DNIPRO UNIVERSITY of TECHNOLOGY 1899

Mining of Mineral Deposits
ISSN 2415-3443 (Online) | ISSN 2415-3435 (Print)
Journal homepage http://mining.in.ua
Volume 13 (2019), Issue 2, pp. 82-90

UDC 622.276.64 https://doi.org/10.33271/mining13.02.082

# ENERGY-SAVING INTENSIFICATION OF GAS-CONDENSATE FIELD PRODUCTION IN THE EAST OF UKRAINE USING FOAMING REAGENTS

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## ABSTRACT

**Purpose.** Development of recommendations on the use of foaming surfactants (FSs) in the overall task of increasing energy and resource conservation of wells at the final stages of the development of gas condensate fields (GCFs).

**Methods.** To achieve the goal and solve the set tasks, following methods were used: active experiment method, regression and correlation analyzes of the obtained statistical data, comparative analysis of technological regulations for the intensification of well production.

**Findings.** Recommendations on the use of the studied FSs for intensifying the extraction of gas-condensate fluids with the specification of the geological and field characteristics of exploited fields in Eastern Ukraine in terms of Shebelynske and Zakhidno-Khrestyshchenske GCF were developed.

**Originality.** The dependence of the cross-correlation coefficient of the "additional gas production with the use of FSs – the number of well stimulation operations" upon the period of the influence of the FSs on the reservoir – well system, being of extreme nature, has been determined. It has been established that the effectiveness of the use of the additional part of productions debit depends linearly on the initial production rate and exponentially on the frequency of the well FS-treatment.

**Practical implications.** It has been determined that the maximum manifestation of the impact of considered FSs on downhole fluid production is achieved after 2 months. Various techniques for the application of the FSs were tested, and the regulations for the corresponding field operations were specified. Optimization of the parameter charts and processing procedures in terms of the concentration of FSs, system connection of the foam injection pipeline to the well, the rational period of introduction of the FSs in the reservoir-well system results in the decrease of the total downtime of wells during the period of operation under conditions of intensification as well as methane pollutions during purges.

***Keywords:*** *resource saving, gas condensate field, geological field conditions, well flow rate, foaming surfactants, foam surface-active substances*

## 1. INTRODUCTION

One of the main problems of well operation in the fields with the later development stages is retrograde condensation and water accumulation in the bottom-hole zone (Hou, Luo, Sun, Tang, & Pan, 2014). Under subnormal pressures, even small volumes of fluid lead to a gradual decrease in flow rates, bottom holes flooding, and complete well shutdown (Sun & Bai, 2017). The easiest way to control water flooding is to blow a well to its wellhead container.

However, under the conditions of the acquired subnormal reservoir pressures, the method of borehole bottom drying up is ineffective since there is no such a pressure in the productive levels which is necessary for returns, even if it is blowing.

It is known that during well blowing (inclusive of oil gas-lift ones), differential pressures can increase significantly by means of speed increasing in fluid flow (for returns) and baric gradient increase in the bottom of the well (Santos, Bordalo, & Alhanati, 2001; Guet & Ooms, 2006). In turn, it can lead to framework violations of the fluid drain holes at the initial stages, and later (due to returns from the drainage zone, secondary accumulation and accumulation in the drain holes nodal structures in the reservoir stresses) and to the destruction of both singular channels and deformations of the whole drainage zones (Law et al., 1998; Bondarenko, Kharin, Antoshchenko, & Gasyuk, 2013).

As a result, use of energy-intensive technologies (blowing down at the well head) results in the blocking of drainage holes (rock deformation), collapse of the columns, and early well abandonment (Falshtynskyi, Dychkovskyi, Saik, & Lozynskyi, 2014; Dychkovskyi et al., 2018).

Another negative effect may be a corrosion process associated with retrograde condensation of water and corrosive hazardous components of the fluid (for example, sulfur, hydrochloric acid, carbon dioxide and carbon dioxide), degassing of hydrogen sulfide from the extracted oil with simultaneous formation of acid solutions (Nicolae & Firu, 2014; Ramachandran, Al-Muntasheri, Leal, & Wang, 2015).

In addition, despite the relatively high temporal efficiency of downhole gas production after well blowing, the frequency of blowing use is increased during some time, which increases the emissions of hydrocarbon gases and their combustion products into the atmosphere as well as the fuel cost and other material resources for well servicing.

Gas blow is one of the most energy-consuming ways to control water flooding since the gas released into the atmosphere is one of the key sources of methane emission in the context of the gas industry. According to the forecasts of the US Environmental Protection Agency (U.S. EPA), shown in Figure 1, in the period from 2020 to 2030, increase in the share of the oil and gas industry as for the formation of global methane emissions is expected to be almost 1% per year (Moumen, Azizi, Chekroun, & Baghour, 2016).

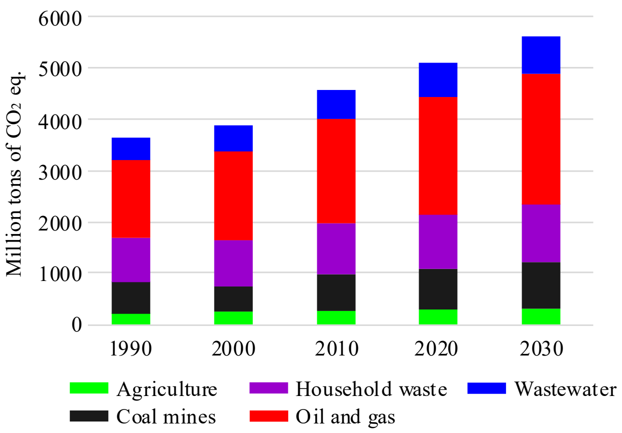


***Figure 1. Global anthropogenic emissions of greenhouse gases (except $CO_2$) according to the data by the US Environmental Protection Agency (2020, 2030 years – forecasts)***

It should be noted that methane is the second most important anthropogenic greenhouse gas after carbon dioxide; therefore, when it is blown to the container, methane pollutes the atmosphere and contributes to the global warming (Dean et al., 2018). Thus, stable operation of wells should involve the whole range of other technical solutions to control their watering:

– selection of optimum diameter and tubing running depth;

– selection of optimum operation condition of a well and blow;

– use of PSAS solutions;

– use of water repellents for selective water blocking in the reservoir;

– use of coiled tubing units;

– use of hydro gas-dynamic and physicochemical combined methods for reducing fluid volumes in productive levels and in the bottom hole zone;

– increase in draw-down pressure and flow rates owing to the use of field compressors, wellhead and deep compressors, turbulators and constriction devices.

It is of particular interest to search the energy-saving technologies to prevent strained rock deformations in the bottom hole zones in oil and gas wells, to reduce the risk of casing collapse as well as the intensity of secondary corrosion processes.

Searching for the ways to increase the efficiency of depleted gas fields development at abnormally low reservoir pressures, the open production levels as well as relevant energy-saving technologies to prevent strains in the bottom hole zones in oil and gas wells, to reduce the risk of casing collapse and the intensity of secondary corrosion processes is a significant problem.

In this sense, use of surfactants has several positive effects. On the one hand, the number of blowdowns decreases provoking the processes of failure of tubings; on the other hand, the intensity of corrosion centres decreases.

Use of foaming surfactants by many enterprises of Ukrainian oil and gas industry is one of the simplest and technologically and economically available ways to control well water flooding which provides a steady positive effect of the production and reduction of methane emissions into the atmosphere during blowing (Fesenko et al., 2007; Shcherbyna et al., 2009). In addition to the patented key decisions, the well-known theory and methods are applied (Orta et al, 2007).

Use of the specialzed surfactants as one of the methods to improve resource and power saving has been applied to analyze real effects of their introduction under specific mining and geological conditions. Moreover, a strategy for their future use to stabilize hydrocarbon production and decrease running energy and resource consumption was worked out. The research was carried out on the basis of oil and gas condensate fields in the Dnipro-Donets Depression. Period of the field studies lasted more than five years, which provided materials for qualitative generalization and parametric analysis.

Use of the technology has a number of its advantages over the current methods for well fluid removal, namely:

– energy saving and environmental protection by reducing methane emissions into the atmosphere during blowing;

– cleaning of the bottom of wells from accumulating fluid with a condensate content more than 50%, which increases the production of gas from these wells;

– ensuring the production of condensate with foam flow;

– reduction of corrosion and loss of asphaltene-resin-paraffin substances;

– reduction of costs for disposal of the removed liquid (water is utilized rather than emulsion).

Research tasks of the paper are as follows:

– to assess the effectiveness of the use of the FSs for the removal of liquid from the bottom of a gas-condensate well at a different volume of the introduced FSs, their concentration and injection order;

– to investigate the dependencies of the effect of the FSs use in terms of various geological and field factors;

– to develop a rational regime map of the process of FSs use under the conditions of gas-condensate fields in the east of Ukraine (Shebelynkahasvydobuvannia Gas Petroleum Department (GPD)) taking into account the specifics of the late stage of field development.

## 2. METHODS

On the basis of field facilities of the Industrial gas authority of Shebelynkahasvydobuvannia GPD, a number of active experimental studies were carried out to control well water flooding and stabilize gas and condensate production, in particular, a sharp decrease in the need for well blowdowns.

In particular, to solve the problem of industrial watering for use, such surfactants as Solpen-10t, RP-1K, RP-1 etc. have been tested and implemented for the wells of the Industrial gas authority of Shebelynkahasvydobuvannia GPD.

Solpen-10t surfactant was considered to be one of the best to use for removing highly mineralized liquid with condensate from the wells in Shebelynske field. It is intended for removal formation waters with mineralization up to 300 g/l, containing gas condensate up to 30% by volume at up to 70°C temperatures.

RP-1 surfactant has been developed for foaming of highly mineralized (up to 300 g/l) water-gas-condensate mixtures (with a condensate content up to 50%) at a wide temperature range (up to 170°C) (Fesenko et al, 2007).

RP-1K surfactant is intended for foaming carbohydrate mixtures at a wide temperature range and removing them from oil and gas wells; it is a carbohydrate solution of polymethylsiloxanes and other additional substances used for removing hydrocarbons from the bottom hole zone of the wellbore (Shcherbyna et al, 2009).

RP-1K reagent as well as similar surfactants has been developed for unstable wells with high condensate factor where other foam inductors do not work for removing condensate. After hydrocarbons foaming and removing hydrocarbon emulsions from a well, it easily disintegrates into water, oil or gas condensate (Orta et al, 2007).

Foam inductor RP-1 is an aqueous solution among surfactants. It consists of surfactants, which are decomposed easily from biological viewpoint. In this context, its foaming capacityand foam elasticity is higher to compare with the known analogues. RP-1 is meant for "reservoir water – condensate" system with up to 50% condensate content. It does not form an emulsion providing separation of the removed liquid.

To ensure complete removal of fluid from a well, we propose following technology for the removal of well fluid with a high content of condensate:

– volumes of fluid, accumulated at the well bottom, is measured;

– RP-1K is injected into the well to ensure foaming and removal of the main amount of condensate (RP-1K is not more than 4% which is calculated per total amount of fluid in the well);

– after removal of condensate, the foamed RP-1K is injected into a well through the annular space of RP-1 (in amounts of 1 – 2% in terms of the volume of formation water available in the well), which will ensure removal of residual formation water and condensate.

## 3. RESULTS AND DISCUSSIONS

In 2013, we carried out industrial tests of surfactant solutions of different compositions and concentrations in the wells of the Industrial gas authority of Shebelynkahasvydobuvannia GPD; massive application program for the surfactants Solpen-10 and Solpen-20 was developed according to the results. Before conducting the research, pipeline of the wells was blown from the gas treatment plant to pure gas (1 – 5 minutes). Volume of the solution of the FS was 100 liters per 1 well-operation at various foam surface-active substances concentrations and various injection technologies. After foam surface-active substances injection, if it is necessary, purging was performed. Solpen-10t was used as a FS.

During the work on the removal fluid from the wells in the Shebelynske GCF, seven different technological methods were applied with the help of the foam surface-active substances solution (Hnitko et al., 2013; Hnitko, Domin, & Zhmurkov, 2014):

1. Injection with 10% FS solution into casing annulus without stopping and blowing wells. Totally 21 well operations have been performed. The effect is obtained as a result of less than half of the treated wells. The production increase within this period was averaged 65%.

2. 20% FS solution injection into casing annulus without stopping and blowing wells. 6 well operations have been done. It is difficult to evaluate the effectiveness of this method, because the work was carried out at six wells, but an increase of 15 – 20% in production was observed only in three wells with gas flow rates above 20 thousand $m^3$/day.

3. FS solution injection into the tube space was carried out without stopping and purging, the well was allowed to work in the annulus space for one day, and then it was switched to tube space operation. Conducting the injection of 10% solution of FS (116 well operations) and 20% FS solution (9 well operations). The increase in production was observed in more than half of the wells (by 65.0 and 55.6% respectively) (Li, Li, Lin, & Li, 2010; Volovetskyi, Shchyrba, Vytiaz, & Doroshenko, 2013). The negative consequence of this method is that some wells could not work in the tube space after switching from the annulus: the flow of fluid from the annulus into the tube and lowering the film from the walls of the tubing created a high hydrostatic column of fluid which resulted in the increase discharge within the productive level (Dubiel, Rzyczniak, Solecki, & Maruta, 2017). So with a film thickness of 1.0 – 1.5 mm on the inner wall of the tubing and an average well depth of 2000 m, when a fluid is lowered from the tubing walls, a column of liquid is formed at the bottom from 120 to 173 m, or the back pressure on the formation is 1.193 – 1.724 MPa, which is quite significant at reservoir pressures of GCF Shebelynka being 2.06 – 3.04 MPa.

4. The injection of the FS solution of 20% into the tube space was carried out without stopping and purging the wells, and the well was put into operation in the annular space for two to three days, after which it was switched to the tube space. A total of 37 well operations were conducted. 54% of the wells demonstrated increase in the production. A negative consequence of the work by this technology was the shutdown of almost 50% of the wells to accumulate the pressure necessary to evacuate the foam mixture; as a results, 16% of the operation time of the well after the FS treatment were idle.

5. 20% injection of the FS solution in the annulus, followed by blowing wells until the foam leaves (1.5 – 3.0 hours). The work was carried out at 7 wells. No positive result was obtained due to the fact that the wells, after a long purge, were "discharged" (a sharp drop in pressure at the bottom hole) and a considerable amount of time has elapsed from their previous mode of operation.

6. The injection of 1% FS solution in the annulus with blowing to obtain dry gas (15 – 30 minutes). In this context, concentration of the Solpen-10t FS solution was 1% of its product concentration, content of the active substance in the injection solution was less than 0.5% by weight. This amount of surfactant is enough for foam formation only for the injected volume of water and not enough for the water-hydrocarbon mixture worsening the mixture evacuation to the wellhead. In particular, hydraulic pressure losses due to liquid-pipe friction are of particular importance. The FS solution was pumped into the wells and acted as a reagent reduced the surface tension at the liquid – pipe surface boundary (reduction of friction pressure losses during purging) and cleared the underground equipment (washing effect) from contamination, which in this case caused a positive effect from the use of FS. In general, the removal of liquid was ensured only by the energy of the gas during purging; i.e., without the formation of foam. In total, 51 well operations were carried out at 21 wells using the technique. Increase in the production was observed at 57% of treated wells, but its value was insignificant and short-term, except for four wells where gas flow rates before treatment were 7 – 20 thousand m$^3$/day.

7. Injection of the 10% FS solution in the annular space with a stop for a day and subsequent purging of the well. A total of 151 well-operations were carried out in terms of 67 wells. Increase in the production was observed at 70% of the treated wells. Disadvantage of the technology is as follows: the wells were stopped for 24 hours after injection to distribute the FS in front of a bottom hole, resulting in an average of 7% of the time the wells were idle. But this negative point is blocked by a positive effect after treatment.

Thus, in the annular space, the input of reagents is more acceptable since it takes more time and effort to evacuate the foam from the tubular space. The latter leads to downtime of the wells, but in the final decision on the issue, the effect of processing analogs or duplicate wells should be taken into account, and the final economic result should be evaluated. The best results are obtained for the injection of 5 – 25% FS solutions, and a more accurate concentration should be calculated or experimentally selected by the actual speed of the multiphase flow.

Optimization of the regime maps and treatment procedures leads to a decrease in the total time of well shutdowns during the period of operation under conditions of intensification.

To determine the effectiveness carried out in 2013 with the use of the FS solution at the GCF Shebelynske gas condensate field, the database on gas production was analyzed depending upon the effect obtained.

The wells were divided into groups according to the gas flow rate from the well $Q$ at a pitch of 5 thousand m$^3$/day; that is, $Q = 0.1 – 5$; 6 – 10...36 – 40; 41 – 45thousand m$^3$/day.

For each group, the efficiency of conducting one well operation was calculated (Table 1).

***Table 1. Effectiveness of the use of FS-solution depending on the flow rate***

| Gas flow rate from the well, $Q$, thousand m$^3$/day | Number of wells in operation | Number of well operations | Effect, thousand m$^3$/day/1 well-op. | Average relative velocity, $W$, m/s |
|---|---|---|---|---|
| 0.2 – 5 | 36 | 79 | 17 | 0.139 |
| 6 – 10 | 31 | 102 | 17 | 0.448 |
| 11 – 15 | 24 | 77 | 29 | 0.662 |
| 16 – 20 | 21 | 50 | 21 | 0.923 |
| 21 – 25 | 13 | 33 | 26 | 1.206 |
| 26 – 30 | 13 | 30 | 25 | 1.443 |
| 31 – 35 | 4 | 9 | 71 | 1.687 |
| 36 – 40 | 5 | 12 | 18 | 2.166 |
| 41 – 45 | 5 | 6 | 17 | 2.260 |
| Total | 152 | 398 | 22 | |

Hydrodynamic criterion "relative velocity" $W$ was used to analyze and determine the possibility of removal fluid from the wells. The relative speed is equal to the ratio of the velocity of the gas-liquid mixture, which rises from the bottom of the well along the tubing, to the reversal speed. The concept of "reversal speed" describes the change in the direction of the fluid layer due to a change in the velocity of the gas moving upwards; that is, the rate at which all the fluid in the layer on the tubing wall reverses and begins to move upwards towards the wellhead with the gas.

The criterion of the relative velocity of the gas-liquid mixture has an important physical meaning, namely:

1. If $W > 1$, then all the fluid from the well is released by the upward flow of gas; that is complete removal of fluid from the bottom of the well takes place. At the same time, if the relative velocity is within 1 – 2, the direction of flow is passing, but a laminar flow mode is formed when the gas velocity exceeds the velocity of the liquid. As a result, a difference appears between the expendable and volumetric content of the liquid; i.e., a part of the liquid is accumulated on the inner surface of the pipes, causing additional pressure losses in the tubing. In turn, that causes a decrease in depression to the reservoir and a corresponding decrease in gas inflow. In such wells, it is necessary to apply the FS periodically.

2. If $W < 1$, then part of the fluid in the layer on the tubing walls begins to move downward against the upward flow of gas. In this case, the nature of the flow changes dramatically, the hydraulic resistance increases significantly and flow pulsations occur, in which the liquid

is either released to the surface in the plug mode periodically, or falls to the bottom in drip mode or layer mode. At the same time, at low flow rates, hydrostatic self-killing of wells is possible, and at higher rates, passing to the pulsation mode with loss of flow rate is probable.

3. With a relative speed of $W \geq 2$ ($Q = 36 - 45$ thousand $m^3$/day), all the liquid in the gas stream moves from the bottom to the mouth and is dispersed in the center of the stream. For such wells, effect of the FS treatment to the additional increase in gas production is insignificant.

To remove the liquid using the FS solution from marginal, it is required to form high-expansion and highly stable foam (Volovetskyi, Shchyrba, Vytiaz, & Doroshenko, 2013). The boundaries are determined by a Froude parameter calculated for the conditions of the lift tube shoe. If foam expansion is foam 5 – 6, all the liquid from the pipe walls is transferred to the flow volume. In this case, difference between the flow and true volumetric gas content disappears, additional pressure losses for fluid retention are reduced, and density of the gas-liquid mixture and back pressure to the reservoir decrease, which causes additional gas flow into the well, and which in turn leads to an increase in its production rate (Li, Li, Lin, & Li, 2010).

To analyze the foam surface-active substances action effectiveness, the distribution of wells by ranges of flow rates was conducted. At the same time, the highest efficiency from well treatment was observed for wells with the initial production rates of 11 – 35 thousand $m^3$/day. The fact can be explained by the values of the calculated relative velocity for such groups of wells.

Figure 2 shows dependence of the specific additional production per well operation under the conditions of GCF Shebelynske gas condensate field upon the average flow rate of the well.

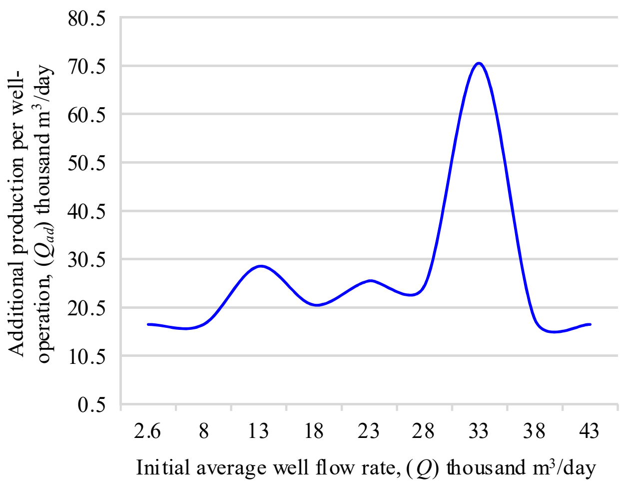


***Figure 2. Dependence of the specific additional production per well operation under the conditions of GCF Shebelynske upon the average of the well rate***

As it follows from the data obtained for the GCF Shebelynske gas condensate field (Table 1), the greatest efficiency from well treatment was observed in the range of the initial production rates from the wells 28 – 36 thousand $m^3$/day.

Similar results were obtained in a comparative analysis of the efficiency using RP-1 and RP-1K reagents using database characterizing the increase in gas production over the periods of their use in different wells in the Shebelynske and Zakhidno-Khrestyshchenske GCF.

Comparative analysis of the effect of the reagents was carried out for the wells in the Shebelynske and Zakhidno-Khrestyshchenske GCF. As it is seen in Figure 3 and 4, the effect of RP-1 and RP-1K reagents ($\Delta Q$) leads to an increase in well flow rate $Q_o$ from 0 thousand $m^3$/day to 70 thousand $m^3$/day. For the conditions of Shebelynske gas condensate field, use of RP-1 reagent for marginal wells causes an increase in daily production from 3 up to 7 thousand $m^3$/day; increase in daily production does not depend on the initial production rate.

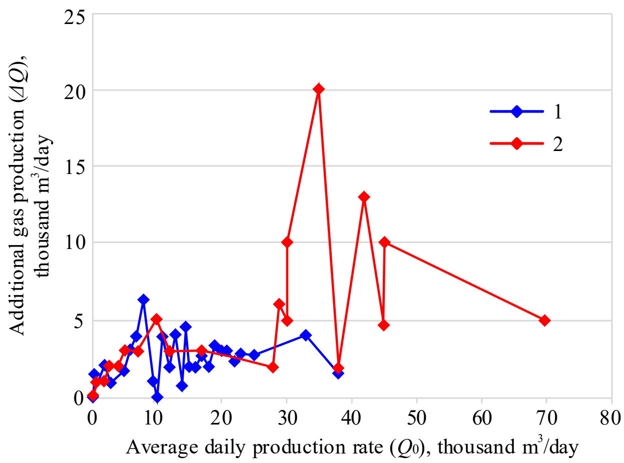


***Figure 3. Dependence of the total additional production after conducting well operations on the average daily production rate of the well during treatment with RP-1 reagent: 1 – Shebelynske deposit; 2 – Zakhidno-Khrestyshchenske deposit***

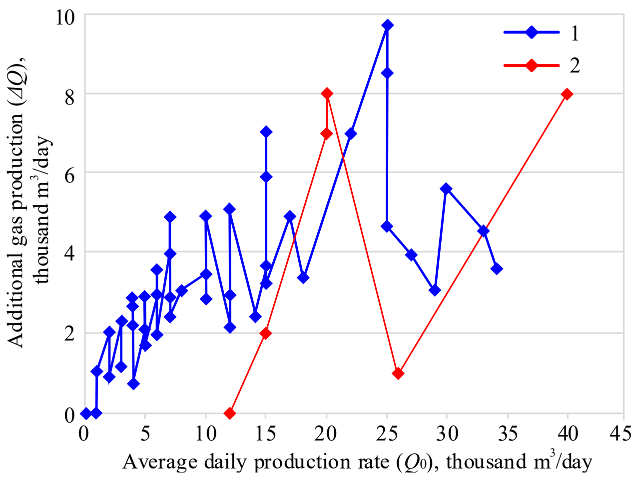


***Figure 4. Dependence of the total additional production after conducting well operations on the average daily production rate of the well during treatment with RP-1K reagent $\Delta Q = F(Q_o)$: 1 – Shebelynske deposit; 2 – Zakhidno-Khrestyshchenske deposit***

For Zakhidno-Khrestyshchenske GCF, increase in daily production was recorded from 2 to 20 thousand $m^3$/day. The largest increase in production was recorded for wells with the initial production rate of 30 – 45 thousand $m^3$/day; it is 12 – 20 thousand $m^3$/day. Use of reagent in wells, with the initial production rate of 40 thousand $m^3$/day, leads to a smaller increase in the additional production. Apparently, this is due to the high gas flow rates, characteristic of high production wells which affects adversely the efficiency of foaming process.

Well treatment with RP-1K reagent for both Shebelynske and Zakhidno-Khrestyshchenske deposits showed the following. With the initial debit up to 25 thousand $m^3$/day, increase in the additional production is observed up to 10 thousand $m^3$/day. At the same time, growth rate is different for the wells in Shebelynske and Zakhidno-Khrestyshchenske fields (Hnitko, Volovyk, Domin, Zhmurkov, & Popovychenko, 2009). With the initial debit of more than 25 thousand $m^3$/day, there is a multidirectional effect of the reagent, which can lead to the increased and decreased production.

According to the results of the carried out research and technological parameters, obtained using RP-1 foaming agent, conclusions have been made that the reagent can be widely used in the wells of the oil and gas complex for cleaning the bottom hole formation zone, wellbore, and when performing complex works on the intensification of hydrocarbon production and capital repairs. Use of FS for cleaning bottom holes and prophylactic treatments allowed not only obtaining additional gas production, but also reducing significantly its emission into the atmosphere during blowdowns, which saves directly the company resources to restore well performance and reduce atmospheric methane pollution.

Studies of the application of various technologies and compositions of FS solutions allowed us developing a systematic approach to preventive well treatments using of FS (Volovetskyi, Shchyrba, & Vytiaz, 2014) and outlining the ways to optimize their performance at the later stages of GCF development (Fesenko & Volosnyk, 2009). Results of individual experiments (Figs. 2 – 4) are summarized in the $Q_{ad\ month} = f\,(Q_{base\ month})$ in Figure 5.

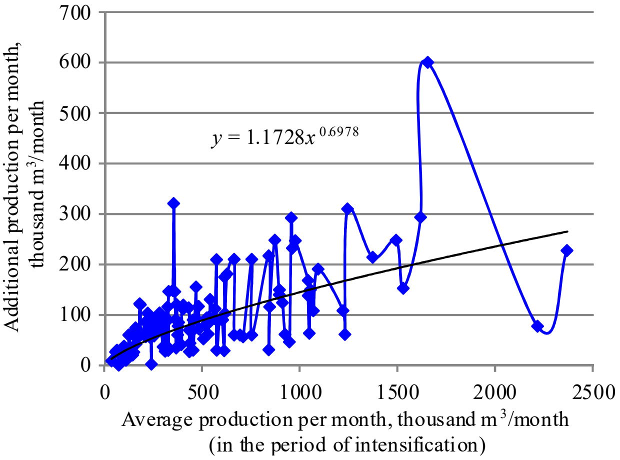


***Figure 5. Dependence of the total additional production after conducting well operations on the monthly average well flow rate when processing reagents RP-1 and RP-1K***

Figure 5 demonstrates the linear trend described by the equation of the power approximation with ~0.7 exponent. Thus, increase in the initial flow rate of wells leads to a directly proportional increase in the additional production.

Figure 6 shows a diagram of the dependence of additional gas production $Q_{ad}$ $(t)$ and the number of well operations $N_{obr}$ $(t)$ on time (when pumping liquid FS). At the same time, it can be seen that FS use for prophylactic purposes in some cases allowed us stabilizing the operation of wells (Fyk & Shendryk, 2006) which led to an increase in the gas production (Fesenko, Fyk, Kryvulia, Shendryk, & Kotsaba, 2011; Biletskyi, Shendrik, & Sergeev, 2012). Maximum effect is observed in the processing of low-yield wells (Fesenko & Volosnyk, 2009).

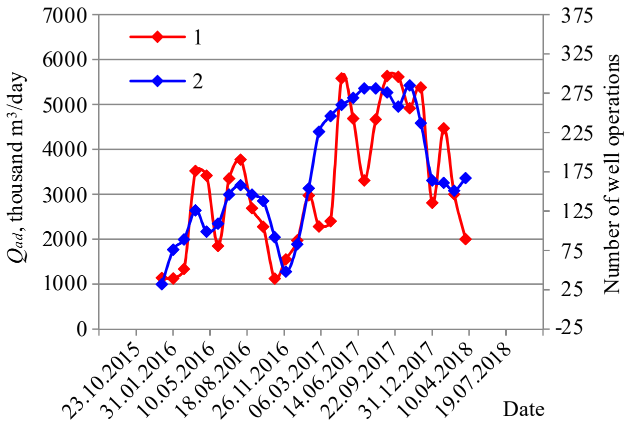


***Figure 6. Dependences $Q_{ad}$ (t), $N_{obr}$ (t) for GCF Shebelynske and Zakhidno-Khrestyshchenske GCF: 1 – additional production; 2 – well operations***

The diagram shows inertia in the production time increase after the carried out operations for well stimulation. It depends upon the large number of downloads as well as upon the individuality of the response of wells with different initial production rates for the processing with the foam surface-active substances.

Polynomials in Figure 6 represent trends for experimental curves $Q_{ad}$ $(t)$, $N_{obr}$ $(t)$.

Mutual correlation coefficient has been calculated for the trends. The, coefficient, demonstated in Figure 7, depends on the temporal displacement of the curves $Q_{ad}$ $(t)$, $N_{obr}$ $(t)$.

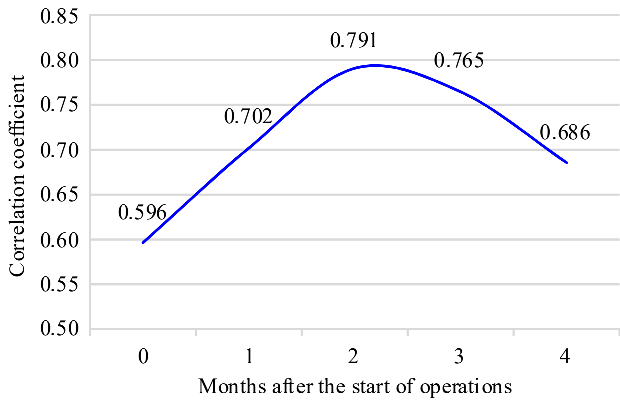


***Figure 7. Dependence of the coefficient of mutual correlation on the time shift of the curves $Q_{ad}$ (t), $N_{obr}$ (t)***

Maximum correlation of curves $Q_{ad}$ $(t)$ and $N_{obr}$ $(t)$ is observed at $\Delta t \sim 2$ months. Figure 6 shows an exact variant for $\Delta t = 2$ months. The result is of significant engineering nature since it helps evaluate adequately a period of reliable assessment of the effect by well operations in terms of intensification.

Deeper generalized analysis of the effect of obtaining additional gas production on the frequency of the well-stimulation well operations gives the exponential trend dependence of $Q_{ad}$ ($N_{obr}$) curve (Fig. 8).

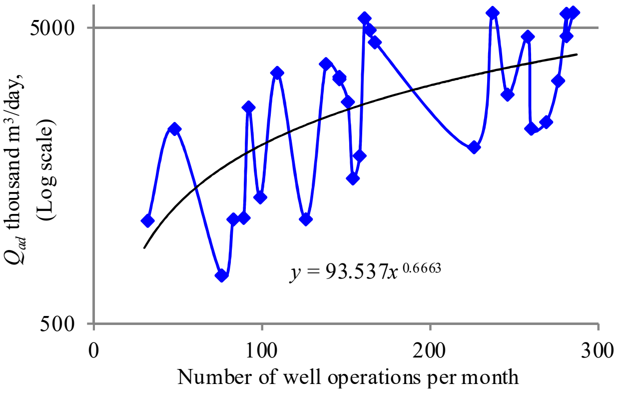


***Figure 8. Dependence of the additional gas production on frequency of the performed well operations $Q_{ad} = F(N_{obr})$ intensification demonstrated on a logarithmic scale***

Along with the increased frequency of well operations, actual effect in real gas production is reduced exponentially. Optimal frequency of borehole operations can only be determined as a result of technical and economic analysis. In this case, optimization criterion should be of economic nature.

## 4. CONCLUSIONS

1. Maximum effect from the application of foam surface-active substances appears with $\Delta t \sim 2$ month delay; it correlates with the number of well treatments within the permanent axis (Pearson criterion is up to 0.8).

2. Together with UkrNDIgaz, Shebelynkahasvydobuvannia GPD tested and applied such specialized foam surface-active substances as RP-1 and RP-1K to control water flooding of wells. It has been identified that their efficiency depends linearly upon the use effectiveness of the foam surface-active substances while depending exponentially upon the well treatment frequency.

3. Various techniques for the application of the foam surface-active substances have been tested, and the regulations for relevant field operations have been clarified. It was determined that regular treatment with a constant frequency is the resultative at minimum fluid flow rates and low pressure deviations from the stable foaming range of the considered reagents. Adjustment of concentration of the solution of foam surface-active substances is important when modes of the fluid velocity and pressure are out.

4. Optimization of the parameter charts and treatment procedures in terms of concentration of the foam surface-active substances, circuital connection of the foam inhibitor pipeline to the well, rational period of introduction of the foam surface-active substances in the reservoir-well system lead to a decrease in the total well downtime during the period of operation under conditions of intensification as well as methane emissions when purging.

5. Further studies should concern the analysis of the effect of foam surface-active substances, their concentration, amount of one-time solution, and formation of water salinity upon the intensification of well gas production.

## ACKNOWLEDGEMENTS

The authors express appreciation to the management of Ukrhazvydobuvannia PJSC and national producers of FSs for the materials provided and assistance in the process of the research conducting under industrial and plant conditions.

## REFERENCES

Biletskyi, V., Shendrik, T., & Sergeev, P. (2012). Derivatography as the method of water structure studying on solid mineral surface. *Geomechanical Processes During Underground Mining*, 181-184. https://doi.org/10.1201/b13157-31

Bondarenko, V.I., Kharin, Ye.N., Antoshchenko, N.I., & Gasyuk, R.L. (2013). Basic scientific positions of forecast of the dynamics of methane release when mining the gas bearing coal seams. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (5), 24-30.

Dean, J.F., Middelburg, J.J., Röckmann, T., Aerts, R., Blauw, L.G., Egger, M., & Dolman, A.J. (2018). Methane feedbacks to the global climate system in a warmer world. *Reviews of Geophysics*, *56*(1), 207-250. https://doi.org/10.1002/2017rg000559

Dubiel, S., Rzyczniak, M., Solecki, M., & Maruta, M. (2017). Analysis of drill stem test (DST) results at Osobnica oil field, in terms of sampling of selected technology parameters. *AGH Drilling, Oil, Gas*, *34*(2), 375. https://doi.org/10.7494/drill.2017.34.2.375

Dychkovskyi, R.O., Lozynskyi, V.H., Saik, P.B., Petlovanyi, M.V., Malanchuk, Y.Z., & Malanchuk, Z.R. (2018). Modeling of the disjunctive geological fault influence on the exploitation wells stability during underground coal gasification. *Archives of Civil and Mechanical Engineering*, *18*(4), 1183-1197. https://doi.org/10.1016/j.acme.2018.01.012

Falshtynskyi, V., Dychkovskyi, R., Saik, P., & Lozynskyi, V. (2014). Some aspects of technological processes control of an in-situ gasifier during coal seam gasification. *Progressive Technologies of Coal, Coalbed Methane, and Ores Mining*, 109-112. https://doi.org/10.1201/b17547-20

Fesenko, Yu.L., Kul, A.Yo., Shcherbyna, O.V., Fyk, I.M., Volosnyk, Ye.O., Kaplunovskyi, A.O., & Shcherbyna, V.H. (2007). *Pinoutvoriuvach "Reahent dlia piny RP-1"*. Patent No. 25655. Ukraina.

Fesenko, Yu.L., & Volosnyk, Ye.O. (2009). Stan i perspektyvy rozrobky Shebelynskoho hazokondensatnoho rodovyshcha. *Oil and Gas Industry*, (5-6), 24-28.

Fesenko, Iu.L., Fyk, I.M., Kryvulia, S.V., Shendryk, O.M., & Kotsaba, V.I. (2011). Osoblyvosti vyznachennia debetiv sverdlovyn hazovykh ta hazokondensatnykh rodovyshch piznoi stadii rozrobky. *Problems of Gas Industry Development in Ukraine: Proceedings Scientific Publication of Ukrainian Scientific Research Institute of Natural Gases*, (XXXIX), 172-177.

Fyk, I.M., & Shendryk, O.M. (2006). Pidvyshchennia vydobutku hazu optymizatsiieiu termobarychnykh umov ekspluatatsii sverdlovyn. *Prospecting and Development of Oil and Gas Fields. Proceedings Scientific publication of Ivano-Frankivsk National Technical University of Oil and Gas*, *4*(21), 66-70.

Guet, S., & Ooms, G. (2006). Fluid mechanical aspects of the gas-lift technique. *Annual Review of Fluid Mechanics*, *38*(1), 225-249. https://doi.org/10.1146/annurev.fluid.38.061505.093942

Hnitko, A.V., Volovyk, L.V., Domin, A.V., Zhmurkov, V.I., & Popovychenko, S.B. (2009). Doslidzhennia efektyvnosti vydalennia ridyny zi sverdlovyn Shebelynskoho HKR v zalezhnosti vid kontsentratsii PAR. *Problems of Gas Industry Development in Ukraine: Proceedings Scientific Publication of Ukrainian Scientific Research Institute of Natural Gases*, (XXXVII), 186-190.

Hnitko, A.V., Domin, A.V., Zhmurkov, V.I., Kohuch, D.M., Ivashko, Z.I., & Bilyk, O.A. (2013). Eksperyment z masovoho zastosuvannia rozchynu poverkhnevo-aktyvnykh rechovyn na sverdlovynakh Shebelynskoho rodovyshcha. *Problems of Gas Industry Development in Ukraine: Proceedings Scientific Publication of Ukrainian Scientific Research Institute of Natural Gases*, (XLI), 160-163.

Hnitko, A.V., Domin, A.V., & Zhmurkov, V.I. (2014). Analiz efektyvnosti robit iz zastosuvannia poverkhnevo-aktyvnykh rechovyn na Shebelynskomu HKR u 2013 rotsi. *Problems of Gas Industry Development in Ukraine: Proceedings Scientific Publication of Ukrainian Scientific Research Institute of Natural Gases*, (XLII), 54-58.

Hou, D., Luo, P., Sun, L., Tang, Y., & Pan, Y. (2014). Study on nonequilibrium effect of condensate gas reservoir with gaseous water under HT and HP condition. *Journal of Chemistry*, (2014), 1-8.
https://doi.org/10.1155/2014/295149

Law, B.E., Ulmishek, G.F., Clayton, J.L., Kabyshev, B.P., Pashova, N.T., & Krivosheya, V.A. (1998). Basin-centered gas evaluated in Dnieper-Donets basin, Donbas foldbelt, Ukraine. *Oil and Gas Journal*, *96*(47), 74-78.

Li, S., Li, Z., Lin, R., & Li, B. (2010). Modeling of sand cleanout with foam fluid for vertical well. *SPE Journal*, *15*(03), 805-811.
https://doi.org/10.2118/120449-pa

Moumen, A., Azizi, G., Chekroun, K.B., & Baghour, M. (2016). The effects of livestock methane emission on the global warming: a review. *International Journal of Global Warming*, *9*(2), 229.
https://doi.org/10.1504/ijgw.2016.074956

Nicolae, I., & Firu, L.S. (2014). Corrosion management – an overview of the corrosion control process in OMV petrom. *SPE International Oilfield Corrosion Conference and Exhibition*, 277-292.
https://doi.org/10.2118/169632-ms

Orta, D.R., Fosdick, M.L., Yang, J., Ramachandran, S., Salma, T., Long, J.J., & Salinas, O. (2007). A novel foamer for deliquification of condensate-loaded wells. *Rocky Mountain Oil & Gas Technology Symposium*.
https://doi.org/10.2118/107980-ms

Ramachandran, S., Al-Muntasheri, G., Leal, J., & Wang, Q. (2015). Corrosion and scale formation in high temperature sour gas wells: chemistry and field practice. *SPE International Symposium on Oilfield Chemistry*, 80-102.
https://doi.org/10.2118/173713-ms

Santos, O.G., Bordalo, S.N., & Alhanati, F.J. (2001). Study of the dynamics, optimization and selection of intermittent gas-lift methods – a comprehensive model. *Journal of Petroleum Science and Engineering*, *32*(2-4), 231-248.
https://doi.org/10.1016/s0920-4105(01)00164-4

Shcherbyna, O.V., Fyk, I.M., Kaplunovskyi, A.O., & Shcherbyna, V.H. (2009). *Pinoutvoriuvach "Reahent dlia piny RP-1k" dlia vydalennia vuhlevodnevoho kondensatu z privybiinoi zony plasta, vyboiu ta stovbura sverdlovyny*. Patent No. 85462. Ukraina.

Sun, X., & Bai, B. (2017). Comprehensive review of water shutoff methods for horizontal wells. *Petroleum Exploration and Development*, *44*(6), 1022-1029.
https://doi.org/10.1016/s1876-3804(17)30115-5

Volovetskyi, V.B., Shchyrba, O.M., Vytiaz, O.Yu., & Doroshenko, Ya.V. (2013). Zbilshennia obsiahiv vidboru hazu v umovakh periodychnoi ekspluatatsii hazokondensatnykh sverdlovyn. *Scientific Helard of Ivano-Frankivsk National Technical University of Oil and Gas*, *2*(35), 111-120.

Volovetskyi, V.B., Shchyrba, O.M., & Vytiaz, O.Iu. (2014). Rozroblennia kompleksnykh zakhodiv, spriamovanykh na pidvyshchennia efektyvnosti vydobuvannia vuhlevodniv pry rozrobtsi rodovyshch na vysnazhennia. *Prospecting and Development of Oil and Gas Fields. Proceedings Scientific publication of Ivano-Frankivsk National Technical University of Oil and Gas*, *3*(52), 154-165.

## ЕНЕРГОЗБЕРІГАЮЧА ІНТЕНСИФІКАЦІЯ ВИДОБУТКУ ГАЗОКОНДЕНСАТНОГО РОДОВИЩА НА СХОДІ УКРАЇНИ З ВИКОРИСТАННЯМ ПІНОУТВОРЮЮЧИХ РЕАГЕНТІВ

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**Мета.** Розробка рекомендацій щодо використання піноутворюючих поверхнево-активних речовин (ПАР) в загальному завданні збільшення енерго- та ресурсозбереження обводнених свердловин на завершальних стадіях розробки газоконденсатних родовищ.

**Методика.** Для досягнення мети і вирішення поставлених завдань використовувалися наступні методи досліджень: метод активного експерименту, регресійний і кореляційний аналізи отриманих статистичних даних, компаративний аналіз технологічних регламентів інтенсифікації свердловинного видобутку.

**Результати.** Розроблено рекомендації щодо використання досліджених ПАР для інтенсифікації видобутку газоконденсатних флюїдів з уточненням геолого-промислових характеристик експлуатованих родовищ Сходу України на прикладі Шебелинського та Західно-Хрестищенського газоконденсатних родовищ.

**Наукова новизна.** Визначено залежність коефіцієнта взаємної кореляції кривих "додатковий видобуток газу при застосуванні ПАР – кількість свердловин-операцій інтенсифікації від періоду впливу ПАР на систему "пласт – свердловина", яка носить екстремальний характер. Встановлено, що ефективність застосування ПАР лінійно залежить від початкового дебіту та експоненціально від частоти обробки свердловини.

**Практична значимість.** Встановлено, що максимальні прояви впливу розглянутих ПАР на свердловинний видобуток флюїдів досягається через два місяці. Випробувані різні методики застосування ПАР, уточнені регламенти відповідних промислових робіт. Оптимізація режимних карт і регламентів обробок у частині концентрації ПАР, схемного підключення інгібіторопровода піноутворення до свердловини, раціонального періоду введення ПАР в систему "пласт – свердловина" призводить до зменшення сумарного часу простоїв свердловин за період експлуатації в умовах інтенсифікації, а також викидів метану в атмосферу при продувках.

***Ключові слова:*** *ресурсозбереження, газоконденсатне родовище, геолого-промислові умови, дебіт свердловини, спінююча речовина, піноутворючі поверхнево-активні речовини*

## ЭНЕРГОСБЕРЕГАЮЩАЯ ИНТЕНСИФИКАЦИЯ ДОБЫЧИ ГАЗОКОНДЕНСАТНОГО МЕСТОРОЖДЕНИЯ НА ВОСТОКЕ УКРАИНЫ С ИСПОЛЬЗОВАНИЕМ ПЕНООБРАЗУЮЩИХ РЕАГЕНТОВ

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**Цель.** Разработка рекомендаций по использованию пенообразующих поверхностно-активных веществ (ПАВ) в общей задаче увеличения энерго- и ресурсосбережения обводненных скважин на завершающих стадиях разработки газоконденсатных месторождений.

**Методика.** Для достижения цели и решения поставленных задач использовались следующие методы исследований: метод активного эксперимента, регрессионный и корреляционный анализы полученных статистических данных, компаративный анализ технологических регламентов интенсификации скважинной добычи.

**Результаты.** Разработаны рекомендации по использованию исследованных ПАВ для интенсификации добычи газоконденсатных флюидов с уточнением геолого-промысловых характеристик эксплуатируемых месторождений Востока Украины на примере Шебелинского и Западно-Хрестищенского газоконденсатных месторождений.

**Научная новизна.** Определена зависимость коэффициента взаимной корреляции кривых “дополнительная добыча газа при применении ПАВ – количество скважинно-операций интенсификации от периода воздействия ПАВ на систему “пласт – скважина”, которая носит экстремальный характер. Установлено, что эффективность применения ПАВ линейно зависит от начального дебита и экспоненциально от частоты обработки скважины.

**Практическая значимость.** Установлено, что максимальное проявления воздействия рассмотренных ПАВ на скважинную добычу флюидов достигается через два месяца. Опробованы различные методики применения ПАВ, уточнены регламенты соответствующих промысловых работ. Оптимизация режимных карт и регламентов обработок в части концентрации ПАВ, схемного подключения ингибиторопровода пенообразования к скважине, рационального периода введения ПАВ в систему “пласт – скважина” приводит к уменьшению суммарного времени простоев скважин за период эксплуатации в условиях интенсификации, а также выбросов метана в атмосферу при продувках.

***Ключевые слова:*** *ресурсосбережение, газоконденсатное месторождение, геолого-промысловые условия, дебит скважины, вспенивающее средство, пенообразующие поверхностно-активные вещества*

### ARTICLE INFO

Received: 15 January 2019
Accepted: 14 May 2019
Available online: 7 June 2019

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