

EXPERIMENTAL STUDIES OF EFFICIENT WELLS COMPLETION IN DEPLETED GAS CONDENSATE FIELDS BY USING FOAMS

VOLOVETSKYI Volodymyr^{1*}, DOROSHENKO Yaroslav², KARPASH Oleh³,
SHCHYRBA Oksana¹, MATKIVSKYI Serhii⁴, IVANOV Oleksandr²,
PROTSIUK Halyna⁵

¹ Branch Ukrainian Scientific Research Institute of Natural Gases Joint Stock Company
“Ukrasvydobuvannya”, 20 Himnaziina Naberezhna str., Kharkiv, Ukraine, e – mail: vvb11@ukr.net

² Department of Oil and Gas Pipelines and Storage Facilities, Institute of Petroleum Engineering,
Ivano-Frankivsk National Technical University of Oil and Gas, 15 Karpatska str., Ivano-Frankivsk, Ukraine

³ Department of Energy Management and Technical Diagnostics, Institute of Architecture, Construction and
Power Engineering, Ivano-Frankivsk National Technical University of Oil and Gas, 15 Karpatska str.,
Ivano-Frankivsk, Ukraine

⁴ Joint Stock Company “Ukrasvydobuvannya”, 26/28 Kudriavska str., Kyiv, Ukraine

⁵ Department of Applied Mathematics, Institute of Information Technologies, Ivano-Frankivsk National
Technical University of Oil and Gas, 15 Karpatska str., Ivano-Frankivsk, Ukraine

Abstract: The reasons for decreasing the well operating parameters of depleted gas condensate fields have been analysed. A new approach has been proposed, which involves restoring the wells productivity by creating foam by means of a device developed for removing liquid from the well bottom. The expediency of using foam has been experimentally investigated for gas condensate wells to be completed and their productivity to be recovered. Techniques for removing liquid contaminants from wells have been developed, which involve injecting non-explosive gas mixtures and foams of various volumes into wells. Computational fluid dynamics modelling of the operation of the device for the wells completion with foam was carried out. The influence of the mass flow rate of an aqueous solution at the inlet to the device on the distribution of volume fraction of the gas and liquid phases, and the quality of the foam has been investigated. The understanding of the regularities of foam destruction processes by hydrocarbon condensate was obtained, and a device design was developed for the complete foam destruction.

KEYWORDS: well, formation pressure, liquid, foam, productivity.

1 Introduction

To obtain the hydrocarbons inflow, wells are completed at the end of drilling, after workover or self-killing due to the accumulation of liquid. The wells productivity depends on the efficiency of completion. Thus, under conditions of poor completion, the gas flow rate is lower than expected. A significant pressure difference between the tubing and annulus can indicate the presence of liquid at the bottomhole, so there is a need to re-complete such wells. Therefore, in order to qualitatively complete wells, a lot of factors should be analysed that enables to ensure the expected production of hydrocarbons.

Today, the development of wells by means of a coiled tubing unit has become widely used. While completing wells by coiled tubing, which is lowered into the inner cavity of the column of tubing strings various chemicals can be supplied including a surfactant solution with nitrogen. Also, depending on different factors, apart from the coiled tubing unit, other equipment and technologies are additionally used in the wells to obtain a positive result in completion.

Nitrogen completion of oil and gas wells by means of a coiled tubing unit has been used in many fields for a long time. High efficiency of wells completion by using coiled tubing is caused by a number of factors: the minimum costs for tripping operations, possibility of performing operations on flushing-out of wells of a different design (both with installation of the packer, and without it), etc. [1].

To increase the efficiency of completion and operation of wells, it is necessary to establish the optimal range of depression for each case, which provides designed yield and productivity without destroying the reservoir and other complications that may lead to additional workover costs [2].

2 Literature review

In [3], it is shown that in depleted fields in Germany, fluid accumulates in wells, which leads to a decrease in productivity. Well-known methods have been applied to solve this problem, but they were not successful in all cases. According to the results of experimental studies, a positive effect of the use of foam was obtained. This approach has been applied to most of the wells in the field, and good results have been achieved as a result of reduced downtime due to fluid build-up.

In [4] it is shown that coiled tubing technology is widely used in the oil and gas industry for cleaning both the wellbore and the bottom-hole as well. When using coiled tubing technology, foams are used as a detergent due to their low density and high viscosity. In the course of the research, 70%, 80% and 90% foam were used. According to the research results, it has been established that 90% high-quality foam is the best for removing dirt. It is obvious that the use of high-quality foam increases the efficiency of cleaning wells from liquid, sand, and dirt.

In [5], the influence of various parameters on the stability of the foam and its properties was investigated. In each test, one parameter was variable and the effect of this change was measured by the properties of the foam. The main parameters that were investigated in this experiment were temperature, foam concentration, pH effect, stabilizers and contaminants. According to the research results, the parameters affecting the stability of the foam were established:

- 1) increasing the temperature above 50 ° C leads to a decrease in stability;
- 2) increasing the concentration of the foaming agent causes increasing in durability;
- 3) increasing the pH of water from 2 to 9 contributes to increasing the stability of the foam, but with a further increase in pH above 9, a decrease in the stability of the foam is observed;
- 4) negative effect of divalent calcium ions on foam stability is greater than monovalent sodium and potassium ions.

In [6], it is shown that at the initial stage of field development, boreholes are operated at high operating pressures and the liquid, together with the gas flow, is brought to the surface. Due to the low reservoir pressure in depleted fields, liquid is partially carried away along with gas and accumulates at the bottom hole, which can lead to the termination of well operation. To remove fluid from the well, surfactants are used, which are fed into the well in different ways. To achieve effective liquid removal, it is necessary to use high quality foam, as evidenced by research results.

Also, cleaning of wells is necessary because liquid and solid particles carried out from them can lead to erosive wear of shaped elements of gas pipelines, which affects their strength [7].

At present gas companies use different technologies of well completion in practice [8-10], but using them does not always provide with a positive result.

One of the important factors in obtaining a positive result of the well completion is the value of reservoir pressure, because when completing gas and gas condensate fields for depletion, it naturally decreases. Due to this, the operating parameters (operating pressure, gas flow) are reduced at wells.

In [11] it was considered the practical experience of well completion of the Yuliivske oil and gas condensate field (OGCF) which is developed in the depletion mode.

Well 77 of the Yuliivske OGCF (horizon V-26n , F-1), perforation interval 3578-3552 m, depth of lowering oil-well tubing (tubing) with a diameter of 73 mm to 3526 m. Initial parameters: P_s - 8.47 MPa, gas flow on the bean $\varnothing$ 8 mm - 61.7 thousand m^3/d for P_t/P_a - 6.27/7.06 MPa. The well was completed by the method of sequential replacement of the killing fluid in the well with a liquid of lower density, i.e. by pumping water and periodically supplying an non-explosive gas mixture (composition by volume: nitrogen - not less than 90% and oxygen - not more than 10%) from a mobile nitrogen compressor station. This reduced the hydrostatic pressure due to the replacement of the liquid column with a water-gas mixture. To remove liquid from the well, a 10% solution of surfactant was injected into the annulus using a pumping unit and the tube space was purged. Well 77 of the Yuliivske OGCF was put into operation in 2007 with a gas flow rate of 38 thousand m^3/d .

The injection of even small concentrations of foam agents into the liquid at the bottomhole, significantly reduces the surface tension at the gas-liquid interface. Due to this, during gas flowing through the liquid containing the foaming substance, foam accumulates in the well. Since the foam density is of a broad range, even a small rate of upward gas flow (0.2-0.5 m/s) provides the removal of the entire foam mass to the surface [12].

Given the fact that a significant number of fields of Public Joint Stock Company (PJSC) "UkrGasvydobuvannya" is in the final stages of completion, it is important to complete wells using the latest technologies. That's why it is advisable to consider the technology of well completion using foam.

During the research and development works, of the Ukrainian Scientific Research Institute of Natural Gases (UkrNDIgaz) scientists develop a lot of new technologies, device designs, etc.

In [13], a foam generator for foaming was described, which enables to obtain highly structured foams of the required parameters (expansion ratio, stability) from a surfactant solution and natural gas.

The foam generator works as follows: under high pressure a surfactant solution is fed by means of the pumping unit into the ejector, where low-pressure gas is sucked, the resulting mixture of liquid and gas is fed through the channel into the vortex chamber. Since the channel is made tangential to the cylindrical surface of the chamber and also a given angle of inclination to its axis, the mixture receives a helical motion to the end of the chamber. Under the action of centrifugal forces, the mixture is divided into a liquid near the walls of the cylinder and a high foam expansion in its center. The liquid can be removed from the foam generator through the drain channel.

The Poltava division of UkrNDIgaz has developed a comprehensive technology for killing and completing wells with abnormally low formation pressure (ALFP) [14]. The process of blocking the bottomhole zone of the formation [15] is new in it with a three-component foaming composition, gel blocking liquid [16], foam generator [17]. The foaming composition and gel blocking solution are heat-resistant over time, formed from components that are easily soluble in hydrochloric acid solution, they are easy to remove from the formation during completion, and they do not reduce the well productivity. The layers blocked by them can withstand repression of the layer up to 4.0 MPa. The foam generator [17] enables to create foam.

The complex technology of killing and completion of wells was successfully tested at the facilities of "Poltavagasvydobuvannya" Gas Production Division while performing workover of wells 102 and 116 of the Yablunivske OGCF. The results of studies of wells production capacity carried out before and after workover operations (WO) are presented in Table 1.

According to the results of industrial research by using complex technology of killing and wells completion with ALFP, we can say that the technology is easy to apply, enables to avoid the absorption of killing fluid, does not clog the formation and facilitates the well completion.

Table. 1 The results of studies of production capacity at wells 102 and 116

Well number	The purpose of WO and the duration	Production capacity before WO		Production capacity after WO	
		Pg, thous.m ³ /d	Pc, t/d	Pg, thous.m ³ /d	Pc, t/d
102	Inspection of tubing 08.07.2003 - 20.07.2003	240.0	24.5	260.0	27.0
116	Inspection of tubing and re-perforation of horizon Bj-17 05.09.2003 - 10.10.2003	80.0	4.3	125.0	15.0

It should be noted that experimental studies on the liquid removal by foams from both wells and pipelines of the gas collection and preparation system have been carried out. Thus, experimental studies have been conducted concerning the use of foams for cleaning the inner cavity of both flowlines of gas condensate wells and gathering gas pipelines.

In [18] the results of industrial researches of the technology for cleaning the internal cavity of the gas condensate wells flowlines of Yuliivskiy oil and gas condensate production facility (OGCPF) are given.

While cleaning the flowline of well 85, the foam expansion ratio ranged from 90 to 100. Due to the experiment, the flowline was cleaned and liquid contaminants with solid impurities and dirty foam were revealed, probably because of the presence of clay or sand, at the well pit. After cleaning the flowline, the coefficient of hydraulic efficiency was determined, which increased by 12%.

When cleaning flowline of well 60, the foam expansion ratio ranged from 40 to 50. Due to the experiment, the flowline was cleaned and liquid contaminants and foam were detected at the complex gas treatment unit-1 (CGTU-1) measuring line in the separator and segregator. After cleaning the flowline, the coefficient of hydraulic efficiency was determined, which increased by 7%.

In [19] comprehensive measures are proposed to increase the operation efficiency of gas condensate wells. One of such measures is monitoring of operational parameters of wells by pressure and temperature sensors installed at the wellhead and at the inlet gas pipelines of the gas treatment unit; calculation of the volume of accumulated fluid in the wellbore and flowline; installation of a complex for automated supply of a surfactant solution both in the annulus of the wells and in the flowlines.

In [20-21], an experimental-industrial test was carried out to determine the efficiency of cleaning the inner cavity of gathering gas pipelines with foams of different expansion ratio. It is established that cleaning the inner cavity of gathering gas pipelines with foams with expansion ratio of 80 to 90 leads to an increase in the coefficient of hydraulic efficiency by 10.5%, and foams with expansion ratio of 50 to 60 by 5.7%. The measures taken to clean the inner cavity of gathering gas pipelines from liquid contaminants have proven their effectiveness and can be recommended for other fields.

3 Methods and materials

While drilling wells, a lot of drilling mud enters the productive formation [22], there is a clogging of the bottomhole zone, which reduces its filtration-capacity properties. As a result, there are difficulties in restoring the collector properties of bottom-hole zone. In addition, the operation of oil and gas condensate wells causes complications related to the destruction of the bottomhole zone, water encroachment [23-25], hydrates [26], corrosion [27-29] and erosion [30] of equipment, etc. To maintain the planned volumes of hydrocarbon production and restore the technical condition of wells in such fields it is required to perform workovers, before which, in accordance with the requirements of RLALP 11.1-1.01-08 (regulatory legal acts on labor protection)"Safety rules in the oil and gas industry of Ukraine", the well must be shut down. Mostly shutting down wells is also accompanied by clogging of productive horizons, and at low formation pressures it especially requires careful selection of the clogging fluid, as cleaning the formation in the lack of formation energy requires the use of certain long-term measures. Thus, in wells with low formation pressure after shutdown, operational parameters are reduced, and sometimes they cannot be completed. Therefore, there is a need for re-development.

Specialists analysed the available technologies for well completing. It resulted in development of the unit for completing wells with foam. Thus, they also have developed the design documentation and made this unit for carrying out industrial researches. Figure 1 shows a 3D scheme of the device.

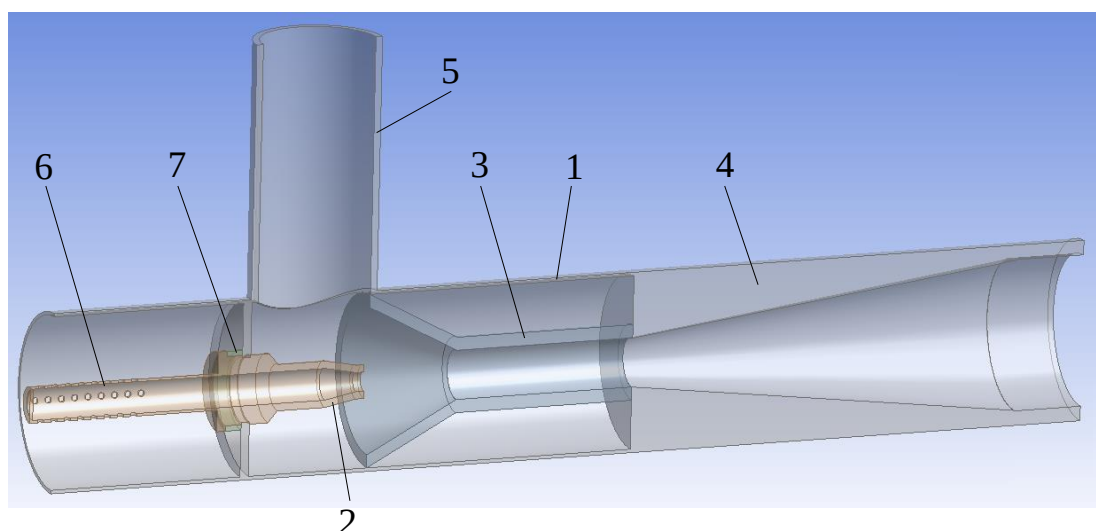


Fig. 1 Scheme of the device for wells completion with foam, 1 - body; 2 - nozzle; 3 - mixing chamber; 4 - cone-shaped diffuser; 5 - radial branch pipe for air or nitrogen supply; 6 - perforated tube for supplying an aqueous solution; 7 - adjusting shim

The quality of the foam depends on the efficiency of the wells completing device. In turn, the efficiency of the device depends on the flow rate of the aqueous solution supplied through the nozzle 2. The flow rate of the aqueous solution affects the characteristics of the flow inside the device, namely the pressure distribution, flow rate, and the processes of mixing the aqueous solution with gas. Therefore, the study of the characteristics of the flow inside the device is important to ensure the efficiency of its operation.

To solve the problem of studying the efficiency of a device for completing wells with foam, the ANSYS Academic 2021 R2 finite element analysis software was chosen, namely the ANSYS Fluent computational fluid dynamics code.

For the modelling of pipeline multiphase flows, CFD incorporates different multiphase models that have proven themselves to be more accurate [31-32].

The Euler approach, namely the model Mixture, was used for research. The model Mixture is designed for several phases that are interpenetrating continua. The Mixture model, allows the phases to penetrate into each other. The volume fractions of the dispersed phase p and the continuous phase q can have any value from 0 to 1.

Continuity equation for mixture:

$$\frac{\partial}{\partial t}(\rho_m) + \nabla \cdot (\rho_m \bar{v}_m) = 0, \quad (1)$$

where ρ_m - density of mixture;

$\bar{v}_m$ - average velocity mixture.

Momentum equation of the mixture

$$\begin{aligned} \frac{\partial}{\partial t}(\rho_m \bar{v}_m) + \nabla \cdot (\rho_m \bar{v}_m \bar{v}_m) = & -\nabla p + \nabla \cdot \left(\mu_m \left(\nabla \bar{v}_m + \nabla \bar{v}_m^T \right) \right) + \\ & + \rho_m \bar{g} + \bar{F} + \nabla \cdot \left(\sum_{k=1}^n \alpha_k \rho_k \bar{v}_{dr,k} \bar{v}_{dr,k} \right), \end{aligned} \quad (2)$$

where $\bar{F}$ - body force;

μ_m - mixture viscosity;

$\bar{g}$ - gravity acceleration;

$\bar{v}_{dr,k}$ - dispersed phase drift velocity k .

Slip velocity is the difference between the dispersed phase p velocity and the continuous phase velocity q

$$\bar{v}_{pq} = \bar{v}_p - \bar{v}_q, \quad (3)$$

where $\bar{v}_p$ - dispersed phase velocity;

$\bar{v}_q$ - continuous phase velocity.

Drift velocity disperse phase

$$\bar{v}_{dr,p} = \bar{v}_{pq} - \sum_{k=1}^n c_k \bar{v}_{pk}. \quad (4)$$

The equation of mixture energy

$$\frac{\partial}{\partial t} \sum_{k=1}^n (\alpha_k \rho_k h_k) + \nabla \cdot \sum_{k=1}^n (\alpha_k \bar{v}_k (\rho_k h_k + p)) = \nabla \cdot (k_{eff} \nabla T) + S_E, \quad (5)$$

where k_{eff} - effective conductivity;

h_k - enthalpy of phase k ;

S_E - energy transfer due to conductivity.

The volume fraction equation for the dispersed phase p is

$$\frac{\partial}{\partial t}(\alpha_p \rho_p) + \nabla \cdot (\alpha_p \rho_p \bar{v}_m) = -\nabla \cdot (\alpha_p \rho_p \bar{v}_{dr,p}) \quad [33]. \quad (6)$$

CFD modelling in ANSYS Fluent was performed by numerically solving these equations, which were closed by a two-parameter turbulence model using a wall function with appropriate initial and limiting conditions.

A 3D geometrical model of wells completion device with foam was drawn (Figure 1). The diameter of the device body is 50 mm, the inner diameter of the perforated tube for supplying

an aqueous solution is 10 mm, and the inner diameter of the radial branch pipe for supplying nitrogen is 34 mm. In order to study the dynamics of the movement of flows in the device for the wells completion with foam, a three-dimensional geometric model of the internal cavity of the device, along which the flows move, was drawn (Figure 2).

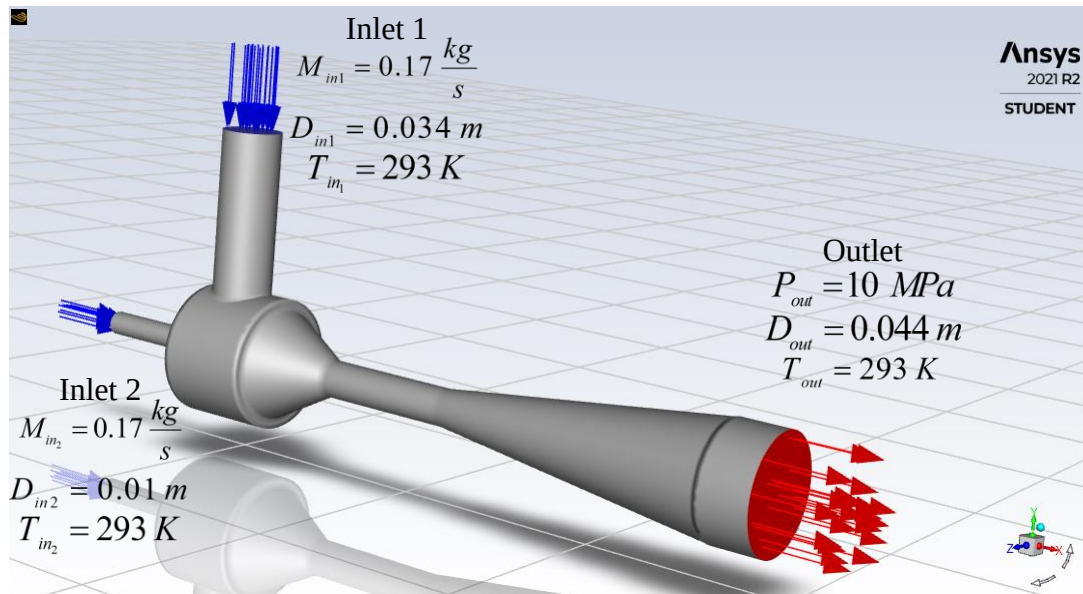


Fig. 2 Design scheme of a wells completion device with foam

The following boundary conditions were set for research (Figure 2). At the inlet to the radial pipe for nitrogen supply (inlet 1, Figure 2) set the fluid. The fluid was nitrogen, which was selected from the ANSYS Fluent database. Nitrogen was specified as the compressible fluid (it was specified that the density of nitrogen should depend on the flow parameters). In this case, the energy equation is automatically added to the solvable equations. Also, at the inlet 1 was set the mass flow rate of nitrogen, which was assumed to be equal to 0.17 kg/s, which corresponds to the performance of a mobile compressor station used for well cleaning. The fluid was also set at the inlet to the tube for the supply of aqueous solution (inlet 2, Figure 2). The fluid was an aqueous solution. Aqueous solution is the main parameter that most affects the quality of the foam, and the effect of which has been studied. The flow rate of the aqueous solution, which was set at the inlet 2 was 0.17 kg/s, 0.95 kg/s, 1.91 kg/s and 2.86 kg/s. A separate simulation was performed for each value of the aqueous solution flow rate.

At the outlet of the mixture of nitrogen with aqueous solution from the device for the wells completion with foam, namely the cone-shaped diffuser was set to a pressure that was taken equal to 10 MPa.

At the inlets of the fluids and at the outlet of the mixture from the device, a temperature of 293 K, a turbulence intensity of 5% (for this value the flow is considered completely turbulent) and a hydraulic diameter were set. The hydraulic diameter was assumed to be equal to the inner diameter of the nozzles through which the fluids fed and the inner diameter of the cone-shaped diffuser at the outlet of the mixture.

The results of CFD modeling were visualized in the postprocessor of the ANSYS Fluent software package, which made it possible to see the structure of the flows in the device for the wells completion with foam and collect comprehensive data about it. The distribution of the volume fraction of nitrogen (Figure 3) and aqueous solution (Figure 4) in the volume of the device for different mass flow rates of aqueous solution at the inlet is constructed. The influence of the mass flow rate of the aqueous solution at the inlet on the quality of the foam at the outlet

of the device was evaluated. Based on the simulation results (Figure 3, Figure 4) it can be seen that the quality of the foam is the best when the mass flow of aqueous solution at the inlet is the highest that can provide pumping units, namely 2.86 kg/s. Decreasing in the mass flow rate of the aqueous solution at the inlet of the cone-shaped diffuser after passing through the two phases of the mixing chamber, there is an increasing displacement of the aqueous solution to the bottom of the diffuser, which leads to deterioration of foam quality. Therefore, the best quality foam will be when the mass flow rate of the aqueous solution will be greatest.

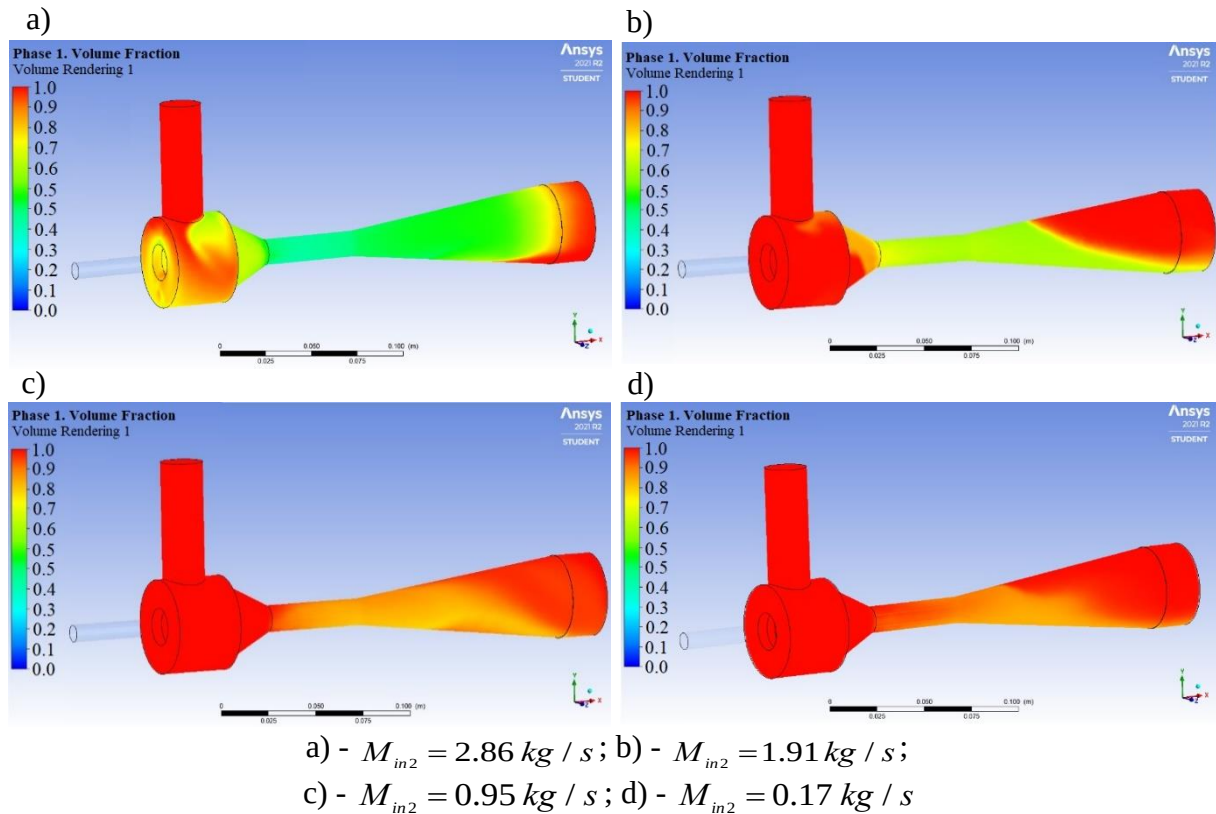
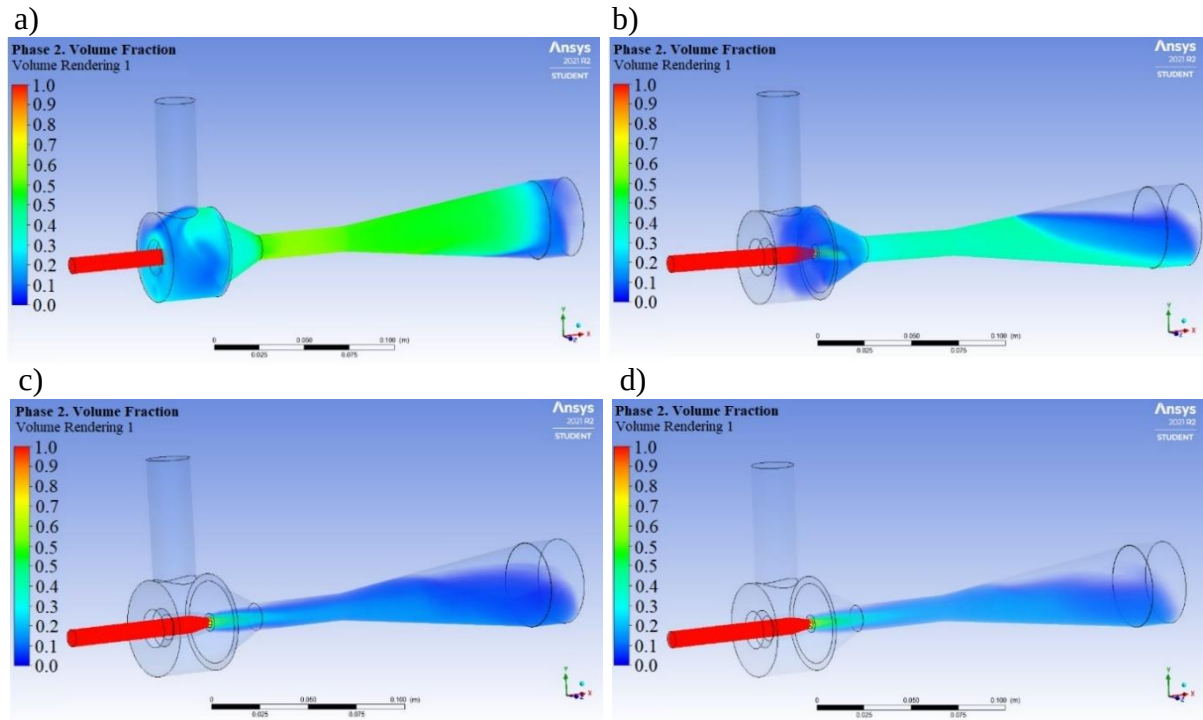


Fig. 3 Distribution of the volume fraction of nitrogen in the volume of the device for the wells completion with foam for different mass flow rates of aqueous solution at the inlet M_{in2}

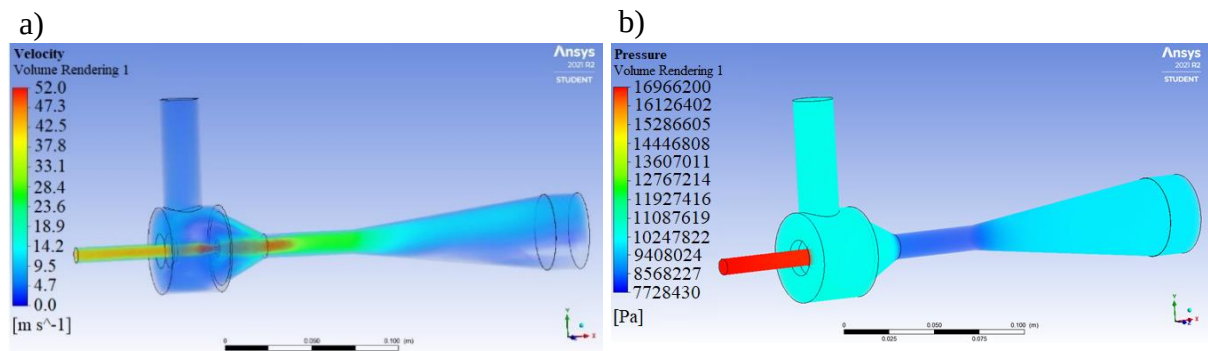
Also, the results of CFD modeling were visualized by constructing the distribution of the modulus of velocity (Figure 5, a) and pressure (Figure 5, b) in the volume of the device for wells completion with foam, for a mass flow rate of aqueous solution at the inlet 2.86 kg/s, when the quality of the foam is the best. The simulation results show that when the flow of aqueous solution passes through the nozzle (Figure 5, a), a jet is formed, which passes at high speed together with nitrogen through the mixing chamber. Such a high flow rate in the mixing chamber leads to the creation of a zone of reduced pressure (Figure 5, b) relative to the pressure of the mixed gas-liquid flow in the diffuser. In this region of low pressure, the high-velocity flow of the aqueous solution interacts with the flow of nitrogen, which moves at a relatively low speed resulting in the formation of bubbles and the formation of foam. The difference in speed between the flow of aqueous solution and the flow of nitrogen affects the foam quality.



a) - $M_{in2} = 2.86 \text{ kg / s}$; b) - $M_{in2} = 1.91 \text{ kg / s}$; c) - $M_{in2} = 0.95 \text{ kg / s}$; d) - $M_{in2} = 0.17 \text{ kg / s}$

Fig. 4 Distribution of the volume fraction of aqueous solution in the volume of the device for the wells completion with foam for different mass flow rates of aqueous solution at the inlet

$$M_{in2}$$



a) - distribution of the velocity modulus in the volume; b) - distribution of the pressure modulus in the volume

Fig.5 The results of CFD simulations of the device for the wells completion with foam

Therefore, the greater the flow rate of the aqueous solution at the inlet, the greater the flow rate in the mixing chamber and the better the quality of the foam. During the passage of the gas-liquid mixture of the diffuser, the flow reduces the speed (Figure 5, b) and there is an increase in pressure (Figure 5, b). After the diffuser, the gas-liquid mixture is fed into the well.

Based on the example of wells in the Shebelynske gas condensate field (GCF) the decision was made to conduct experimental researches on well completion by the foam created by means of the given unit. The Shebelynske GCF was introduced into research and development in 1956. The operational well fund of the Shebelynske field makes about 550 units.

It should be noted that while developing the Shebelynske GCF at wells there are many different problems, including the accumulation of liquid at the bottom hole of wells and in the

flowlines [34]. Due to this, operating wells there is a decrease in flow rates, as well as shutting down wells due to the presence of liquid, which leads to self-killing. Appropriate measures are being developed and taken to solve the problems.

The Shebelynske GCF wells, which operate at low flow rate due to the accumulation of liquid column at the bottom hole, and which are periodically shut down, were selected for the experimental study.

In order to conduct the experiment, it is necessary to choose the optimal surface-active agent paying attention to its characteristics. To do this, UkrNDIgaz specialists performed a number of laboratory tests on the properties of various surfactants, which can be further used to generate foam and remove liquid from the wellbore.

Thus, the foaming properties of surfactants Stinol-NG, Savinol, Sulfanol and Solpen-10T were laboratory tested. Based on the studies of these surfactants, the foam stability was determined for the studied model of mineralized formation water containing 50 g/l of calcium chloride (CaCl₂) and 100 g/l sodium chloride (NaCl), with a density of 1.075 g/cm³ to 1.087 g/cm³ at a temperature of 20° C and surfactant concentrations of 0.5%, 1%, 1.5% and 2%. In addition, a stable condensate with a density of 0.757 g/cm³ to 0.765 g/cm³ of various concentrations was added to the tested model. It was found that the solution of Solpen-10T has the best foam stability characteristics among the four surfactants.

In addition, laboratory tests of the foaming properties for surfactants Stinol-NG, Savinol, Sulfanol and Solpen-10T were conducted. The foaming properties of surfactants were considered in diverse environments. For laboratory studies a model of formation water was used with a specific gravity $\rho = 1.080$ g/cm³, with the composition: Na⁺⁺K⁺ - 26300 mg/l; Ca²⁺ - 5045 mg/l; Mg²⁺ - 3100 mg/l; Cl⁻ - 59950 mg/l. The results of laboratory tests are presented in Table 2.

Table. 2 Solpen-10T, Stinol-NG, Savinol and Sulfanol: comparative foaming properties

No.	Surfactant mixture composition	Surfactant								
		Solpen-10T		Stinol-NG		Savinol		Sulfanol		
	Environm	Surfactant concentration, mass %	Foam expansion ratio, ER	Foam stability, y, s	Foam expansion ratio, ER	Foam stability, s	Foam expansion ratio, ER	Foam stability, y, s	Foam expansion ratio, ER	Foam stability, y, s
1	Reservoir water model at 20 °C	1	2.0	101	0	0	5.2	288	1.4	0
2		2	4.9	326	1.2	20	5.4	298	1.8	10
3		4	6.0	545	1.3	20	4.9	324	2.0	20
4		6	7.6	503	1.5	25	5.2	328	2.0	26
5		8	9.0	510	1.6	22	5.4	347	4.4	41

Fig. 6 and 7 show the dependencies of Solpen-10T, Stinol-NG, Savinol and Sulfanol expansion ratio and foam stability on the surfactants concentrations, mass %

Thus, based on the results of laboratory studies, it was found that Solpen-10T surfactant has the best characteristics in terms of foam stability. Subsequently, laboratory tests were performed to determine the physical and chemical parameters for compliance with technical conditions and quality passport.

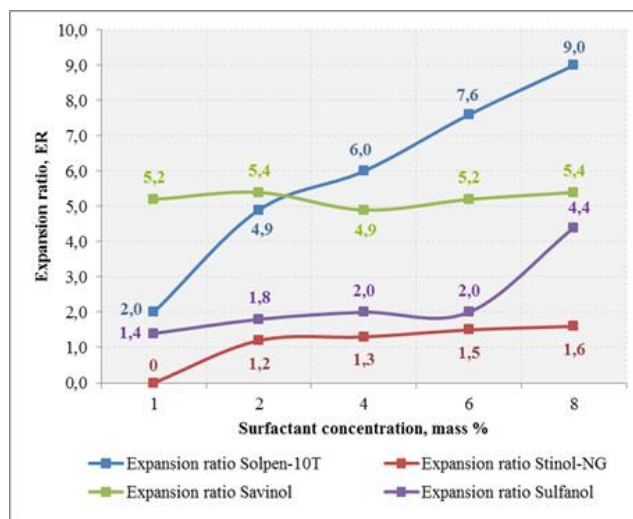


Fig. 6 Dependencies of the Solpen-10T, Stinol-NG, Savinol and Sulfanol foam expansion ratios on the surfactants concentrations, mass %

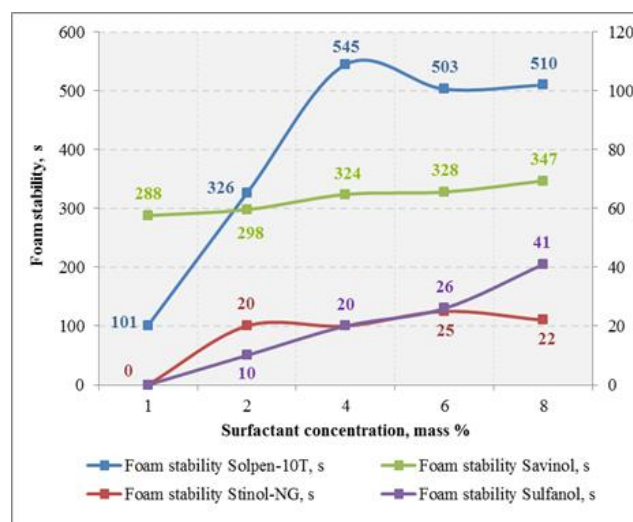


Fig. 7 Dependencies of the Solpen-10T, Stinol-NG, Savinol and Sulfanol foam stability on the surfactants concentrations, mass %

4 Results and discussion

On the example of two wells 566 and 126 of the Shebelynske GCF experimental researches of their development for removal of liquid from a bottom hole and recovery of their productivity are carried out. To implement it, based on the analysis of operational parameters, two methods were developed, which included:

- 1) Completion of wells to restore their productivity by injecting a non-explosive mixture and foam with a volume of 0.4 m³ into the tubing, while removing the liquid through the annulus to the pit of the well;
- 2) Completion of wells to restore their productivity by injecting a non-explosive mixture and foam with a volume of 0.5 m³ into the annulus, while removing the liquid through the tubing to the pit of the well.

Experimental studies were performed on well 566 of the Shebelynske GCF using the first method. A plan was drawn up for the completion of well 566 of the Shebelynske GCF. It contains the main geological and industrial data of the well (artificial bottom hole - 2196 m,

production column with a diameter of 146 mm - 2203 m, the depth of the tubing with a diameter of 73 mm - 1856.54 m, perforation interval 1777 - 2153 m, Pg - 0.2 thousand m³/d, etc.), tools, materials and necessary equipment (manometers, device, back valve, water, surfactant Solpen-10T, pumping unit, tank truck, three mobile nitrogen compressor stations), preparatory works, technology of carrying out works and health and safety measures.

According to the plan, the technology of work was as follows:

- the technical condition of the Christmas tree was checked, as well as the tightness of the valves;
- the operating valve of tubing to the flowline was shut down (Figure 8);
- the pressure of the tubing and annulus (Pt, Pa) was measured and the position of the valves on the Christmas tree was checked;
- exemplary manometers on the tubing and annulus of the Christmas tree were installed;
- before the start of the work, the operational parameters were measured, in particular, the pressures were: Pt - 0.99 MPa, Pa - 1.76 MPa;
- the liquid level in the well was measured using an echo sounder several times. Based on the level measurement results, the accumulated volume of liquid in the tubing and annular space was calculated;
- a flange with a quick-disconnect connection was installed on the gate valve of the tubing, to which special equipment was connected (a pumping unit and three mobile nitrogen compressor stations, a device) and a back valve was installed on the discharge line;
- a discharge line was pressurized at one and a half times the expected working pressure;
- in a measuring container of the pumping unit 2% solution of surfactant Solpen-10T was prepared;
- the gate valve of the tubing was opened;
- a non-explosive gas mixture (composition by volume: nitrogen not less than 90% and oxygen not more than 10%) was injected into the tubing through the unit device by three mobile nitrogen compressor stations;
- when performing the work, the tubing and annular pressures were monitored, as well as the output of the well;
- provided that the pressure in the tubing increased to 4.0 MPa, the surfactant solution was fed into the device using a pumping unit and, accordingly, to inject foam into the tubing of the well, while monitoring the surfactant consumption. After 0.4 m³ of surfactant solution was supplied, the pumping unit was stopped, while the non-explosive gas mixture continued to be pumped by three mobile nitrogen compressor stations;
- the operating valve of the annulus was opened to the well flare pit;
- provided that the pressure in the tubing increased to 4.0 MPa, the surfactant solution was fed into the device using a pumping unit and, accordingly, to inject foam into the tubing of the well, while monitoring the surfactant consumption. After 0.4 m³ of surfactant solution was supplied, the pumping unit was stopped, while the non-explosive gas mixture continued to be pumped by three mobile nitrogen compressor stations;
- the release of foam (liquid) was monitored on the flare pit of the well;

- after the appearance of foam (liquid) at the flare pit, the surfactant solution was fed into the device using a pumping unit and, accordingly, to inject foam into the well tubing, while monitoring the surfactant consumption. After 0.4 m³ of the surfactant solution was supplied, the pumping unit was stopped, while the non-explosive gas mixture continued to be pumped by three mobile nitrogen compressor stations;

- after the end of foaming out (liquid) at the flare pit, the operating valve of the annulus to the flare pit was shut down;

- the pressure in the tubing and annular space was controlled and its growth was monitored;

- the operating valve of the annular space to the flare pit was opened;

- the surfactant solution was fed into the device using a pumping unit and, accordingly, the foam was injected into the tubing of the well, while monitoring the surfactant consumption. After 0.4 m³ of surfactant solution was supplied, the pumping unit was stopped, while the non-explosive gas mixture continued to be pumped by three mobile nitrogen compressor stations;

- the process of foaming out (liquid) at the flare pit was monitored;

- the surfactant solution started to be supplied into to the device using a pumping unit and, accordingly, to inject foam into the tubing, while monitoring the surfactant consumption. After 0.4 m³ of surfactant solution was supplied, the pumping unit was stopped, while the non-explosive gas mixture continued to be pumped by three mobile nitrogen compressor stations;

- foaming out (liquid) at the flare pit was monitored;

- the pressure in the tubing and annular space was controlled and its growth was monitored;

- the surfactant solution stated to be fed into the device using a pumping unit and, accordingly, foam was injected into the tubing of the well, while monitoring the surfactant consumption. After 0.4 m³ of the surfactant solution was supplied, the pumping unit was stopped, while the non-explosive gas mixture continued to be pumped by three mobile nitrogen compressor stations;

- at the end of foaming out (liquid) at the flare pit, the completion work was stopped. The work of three mobile nitrogen compressor stations was stopped and the gate valve of the tubing and the operating valve of the annular space were shut down;

- the pressure from the discharge line to atmospheric was bled and it was dismantled;

- the pressure in the tubing and annular space was checked and its growth was monitored;

- after the growth of the tubing and annular pressures, the operating valve of the tubing was opened to the flowline for flowing hydrocarbons;

- the well was put into operation and its parameters were monitored;

- the production capacity of the well was measured using the gas treatment unit;

- the fluid level was measured in the well with an echo sounder several times. Based on the level measurement results, the accumulated volume of liquid in the tubing and annular space was calculated;

- compliance with operational parameters in accordance with the technological regime was monitored.

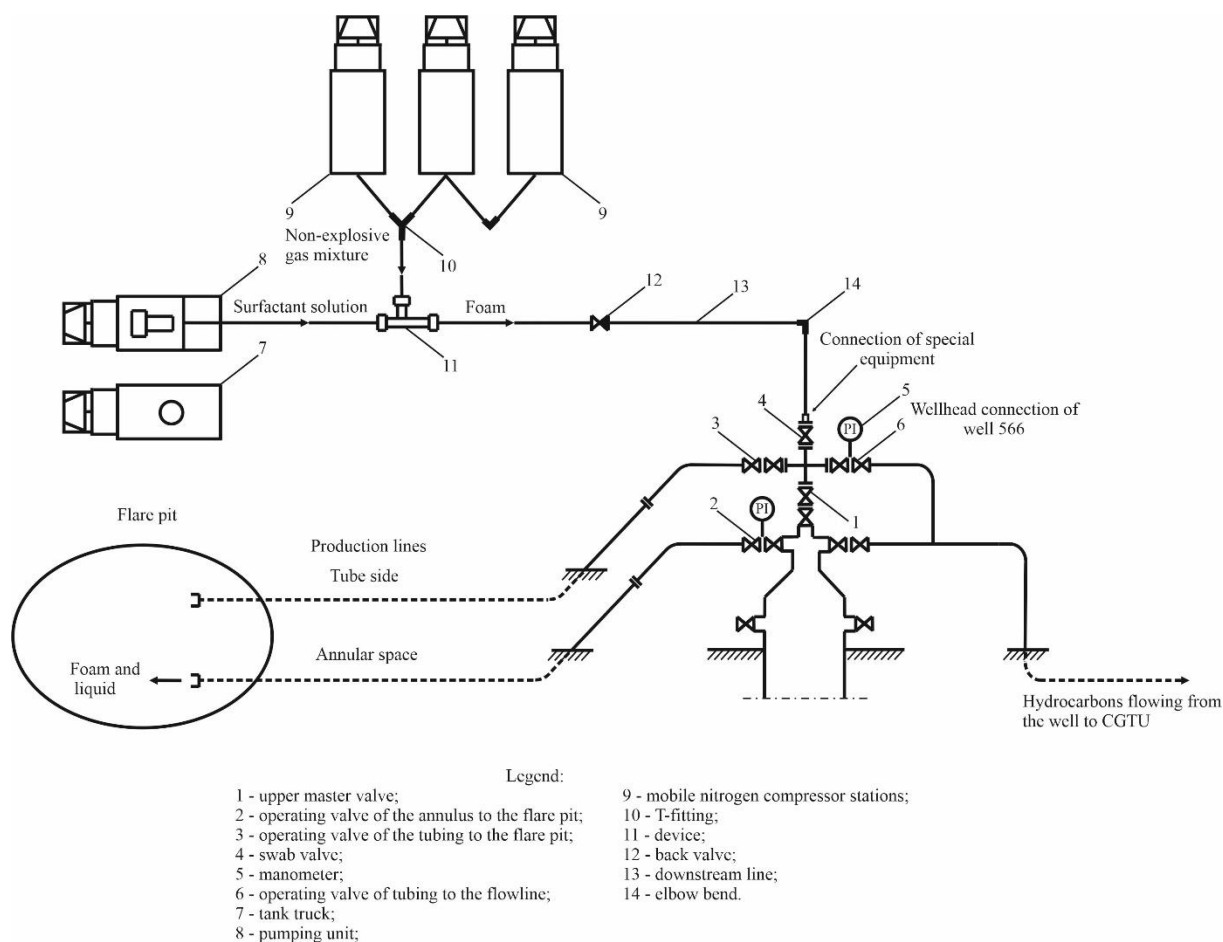


Fig. 8 Scheme of the wellhead manifold and connecting special equipment while completing well 566 of the Shebelynske GCF

While performing the work, the foam expansion ratio ranged from 110 to 120. Thanks to the experiment at the well pit, liquid contamination and dirty foam were revealed. After completing the work, the dynamics of working pressures was monitored. The well was put into operation and the parameters of its operation mode were monitored. The actual parameters of the well operation were measured. According to the results of well studies, an increase in gas production was obtained, which is shown in Table 3.

Experimental studies were performed at well 126 of the Shebelynske GCF using another methodology. A plan was drawn up to complete well 126 of the Shebelynske GCF. It contains the main geological and industrial data of the well (artificial bottom hole - 2196 m, production column with a diameter of 146 mm - 2203 m, the descent depth of the tubing with a diameter of 73 mm - 1856 m, perforation interval - 1777 - 2153 m, P_g - 0.3 thousand m³/d, etc.), tools, materials and necessary equipment (manometers, device, back valve, water, surfactant Solpen-10T, pumping unit, tank truck, three mobile nitrogen compressor stations), preparatory work, technology of carrying out works and health and safety measures..

According to this plan, the technology of the works was as follows:

- the technical condition of the Christmas tree was checked, as well as the tightness of the valves;
- the operating valve of tubing to the flowline was shut down (Figure 9);
- the pressure of tubing and annulus (P_t , P_a) was measured and the position of the valves was checked on the Christmas tree;

- exemplary manometers were installed on the tubing and annulus of the Christmas tree;
- before starting the works, the operational parameters were measured, in particular the pressures were: Pt - 0.78 MPa, Pa - 1.71 MPa;
- the liquid level in the well bore was measured with an echo sounder several times. Based on the level measurement results, the accumulated volume of liquid in the tubing and annulus spaces was calculated;
- in two places on the flange connection the line was disconnected and dismantled which is connected to the pit between the Christmas tree and the discharge line of the the annulus;
- a flange with a quick-release connection was installed on the operating valve of the annulus to the flare pit, to which special equipment (pumping unit and three mobile nitrogen compressor stations, device) was connected and a back valve was installed on the discharge line;
- the discharge line was pressurized to one and a half times the expected operating pressure;
- 2% surfactant solution Solpen-10T was prepared in the measuring chamber of the pumping unit;
- the operating valve of the annulus to the flare pit was opened;
- a non-explosive gas mixture (composition by volume: nitrogen not less than 90% and oxygen not more than 10%) was injected into the tubing through the unit device by three mobile nitrogen compressor stations;
- while operating the tubing and annulus pressure was monitored, as well as the output of the well;
- provided that the pressure in the annulus increased to 5.0 MPa, the surfactant solution was supplied to the device by means of a pumping unit and accordingly foam was injected into the tubing, while monitoring the surfactant consumption. After supplying 0.5 m³ of surfactant solution, the pumping unit was stopped, while the non-explosive gas mixture was continued to be pumped by three mobile nitrogen compressor stations;
- the operating valve of the tubing was opened to the flare pit of the well;
- provided that the pressure in the annulus increased to 5.0 MPa, the surfactant solution was supplied to the device using a pumping unit and accordingly inject foam into the wellbore, while monitoring the surfactant consumption. After supplying 0.5 m³ of surfactant solution, the pumping unit was stopped, while the non-explosive gas mixture was continued to be pumped by three mobile nitrogen compressor stations;
- the foaming out (liquid) was monitored on the flare pit of the well;
- provided that the pressure in the annulus increased to 5.0 MPa, the surfactant solution was supplied to the device using a pumping unit and accordingly foam was injected into the annulus of the well, while monitoring the surfactant consumption. After supplying 0.5 m³ of surfactant solution, the pumping unit was stopped, while the non-explosive gas mixture was continued to be pumped by three mobile nitrogen compressor stations;
- after foaming out (liquid) was over on the flare pit the operating valve of the tubing was closed to the flare pit;
- the pressure in the tubing and annulus space was checked and its increasing was monitored;
- provided that the pressure in the annulus increased to 5.0 MPa, the operating valve of the tubing was opened to the flare pit;

- the surfactant solution was supplied to the device by means of a pumping unit and accordingly inject foam into the tubing of the well, while monitoring the surfactant consumption. After supplying 0.5 m³ of the surfactant solution, the pumping unit was stopped, while the non-explosive gas mixture was continued to be pumped by three mobile nitrogen compressor stations;

- the foaming out (liquid) was monitored on the flare pit;

- the surfactant solution was supplied to the device using a pumping unit and, accordingly, to inject foam into the annulus of the well, while monitoring the surfactant consumption. After supplying 0.5 m³ of surfactant solution, the pumping unit was stopped, while the non-explosive gas mixture was continued to be pumped by three mobile nitrogen compressor stations;

- the release of foam (liquid) was monitored at the flare pit;

- the surfactant solution was supplied to the device using a pumping unit and, accordingly, to inject foam into the annulus of the well, while monitoring the surfactant consumption. After supplying 0.5 m³ of surfactant solution, the pumping unit was stopped, while the non-explosive gas mixture was continued to be pumped by three mobile nitrogen compressor stations;

- at the end of foaming out (liquid) on the flare pit, work on completion was stopped. The operation of three mobile nitrogen compressor stations was stopped and the operating valve of the annulus on the flare pit was shut down as well the operating valve of the tubing to the flare pit of the well;

- the pressure from the discharge line was bled off to atmospheric and it was dismantled;

- the pressure on the tubing and annulus space was controlled and its growth was monitored;

- after the increase of tubing and annulus pressures the operating valve of the tubing to the flowline was opened to let hydrocarbons flow;

- a line was installed on the flange connection, which is connected between the Christmas tree and the discharge line of the annulus to the pit;

- the well was put into operation and its parameters were monitored;

- the production capacity of the well was measured at the gas treatment unit;

- the liquid level in the well was measured with an echo sounder several times. Based on the level measurement results, the accumulated volume of liquid in the tubing and annulus space was calculated;

- compliance with operational parameters was monitored according to the technological mode.

While operating, the foam expansion ratio ranged from 120 to 130. Due to the experiment at the well pit, the liquid contamination was revealed, as well as dirty foam. After finishing the works, the dynamics of working pressures was monitored. The well was put into operation and the parameters of its operation mode were monitored. The actual parameters of the well operation were measured. According to the results of well studies, an increase in gas flow was obtained, which is shown in Table 3.

Summing up, we can say that UkrNDIgaz specialists together with Shebelynskyi OGCPF employees got a positive effect from completion of wells 566 and 126 of the Shebelynske GCF and restoring their productivity by removing the liquid from the bottomhole and well bore with foam generated by injecting the surfactant solution in the device and, accordingly, by injecting a non-explosive gas mixture. This was done in accordance with the developed individual work plans. The results of work performed on well completion 566 and 126 are presented in Table 3.

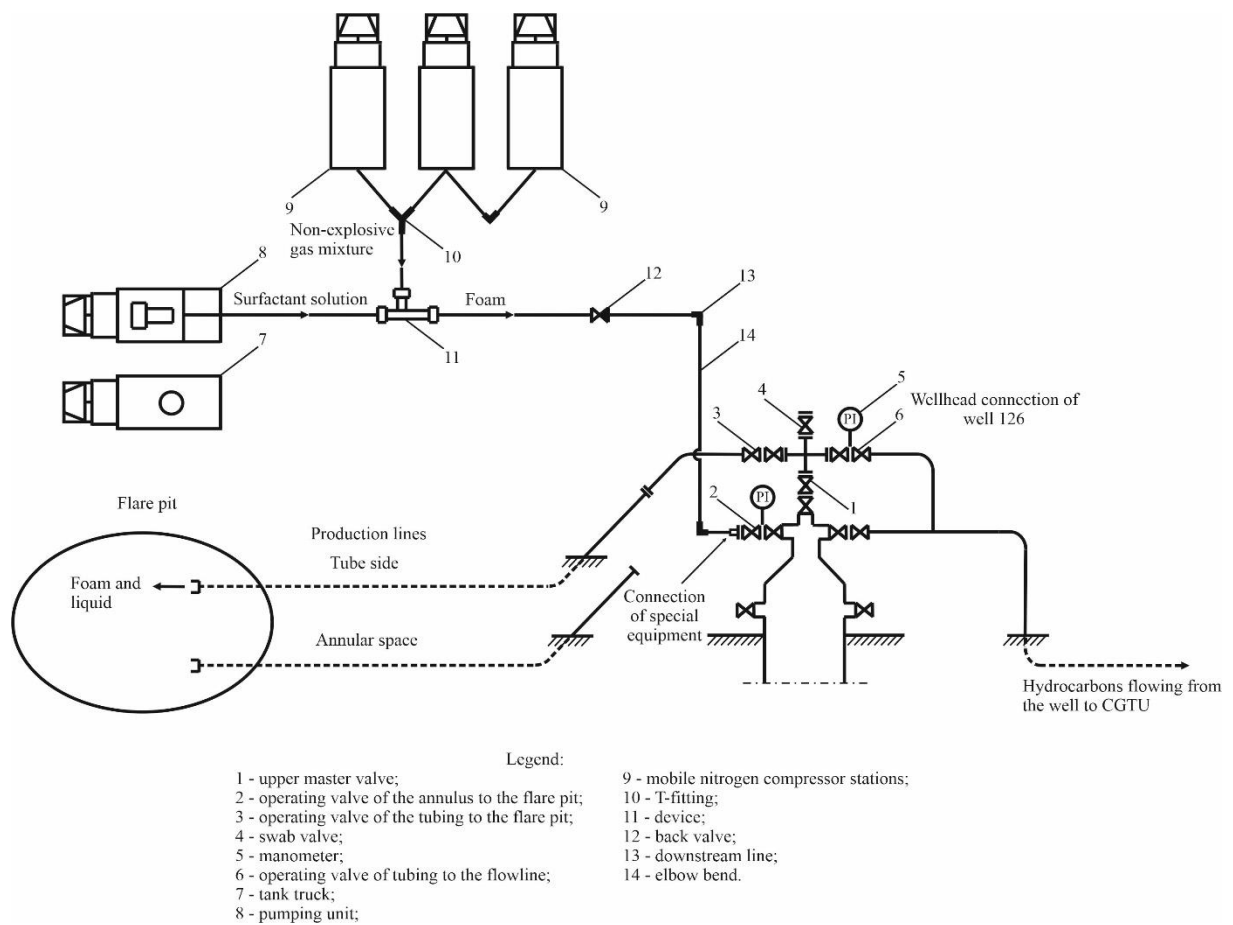


Fig. 9 Scheme of the wellhead manifold and connecting special equipment while completing well 126 of the Shebelynske GCF

Table. 3 The results of experimental studies of well development aimed at restoring their productivity

Number of well	Well parameters before starting work			Well parameters after finishing work		
	Pt, MPa	Pa, MPa	Pg, th.m ³ /d	Pt, MPa	Pa, MPa	Pg, th.m ³ /d
566	0.99	1.76	0.2	0.99	1.09	2.6
126	0.78	1.71	0.3	0.78	1.07	4.9

According to the results of research, it was possible to restore the wells productivity. It is obvious that according to the results of experimental and industrial tests, well development technology can be recommended for other wells. Given the positive results, the technology described above can be used both for the wells development and for the removal of liquid from them.

CONCLUSION

1. The proposed technology of well completion by using foam is efficient for the restarting of operation of shut-in gas condensate wells due to the accumulation of liquid at the bottomhole and in the wellbore. This technology is especially relevant for wells of depleted fields with low formation pressure, which will further decrease in the future.

2. Two methods were developed, which provided for the wells completion to restore their productivity by injecting a non-explosive mixture and foam of different volume into the tube (annulus) space, while removing liquid through the tubing (annulus) into the pit. Individual work plans were drawn up for each of wells 566, 126 of the Shebelynske GCF, on the basis of which experimental studies were carried out.

3. According to the results of experimental studies on two wells 566 and 126 at the Shebelynske GCF a positive result was obtained, which is to remove liquid from the bottomhole and the wellbore, as well as to increase the flow rate from 0.2 thousand m³/d to 2.6 thousand m³/d and from 0.3 thousand m³/d to 4.9 thousand m³/d.

4. Based on CFD modeling of the device for the wells completion with foam, it was found that the mass flow of aqueous solution at the inlet to the device has a significant impact on the quality of the foam. The reason for this is the interaction of a high-velocity stream of aqueous solution with a stream of nitrogen moving at a relatively low speed in the mixing chamber. Thus, the best foam quality was observed when the mass flow rate of aqueous solution at the inlet was the highest that can be provided by pumping units, namely 2.86 kg/s. The performed researches give an understanding of the regularities of foam formation processes in the device for the wells completion. The acquired knowledge is useful for gas field operators who are engaged in improving the efficiency of well operation.

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