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Developing a complex of measures for liquid removal from gas condensate wells and flowlines using surfactants

V.B. Volovetskyi [a,*], Ya.V. Doroshenko [b], G.M. Kogut [c], I.V. Rybitskyi [c], J.I. Doroshenko [b], O.M. Shchyrba [a]

[a] Branch Ukrainian Scientific Research Institute of Natural Gases Public Joint Stock Company "Ukrgasvydobuvannya", 20 Himnaziina Naberezhna str., Kharkiv, Ukraine

[b] 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

[c] 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

* Corresponding e-mail address: vvb11@ukr.net

ORCID identifier: https://orcid.org/0000-0001-8575-5143 (V.B.V.)

ABSTRACT

Purpose: The purpose of this work is to consider the complications that arise while operating gas condensate wells, in particular, the accumulation of hydrocarbon condensate, formation and condensation water at wells and flowlines, to develop a method for removing liquid from wells and flowlines before it entering a gas treatment unit and being treated with surfactants and to develop a method for the foam destruction in the gas-liquid flow.

Design/methodology/approach: The operational parameters of gas-condensate wells of the Yuliivske oil and gas condensate field (OGCF) have been analysed. Wells have been identified that are operated in difficult conditions due to the accumulation of the liquid at the bottom hole and in flowlines. The volume of the liquid accumulated at the bottom hole of gas condensate wells is estimated. The quantity of surfactants, the volume and concentration of the solution required to remove the liquid were calculated individually for each well. The program of experimental researches has been made. The efficiency of the application of surfactant solution was experimentally determined and a positive result was achieved in the form of an increase in production by 10%. A new approach to the use of surfactant solution, as well as the foam destruction, has been proposed. The studies were performed within the framework of research and development work by the specialists of the Ukrainian Scientific Research Institute of Natural Gases.

Findings: Comprehensive measures are proposed to increase the efficiency of gas condensate wells operation. They are monitoring of operational parameters of wells by pressure and temperature gauges 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 of automated feeding a surfactant solution of both in the annulus of the wells and in the flowline. For this purpose, two options for the complex and arrangement are proposed. The proposed options involve the use of various equipment and have a different principle of operation. To prevent foam from entering the gas treatment unit, a method of its destruction has been proposed. The implementation of the proposed comprehensive measures will allow controlling the well operation mode, timely liquid removal from the well and the flowline and ensure stable hydrocarbon production.

Research limitations/implications: The obtained results of laboratory and experimental studies have shown that using a surfactant solution is reasonable to remove the liquid from gas condensate wells. To increase the efficiency of the measure, a new method of feeding surfactant solution was developed by installing a unit for automated feeding (UAF) of a surfactant solution at the mouth.

Practical implications: The results of laboratory tests allow using a surfactant solution reasonably in order to remove the liquid from gas condensate wells, as well as possible further destruction of foam in the gas-liquid flow for increasing both the efficiency of the extraction and production volume.

Originality/value: On the basis of previously performed experimental research, it has been established that it is advisable to use a surfactant solution to remove the liquid from gas condensate wells and flowlines. A new method of removing liquid from gas condensate wells and flowlines has been developed, as well as a method of destroying foam in a gas-liquid flow, which are original and can be implemented.

Keywords: Well, Gas, Flowline, Gas pipeline, Liquid removal, Hydrocarbon extraction, Internal cavity cleaning

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Today, Ukraine is facing an acute problem of reducing dependence on imported hydrocarbons. The way to solve this problem is to reduce the consumption of natural gas, the use of energy-saving technologies, the transition to renewable energy sources, as well as increasing own production of hydrocarbons. Today there is a positive trend in increasing gas production by both state and private companies. The leader in natural gas production in Ukraine is PJSC "Ukrgasvydobuvannya", despite the fact that most fields are at the final stage of development. In order to maintain a stable hydrocarbon production various organizational and technical measures are being developed and taken.

While operating gas and gas condensate wells, especially depleted fields, there are many problematic issues that negatively affect the production of hydrocarbons. The well productivity and, consequently, the production level depend on their timely solution. Therefore, a comprehensive approach is needed, which involves a detailed analysis of problems and the search for alternative solutions. Thus, the problem of ensuring stable well operation of depleted fields is urgent, which requires urgent measures. One of the promising approaches for solving the problem is the automation of the technological process for hydrocarbon extraction from wells in the field of PJSC "Ukrgasvydobuvannya".

For example, in the wells of the Yuliivske oil and gas condensate production facility (OGCPF) fields, measures are being developed aimed at stabilizing hydrocarbon production, which makes it possible to yield a positive result. One of which is the automation of well operation control.

Attention is drawn by the authors [1] to the fact that at the final stage of field development, a significant reduction in reservoir pressures has a negative impact on ensuring stable production and implementation of planned tasks. A characteristic feature of this period of field development is an intermittent operation. The operation of such wells is characterized by certain complications: they cannot work with others, it is difficult to control their work, to determine the shutdown period, to predict emergencies and so on.

During the operation of gas condensate wells at the final stage of field development, one of the main complications is the accumulation of the liquid both at the bottom hole and in the inner cavity of the flowlines. This complication negatively affects the stable operation of wells, leads to intermittent shut-downs of wells and, consequently, reduces gas production. Therefore, it is advisable to develop effective measures for the reliable well operation in conditions of the liquid accumulation in wells and flowlines. The use of equipment and technology with automated control is relevant.

2. Literature review

While operating gas and gas condensate wells, a gas flows from the reservoir to the bottom hole, and then through the tubing string and flowlines the gas enters the gas treatment unit (GTU). Along with the gas, a liquid movement can also occur. Due to the reduction of formation pressures and flow rates, the liquid gradually accumulates at the bottom hole of the wells and in the lower sections of the flowlines, which leads to a decrease in well productivity. Therefore, it is necessary to remove intermittently the liquid from the wells and clean the inner cavity of the flowlines.

Also, taking into account the individual features of the gas gathering system and gas treatment, due to various factors, there is an accumulation of the liquid in gas pipelines (gathering, field). The liquid leads to an increase in pressure losses along the length of gas pipelines and their shaped elements, which in turn affects the productivity of wells, energy consumption for transportation. The amount of hydraulic energy losses along the length of the gas pipeline due to the presence of contaminants in their inner cavity is characterized by the coefficient of hydraulic efficiency [2,3]. In [4,5], the value of the pressure loss of gas-liquid flows in the shaped elements of gas pipelines is determined by CFD modelling. Also, CFD modelling is an effective tool for the study of erosion processes that occur in the shaped elements of gas pipelines [6] and affect their stress-strain state [6,7].

Accumulation of the liquid in the lowered sections of the route of field gas pipelines leads to the increase in inside-pipe corrosion processes, which affect the efficiency of the pipelines [8]. In [9] it was shown that the accumulation of water in the inner cavity of gas pipelines contributes to corrosion damage to the pipe wall. In addition, natural gas contains between 60% and 98% methane and many impurities such as water (H_2O), carbon dioxide (CO_2), hydrogen sulfide (H_2S) and oxygen (O_2). These impurities are also able to promote the corrosion process in pipelines [10]. To reduce the risk of unforeseen destruction of the pipeline, it is necessary to diagnose its technical condition [11], to detect both external and internal corrosion of the pipe wall [12,13]. The structure of the risk management system for safe maintenance of pipelines taking into account diferent influences is formed in [14]. To restore the efficiency of worn-out gas pipelines, especially in hard-to-reach places, the technology of trenchless renovation proposed in [15] by pulling a new polyethylene pipe with a piston is efficient.

Taking into account the above, it is necessary to increase the hydraulic efficiency of gas pipelines by using various methods of cleaning their inner cavity. Today there are many different methods for cleaning the inner cavity of gas pipelines, namely: the use of devices for removing liquid, feeding a solution of surfactants, creating a high-speed gas flow, using various cleaning pistons, such as mechanical, rubber, foam, gel, viscoelastic, etc. Of course, their use in practice has both advantages and disadvantages. Before applying any method, various criteria must be considered, for example, not only ease of use and efficiency, but also their cost and environmental impact. Thus, preference should be given to methods that are characterized by minimal losses of hydrocarbons, ease of use, low cost and minimal impact on the environment [16,17].

In [18] effect of surfactant addition in two-phase air-water adiabatic flows in a horizontal pipe 60 mm ID has been experimentally studied. Due to the presence of the surfactant, foam formed in the mixing section, which implied a significant change in the flow patterns that were photographically recorded and classified into three main types: plug, stratified wavy and stratified with foam entrainment, as far as the air superficial velocity is increased at constant water superficial velocity. An apparent increase of the void fraction within 6% and 39% has been highlighted, which suggests that surfactants may be very useful for deliquification purposes.

In [19] experimentally defined that it is not possible to generate foam in the stratified regime, nevertheless when the regime pass from stratified wavy to slug regime is possible to generate foam within the pipe. Defined that when a liquid loading issue occurs, the liquid accumulating into the pipe will reach a critical hold-up necessary to pass from the stratified regime to the slug regime, i.e. enabling the foam generation. The critical hold-up is dependent by several parameters, among which superficial gas velocity, pipe ID, inclination of the pipe, etc. Foam stability was studied at bubble scale.

In [20], the quality of the foam is recommended to be determined by analyzing the average size and texture of the foam bubbles. The results of the research showed that the larger the average size of the foam bubble, the better the foam cleans the inner cavity of the pipeline. For effective cleaning of pipelines you need to know the composition of liquid contaminants to select surfactants with the best characteristics of foam resistance [21].

In [21] the results of experimental studies of the conditions of foam formation and its stability are presented.

Experimental studies were carried out for four different foaming agents. The main factors affecting the process of foam formation in pipelines are listed. The influence of air velocity in the pipeline on the process of foam formation has been studied. It has been found that it is impossible to generate foam if the two-phase flow regime is stratified. When the mode changes from stratified to dispersed, foam is formed in the pipeline. The delay in foam generation depends on several parameters, including the gas velocity, pipe diameter, its slope. Photofixation of the formed foam with a certain time interval made it possible to compare the foam stability obtained from different foaming agents.

In [22] propose a new method of continually removing the loading liquid with periodical foamer injection manually. The integration of original ethylene glycol and newly injecting efoamer developed a new kind of foam drainage technology, for the severely loading or remote wells.

In [23] several sets of laboratory-scaled experiments were conducted to investigate the efficiency of surfactants in well deliquification in presence of oil. It was observed that the type of foam produced for every surfactant is different. The quantity of foam, the density of foam, and bubble size also vary depending on the surfactant, concentration, and oil fraction. Oil fraction reduces the foamability of all the surfactants. The images taken allow a direct comparison between different surfactants, in order to establish which is the more suitable.

It is obvious, to ensure stable production of hydrocarbons various methods are used and measures are taken to remove the liquid from gas and gas condensate wells, as well as to clean gas pipelines from pollution.

It is known from scientific publications that the problem of removing the liquid from gas and gas condensate wells and flowlines can be solved as follows:

- blowing through tubing string to the pit;
- blowing wells into low-pressure gas gathering networks;
- blowing the well to the gas treatment unit;
- lowering tubing to different depths;
- replacement of tubing strings with pipes of smaller diameter;
- feeding solution and solid surfactants into wells, etc.

To remove the accumulated liquid from wells, as well as from the inner cavity of connecting pipelines (flowlines, collectors, gas pipelines), reducing their hydraulic resistance is provided by their blowing into the atmosphere on a flare [24,25].

The well is purged by intermittently connecting to a low-pressure gas network. The gas from the well together with the liquid enters the low-pressure gas-gathering manifold, is separated from the water in the separators and is compressed or flared [26].

When operating gas and gas condensate wells, they are purged to a gas treatment unit. At the same time, the operating pressure and, accordingly, the technological mode of wells operation change, that causes an increase in the speed of the gas-liquid flow to remove the liquid from the well and the flowline to the gas treatment unit. The high-speed gas-liquid flow is regulated by changing the pressure at the inlet of the gas treatment unit (GTU) by an adjustable bean (AB). When AB is opened, the pressure decreases, and when it is closed, it increases, the gas-liquid flow rate increases and decreases accordingly. After closing the valve on GTU, transportation of gas-liquid flow is stopped. This measure should be carried out on wells that operate with high operating pressure and high flow rate [27]. It is used intermittently in the wells of the Yuliivske OGCPF fields.

Also, the liquid from gas and gas condensate wells is removed by lowering the tubing strings to different depths. For the operation of wells, the optimal diameter of tubing is selected, taking into account the flow rate, the gas flow rate at the bottom hole, pressure losses along the tubing strings and geological and production data on the well operation. At high formation pressures, the tubing strings are lowered above the upper perforations, to the upper perforations and to the middle of the perforation interval. At low formation pressures and the presence of fluid in the well products, the tubing strings are lowered to the lower holes of the perforation interval. The diameter of the tubing strings is chosen so as to ensure complete and continuous removal of the liquid from the bottom hole with minimal pressure loss in the wellbore.

To remove the liquid, hydrocarbon condensate and formation water from gas condensate wells, the gas flow rate is increased, replacing the tubing strings with pipes of smaller diameter. This measure is effective and has found wide application [28].

In the fields, the injection of surfactant solution into gas and gas condensate wells and their flowlines has become widely used in order to improve the removal of the liquid by the gas flow to the pit, the gas treatment unit. In this case, the liquid is taken away to the separator under the condition of the actual well operation mode or its change for a certain period of time. Also, provided that the wells are put into operation on the measuring line through the separator and the pressure on the flare line is partially reduced for a certain time. Before performing surfactant injection works, wells are selected in which the presence of the liquid, formation or condensation water and hydrocarbon condensate is observed. Taking this into account, proposals are being developed for the use of the required surfactant reagent, the amount and method of its injection. The required surfactant concentration for liquid foaming and their type are chosen depending on the salinity of the fluid and its amount in the well production.

In addition, solid surfactants are used in off-road conditions in the presence of a packer in wells and for other reasons. A number of formulations of briquetted chemical reagents (BHR) of multifunctional action have been developed. Complex BHR compositions are of a fairly high quality and are designed to remove the liquid [29]. Solid surfactants are fed through the wellhead manifold, and they are lowered to the bottom hole through the tubing string.

Given the above, the problem of removing liquid from wells and their flowlines is quite acute, which causes to use the latest technologies. It should be noted that significant investments are usually required to remove the liquid from wells and flowlines. Obviously, it is advisable to analyse the available technologies in detail to solve this problem and propose alternative ways.

3. Methods and materials

One of the effective measures to remove the fluid from the bottom hole of the wells and the internal cavity of the flowlines is the use of surfactant solution. From practical experience, there are various ways to feed surfactant solution into wells and flowlines:

- constant feeding through inhibitor lines into the annulus of the well or in the flowline from GTU by means of metering pumps;
- constant feeding to the annulus of the well or flowline by means of a standard dosing unit, which is located at the well mouth;
- intermittent feeding into the annulus (tubing) of the well or flowline by a mobile pump unit, which is connected at the kill units, and in their absence to the arranged lines, such as a gate valve or in the connection of Christmas tree, etc.

At the final stage of field development, an important problem is the self-killing of wells with the liquid, which raises the issue of choosing the technology of their further operation. To do this, it is necessary to determine the operating conditions of wells, namely to determine whether the well operation is stable or unstable.

To determine the operating conditions of gas and gas condensate wells the main factors should be considered, in particular:

- the minimum gas velocity for the liquid to be removed from the bottom hole to the surface;
- the gas velocity at the inlet of the tubing;
- modified Froude number;
- the minimum required flow rate for removal of the liquid from the bottom hole to the surface;
- the optimal tubing diameter for removing the liquid from the bottom hole to the surface;
- the liquid volume accumulated at the bottom hole [30].

One of the important factors that negatively affects the stable operation of wells is liquid accumulation. The volume of the liquid in a well can be determined by measuring the level of the liquid column using various instruments, in particular, an echo sounder. Thus, the distance from the mouth to the liquid column in the pipe and annulus is measured by an echo sounder. The approximate volume of the liquid can be determined by simplified calculation formulas.

Let us consider the sequence of work on the injection of surfactant solution by a pump unit using the example of wells of the Yuliivske OGCF. During the year (monthly) the analysis of operational parameters of gas condensate wells of the Yuliivske OGCF was carried out. Wells have been identified that are operated in difficult conditions due to the accumulation of the liquid at their bottom hole and in the flowlines. Laboratory studies of the liquid composition from gas condensate wells 50, 58, 63, 65, 66, 68, 73, 83 of the Yuliivske OGCF were carried out. Accordance with the above methodology a number of calculations were performed.

The following values were used in calculation methodology for wells 50, 58, 63, 65, 66, 68, 73, 83 of Yuliivsky OGCF [31,32]:

1) The volume of liquid accumulated at the bottom hole:
   a) the height of the liquid column in the tube side and annular channel of wells was measured;
   b) the approximate volume of liquid accumulated at the bottom hole was calculated by the formula:

$$V_l = F \cdot \frac{10^5 \cdot (P_{an} - P_{ts})}{\rho_l} = \frac{0{,}785 \cdot 10^5 \cdot (P_{an} - P_{ts}) \cdot d_{in}^2}{\rho_l},\ \mathrm{m}^3 \qquad (1)$$

where P_{ts}, P_{an} – pressure in tube side and annular channel, MPa;

d_{in} – tubing internal diameter, m;

ρ_l – liquid density, kg/m^3;

2) Gas velocitiy at the inlet to the tubing according to the formula:

$$W_g = \frac{q_{bh}}{F} = \frac{4 \cdot q_g \cdot z_{bh} \cdot P_a \cdot T_{bh} \cdot 10^3}{\pi \cdot d_{in}^2 \cdot P_{bh} \cdot T_{st} \cdot 86400},\ \mathrm{m/s} \qquad (2)$$

where q_g – gas flow rate under standard conditions, thousand, m^3/day;

z_{bh} – gas compressibility factor at P_{bh} and T_{bh};

P_a – atmospheric pressure, MPa;

T_{bh} – temperature of the bottom hole, K;

P_{bh} – pressure at the bottom hole, MPa;

T_{st} – standard temperature, K.

3) Liquid velocity at the inlet to the tubing according to the formula:

$$W_l = 1.47 \cdot 10^{-5} \cdot \frac{q_l}{d_{in}^2}, \text{ m/s} \quad (3)$$

where q_l – liquid flow rate, m^3/day.

4) Froude parameter for gas-liquid mixture according to the formula:

$$Fr_{gl} = \frac{(W_g+W_l)}{g \cdot d_{in}}, \quad (4)$$

where W_g, W_l – gas and liquid velocity at the inlet to the tubing, m/s;
g – gravity acceleration, m/s^2.

5) The amount of surfactant required to remove the liquid according to the formula [33]:

$$M = \frac{100 \cdot C \cdot V_l}{a}, \text{ kg} \quad (5)$$

where C – surfactant concentration, necessary for liquid foaming, removes according to the Ca^{+2} and Mg^{+2} and condancate volume in the product, g/l;
V_l – volume of accumulated fluid in the well to be foamed, m^3;
a – active surfactant mass (commodity concentration), %.

The initial data for the calculations are shown in Table 1.

Table 1.
Initial data for calculations wells of the Yuliivskyi OGCPF

Well number	Well flow rate q_g, thousand m^3/day	Perforation interval, m	Depth of descent of elevator pipes, m	Inner diameter of elevators pipes, m	The pressure at the bottom hole of the well, MPa	The temperature at the bottom hole of the well, K	The pressure at the wellhead, MPa	The temperature at the wellhead, K
50	16.1	3770-3370	3355	0.062	3.90	371	1.7	287
58	10.8	3643-3570	3553	0.062	3.88	371	1.7	283
63	14.5	3643-3635	3607	0.062	3.90	358	1.6	290
65	5.0	3078-2991	2977	0.062	3.86	348	1.5	284
66	19.8	4060-3043	3029	0.062	3.90	368	1.9	283
68	11.4	3139-3112	3132	0.062	3.90	352	1.6	286
73	10.2	3550-3533	3513	0.062	3.88	373	1.6	285
83	9.8	3739-3734	3694	0.062	3.86	375	1.7	288

Table 2.
Results of calculations and recommendations for wells of the Yuliivske OGCF

Well number	Well flow rate q_g, ths.m^3/d	Volume of accumulated liquid at the bottom hole V_l, m^3	Froude number for gas-liquid mixture, Fr_{gl}	Amount of surfactant (Solpen-10 T) per 1 well / operation M, kg	Surfactant solution volume for feeding per 1 well/operation $V_{surfactant}$, L	Surfactant solution concentration per 1 well/ operation N, %	Recommendations regarding depth of lowering tubing string relative to perforation interval, m
50	16.1	0.414	6.1	6.8	100	6.5	3636 (⅔)
58	10.8	0.347	3.2	6.4	100	6.2	3618 (⅔)
63	14.5	0.447	4.5	7.3	100	7.0	3639 (½)
65	5.0	0.175	1.1	5.3	100	5.0	3049 (⅔)
66	19.8	0.269	11.2	6.0	100	5.8	3721 (⅔)
68	11.4	0.427	3.0	7.0	100	6.8	3130 (⅔)
73	10.2	0.157	5.0	5.1	100	4.9	3544 (⅔)
83	9.8	0.137	4.3	4.7	100	4.5	3737 (½)

To ensure the removal of the liquid from the bottom hole of these wells, it is necessary to use surfactants of a certain volume and concentration, as well as the tubing string should be lowered to the optimal depth. The results of calculations and recommendations for the wells of the Yuliivske OGCF are presented in Tables 2, 3 and graphically in Figure 1.

The quantity of required surfactants (Solpen-10 T) has been determined for the considered wells of the Yuliivske OGCF. In this case, the volume of the accumulated liquid V_l and the volume of injected solution were considered to be removed. Further experimental studies were performed taking into account the results of calculations (Tab. 2). The program of carrying out experimental research which indicates their technology, necessary equipment, sequence of work performed.

Table 3.
Results of experimental research

Well number	Well flow rate q_g, ths. m^3/d	Amount of surfactant (Solpen-10 T) per 1 well/operation M, kg	Surfactant solution volume for feeding per 1 well/ operation $V_{surfactant}$, L	Surfactant solution concentration per 1 well/ operation N, %	Intermittence of feeding, times/month
50	16.1	8.9	120	7.1	3
58	10.8	7.8	120	6.2	3
63	14.5	9.3	120	7.5	3
65	5.0	6.4	100	6.2	2
66	19.8	7.3	120	5.8	3
68	11.4	9.1	120	7.3	2
73	10.2	5.8	100	5.6	3
83	9.8	5.4	100	5.2	2

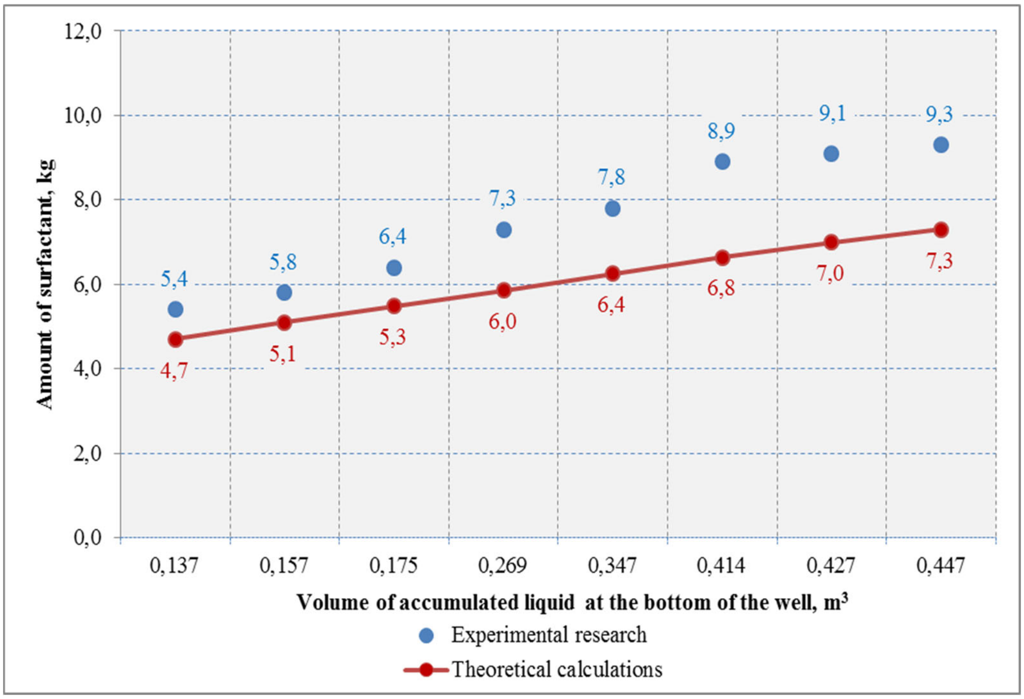

Fig. 1. The dependence of the required amount of surfactants to remove fluid from the bottom of the well on the volume of accumulated fluid

Thus, in practice, surfactants were used by the workers of the Yuliivske OGCPF in the above-mentioned wells in accordance with the results of calculations performed by specialists of the Ukrainian Scientific Research Institute of Natural Gases (UkrNDIgaz). The work was performed in order to increase the productivity of wells by removing liquid from the wells and reducing the repression of the accumulated liquid into the formation.

Before feeding the surfactant solution into the wells, studies were carried out, in particular individual measurements of the flow rate of gas, water and condensate at CGTU-2. On that day, the technical condition of the well shut-down valves was checked. Pressure measurements in the tubular and annular spaces and certain calculations were performed. After performing such operations, the surfactant solution was injected into the annulus of the wells using special equipment: cementing unit (CU-320) and tank truck. Surfactants were injected both into wells operating non-stop and into ones stopped for 12-24 hours to build up pressure. After completion of work on feeding surfactant solution into wells operated non-stop, the production capacity was measured for 2 days. The wells that were shut down were blown through tubing, after which they were put into operation and the production capacities were measured for 2 days. According to the research results, after feeding surfactant solution into the above wells, the downtime for building-up pressure decreased. Within a month, these wells additionally increased gas production.

Based on the results of calculations and experimental research, recommendations are given to determine the required amount of surfactant, the volume of solution to be injected, as well as its concentration and intermittence of feeding. The research results are shown in Table 3.

From the graphical dependence shown in Figure 1, it can be seen that the required amount of surfactant determined by calculation is slightly less than determined experimentally. The discrepancy is from 12.1% to 23.6%. On average, the discrepancy for the eight wells of the Yuliivske OGCF is 18.3%. This discrepancy is due to the presence of condensate in the liquid and mineralization of liquid. Given this, it is advisable to supplement formula (5) with a correction factor. Then the amount of surfactant required to remove fluid from the well will be equal.

$$M = \frac{100 \cdot C \cdot V_l}{a} \cdot k, \text{ kg} \tag{6}$$

where k – the coefficient that takes into account the presence of condensate in the liquid and mineralization of liquid. The coefficient k should be taken equal to 1.18.

The results obtained by calculation in Table 2 differ slightly from the results of the experimental studies shown in Table 3. So, before using a surfactant solution in practice, it is necessary to carry out research. Experimentally selected formulae of surfactant solutions make it possible to ensure the removal of the liquid from wells to the surface, reduce downtime of wells, ensure their stable operation, as well as increase the productivity of wells by up to 10%. Therefore, the maximum gas extraction from wells can be achieved by selecting the optimal modes of their operation and taking various measures based on the results of previous experimental studies.

Given that the Yuliivske OGCF is depleted and is at the final stages of development, the issue of stable production [34] of gas and liquid hydrocarbons remains relevant. Therefore, the implementation of the above measures will optimize the well operation.

4. Results and discussion

The authors analysed the available methods of feeding the surfactant solution into the well and the flowline, identified their advantages and disadvantages. Based on the analysis results it has been decided that it is advisable to develop a set of measures to remove the liquid from gas condensate wells and flowlines, as well as to defoaming in the gas-liquid flow, as foam can come together with hydrocarbons to GTU.

Basing on the relevance of these measures, in order to solve two problems with the possibility of further implementation in production, the authors propose to develop technical solutions, namely:

1) develop a method of removing liquid from gas condensate wells and flowlines;
2) to develop a method of defoaming in the gas-liquid flow.

4.1. Development of a method for removing liquid from a gas condensate well and a flowline

The gas-liquid flow (hydrocarbon raw material) from the wells through flowlines enters the gas treatment unit (GTU). During the well operation both in the wellbores and in the inner cavity of the flowlines various kinds of contaminants can accumulate, which are usually a multicomponent mixture, which includes formation and condensation water, hydrocarbon condensate, mechanical impurities, salts, methanol, etc. The presence of pollution leads to deviations of operating parameters from the technological mode and a decrease in the volume of hydrocarbon production. Based on the results of the analysis of operating parameters and taking into account the calculated volumes of the accumulated liquid, the GTU staff decide to use a surfactant solution and determine its required volume. In case of complications are revealed which related to a decrease in gas production or an increase in the pressure drop in the well and/or flowline and the value is higher than one provided by technological mode, the GTU personnel can adjust the volume of surfactant solution by increasing or decreasing it.

To solve the problem, an automated surfactant solution feeding has been proposed basing on the analysis of the mode of operation of wells, as well as calculations to determine the volume of the accumulated liquid in the wellbore and/or flowline.

In order to implement the proposed technological solution, it is necessary to ensure receiving and archiving reliable well operating parameters of in real time, for example, by installing pressure and temperature gauges both at the mouth and at the inlet gas pipelines of GTU (Fig. 2). Based on available operating data, using well-known techniques or specialized software, the staff work out hydraulic resistance of tubing strings and flowlines, volumes of the accumulated liquid in the wellbore and/or flowline and the volume of surfactant solution for its removal. If the calculations results confirm the presence of liquid accumulation in the wellbore and/or in the internal cavity of the flowline (especially when the flowline is long and has one or more lowered areas where liquid intermittently accumulates, creating additional local resistance), it is necessary to feed surfactant solution to s annulus and/or flowline, respectively. For this purpose, a unit of automated feeding (UAF) of surfactant solution to the well and/or flowline is proposed, which should be placed at the wellhead.

Thanks to UAF the productivity of wells increases, and also there is no increase in pressure losses over the value provided by the technological mode.

The intermittence of feeding and the amount of surfactant solution required to remove the accumulated liquid (water and hydrocarbon condensate) from the wellbore and the internal cavity of the flowline should be determined by GTU personnel, who enter the necessary settings to the UAF, which provides automated surfactant feeding.

The technical result is to ensure stable operation of the well in case of liquid accumulation in the wellbore and flowline by metered feeding surfactant solution and removal of the liquid contaminants by the power of the gas-liquid flow with the bottom hole to the GTU.

To explain the essence of the proposed method, Figure 2 shows a flow chart containing UAF of the surfactant solution. Figure 3 shows a variant of the technological scheme shown in Figure 2.

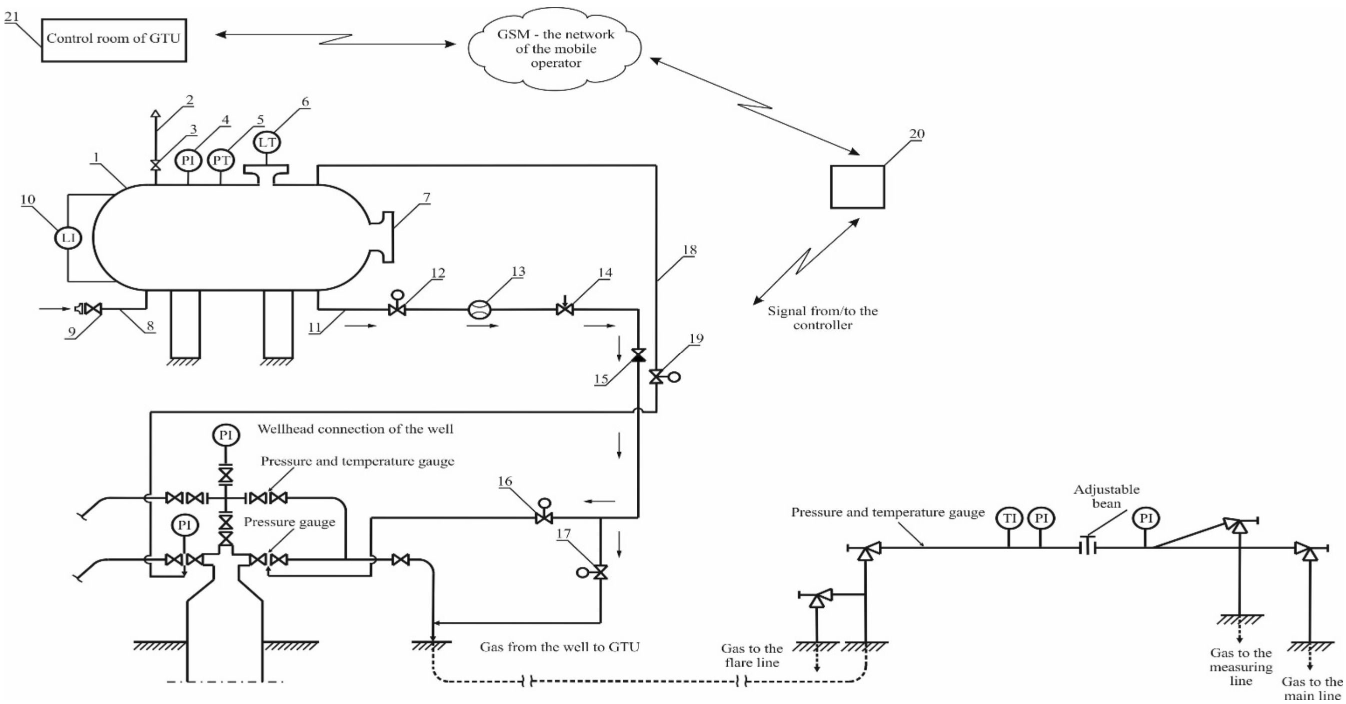

Fig. 2. Diagram of the wellhead connection of the well for automated feeding surfactant solution into the well and the flowline

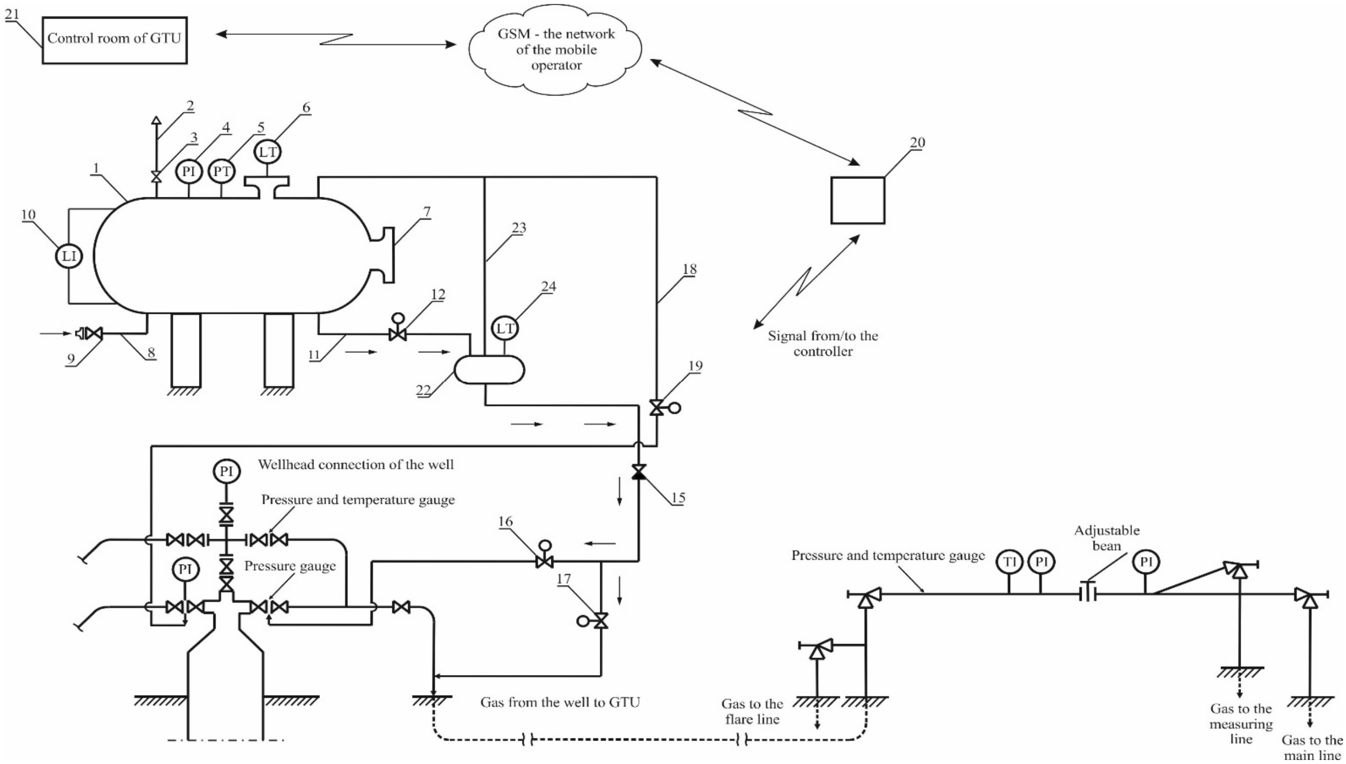

Fig. 3. Diagram of the wellhead connection of the well for automated feeding surfactant solution into the well and the flowline

The technological scheme contains: the tank 1 for filling and storage of surfactant solution, which is equipped with the flare 2 with the valve 3, the manometer 4, the pressure gauge 5, the level sensor 6, and the equipment for remote data transmitting. Due to this, pressure and surfactant solution volume are transmitted via GSM network of the mobile operator and monitored from GTU. In the tank 1 there is the manhole 7 for maintenance, which is connected to the line 8 for filling with surfactant solution, equipped with the shut-off valve 9 with the non-return flanges, a nipple with quick-release connection and a plug and the level indicator of surfactant solution 10. The line 11 is connected to the tank 1 for feeding surfactant solution into the well and/or flowline, on which the valve with electric drive 12 is mounted, a device for measuring the surfactant solution flow, in particular, the flow meter 13, the control valve 14, the check valve 15, the electrically-actuated valves 16 and 17. Also the line 18 is connected to the tank 1 for feeding gas into the tank 1, where the valve with electric drive 19 is installed. In addition, the control console 20 is installed, in which the controller is mounted with access to the modem. There is a 3G cellular modem, or analogue for controlling the complex and transmitting data via GSM communication to control room of GTU 21.

Alternatively, a surfactant flow meter may comprise the working tank 22 to which the gas feeding line 23 is connected and the level sensor 24 is installed.

The method is as follows. The staff remotely control the parameters of the well operating mode (pressure, temperature at GTU and mouth, productivity). If the index of actual hydraulic resistance of tubing strings and flowlines increases above the set limit value, the personnel estimate the volume of the accumulated liquid in the well and/or flowline and the required volume of surfactant solution for its removal. To increase the efficiency of calculations, it is advisable to use specialized software packages. Depending on need, the estimated or adjusted volume of surfactant solution is fed by the staff using UAF.

In the case of remote controlling UAF of the surfactant solution, a command is given by the staff from the control room of GTU 21 to the control console 20. The signal via modem is transmitted to the controller, which sends a signal to the electric drive opening valves equipped with electric drive 19, 12, 16 or 17. In the tank 1 the pressure increases to the same value as in the well. The surfactant solution from the tank 1 goes through the flow meter 13 and the control valve 14 into the well and/or flowline. The check valve 15 prevents the gas flow from going to the control valve 14. By installing the flow meter 13, the supply volume of the surfactant solution is controlled. From the flow meter 13 the signal is transmitted to the controller on the control console 20, and further to closing the control valve 14. In addition, local control of UAF is provided.

According to another variant of the technological scheme instead of the flow meter 13, as a device for measuring the consumption of surfactant solution, the working tank 22 is used, which is installed between the electric valve 12 and check valve 15. The surfactant solution from the tank 1 enters the working tank 22 well and/or flowline. The check valve 15 excludes the possibility of gas entering the working tank 22. Thanks to the installation of the tank 22, the supplied quantity of the metered surfactant solution is controlled, and its filling is controlled by the level sensor 24 remotely.

As the surfactant solution is consumed from tank 1, it is intermittently filled in the following sequence: the valves with electric drive 12, 16, 17 on line 11 and the valves with the electric drive 19 on the line 18 are closed. In tank 1 the pressure is reduced to atmospheric by opening the valve 3 to the flare 2. Dropping the pressure to atmospheric is controlled by the manometer 4. After reaching atmospheric pressure, connecting to the line 8 is made and the shut-off valve 9 is opened to fill the tank 1. The level of filling the tank 1 is controlled on base of the level of the surfactant solution 10. After filling the tank 1, the shut-off valve 9 on the line 8 is closed, the valve 3 is closed to the flare 2 and UAF is put into operation.

The power supply of the complex is provided from the power supply network with a voltage of 220 V. If it is impossible to the supply of electricity from stationary sources, alternative energy sources are used. In this case, the power supply of UAF is provided by an autonomous power consumption system containing equipment (solar panel, controller, batteries, etc.) with low power consumption.

To prevent the surfactant solution from freezing in tank 1 in case of lowering the ambient temperature below 0ºC, it is advisable to heat it or add a special liquid.

The advantage of the proposed method is the ability to dose the surfactant solution into both the well and the flowline, and control the amount of solution flow. Based on the analysis of the operating parameters of the wells and calculations, it is possible to choose the optimal volume and intermittence of feeding the surfactant solution, which prevents the liquid accumulation in the wellbore and in the inner cavity of the flowline. Implementing the method ensures reliable operation of gas condensate wells and stable production of hydrocarbons [35].

The method can be used to increase the efficiency of pipelines operation (gathering and field pipelines) in the case of their significant length and in the presence of low areas where liquid accumulation is possible, for metered supplying surfactant solution to the internal cavity. These measures make it possible to remove the accumulated liquid from the pipelines, increase their hydraulic efficiency.

It should be emphasized that the given method of liquid removal from gas condensate wells and flowlines should be implemented at the mouth of wells CGTU-2 of the Yuliivske OGCF, as it does not require reconstruction of the existing gas gathering and treatment system, but only the installation of new equipment.

In view of the above, it is advisable to consider the solution of another equally important problem, as foam destruction in the gas-liquid flow.

4.2. Development of a method for foam destruction in a gas-liquid flow

To ensure stable operation of both wells and pipelines (flowlines, gathering and field pipelines), the gas gathering and treatment systems remove the accumulated liquid using a surfactant solution.

In the case of surfactants use, foam is formed, which together with the gas-liquid flow and liquid contaminants from the wells through pipelines enter the gas collection and treatment system and is destroyed in the separators completely or partially. Remains of undistracted foam can negatively affect the efficiency of the segregation equipment and, accordingly, the gas purification quality. Consequently, foam can enter GTU with different characteristics, in terms of multiplicity and stability. Therefore, mechanical and chemical methods or their combination are used at GTU to defoam. The foam is mechanically destructed using nets or nozzles installed at the inlet or inside the separators. The chemical method involves the use of various chemical reagents that are fed into the gas-liquid flow with foam.

To solve this problem, a method of foam destruction in a gas-liquid flow by mixing it with a degassed liquid as far as possible from the inlet to the separator of the main and/or measuring line GTU. Stable hydrocarbon condensate is dosed to the gas-liquid flow intermittently or continuously by a pump from an additionally mounted tank. The basis for such a technical solution is the results of laboratory tests conducted following current methods in Ukraine.

It was found that a drastic decrease in the foam stability occurs in case of increase in the volume of stable hydrocarbon condensate with a density of 0.736 g/cm^3 to 0.757 g/cm^3, which is added to the studied sample of mineralized formation water with a density of 1.075 g/cm^3 to 1.083 g/cm^3, which contains 50 g/l of calcium chloride ($CaCI_2$) and 100 g/l of sodium chloride (NaCI), at the concentration of surfactant solution (Solpent-10 T, Stinol-NG, Savinol, Sulfanol, Pinosil-NHI, Fomelit, SE-235-A, Pyrene-10, etc.) from 1% to 5% at temperatures of 20ºC and 60ºC. According to the research results, the addition of 10% stable hydrocarbon condensate reduces the stability of the foam at least twice, 20% – at least three times, and 30% – not less than four times.

The technical result is to ensure effective cleaning of the transported gas-liquid flow from wells through pipelines (flowlines, gathering and field pipelines) from the foam formed due to the use of surfactant solution, and to increase the reliability of operating gas production equipment of GTU.

To explain the essence of the proposed method, Figure 4 shows a flow chart that provides the feeding stable hydrocarbon condensate in the gas-liquid flow.

The gas-liquid flow (hydrocarbon feedstock) goes from wells through flowlines, as well as from other GTU by gathering pipeline (field) pipelines goes to the equipment of shut-down units 1, where it passes through the reduction unit (adjustable bean, etc.), which regulates well operation mode. Subsequently, the gas-liquid flow enters the separator of the surface infrastructure: the separator 2 of the first stage of the main line; or the separator 3 of the first stage of the measuring line; or simultaneously in the separators 2 and 3, where there a primary purification of the gas from mechanical impurities and liquid takes place. Further, the gas from the separators 2 and/or 3 is supplied according to the individual technological scheme of GTU. The liquid from the separator 3, which can be fed to the individual measuring segregator, is fed into the same segregator 4 as from the separator 2. This further separates the entire volume of the liquid from the two lines into formation water and unstable hydrocarbon condensate, as well as partial gas emission. Next, the unstable hydrocarbon condensate enters the tank 5 for its degassing (it is possible to use several tanks and/or a unit for stabilizing hydrocarbon condensate), where the gas is completely separated. After that, the stable hydrocarbon condensate flows to the gas storehouse and, if necessary, in an additional container 6 for stable hydrocarbon condensate, and then the pump 7 feeds it into the gas-liquid flow, in particular, a straight section of the pipeline at the maximum possible distance from the inlet to separators 2 and/or 3.

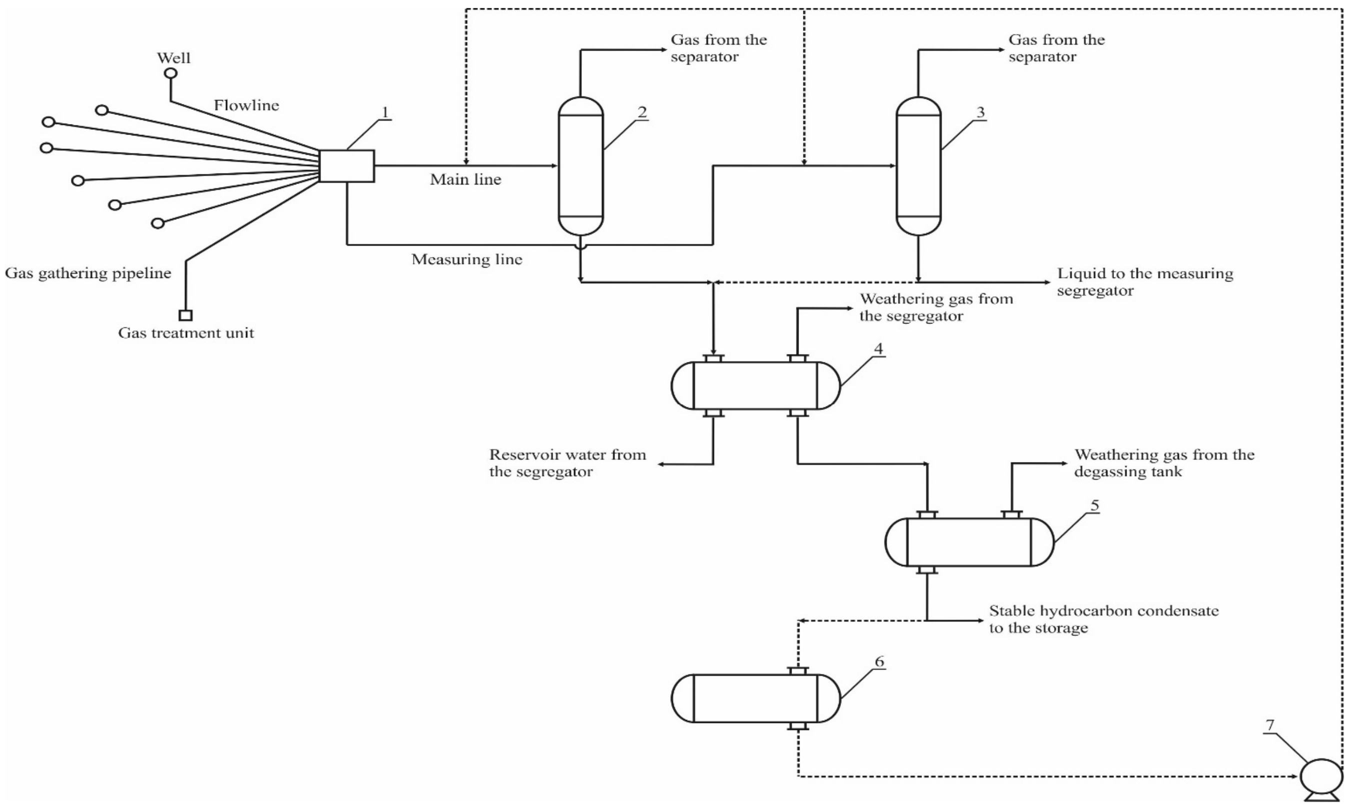

Fig. 4. Scheme of feeding stable hydrocarbon condensate to the main and/or measuring line (separator 2 and/or 3)

The foam destruction is carried out as follows. At GTU the staff control the parameters of the well operating mode, gathering (field) pipelines (pressure, temperature, productivity, etc.). In case of complications arising, which are associated with the liquid accumulation in wells or pipelines, the surfactant solution is used to remove it. Before feeding the surfactant solution into wells or pipelines, the condition of separators 2 and/or 3 is carried out and they are adjusted, the operating parameters are measured and the gas-liquid flow rate is estimated to predict the time of its inflow into GTU. The surfactant solution is fed into wells or pipelines.

To destroy the foam that comes with the gas-liquid flow, it is necessary to ensure the presence of stable hydrocarbon condensate in tank 6.

Foam inflow is visually monitored by intermittently opening the valves on the inlet gas pipelines of the shutdown devices and piping of the separators manifold, taking into account a certain gas-liquid flow rate. After detecting foam in the gas-liquid flow, the appropriate shut-off valve is opened and the pump 7 is turned on, which is dosed intermittently or continuously the stable hydrocarbon condensate from the tank 6 into the gas-liquid flow at the maximum possible distance from the inlet to the separators 2 and/or 3.

The intermittence and duration of feeding stable hydrocarbon condensate in the gas-liquid flow for the foam destruction are estimated by the results of the foam presence in the gas production equipment of UPG.

The foam destruction occurs directly in the pipeline from the place of feeding stable hydrocarbon condensate in the gas-liquid flow to the separators 2 or 3 and in the separators 2 or 3, or simultaneously to the separators 2 and 3 and in separators 2 and 3. The use of the proposed method will improve gas purification efficiency. The separators 2 and 3 can also be connected in series to increase the efficiency of gas purification from foam [36].

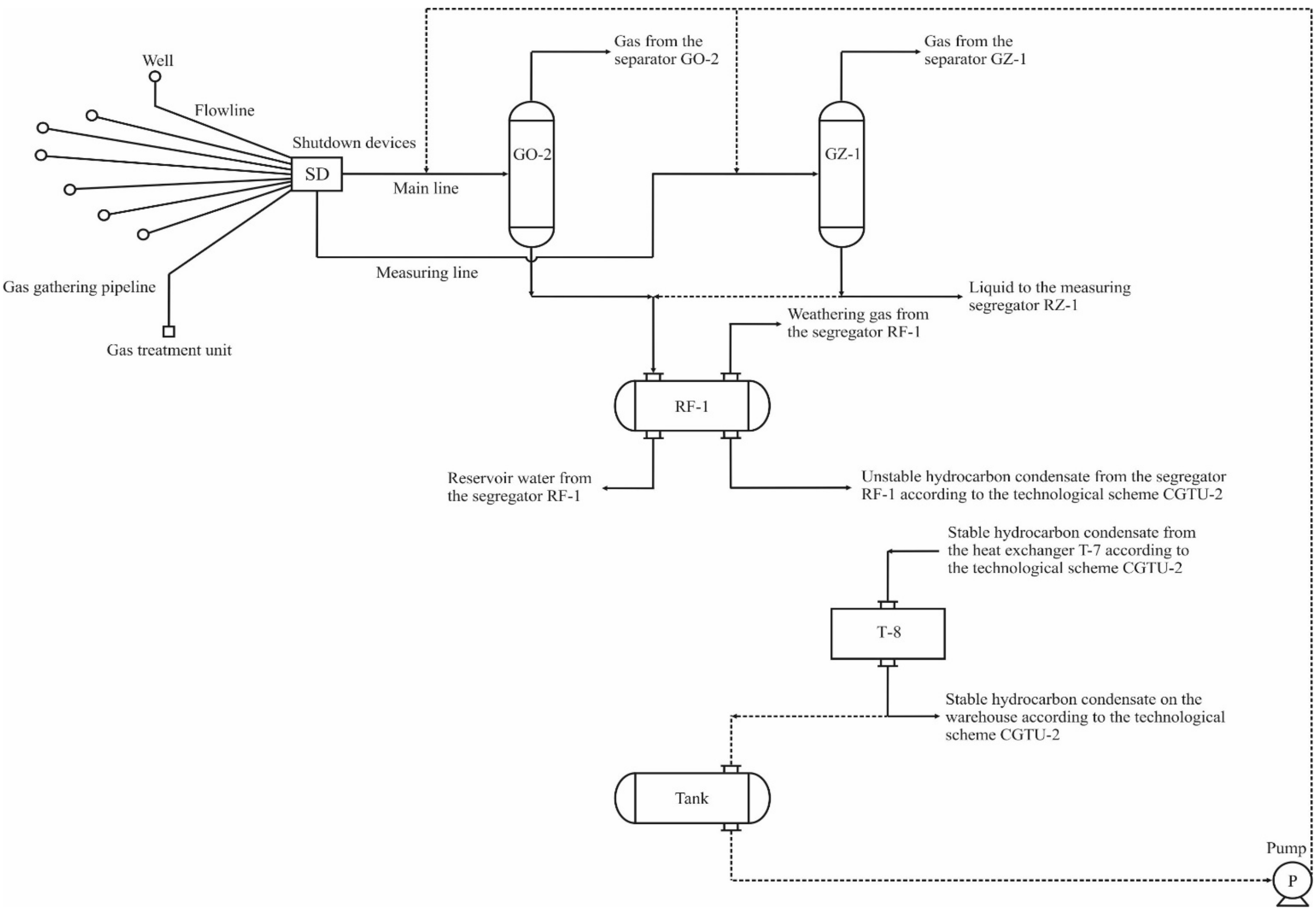

Fig. 5. Scheme of feeding stable hydrocarbon condensate to the main and/or measuring line (separators GO-2and/or GZ-1) CGTU-2 of the Yuliivske OGCF

The advantages of this method include the possibility of metered feeding stable hydrocarbon condensate in the gas-liquid flow which enters the separator, allowing to control the process of foam destruction. Also, the proposed method allows destroying the foam effectively by reducing its stability under the action of stable hydrocarbon condensate, which improves the purification quality of the gas coming from wells through pipelines (flowlines, gathering and field pipelines) to GTU.

In view of the above, it is necessary to adapt the presented method of foam destruction in the gas-liquid flow to the conditions of CGTU-2 of the Yuliivske OGCF.

4.3. Implementing the method for foam destroying in the gas-liquid flow at CGTU-2 of the Yuliivske OGCF

The technical result is to ensure effective cleaning of the transported gas-liquid flow from wells through pipelines (flowlines, gathering and field pipelines) from foam formed due to the use of the surfactant solution, and increase the reliability of operating the gas production equipment of CGTU-2 of the Yuliivske OGCF.

To explain the essence of the proposed method, in Figure 5 a process flow diagram is given that provides the supply of stable hydrocarbon condensate in the gas-liquid flow, similar to the process flow diagram described in Figure 4, but for the conditions of CGTU-2 of the Yuliivske OGCF.

To implement this method on CGTU-2 of the Yuliivske OGCF, the following technological scheme is required (Fig. 6), which contains: the atmospheric tank 1, the level sensor 2, the breathing valve 3, the line for filling the tank with stable hydrocarbon condensate from the heat exchanger T-8 4, the shut-off valve 5, the level indicator 6, the line for feeding stable hydrocarbon condensate to the pump 7, the pump 8, the line for supplying stable hydrocarbon condensate into the gas-liquid flow, in particular, a straight section of the gas pipeline at the maximum possible distance from the inlet to the separator GO-2 and/or separator GZ-1 of the CGTU-2 measuring line 9, the check valve 10.

As the tank 1 is emptied from stable hydrocarbon condensate, it is intermittently filled. To fill the tank 1, the shut-off valve 5 is opened for flowing stable hydrocarbon condensate from the heat exchanger T-8 of CGTU-2.

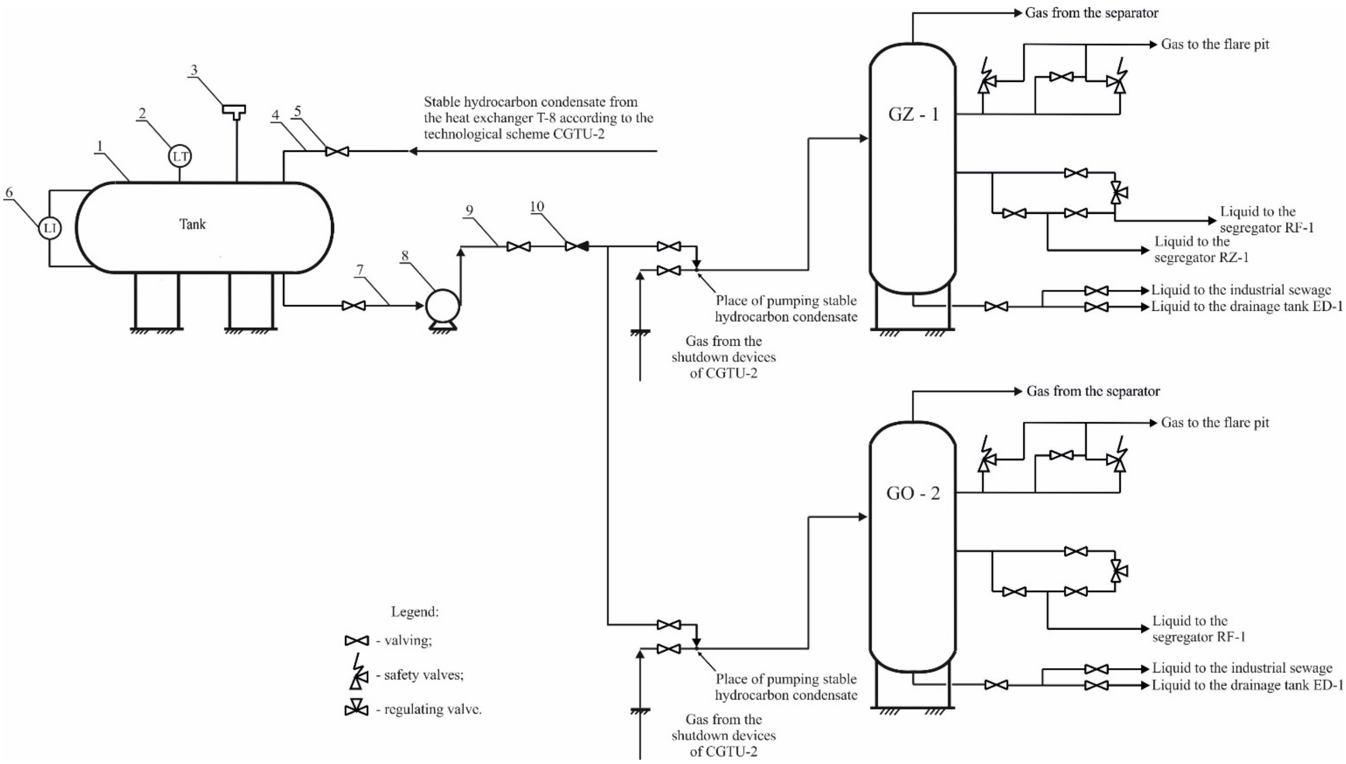

Fig. 6. Scheme of tank connection for feeding stable hydrocarbon condensate to the main and/or measuring line (separators GO-2and/or GZ-1) CGTU-2 of the Yuliivske OGCF

The foam is destructed in the following way. At CGTU-2, personnel control the parameters of the well operation mode, gathering (fied) pipelines (pressure, temperature, productivity, etc.). In case of complications associated with the accumulation of the liquid in wells or pipelines, a surfactant solution is used to remove it. Before feeding the surfactant solution into wells or pipelines, the condition of the separator of the first stage of the main line GO-2 and/or the separator of the first stage of the measuring line GZ-1 and adjust them for operation, measure operating parameters and estimate the rate of the gas-liquid flow to predict the time of its entry into CGTU-2. The surfactant solution is fed into wells or pipelines.

To destroy the foam coming with the gas-liquid flow, it is necessary to ensure the presence of stable hydrocarbon condensate in the tank 1.

The inflow of foam is visually monitored by intermittently opening the valves on the inlet pipelines of the unit of shut-down devices and the separators manifold, taking into account the specified rate of the gas-liquid flow. After detecting foam in the gas-liquid flow, the appropriate shut-off valve is opened and the pump 8 is switched on, which feeds intermittently a metered quantity or continuously supplies stable hydrocarbon condensate from the tank 1 into the gas-liquid flow at the maximum possible distance from the inlet separators GO-2 and/or GZ-1.

The intermittence and duration of supply of stable hydrocarbon condensate in the gas-liquid flow for the foam destruction are determined by the results of studies of the presence of foam in the gas production equipment of CGTU-2.

The destruction of foam occurs directly in the pipeline from the place of feeding stable hydrocarbon condensate in the gas-liquid flow to the separators GO-2 or GZ-1 and in the separators GO-2 or GZ-1, or simultaneously to the separators GO-2 and GZ-1 and in the separators GO-2 and GZ-1. The use of the proposed method will improve the quality of gas purification. The separators GO-2 and GZ-1 can also be connected in series to increase the efficiency of gas purification from foam.

It should be noted that to provide additional opportunities for the foam destruction in the gas-liquid flow, a similar measure can be implemented for the separators GO-3 and GZ-2.

5. Discussion and proposals

Technological processes of liquid removal from gas condensate wells and flow lines by surfactants have not been sufficiently studied to date, and in the open literature there are no both calculated and experimental data on the required amount of surfactants. Therefore, this paper presents and analyzes the results of experimental studies on the use of surfactants for cleaning wells and flow lines of depleted gas condensate fields and evaluating the effectiveness of their use.

The results of theoretical calculations and experimental studies have shown that the amount of surfactants required to remove liquid contaminants from gas condensate wells depends significantly on the volume of accumulated fluid at the bottom of the well. This dependence is close to linear and with increasing volume of accumulated fluid increases the required amount of surfactant to remove it from the well (Fig. 1). Moreover, it was found that the required amount of surfactants determined by calculation is slightly less than determined experimentally. The average discrepancy is 18.3%. This discrepancy is explained by the presence of condensate in the fluid at the bottom of the well and the mineralization of the fluid. Therefore, the known formula (5) was refined to calculate the required amount of surfactants. Therefore, one of the results of these studies is the obtained formula (6) for calculating the required amount of surfactant to remove fluid from the bottom of the well, which takes into account the presence of condensate in the fluid and mineralization of the fluid. The obtained results can serve as an operational guide for selecting the required amount of surfactants to clean gas wells from liquid contaminants.

The obtained results made it possible to implement the idea of high-quality cleaning of wells and flow lines from liquid contaminants in order to increase the efficiency of gas condensate wells. This was made possible by the development of a new approach to the use of surfactant solution and to the destruction of foam to prevent it from entering the gas collection and preparation systems. The developed approach consists in automated supply of surfactant solution to the wells on the basis of analysis of the mode of their operation and calculations according to formula (6) of the required amount of such solution. The approach to the destruction of the foam is to supply a stable hydrocarbon condensate from an additional installed tank in the pipeline through which the foam moves. The stable hydrocarbon condensate must be fed into the pipe with foam at the maximum possible distance from the entrance flow to the separator. Experimental studies have shown that the proposed approaches can be used to increase hydrocarbon production.

6. Conclusions

1. The results of theoretical calculations and experimental research have shown that the amount of liquid contami-

nants accumulated in the well has a strong effect not only on the flow rate of wells, but also on the required amount of surfactants for their purification. The relationship between the amount of surfactant required to remove all fluid accumulated in the well and the volume of this fluid has been clarified. A coefficient is added to the formula for calculating the required amount of surfactant, which takes into account the presence of condensate in the liquid and the mineralization of the liquid.

2. The operational characteristics of gas condensate wells of the Yuliivske OGCF are analysed. The wells that are operated in difficult conditions due to the accumulation of fluid at the bottom hole and in the loops are identified. The volume of the liquid accumulated at the bottom hole of gas condensate wells is determined. The quantity of surfactants, the volume and concentration of the solution required to remove the liquid were calculated individually for each well. The program of experimental researches is made. The efficiency of the surfactant solution application has been experimentally determined and a positive result in the form of a 10 % increase in production was achieved.
3. The complex measures have been developed, which provide for the removal of liquid from gas condensate wells and flowlines and the foam destruction in the gas-liquid flow, which should be implemented. Thus, to remove the liquid from gas condensate wells and flowlines, an installation of a unit for automated feeding surfactant solution has been proposed at the mouth of the well. Thanks to the installation of UAF equipped with remote and local control, if such a need arises, the surfactant solution can be fed into the annulus of the well, as well as into the internal cavity of the flowline or gas pipeline. For this purpose, two options for a set of the equipment installing are proposed, which involve the use of different equipment and have a different principle of operation. Such an approach will allow choosing the optimal mode of well operation.
   1) To prevent from foam forming in the gas-liquid flow at GTU, which can negatively affect the segregation equipment, and, accordingly, the gas purification quality, it is proposed to use the method of foam destruction in the gas-liquid flow. This method involves the arrangement of a technological scheme for feeding stable hydrocarbon condensate in the gas-liquid flow entering the separators of the first separation stage, both the main line and the measuring one.
   2) The ways of implementing the foam destruction method which was adapted to the conditions of CGTU-2 of the Yuliivske OGCF are also given.
4. The proposed set of measures will allow timely to remove the liquid from wells and the internal cavity of flowlines or gas pipelines, to ensure stable gas extraction from depleted fields.
5. As depleted fields will continue to experience many different complications related to the accumulation of the liquid in a well and pipelines system for the gas collection and treatment, it is advisable to develop and implement new methods and ways to solve problems.

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