UDC 622.276.054

R. M. Kondrat, Dr. Sc. (Tech.), Prof.,
N. S. Dremliukh,
A. V. Uhrynovskyi, Cand. Sc. (Tech.)

Ivano-Frankivsk National Technical University of Oil and Gas, Ivano-Frankivsk, Ukraine, e-mail: rengr@nung.edu.ua; nataliadremluh@ukr.net

STUDY OF FOAM FORMATION PROCESS WITH USE OF WATER SOLUTIONS OF FOAM-FORMING PAIRS AND FOAM STABILIZERS

Р. М. Кондрат, д-р техн. наук, проф.,
Н. С. Дремлюх,
А. В. Угриновський, канд. техн. наук

Івано-Франківський національний технічний університет нафти і газу, м. Івано-Франківськ, Україна, e-mail: rengr@nung.edu.ua; nataliadremluh@ukr.net

ДОСЛІДЖЕННЯ ПРОЦЕСУ ПІНОУТВОРЕННЯ З ВИКОРИСТАННЯМ ВОДНИХ РОЗЧИНІВ ПІНОТВОРНИХ ПАР І СТАБІЛІЗАТОРІВ ПІНИ

Purpose. Evaluation of foam-forming properties of various surface-active substances (SAS) with addition of stabilizing agents to obtain stable foams.

Methodology. A laboratory model of a well was developed to study the impact of type, concentration and temperature of SAS and stabilizing agents on the foam formation process properties in fresh water. In the course of studies the height of foam level in the glass column at the end of the foam formation process and time required to extract the half of fluid bound in the foam were determined; according to their values, the foam expansion ratio and stability were defined.

Findings. Based on the results of experimental studies using the laboratory model of a well, graphical dependencies of the foam expansion ratio and stability on determining parameters (SAS and stabilizing agent type, concentration and temperature) were plotted; according to these parameters, SAS type and stabilizing agents were selected to ensure the highest values of the foam expansion rate and stability. Using mathematical statistical methods, the optimum values of SAS and foam stabilizing agent concentration were determined, at higher values the foam expansion ratio and stability vary insignificantly. Two compositions of SAS and foam stabilizing agents were developed – one of them is proposed to be used for flushing out sand plugs in the bottom hole, the other one shall be used for continuous injection into the well annular space to prevent solid phase accumulation down the hole.

Originality. Based on the experimental studies, patterns of SAS water solutions foaming with and without addition of foam stabilizing agents were determined, a new composition of SAS and stabilizing agents was developed for stable foam formation with modelling of bottom-hole temperature (from 20 to 60 °C).

Practical value. The optimum values of foam-forming SAS and stabilizing agent concentrations in water solutions were determined to obtain stable foams. Research results can be used to flush out sand plugs in the bottom holes at depleted gas and gas condensate fields and to prevent accumulation of solids down the hole.

Keywords: *stabilizing agents, foam expansion ratio and stability, well model, foam formation*

Introduction. The operation of gas and gas condensate wells with unstable reservoirs is accompanied by removal of rock particles from the formation and their accumulation at the bottom hole with formation of sand plugs.

Sand plugs cause the well flow rate reduction and may result in tubing string sticking. While operating wells, sand plugs are mainly flushed with water solutions of surface-active substances (SAS). Use of SAS water solution as a flushing-out agent in depleted gas fields with reduced formation pressure may lead to the formation absorbing a considerable amount of water, which is difficult to be removed from the formation. As a result, it sometimes happens that after flushing-out of sand plugs, the well flow rates are considerably lower than they were before that.

At depleted gas fields, low-density flushing-out agents, in particular, foams with high expansion ratio and considerable stability, should be used to remove sand plugs.

The foam stability is of great importance for removal of sand with a flushing-out agent from the bottom hole. Low foam stability may result in foam-breaking and solid phase particles will fall out and deposit on the tubing string couplings and form bridge sand plugs in the annular space. To enhance the foam stability, stabilizing agents are used. They are organic compounds having a high hydrophilic ability and water solubility, they reduce solution and film viscosity, inhibit fluid flowing-out of the foam.

In oil and gas industry practice organic polymers are used as stabilizing agents. They consist of a row of repeatable or similar groups of atoms called monomers and are carbon compounds. The starch (industrial starch, modified starch), guar and xanthane gums, technical gelatine belong to natural polymers (biopolymers). Carboxymethyl cellulose and hydroxyethyl cellulose belong to organic polymers [1].

There are also known foam stabilizers based on mud powder. They are used to drill in productive formations [2]. To increase resistance of mud fluid to action of high temperatures, carboxyl-containing reagents (hydrolyzed polyacrylonitrile, M-14, metacryl copolymer, polyacrylimide) are used, they are heat-resistant, but ensure satisfactory salt resistance for monovalent cations only. The reagents are characterized by low inhibitory properties relative to unstable clays and argillites [1]. Polyacrylimide is also used for acid bath thickening during the bottom-hole zone acid treatment, for alignment of the fluid displacement front of low-permeability formation compartment [3, 4].

Carboxymethyl cellulose is successfully used as a substitute for conventional gelling agents during hydraulic fracturing of formation [5].

M. A. Yusupkhodzhaiev's [6] studies are known which suggest application of carboxymethyl cellulose as a stabilizing agent for sand plug removal, but there are no literary data on use of stabilizing agents for fluid removal from the bottom hole using foaming at gas and gas condensate fields.

Analysis of the recent rsearch and publications. A number of published works have been devoted to issues of foam systems use for flushing out sand plugs and fluid removal from the bottom holes of gas and gas condensate wells. But most studies on foam systems were performed without application of foam stabilizing agents, thus, serving as a basis for additional studies.

Unsolved aspects of the problem. There are no literary data on the impact of stabilizing agents on foam expansion ratio and stability. The data on application of different types of SAS and foam stabilizing agents for flushing out sand plugs using foam systems have been covered insufficiently.

Objectives of the article. Considering the results of the latest studies analysis, additional studies should be performed to select a composition of SAS and foam stabilizing agents for flushing out sand plugs in the bottom holes at depleted gas and gas condensate fields and determine the optimum values of solution concentrations of foam-forming SAS and stabilizing agents to obtain stable foams.

Presentation of the main research. Unlike incompressible fluids, foam systems are less dense and have higher removal ability, which allows flushing sand plugs out of the well without negative impact on the formation in comparison with other flushing-out fluids.

The following foam types are used in oil and gas industry practice: two-phase foam (obtained by aeration of SAS treated water), three-phase foam (prepared by mud solution aeration with SAS addition), foam-acid (aerated acid solution with SAS addition).

Two-phase foams are used for flushing out sand plugs in the wells with 0.2–0.7 formation pressure from hydrostatic pressure, well development and fluid removal from the bottom hole of gas and gas condensate wells. Three-phase foams are used for flushing out sand plugs in the wells, where the formation pressure is equal to hydrostatic pressure, for drilling in productive formations with low formation pressures. Acid foams are used for treatment of the formation bottom-hole zones to intensify gas and oil flow to the well bottom hole.

The three-phase foam, based on mud solution, is more stable than the two-phase one. The three-phase foam disadvantage is that during flushing-out of wells using three-phase foams within the open circulation system, more SAS, chemical agents and power are required to prepare new portions of a flushing-out agent. A three-phase stable foam, rising to the day surface in large amounts, is not subject to breaking and requires large financial costs for its disposal; this factor restricts its use in compliance with more stringent environmental protection requirements Two-phase foam is mainly used for flushing out sand plugs [2].

In oil and gas industry practice water solutions of various foam-forming SAS are used for foam preparation, natural gas, nitrogen, carbon dioxide and other gases are used as the gas phase [2].

The surface-active substance (SAS) is the main component giving viscoplastic and elastic properties to the foam. Absorbing on the gas bubble shells, SAS has a significant effect on the property of bubbles and all types of processes occurring with application of foam systems [6].

The following factors have an effect on SAS foam-forming ability: SAS molecular structure, SAS concentration in the solution, temperature, surface tension force, various admixtures. The foam-forming ability of SAS solutions depends on the arrangement of hydrophilic group in the molecule: the closer it is arranged to the centre of a molecule, the higher foam-forming ability is [2].

The most important characterizing parameters of the foam system are as follows: density, viscosity, expansion ratio, resistance and elastic properties (compressibility) [6].

Various criteria are used for evaluation of SAS foam-forming properties: foam-forming ability of the solution, foam expansion ratio, foam stability (resistance) and dispersion ability [7].

The foam-forming ability of the solution (foaming property) is the foam amount expressed in volume (ml) or column height (mm) may be obtained in certain conditions (foam-forming method, temperature, SAS concentration, expandable fluid, etc.) from a certain solution volume [8].

The foam expansion ratio is the formed foam volume ratio V_f to foam-forming fluid volume V_{fl} [2].

The expansion ratio is a characteristic of the foam structure. The more foam volume is obtained from one and the same volume of foam-forming fluid, the larger gas bubbles will be in the foam (with other identical conditions), and the foam will be less stable [2].

The foam stability is the value inverse to rate of volume flow of foam subsidence – the ratio of period required to extract the half of fluid bound in the foam to the extracted volume of fluid.

The foam stability depends on many factors: SAS type and concentration, content of the stabilizing agent, electrolyte and other admixtures in the foam-forming solution, as well as on the medium acidity and content of salts in foam-forming solutions. The foam expansion ratio and stability are low in hard water, being very low in sea water [2].

With pressure increase, the foam stability rises considerably, while with temperature rise it goes down. If SAS concentration in the solution increases, the foam stability increases and reaches the maximum value at the critical concentration of micelle formation and then it goes down [2].

The foam dispersion is characterized by an average size of gas bubbles or size distribution of bubbles. With pressure increase, the diameter of bubbles in the foam goes down, and the foam dispersion goes up [6].

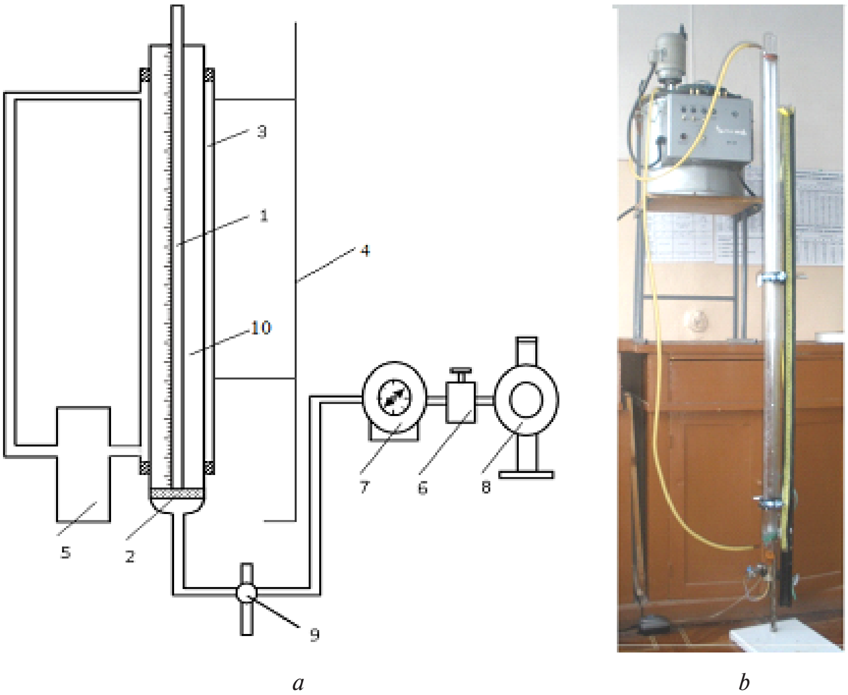
Description of the pilot unit and research procedure. Experiments on selection of SAS and chemical foam stabilizing agents for foam formation with high foam-forming properties were performed on the pilot plant whose schematic diagram and general view are shown in Fig. 1.

The unit consists of the following main parts: internal glass column 1 1.5 m long with the outer diameter of 0.03 m and with quartz porous membrane 2 in the lower part, external glass column 3, 1.4 m long with the outer diameter of 0.044 m fixed to stand 4 by means of two fasteners.

The required temperature in the annular space of the glass columns was maintained using thermostat 5. 20 cm^3 of analysed SAS solution was poured into column 1, then gas (air) was vented upward through porous membrane at constant flow rate of 16.6 cm^3/s (1l per 60 s). The gas flow rate was regulated using flow regulator 6 and recorded using gas meter 7. Compressor 8 served as a source of gas (air) for the research. After passing 0.5 l of gas (in 30 s after the beginning of the research) its supply to the column was stopped using three-way cock 9, the foam expansion ratio and stability were determined.

Various surface-active substances were used for foam formation. They belong to four basic classes: anionic, non-ionic, cationic and amphoteric. The range of SAS, used to remove sand plugs, is quite wide, but anionic and non-anionic SASs having a high foam-forming ability are applied most often.

The solutions of savenol SWP, stinol and sofir M2 in fresh water with mass concentrations of 0.125; 0.25; 0.5; 1; 2; 4 % were studied. Among the mentioned SASs, savenol SP is a mixture of hydrated non-ionic SAS, stinol is a synergetic mixture of anionic and non-ionic SAS, sofir M2 is an anionic SAS. Savenol SWP, stinol and sofir M2 are non-toxix SASs manufactured by do-



a *b*

Fig. 1. Schematic diagram (a) and general view (b) of laboratory plant to study foam-forming properties of surface-active substance solutions:

1, 3 – glass columns; 2 – quartz porous membrane; 4 –stand; 5 – thermostat; 6 – gas flow regulator; 7 – gas meter; 8 – compressor; 9 – three-way cock; 10 – measuring bar mestic enterprises and used during repair works in gas and gas condensate wells, as well as for intensification of fluid removal by foaming.

During the research natural biopolymers xanthan gum (xanthan resin), guar gum (guar resin) and carboxymethyl cellulose (CMC) with mass concentration of 0.25 and 0.5 % were used as foam stabilizing agents. The listed biopolymers decompose in soil and are environmentally safe, in some cases they may serve as sources of feeding plants with monosaccharides and disaccharides formed during their decomposition [9]. The xanthan and guar gums are also used in cosmetic, pharmaceutical and food industries as a gelling agent, structure-forming agent, thickener and stabilizing agent [10].

The experiments were performed at 20, 40 and 60 °C and 0.1013 MPa of atmospheric pressure.

Research results. The generalized research results are shown in Figs. 2–5 as a dependence of foam expansion ratio K and stability S on mass concentrations of SAS in water solution at different temperatures with and without foam stabilizing agents.

The analysis of experimental data on foam-forming properties of various SASs testifies that with increasing temperature, expansion ratio of the foam formed from water solutions of the analysed SAS increases continuously and the foam stability reduces.

Savenol SWP demonstrated the highest foam-forming ability, stinol and sofir M2 – to a less degree. Solutions of savenol SWP and sofir M2 in fresh water have the most stable foam, stinol solution has the least stable foam for all the temperature values analysed.

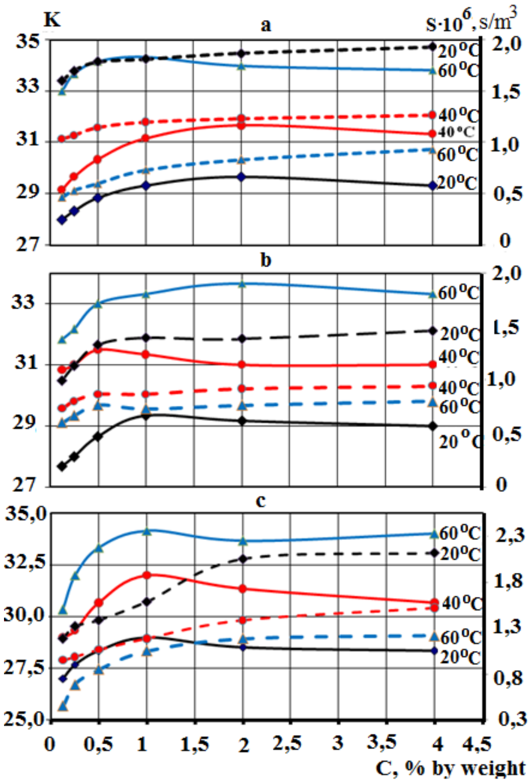


Fig. 2. Dependence of foam expansion ratio and stability on SAS mass concentration in fresh water at different temperatures:

a – savenol SWP; b – stinol; c – sofir M2; ——— – foam expansion ratio; - - - – foam stability

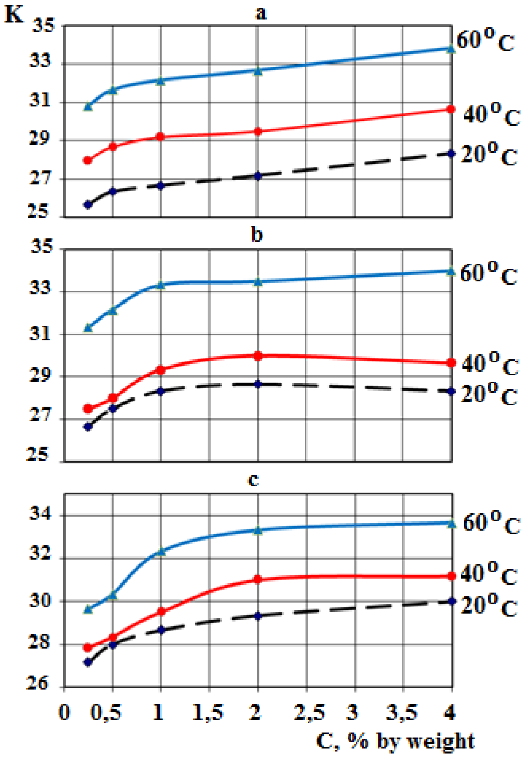


Fig. 3. Dependencies of the foam expansion ratio on SAS mass concentration of +0.5 % xanthan gum in fresh water at different temperatures for:

a – savenol SWP; b – stinol; c – sofir M2

For savenol SWP foam-forming properties vary within the following limits: at 20 °C foam expansion ratio is 27.67–29.67, foam stability is $1.6 \cdot 10^6$– 1.93×10^6 s/m^3; at 40 °C foam expansion ratio is 29.33–31.67, foam stability is $1.03 \cdot 10^6$ –$1.27 \cdot 10^6$ s/m^3; at 60 °C foam expansion ratio is 33–34.33, foam stability is $0.47 \cdot 10^6$–$0.93 \cdot 10^6$ s/m^3.

For stinol foam-forming properties vary within the following limits: at 20 ° C foam expansion ratio is 27.67–29.33, foam stability is $1 \cdot 10^6$ –$1.47 \cdot 10^6$ s/m^3; at 40 °C foam expansion ratio is 30.83–31.5, foam stability is $0.73 \cdot 10^6$–$0.95 \cdot 10^6$ s/m^3; at 60 °C foam expansion ratio is 31.83–33.67, foam stability is $0.6 \cdot 10^6$–$0.8 \cdot 10^6$ s/m^3.

For sofir M2 foam-forming properties vary within the following limits: at 20 °C foam expansion ratio is 27–29, foam stability is $1.13 \cdot 10^6$–$2.07 \cdot 10^6$ s/m^3; at 40 °C foam expansion ratio is 29–32, foam stability is $0.9 \cdot 10^6$–$1.47 \cdot 10^6$ s/m^3; at 60 °C foam expansion ratio is 30.33–34.17, foam stability is $0.4 \cdot 10^6$–$1.17 \cdot 10^6$ s/m^3.

For all the temperature values analysed a general tendency is observed: the foam expansion ratio and stability increase with increase of SAS concentration in fresh water.

By the results of statistical treatment of experimental data, using the least squares method, the optimum concentration of the analysed SAS in fresh water without addition of foam stabilizing agents is 0.5 %. With further increase of SAS concentration in fresh water, the foam

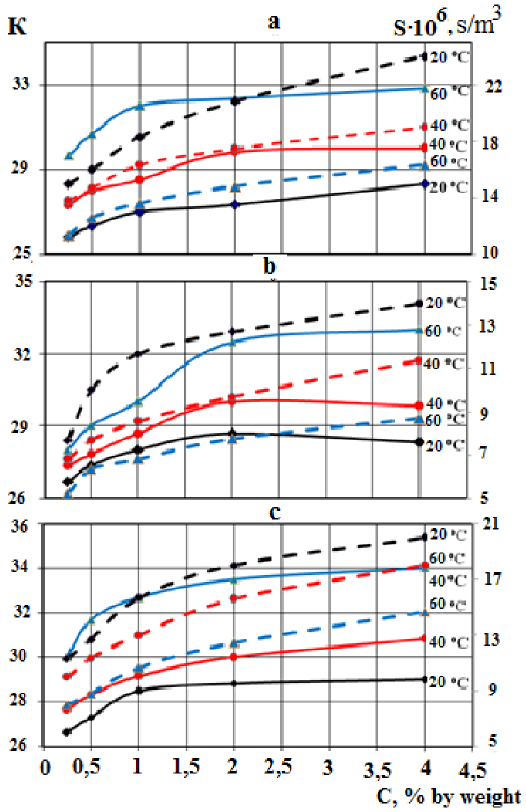


Fig. 4. Dependencies of the foam expansion ratio and stability on SAS mass concentration of +0.5 % guar gum in fresh water at different temperatures for:

a – savenol SWP; b – stinol; c – sofir M2; —— – foam expansion ratio; - - - – foam stability

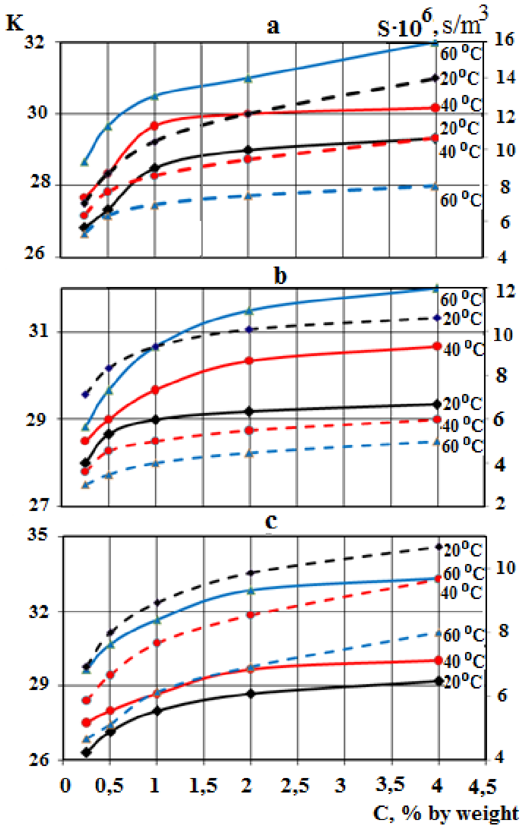


Fig. 5. Dependencies of the foam expansion ratio and stability on SAS mass concentration of +0.5 % CMC in fresh water at different temperatures for:

a – savenol SWP; b – stinol; c – sofir M2; —— – foam expansion ratio; - - - – foam stability

expansion ratio and stability increase insignificantly, the interval of SAS concentration change from 2 to 4 % remains almost unchanged.

The article presents the research results with use of stabilizing agents having 0.25 % of mass concentration, as at this concentration of stabilizing agents inhomogeneous (gas bubbles of different size) and unstable foam was obtained in comparison with the foam at 0.5 % concentration of stabilizing agents.

The analysis of the research results proves that at 0.5 % concentration of stabilizing agents in SAS solution in fresh water, the foam expansion ratio reduces, while the foam stability increases.

According to the research analysis, the foam is very stable when xanthan gum is added. It does not deposit in the glass column, the fluid is not produced from the foam during the period of more than 10 minutes. If guar gum and carboxymethyl cellulose are used after termination of air supply into the glass column, a gradual reduction of the foam column height is observed as a result of dispersion system breaking and extraction of fluid from the foam.

Solutions of sofir M2 and savenol SWP in fresh water with all the analysed stabilizing agents have the highest foam expansion ratio. Solutions of savenol and stinol in fresh water with xanthan gum have the highest foam stability. The foam is stable, homogeneous, with bubbles being of the same size.

During the research of SAS solutions with mass concentration of 0.125 and 0.25 % in fresh water with addition of stabilizing agents, inhomogeneous foam with bubbles of different size was obtained. The foam was breaking into parts.

The optimum concentration of the analysed SAS in fresh water with addition of stabilizing agents is 1 %, the optimum concentration of xanthan and guar gum is 0.5 % (according to the statistical treatment results of experimental data using the least squares method).

Foam stabilizing agents of xanthan and guar gums, which were not previously used in technological processes of sand plugs removal in the bottom holes, fluid removal from the bottom hole by foaming, ensure higher values of foam stability in comparison with carboxymethyl cellulose used during well drilling and repair.

Conclusion. According to the experimental research results, the foam expansion ratio and stability of the analysed SAS water solutions (savenol SWP, stinol and sofir M2) with stabilizing agents (guar and xathane gums, carboxymethyl cellulose) were evaluated. The compositions of foam-forming SAS and foam stabilizing agents were selected for formation of stable foam within temperature range from 20 to 60 °C, which may be used as flushing-out agents for removal of sand plugs in the bottom holes at depleted gas and gas condensate fields. According to the research results, the foams, formed from solutions of savenol SWP and stinol in fresh water with addition of xanthan gum, are the most stable. The optimum mass concentration of savenol SWP and stinol in fresh water is about 1 and 0.5 % of xanthan gum. Using these SASs and thickener, a stable foam is formed; it does not break in time with expansion ratio from 25.67 to 33.83 within temperature range from 20 to 60 °C.

To prevent accumulation of solid phase, coming from the formation in the bottom holes, it is recommended to inject water solution of SAS and foam stabilizing agents compositions with mass concentration of 1 % of savenol SWP or stinol and 0.5 % of guar gum into the well annular space.

References.

1. Minibaev, V.V., 2010. *Research and development of flushing-out fluids based on acrylic agents of multifunctional purpose*. PhD. Scientific Centre NVMT of the Russian Academy of Science.

2. Gasumov, R.A. and Minlikaev, V.Z., 2013. *Procedure and technology of well repair. Volume 1*. Moscow: LLC “Gazprom ekspo”.

3. Rudyi, M.I. and Rudyi, S.M., 2012. Thickened acid solutions based on acrylamide polymers and copolymers. *Equipment and technologies for oil and gas complex*, 4, pp. 36–39.

4. Altunina, L.K., Berezina, Ye.M., Manzhai, V.N., Nasibullina, Yu.R. and Shelest, N.N., 2011. Gel-forming composition of polyacrylimide and aluminium salts for oil recovery enhancement. *Izvestiya vysshikh uchebnykh zavedeniy. Neft i gaz*, 4, pp. 90–94.

5. Kalinin, V.R., Kozlov, Ye.N., Leontyev, D.S. and Kustyshev, A.V., 2015. CMC as a cost-effective alternative of GDP fluids based on guar, guar carboxymethylhydroxypropyl and surface-active substances. In: *All-Russian scientific and technical conference. Drilling of oil and gas wells. Machines and equipment of oil and gas fields. Development and operation of oil and gas fields*.

6. Yusupkhodzhaev, M.A., 2009. *Experimental research on foam systems for flushing-out process of sand plugs under low formation pressures using coil tubing*. PhD. I.M.Gubkin Russian State University of Oil and Gas.

7. Lutfullina, G.G. and Zinnatullina, Z.A., 2015. On possibility of regulation of SAS compositions foam-forming ability. *Kazan Technological University bulletin*, 18(15), pp. 197–199.

8. Paraska, O.A., Karvan, S.A. and Rak, T.S., 2014. Determination of foam formation properties in solutions of surface-active substances. *East European Journal of Advanced Technologies*, 3(69), pp. 36–41.

9. Struminska, O.O., Bailiak, M.M. and Kurta, S.A., 2014. Microbiological properties of natural film-forming agents. *East European Journal of Advanced Technologies*, 2(68), pp. 34–40.

10. Mysakov, D.S., Chugunova, O.V., Zavorokhina, N.V. and Pankratieva, N.A., 2014. Use of xanthan resin as a structure-forming agent during production of biscuit half-finished product. *New technologies*, 3, pp. 13–20.

Мета. Оцінка пінотворних властивостей водних розчинів різних поверхнево-активних речовин (ПАР) з додаванням речовин-стабілізаторів для отримання стабільних пін.

Методика. Створена лабораторна модель свердловини, з використанням якої досліджено вплив на характеристики процесу піноутворення типу та концентрації ПАР і речовин-стабілізаторів піни у прісній воді та її температури. У дослідах визначали висоту рівня піни у скляній колонці в кінці процесу піноутворення й тривалість часу виділення з піни половини об’єму рідини, зв’язаної в піну, за значенням яких визначали кратність і стійкість піни.

Результати. За результатами експериментальних досліджень на лабораторній моделі свердловини побудовані графічні залежності кратності та стійкості піни від визначальних параметрів (типу й концентрації ПАР і речовин-стабілізаторів та її температури), за якими вибирали тип ПАР і речовини-стабілізатори, що забезпечують найбільші значення кратності та стійкості піни. З використанням методів математичної статистики визначали оптимальні концентрації ПАР і речовин-стабілізаторів піни, вище яких кратність і стійкість піни змінюється мало. Розроблені дві композиції ПАР і речовин-стабілізаторів піни, одна з яких пропонується для промивання піщаних корків на вибої свердловини, а інша – для безперервного введення в затрубний простір свердловини з метою попередження накопичення твердої фази на вибої.

Наукова новизна. На основі експериментальних досліджень встановлені закономірності спінювання водних розчинів ПАР без додавання та з додаванням речовин-стабілізаторів піни, розроблено новий композиційний склад ПАР і речовин-стабілізаторів для утворення стійкої піни з моделюванням вибійної температури (від 20 до 60 °C).

Практична значимість. Визначені оптимальні значення концентрацій пінотворних ПАР і речовин-стабілізаторів у водних розчинах для отримання стійких пін. Результати досліджень можуть бути використані для промивання піщаного корка на вибоях свердловин на виснажених газових і газоконденсатних родовищах та попередження накопичення твердої фази на вибої.

Ключові слова: *речовини-стабілізатори, кратність і стійкість піни, модель свердловини, піноутворення*

Цель. Оценка пенообразующих свойств водных растворов различных поверхностно-активных веществ (ПАВ) с добавлением веществ-стабилизаторов для получения стабильных пен.

Методика. Создана лабораторная модель скважины, с использованием которой исследовано влияние на характеристики процесса пенообразования типа и концентрации ПАВ и веществ-стабилизаторов пены в пресной воде и его температуры. В опытах определяли высоту уровня пены в стеклянной колонке в конце процесса пенообразования и продолжительность времени выделения из пены половины объема жидкости, связанной в пену, по значению которых определяли кратность и стойкость пены.

Результаты. По результатам экспериментальных исследований на лабораторной модели скважины построены графические зависимости кратности и устойчивости пены от определяющих параметров (типа и концентрации ПАВ и веществ-стабилизаторов и его температуры), по которым выбирали тип ПАВ и веществ-стабилизаторов, которые обеспечивают наибольшие значения кратности и устойчивости пены. С использованием методов математической статистики определяли оптимальные концентрации ПАВ и веществ-стабилизаторов пены, выше которых кратность и устойчивость пены изменяются мало. Разработаны две композиции ПАВ и веществ-стабилизаторов пены, одна из которых предназначается для промывки песчаных пробок на забое скважины, а другая – для непрерывного ввода в затрубное пространство скважины с целью предупреждения скопления твердой фазы на забое.

Научная новизна. На основе экспериментальных исследований установлены закономерности вспенивания водных растворов ПАВ без добавления и с добавлением веществ-стабилизаторов пены, разработан новый композиционный состав ПАВ и веществ-стабилизаторов для образования устойчивой пены с моделированием забойной температуры (от 20 до 60 °С).

Практическая значимость. Определены оптимальные значения концентраций пенообразующих ПАВ и веществ-стабилизаторов в водных растворах для получения устойчивых пен. Результаты исследований могут быть использованы для промывки песчаной пробки на забоях скважин на истощенных газовых и газоконденсатных месторождениях и предупреждения скопления твердой фазы на забое.

Ключевые слова: *вещества-стабилизаторы, кратность и устойчивость пены, модель скважины, пенообразование*

Рекомендовано до публікації докт. техн. наук І. І. Чудиком. Дата надходження рукопису 26.05.16.

UDC 528.41: 622.1

S. V. Biehichev, Cand. Sc. (Tech.), Assoc. Prof.,
H. S. Ishutina, Cand. Sc. (Tech.),
L. O. Chumak, Cand. Sc. (Tech.), Assoc. Prof.

State Higher Educational Institution “Prydniprovs’ka State Academy of Civil Engineering and Architecture”, Dnipro, Ukraine, e-mail: sergey_begichev@ua.fm; anuta14044@meta.ua; gurchum@gmail.com

MODELLING GEODETIC NETWORK TO IMPROVE RELIABILITY OF SURVEYING PROVIDING OF MINING OPERATIONS

С. В. Бєгічев, канд. техн. наук, доц.,
Г. С. Ішутіна, канд. техн. наук,
Л. О. Чумак, канд. техн. наук, доц.

Державний вищий навчальний заклад „Придніпровська державна академія будівництва та архітектури“, м. Дніпро, Україна, e-mail: sergey_begichev@ua.fm; anuta14044@meta.ua; gurchum@gmail.com

МОДЕЛЮВАННЯ ГЕОДЕЗИЧНОЇ ОСНОВИ ДЛЯ ПІДВИЩЕННЯ НАДІЙНОСТІ МАРКШЕЙДЕРСЬКОГО ЗАБЕЗПЕЧЕННЯ ГІРНИЧИХ РОБІТ

Purpose. The purpose of this work is to develop a model of a geodetic reference network (in the form of a transition graph), which is located on the territory of mining leases and is prone to disruption as a result of impact of man-made factors to improve the reliability of surveying maintenance of open and underground mining.

Methodology. To assess the state of geodetic framework using graph theory and stochastic processes the estimation of its reliability has been done. The analytical model of surveyor-geodetic network as a graph of conversions has been developed. The matrix of conditional distribution functions of duration of stay of the geodetic network in different states and matrix of transition probabilities from the previous state to the next has been complied. The average time of duration of stay of geodetic network in a reliable and unreliable state using semi-Markov process has been estimated.

Findings. The choice of mathematical model which describes the state of geodetic network in a particular time to the fullest extent possible has been substantiated. The length of stay of geodetic network in each of its possible fixed states has been determined.

Originality. The use of graph theory and stochastic processes to create a mathematical model of transitions of surveyor-geodetic network of a reliable state into an unreliable one as a result of displacement of rocks, the earth’s surface and geodetic points located on it has been proposed for the first time. The duration of stay of the geodetic network in each of its possible fixed states has been determined. It allows carrying out a complex of works timely to restore geodetic network to ensure reliable surveying mining and experimental studies.

Practical value. The creation of a mathematical model of the geodetic network in the form of the transition graph by applying graph theory and semi-Markov process, allows identifying the time of decrease in reliability of geodetic

---