами, газорідинна суміш, аеровані рідини, пінні розчини*

Цель. Установление и исследование рациональных конструктивных параметров пеногенерирующих устройств. Поставленная цель достигается через реализацию следующих задач:

- выполнение компьютерных исследований многосопловых пеногенерирующих устройств и выбор оптимальных геометрических параметров и режимов их работы, которые бы обеспечили высокую эффективность промывки скважины пенами;
- установление взаимосвязи между геометрическими формами, параметрами, режимами работы пеногенерирующих устройств и эффективностью пенообразования в результате проведения экспериментальных и промышленных исследований;
- разработка и обоснование рациональной схемы обвязки оборудования и устройств для промывки нефтегазовых скважин пенами в процессе промышленных исследований.

Методика. Включает:

- экспериментальное определение основных параметров и режимов работы с учетом изменения конструкции пеногенерирующего устройства;
- компьютерное моделирование пеногенерирующего устройства проводилось с целью оптимизации его внутренних конструктивных элементов.

Результаты. Установлены взаимосвязи между геометрическими формами, параметрами, режимами работы пеногенерирующих устройств и эффективностью пенообразования.

Научная новизна. 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;

- 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, влияющих на формирование потоков жидкости, воздуха и пены.

Практическая значимость. Определены оптимальные геометрические формы и параметры, установлены оптимальные режимы работы пеногенерирующих устройств, которые являются основой для создания новых высокоэффективных 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: *пятисопловое пеногенерирующее устройство, бурение пенами, газожидкостная смесь, аэрированные жидкости, пенные растворы*

Рекомендовано до публікації докт. техн. наук В. С. Білецьким. Дата надходження рукопису 07.10.16.

UDC 622.276.054

R. M. Kondrat, Dr. Sc. (Tech.), Prof.,
L. I. Khaidarova

Ivano-Frankivsk National Technical University of Oil and Gas, Ivano-Frankivsk, Ukraine, e-mail: lilya.matiishun@gmail.com

ENHANCED GAS RECOVERY FROM DEPLETED GAS FIELDS WITH RESIDUAL NATURAL GAS DISPLACEMENT BY NITROGEN

Р. М. Кондрат, д-р техн. наук, проф.,
Л. І. Хайдарова

Івано-Франківський національний технічний університет нафти і газу, м. Івано-Франківськ, Україна, e-mail: lilya.matiishun@gmail.com

ПІДВИЩЕННЯ СТУПЕНЯ ВИЛУЧЕННЯ ГАЗУ З ВИРОБЛЕНОГО ГАЗОВОГО РОДОВИЩА ВИТІСНЕННЯМ НЕВІДІБРАНОГО ПРИРОДНОГО ГАЗУ АЗОТОМ

Purpose. Evaluation of technological efficiency of a method for increasing final gas recovery from a depleted gas field with residual natural gas displacement by nitrogen.

Methodology. Computer research on the regularities of residual natural gas displacement by nitrogen from a circular shaped depleted gas field using licensed computer program CMG (Computer Modelling Group).

In the research is founded change in time of technological development indicators of gas production from the field for different values of a pressure of early nitrogen injection into the gas field and for duration of injection time.

Findings. According to the results of the computer research on the patterns of residual natural gas displacement by nitrogen from depleted gas field, there is received change of reservoir pressure by the years, flow rate of production well of gas and nitrogen, and gas recovery factor depending on the pressure of early nitrogen injection into the gas field and duration of injection period.

Originality. For the first time regularities of the process of residual natural gas displacement by nitrogen and optimal values of the pressure of early nitrogen injection into the gas field and duration of injection period are obtained for circular shaped depleted gas field.

Practical value. Injection of nitrogen into depleted gas field for the corresponding values of pressure of early nitrogen injection and duration of the period of its injection allows intensifying the process of further development of the field as well as increasing the current production of gas and gas recovery factor by 5–10 %.

Keywords: *field, well, gas, nitrogen, injection, gas recovery, pressure, flow rate*