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Experimental effectiveness studies of the technology for cleaning the inner cavity of gas gathering pipelines

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ABSTRACT

Purpose: The purposes of the article are to determine the hydraulic efficiency of two gas gathering pipelines of the Yuliivskyi oil and gas condensate production facility (OGCPF) and develop a set of measures to increase it; to experimentally determine the efficiency of using foams to increase the hydraulic characteristics of the gas gathering pipelines in the Yuliivskyi OGCPF; to develop a set of measures that will help to improve the hydraulic characteristics of gas gathering pipelines.

Design/methodology/approach: The research methodology consists in determining the hydraulic efficiency of gas gathering pipelines before and after cleaning their inner cavity with foams with different expansion ratios and comparing the obtained values, which allows to objectively assess the efficiency of this cleaning method. 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: The pilot testing was carried out to determine the efficiency of cleaning the inner cavity of gas gathering pipelines with foams with different expansion ratios. It showed positive results. It was determined that cleaning the inner cavity of gas gathering pipelines with foams with the expansion ratio from 80 to 90 led to an increase in the hydraulic efficiency coefficient by 10.5%, and with foams with the expansion ratio from 50 to 60 – by 5.7%. The measures taken to clean the inner cavity of gas gathering pipelines from liquid contaminations have proven their efficiency and can be recommended for other fields.

Research limitations/implications: The obtained results show that it is reasonable to conduct the experimental studies on the efficiency of cleaning the inner cavity of gas gathering pipelines with the foams with higher expansion ratios. To achieve the maximum quality of cleaning the gas gathering pipelines, it is necessary to develop a new method that will combine the use of foam and gel piston.

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Practical implications: The performed experimental studies help to take a more reasonable approach to cleaning the inner cavity of gas gathering pipelines with foams and to predict in advance the effect of the foam expansion ratio on the hydraulic efficiency of gas gathering pipelines.

Originality/value: The experimental studies on the effect of foam expansion ratios on the hydraulic efficiency of gas gathering pipelines are original.

Keywords: Gas, Foam, Gas gathering pipeline, Hydraulic efficiency, Cleaning the inner cavity of pipelines

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ANALYSIS AND MODELLING

1. Introduction

Most of the fields of PJSC “Ukrgasvydobuvannya” are developed until depletion. As a result, there is a gradual decrease in reservoir pressure and well production rates. This leads to the decrease in gas flow velocity along the way from the formation to the gas treatment unit (GTU), and liquid accumulation in different sections of the bottom holes, flowlines, and gas gathering pipelines. Thus, liquid accumulation causes the reduction in the hydrocarbons production and in the volume of gas transported by pipelines to the gathering and treatment system. In order to improve the hydraulic characteristics of pipelines, measures should be taken to clean the flowlines and gas gathering pipelines.

At present, gas gathering pipelines are cleaned from liquid (water and hydrocarbon condensate) by different methods:

- using liquid extraction equipment;
- switching the pipeline to the self-cleaning mode (purging);
- using surfactants;
- using cleaning devices, etc.

Different liquid extraction equipment is used in practice. For example, condensate tanks, expansion chambers, drips, etc. are installed on gas gathering pipelines. They have both advantages and disadvantages. The advantages include simple design and a relatively small investment. On gas pipelines, they are installed in the places of probable fluid accumulation, in particular in lower sections. However, the disadvantages can include the need for periodic maintenance to remove the liquid, as liquid accumulation can create additional local restrictions and adversely affect the volume of transported gas.

Gas pipeline purging is considered a simple and effective method. It can be applied to gas pipelines of different diameters and with angle valves. However, this method has such disadvantages as gas loss and environmental pollution. Therefore, in practice gas pipelines are purged with decreasing the pressure and switched to lower inlet pressure, which increases the gas flow rate for a certain period of time.

Another solution to this problem is to use surfactants, which are fed into the gas gathering pipeline mainly by pumps from the gas treatment unit or from mobile pumping units. Foaming agents reduce the liquid-gas interfacial tension and thereby contribute to foam formation. The formed foam is better carried by the gas flow, because its density is lower than the liquid density. Thus, surfactants facilitate liquid foaming so that it can be removed from the inner cavity of gas pipeline with the gas flow.

Another method of cleaning the inner cavity is to use a variety of cleaning tools, which can be of different design, composition, etc. For example, there are mechanical, rubber, foam and gel pistons and many others. In order to select the necessary piston, a number of factors should be taken into account, such as the length and diameter of the gas gathering pipeline, local restrictions (valvings, bends, tees), pipeline route profile, etc. When applying mechanical and rubber pistons, there are certain complications, which include the rapid wear of production nodes, the possibility of hydraulic shocks and sticking of the cleaning tools in the pipe. Besides, this method can be used only in the pipelines with straight-through valves and smooth transitions. Thus, under the existing conditions of the gas gathering pipeline, it is advisable to individually select the necessary type of piston based on the experimental investigations.

2. Literature review

At present, current condition of the gas transmission system of PJSC “Ukrgasvydobuvannya” is important for stabilizing the hydrocarbons production and its increase. This issue should be studied by performing numerous calculations and investigations, the results of which can demonstrate the state of gas production and gathering pipelines, which, in case of allowable design capacity, transport a smaller volume of natural gas.

In the article [1], the authors analyzed the state of the gas gathering pipeline, by which gas from the gas gathering station (GGS) of the Narizhnianske oil and gas condensate field (OGCF) flows to the complex gas treatment unit-2 (CGTU-2) of the Yuliivske (OGCF). The hydraulic efficiency of the gas gathering pipeline and the contamination volumes were calculated. It was found out that the calculation results of contamination volumes were approximate, as they differed from the measurement results of the liquid volume removed from the gas gathering pipeline to the measuring line of the CGTU-2 (in particular, to the separator and segregator). To ensure a reliable operation of the gas gathering pipeline, it was proposed to connect in series two separators (the main separator GZ-1 and the experimental separator GZ-2), periodically inject the surfactant solution and, based on the research findings, choose the optimal mode for the high-speed gas flow and liquid removal from the inner cavity to the CGTU-2 of the Yuliivske OGCF.

In the article [2], the authors analyzed the condition of the gas gathering pipeline through which gas is transported from the CGTU-1 of the Skvortsivske OGCF to the CGTU-2 of the Yuliivske OGCF. The gas flow rate and hydraulic efficiency of the gas gathering pipeline were calculated. It was established that liquid contaminants were formed in the inner cavity as a result of: mechanical dripping liquid removal from the separation equipment, liquid condensation from the gas flow by the pipeline route profile, decrease in gas flow rate. According to the research results, the most effective cleaning of the inner cavity was to create a high-speed gas flow to remove the liquid.

In the article [3], based on the analysis of actual data on the operation of gas gathering pipelines, different numerous value calculations and industrial studies, the authors for the first time defined the main factors that negatively affected the hydraulic efficiency coefficient. This would help to carefully control the factors in order to prevent the reduction in hydraulic efficiency and decrease in the volume of transported gas, which could negatively affect the achievement of production targets.

Contaminants, in particular formation water and hydrocarbon condensate, accumulate in the inner cavity of gas production and gathering pipelines of gas condensate fields, which are at the final stage of development. They cause significant losses of hydraulic energy both along the length of these pipelines and in the shaped elements. The hydraulic efficiency coefficient is used to determine the magnitude of hydraulic energy losses along the length of gas pipeline due to the presence of contaminants in its inner cavity. However, it is extremely difficult to determine the magnitude of hydraulic energy losses of multiphase flows in the shaped elements, because the changes in flow direction cause the centrifugal force, and the phase with higher density is more affected by it. This leads to the uneven distribution of phases, friction between them, and loss of momentum. As the concentration of dispersed phase increases, its influence on the flow of transported medium and energy loss increases. One of the methods of studying the motion of multiphase flows and their hydraulic energy loss in the shaped elements of gas pipelines is CFD modeling, which was performed in the articles [4,5]. Besides, the contaminants in the inner cavity of gas production and gathering pipelines lead to the intensification of inline corrosion and erosion processes. These are very complex processes that depend on many parameters. Therefore, it is efficient to apply the CFD modeling method to study them, as it was in the article [6]. Due to the presence of contaminants in the inner cavity of gas pipelines, the corrosion [7-9] and erosion [5,10] processes affect the stress-strain state of the wall, especially of the shaped elements [5,10] and increase accident risk. One of the effective ways to reduce these risks, especially in hard-to-reach places, is to pull a new polyethylene pipe in a defective steel pipe using a pig [11].

To ensure the reliability of gas pipelines, it is necessary to control the main operating parameters, in particular the dynamics of pressure and temperature changes [12-14], to promptly detect the corrosion defects of the pipe surface [15], and minimize the natural and man-made risks [16].

Nowadays there are many different methods of cleaning the inner cavity of gas pipelines, in particular: using liquid extraction equipment, feeding a solution of surfactants, creating a high-speed gas flow, using various cleaning pistons, for example, mechanical, rubber, foam, gel, viscoelastic, etc. One of the promising methods of cleaning gas pipelines is using foam pigs.

In the article [17], the processes of cleaning the inner cavity of gas pipelines from liquid contaminants were experimentally investigated. The experimental unit consisted of the connected glass and plastic tubes of different lengths, bends, ascending and descending sections, and taps. The effect of surfactant concentration on the foam quality under different conditions was experimentally determined. The studies showed the preliminary results on the foam stability of different surfactants with the same concentration. Useful information on the selection of surfactants with the best characteristics of foam stability was obtained.

E. Tuna [18] recommends determining the foam quality by means of analyzing the average size and texture of the foam bubbles. It was determined experimentally that the larger the average size of the foam bubble was, the better the foam cleaned the inner cavity of the pipeline.

In the article [19], the influence of surfactants on the flow rate and pressure drop magnitude in the ascending sections of the pipeline was studied by means of electric tomography. The studies of the of two-phase flow gas dynamics showed that during the flow of surfactant through the pipeline with the inclination angles of 0°, 2.5° and 5°, the transition from the stratified wave flow changed into the annular flow. However, in the case of 10° pipeline inclination, there was no stratified flow regime in the in the air-water flow. In the air-surfactant solution system, the stratified flow regime could be found in the range U_{SH} = 10 m/s – 28 m/s and U_{SL} = 0.07 m/s – 0.2 m/s. At all inclination angles, there was a change in the pressure gradient. Using a surfactant had a certain effect on the two-phase flow, which influenced the value of pressure gradient in different flow regimes, in particular the slug flow regime and the annular flow regime. In case of the annular flow regime, the pressure gradient depended not on the influence of the angle, but only on the properties of the two-phase flow.

In the article [20], the two-phase gas/liquid flows in vertical pipes were systematically investigated. Water and SDS surfactant solutions at various concentrations were used as the working fluids. In particular, the authors of the paper focused on the effect of surfactant addition on the flow regimes, the corresponding pressure gradients, and the bubble sizes and velocity. Adding surfactant lowered the air critical Reynolds numbers for the bubble–slug flow and the slug flow transitions. The pressure gradients of SDS solutions were lower than those of pure water especially in the slug flow and the slug–churn flow regimes, implying turbulent drag reduction. At low Reair, the bubble sizes of the surfactant solution were lower than those of pure water due to the increase in viscosity. With increasing and at high Reair, the bubble sizes of the SDS solution became greater than those of pure water which was attributed to the effect of surface tension.

Many studies on the use of foam for cleaning the gas pipelines have been carried out by the specialists of the Ukrainian Scientific Research Institute of Natural Gases (UkrNDIgaz), in particular by I. Kaptsov, V. Honcharov and others. This technology involves the generation of foam with a certain expansion ratio by means of feeding surfactants and gas into the foamer. This method can be used for gas pipelines of various diameters, which are equipped with straight-through and angle valves. Besides, this method prevents pressure surge and does not require gas pipeline shutdown [21].

The specialists of UkrNDIgaz developed a method of gas-liquid cleaning of gas pipelines using foam. To implement this method the mobile foamer was designed, all necessary design documentation was prepared and the commercial prototype of foamer was produced. It passed the field tests in the wells and flowlines of LvivGasVydobuvannya Gas Production Division (GPD). The results of tests performed in production conditions of well 63 of the Lokachynske gas field proved the effectiveness of the foamer, which generated the medium expansion foam [22].

In addition, the foam generator passed the field tests in well 9 of the Yuliivske OGCF of the KharkivGasVydobuvannya GPD and well 27 of the Lokachynske gas field of the LvivGasVydobuvannya GPD. Research results showed the effectiveness of cleaning and inhibiting the wells and their flowlines.

The article [23] shows that the cleaning efficiency depends on the concentration of foaming agents used to generate the foam. Foam expansion ratio affects the cleaning process to some extent. The increase in foam expansion ratio intensifies the cleaning process. Thus, the cleaning time of the same amount of contaminations under the same cleaning modes reduces by half for the foam with the expansion ratio of ER = 240 compared with the foam with the expansion ratio of ER = 150. However, further increase in the foam expansion ratio (ER > 300) makes the cleaning process less efficient.

Adding stabilizers to the foaming agent has a positive effect on the cleaning process. Stabilized high-expansion foams with alkylsulfates including higher fatty alcohols in the ratio of 10:1 used as stabilizers double the cleaning efficiency as compared with non-stabilized foams. Stabilizers increase the structural and mechanical properties of the foam and its damage tolerance to dynamic loading [23].

The paper [24] deals with the investigation of foam cleaning technology for gas pipelines. The cleaning efficiency depends on the nature of contamination, physical and chemical properties of the foaming agent, and the thermogasdynamic conditions. Besides, the generated foam structure is an important factor.

Foam structure depends on its expansion ratio (ER), which is the ratio of foam volume to the volume of the foaming agent solution from which it is made:

$$ER = \frac{V_f}{V_{fs}} = \frac{V_g + V_{fs}}{V_{fs}} \tag{1}$$

where V_f is the volume of foam formed during the foaming process; V_g, V_{fs} are the volumes of gas and foaming agent solution, respectively.

Foams are generally subdivided into three groups: low expansion (1<ER<20), medium expansion (20<ER<200) and high expansion (ER≥200) foams.

The article [25] provides the results of the industrial research on cleaning the inner cavity of the flowlines of gas condensate wells in the Yuliivskyi OGCPF. The operation of gas condensate wells 85 and 60 of the Yuliivske field is characterized by complications, in particular liquid accumulation in the lower sections of the flowlines. The hydraulic efficiencies of the flowlines of wells 85 and 60 were calculated, which were 80% and 78%, respectively. The calculations results showed that the actual hydraulic resistance coefficient significantly exceeded the theoretical coefficient due to the presence of contaminants. It was proposed to use foam to clean the inner cavity of the flowlines of two wells.

When cleaning the flowline of well 85 the foam expansion ratio was between 90 and 100. The experiment resulted in the clean flowline and the appearance of liquid contaminants with solid admixtures and dirty foam in the flare pit, probably due to the presence of clay or sand. After the completion of flowline cleaning, the hydraulic efficiency coefficient was defined, which increased by 12%.

During the flowline cleaning of well 60 the foam expansion ratio was between 40 and 50. The experiment resulted in the clean flowline and the appearance of liquid contaminants and foam in the measuring line of the CGTU-1, in the separator and segregator. After the completion of flowline cleaning, the hydraulic efficiency coefficient was defined, which increased by 7%.

3. Methods and materials

During the development of the Yuliivske, Skvortsivske, Narizhnianske, and Nedilne fields of the Yuliivskyi OGCPF there can arise problems leading to complications in the hydrocarbons production. Each field has its own peculiar features, which should be taken into account to prevent different complications. The timely solution of these problems affects the further operation of wells.

For example, the Yuliivskyi OGCPF (Fig. 1) benefits from the optimization of wells operation and the rational use of crude hydrocarbons due to the construction of gas pipelines between gas treatment units [26,27].

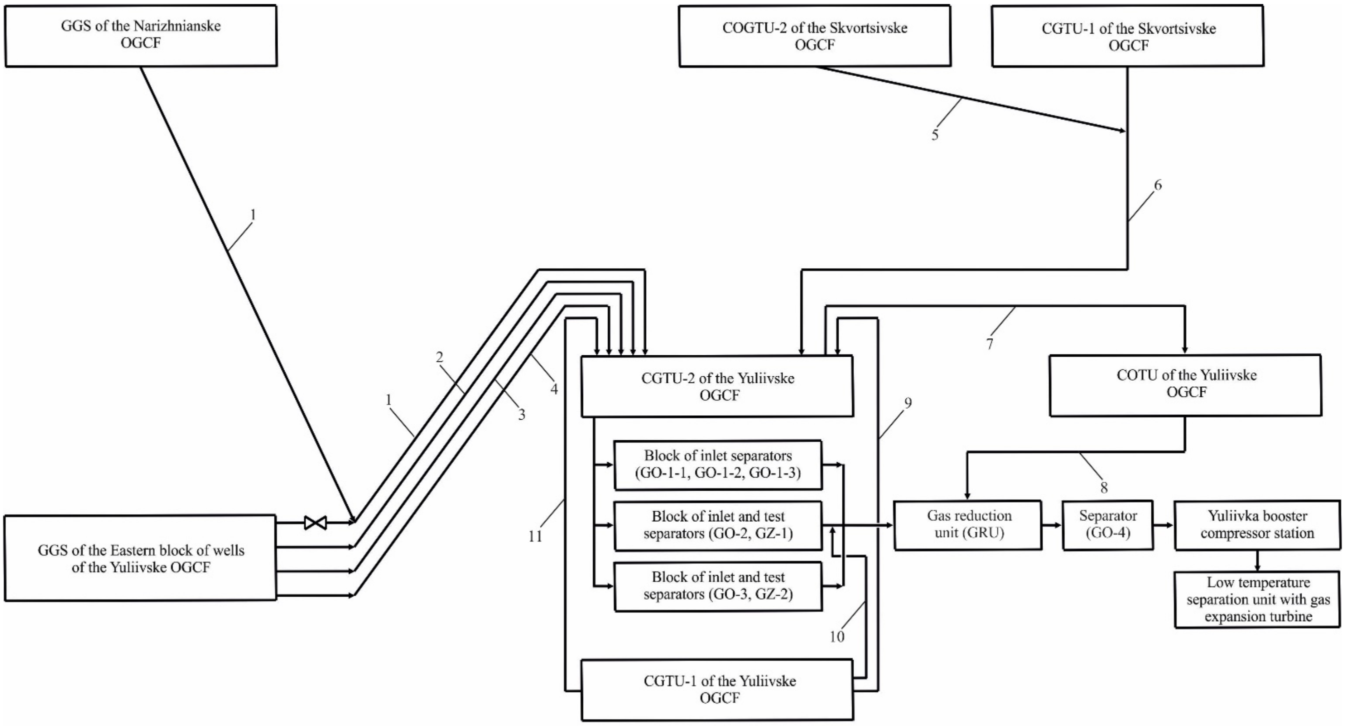

Fig. 1. Connection scheme of the gas gathering pipelines between the production sites of the Yuliivskyi OGCPF

Figure 1 shows the connection scheme of the gas gathering pipelines at the Yuliivskyi OGCPF:

- 1 is the gas gathering pipeline from the GGS of the Narizhnianske OGCF to the CGTU-2 of the Yuliivske OGCF, which is used for extracting liquid hydrocarbons, hydrocarbon condensate and propane-butane fraction;
- 2, 3, 4 are the gas gathering pipelines from the GGS of the Eastern block of wells to the CGTU-2 of the Yuliivske OGCF, which are used for dividing the wells into three groups (low pressure, medium pressure and high pressure wells) and putting them into operation with three separators and three gas pipelines, which helps to reduce pressure fluctuations, increase the hydraulic efficiency and hydrocarbons production;
- 5 is the gas gathering pipeline from the Complex oil and gas treatment unit-2 (COGTU-2) to the CGTU-1 of the Skvortsivske OGCF, which is connected to the gas gathering pipeline from the CGTU-1 of the Skvortsivske OGCF to the CGTU-2 of the Yuliivske OGCF and is used to increase the volume of the extracted propane-butane fraction;
- 6 is the gas gathering pipeline from the CGTU-1 of the Skvortsivske OGCF to the CGTU-2 of the Yuliivske OGCF, which is used to increase the volume of extracted liquid hydrocarbons, hydrocarbon condensate and propane-butane fraction;
- 7 is the gas gathering pipeline from the CGTU-2 to the Complex oil treatment unit (COTU) of the Yuliivske OGCF, which is used for bringing the wells into production to the first and second separation stages and removing liquid from the flowline;
- 8 is the gas gathering pipeline from the COTU to the CGTU-2 of the Yuliivske OGCF, which is used for supplying the associated gas from the measuring line to the gas reduction unit;
- 9, 10, 11 are the gas gathering pipelines from the CGTU-1 to the CGTU-2 of the Yuliivske OGCF, which are used for putting wells into operation at lower pressure at the first separation stage and increasing the hydrocarbons production.

During the operation of the gas gathering pipelines (1-6) of the Yuliivskyi OGCPF there are complications that lead to a decrease in the hydraulic efficiency, which is due to many factors. According to the results of calculations, the hydraulic efficiency coefficient of the gas gathering pipelines varies widely. Therefore, the hydraulic efficiency studies were performed at regular intervals during the year.

The analysis of the operating parameters of gas gathering pipelines, calculations and research shows that the reduction of the hydraulic efficiency coefficient depends on a number of factors, namely:

1) ingress of contaminants usually into the inner cavity during the construction of gas gathering pipeline, in particular during the construction and installation operations;
2) change in the volume of transported gas because of the reduced production rate due to various reasons from one well or a group of wells, which are operated at the gas treatment unit, with the gas then fed into the gas gathering pipeline;
3) reduction in gas treatment quality and, as a consequence, liquid removal (formation water with the admixture of methanol, salts, clay, sand, products of pipe corrosion and hydrocarbon condensate) with the gas flow from separators to the gas gathering pipeline, occurrence of instantaneous releases due to the disturbances in the operation of gas treatment unit;
4) liquid condensation in the inner cavity at a certain gas temperature in the pipeline;
5) change in the condition of the gas pipeline inner surface – roughness of pipes (it is changed under the following conditions: friction of the gas flow on the pipe inner surface due to the presence of solid particles, accumulation of pyrophoric deposits, wetting the pipe walls with hydrocarbon condensate and adhesion of solid particles, etc.);
6) corrosion of the inner surface of the pipe wall, caused by various factors (the presence of aggressive components in the gas: hydrogen sulfide, carbon dioxide, acids, etc.);
7) pipeline route profile – ascending and descending sections, natural and artificial obstacles;
8) local restrictions – bends, reducers, tees, extensions, narrowings, welding joints, thermowells, as well as valvings (gate valves, globe valves, angle valves) etc.;
9) hydrate formation due to changes in the thermodynamic properties during gas transportation. Hydrates in gas pipelines are deposited in straight sections and in local restrictions (bends, tees, welded joints), in places of diameter transitions, lower sections of the route, valving, etc. Hydrates can also be deposited in the unpredictable places of different sections of gas pipelines if there are conditions for their formation;
10) reduction in gas flow rate due to accumulated liquid (formation and condensation water, hydrocarbon condensate, methanol) in the lower sections;
11) diameter changes in gas pipelines cause temperature reduction;
12) pressure increase in the consumer’s gas pipeline, which leads to pressure increase in the entire gas flow area from the wellhead to the gas treatment unit, and

subsequently to changes in the initial and final pressure in the gas gathering pipeline, which may cause reduction in the volume of transported gas;

13) physical and chemical characteristics of transported products (composition, density, moisture and hydrocarbon dew point);
14) gas pipeline material (steel grade) and condition of the factory fabricated inner cover;
15) impact of changes in the ambient temperature if the gas gathering pipeline has the aboveground sections;
16) liquid inflow from another gas gathering pipeline;
17) actual diameter of the gas gathering pipeline is much larger than necessary;
18) instantaneous liquid releases from the inner cavity of gas gathering pipeline to the gas treatment unit.

Reduction in the hydraulic efficiency of gas gathering pipelines can lead to changes in their operating parameters and have a significant negative impact on the operating mode of gas pipelines, which in some cases can lead to a decrease in the volume of transported gas or even termination of transportation.

In practice, various methods are used to increase the hydraulic efficiency of gas gathering pipelines (1-6). Of course, their use has both advantages and disadvantages. Therefore, before applying any method, it is necessary to consider various criteria, for example, not only the ease of use and efficiency, but also their cost and environmental impact. Thus, preference should be given to the methods with the minimal losses of hydrocarbons, ease of use, low cost, and minimal environmental impact [28].

4. Results and discussion

At the Yuliivskyi OGCPF, the field workers and UkrNDIgaz specialists jointly investigated the procedure of foam-based cleaning of the gas gathering pipelines. The experiments were carried out on two gas gathering pipelines. In particular, one gas gathering pipeline was from the GGS of the Eastern block of wells to the CGTU-2 of the Yuliivske OGCF with an outer diameter of 114 mm, wall thickness of 12 mm and length of 5520 m. The second pipeline was from the CGTU-1 of the Skvortsivske OGCF to the CGTU-2 of the Yuliivske OGCF with an outer diameter of 159 mm, wall thickness of 8 mm and length of 12465 m with transition to an outer diameter of 114 mm, wall thickness of 12 mm and length of 350 m.

It was decided to carry out the experimental studies on these gas gathering pipelines based on the following criteria:

- a relatively long length of the gas gathering pipelines (one was about 5.6 km and the other one – about 13 km);
- the actual value of the hydraulic resistance coefficient, exceeding the theoretical one (in particular due to the presence of different contaminations in the inner cavity of the gas gathering pipelines, which are usually a multicomponent mixture that includes formation and condensation water, hydrocarbon condensate, mechanical impurities, salts, methanol, etc.);
- low hydraulic efficiency coefficient;
- the existence of ascending and descending sections;
- the presence of many local restrictions (bends, tees etc.).

Prior to conducting the experiment, it was necessary to select the optimal surfactant based on the studies of its properties. Therefore, the UkrNDIgaz specialists performed laboratory studies on the properties of various surfactants, which could be further used to create foam and clean the inner cavities of the gas gathering pipelines.

Thus, laboratory studies of the foaming properties of surfactants Stinol-NG, Savinol, Sulfanol and Solpen-10T were performed. Based on the studies of these surfactants we determined the foam stability of the investigated model of mineralized formation water, containing 50 g/l of calcium chloride ($CaCl_2$) and 100 g/l of sodium chloride (NaCl), with a density ranging from 1.075 g/cm^3 to 1.087 g/cm^3 at a temperature of 20ºC and surfactant solution concentrations of 0.5%, 1%, 1.5% and 2%. In addition, a stable condensate with a density ranging from 0.757 g/cm^3 to 0.765 g/cm^3 of various concentrations was added to the studied model. It was found that of the four surfactants, Solpen-10T 2% had the best characteristics in terms of foam stability.

Besides, laboratory studies of the foaming properties of surfactants Stinol-NG, Savinol, Sulfanol and Solpen-10T were carried out. The foaming properties of surfactants were investigated in different media. The laboratory studies involved a model of formation water with a specific gravity ρ = 1.080 g/cm^3 and the following composition: Na^++ K^+ – 26300 mg/l; Ca^{2+} – 5045 mg/l; Mg^{2+} – 3100 mg/l; Cl^- – 59950 mg/l. The results of laboratory tests are shown in Table 1.

Figures 2 and 3 show the dependencies of the expansion ratio and foam stability of the surfactants Solpen-10T, Stinol-NG, Savinol and Sulfanol on the surfactants concentrations, mass %.

The results of laboratory studies showed that of the four surfactants, Solpen-10T has the best properties in terms of foam stability. It was also found that at a surfactant concentration of 4% the foam stability was 545 s, and in the case of concentration increase to 6% the stability decreased and was 503 s. Thus, the foam stability rose as the concentration of surfactant solution increased to a certain limit, and then decreased. The reason for this is the dependence of foam stability on many factors, in particular on the structure of surfactant molecules and its concentration, temperature and pH of the solution, etc.

Table 1.
Comparison of the foaming properties of surfactants Solpen-10T, Stinol-NG, Savinol and Sulfanol

No.	Foaming agent composition		Surfactants							
			Solpen-10T		Stinol-NG		Savinol		Sulfanol	
	Medium	Surfactant concentration, mass %	Expansion ratio, ER	Foam stability, s	Expansion ratio, ER	Foam stability, s	Expansion ratio, ER	Foam stability, s	Expansion ratio, ER	Foam stability, s
1	Formation water model at 20ºC	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
6	Formation water model + 10% of diesel fuel at 20ºC	2	1.3	15	0	0	0	0	0	0
7		4	2.5	35	0	0	1.5	70	0	0
8		6	3.8	43	1.1	0	1.5	85	0	0
9		8	4.8	60	1.2	0	1.6	88	0	0

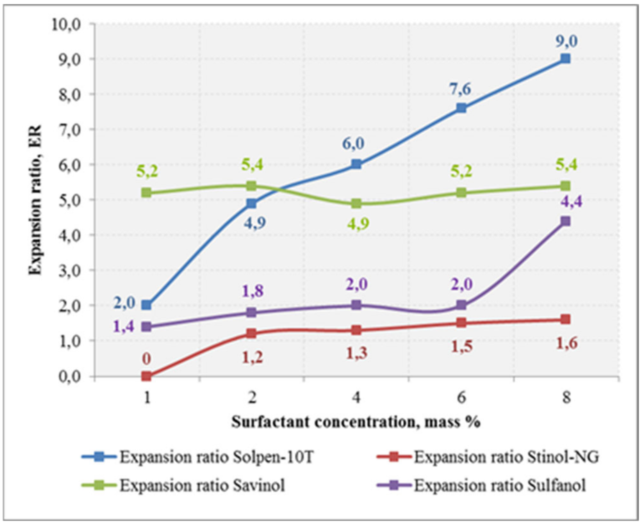

Fig. 2. Dependencies of the foam expansion ratios of Solpen-10T, Stinol-NG, Savinol and Sulfanol on the surfactants concentrations, mass %

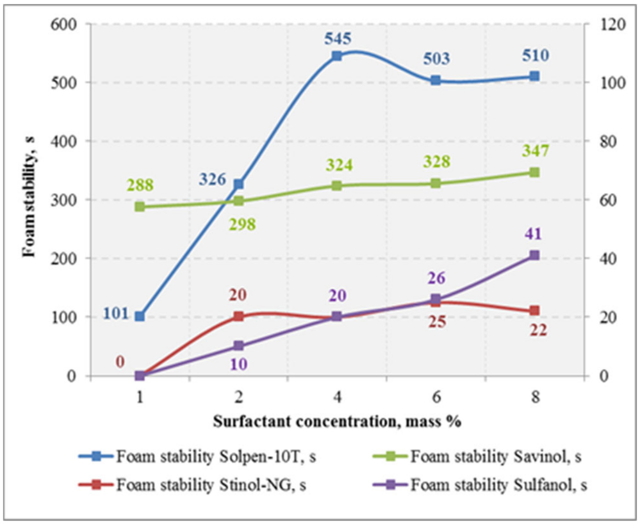

Fig. 3. Dependencies of the foam stability of Solpen-10T, Stinol-NG, Savinol and Sulfanol on the surfactants concentrations, mass %

The foaming properties increase with increasing the surfactant concentration to the maximum value corresponding to the maximum saturation of the surface adsorption layer with molecules, after which it decreases or remains constant up to the solubility limit of this surfactant.

UkrNDIgaz specialists conducted laboratory tests to determine the physicochemical parameters of the surfactant Solpen-10T for compliance with the technical specifications and quality certificate.

The studies involved a model of mineralized formation water with a specific density of 1.087 g/cm^3 containing 50 g/l of calcium chloride ($CaCl_2$) and 100 g/l of sodium chloride (NaCl). In addition, a stable condensate with a specific gravity of 0.789 g/cm^3 was used. The results of laboratory tests of surfactant are given in Table 2.

The results of laboratory tests showed that the provided sample of surfactant Solpen-10T met the requirements of TU U 24.6-23913269-001-2001 and the quality certificate. Therefore, this surfactant could be used for industrial researches.

The first experiment was conducted on the gas gathering pipeline from the GGS of the Eastern block of wells to the CGTU-2 of the Yuliivske OGCF (Fig. 4).

Table 2.
Results of laboratory studies of the physicochemical parameters of the surfactant Solpen-10T

No.	Parameter name	Norm according to TU	Surfactant Solpen-10T
1	Appearance and color	Brown liquid. Allows precipitation	Corresponds
2	Specific density at 20ºC, g/cm^3	not less than 1.040	1.050
3	Hydrogen ion concentration, pH of 1% solution	5-10	8
4	Foam stability of 0.5% solution at 20ºC with 10% of the hydrocarbon condensate, s	not less than 300	1440
5	Foam stability of 0.5% solution at 60ºC with 10% of the hydrocarbon condensate, s	not less than 150	840
6	Foam stability of 1.0% solution at 60ºC with 30% of the hydrocarbon condensate, s	not less than 150	900

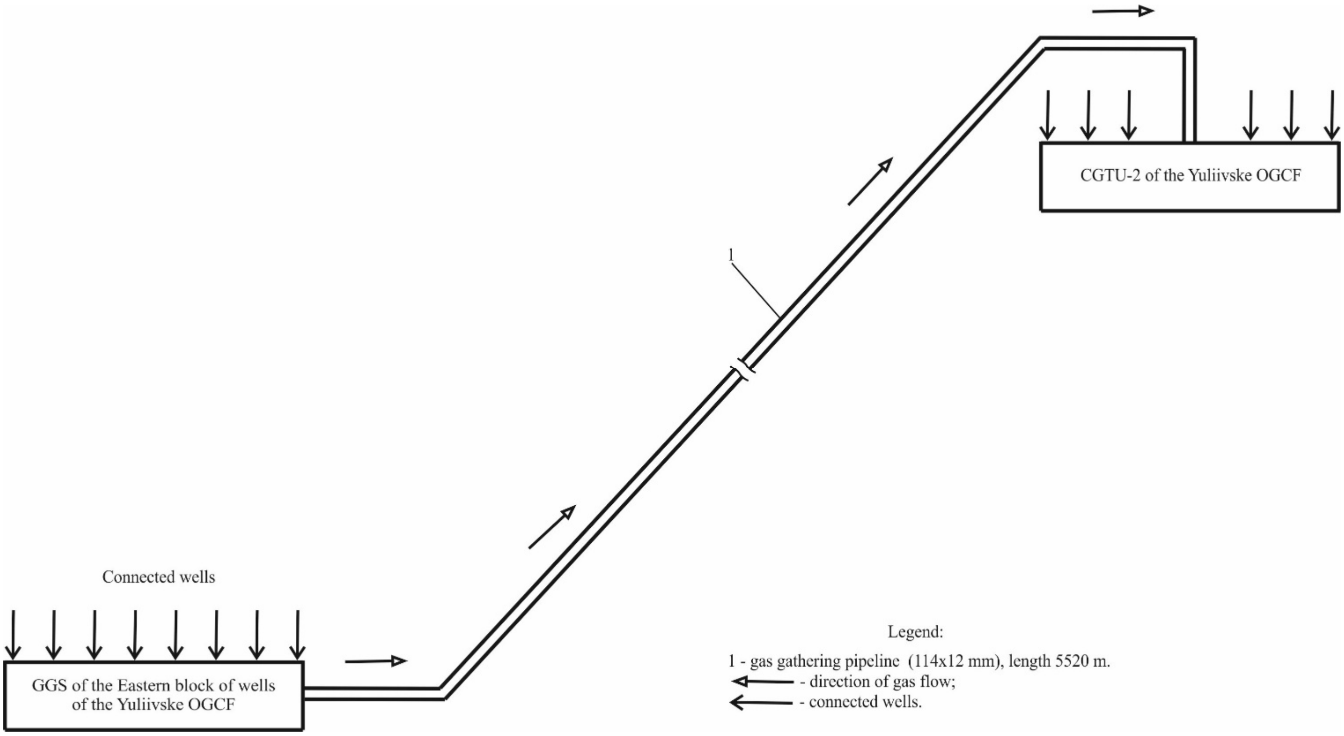

Fig. 4. Connection scheme of the gas gathering pipeline from the GGS of the Eastern block of wells to the CGTU-2 of the Yuliivske OGCF

Prior to cleaning, the operating parameters of the gas gathering pipeline were measured and the hydraulic efficiency coefficient was calculated to be 79%. The studies were performed as follows:

1) the pressure and temperature at the inlet and outlet of the gas gathering pipeline and the volume of gas transported to the GGS of the Eastern block of wells were measured;
2) wells 83, 84 (23), 70, and 14 at the GGS of the Eastern block were shut down, the valvings on the shutdown devices and the valving No. 15 on the gas supply line to the separator S-1-3 were closed (Fig. 5);
3) the pressure in the gas gathering pipeline was reduced to 2.5 MPa to the pressure of the first separation stage to the CGTU-2 and the valving No. 1 on the shutdown devices was closed. After that, the valving No. 2 on the shutdown devices was opened and the pressure was reduced to 1.0 MPa in the gas gathering pipeline to the CGTU-1 of the Yuliivske OGCF and local consumers, and then the valving No. 2 was closed;

4) liquid was removed from the separator S-1-3 at the GGS of the Eastern block, for this purpose, the valving No. 19 was opened on the bypass line so that the fluid flowed into the segregator R. Only after the fluid was completely removed, the valving No. 19 was closed;
5) the pressure in the gas gathering pipeline was reduced to 0.5 MPa. For this purpose, the valving No. 13 on the separator S-1-3 flare line was opened, and then closed. This helped to create a high-speed flow, partially remove contaminants from the inner cavity of the gas gathering pipeline and collect them in the flare separator;
6) the valvings on the flare line of the measuring tank EZ-1 leading to the flare pit were opened to reduce pressure to the atmospheric level;
7) the valving No. 20 was opened on the liquid removal line from the separator S-1-3 to the measuring tank EZ-1 for the supply of gas and liquid. The liquid was collected in the measuring tank EZ-1 and gas was supplied to the flare pit;
8) cleaning operations of the inner cavity started as soon as the pressure in the gas gathering pipeline decreased to the atmospheric level;
9) at the CGTU-2, special equipment (a mobile pumping unit, two mobile nitrogen compressor stations, a device [29]) was connected to the flare line and the back valve was installed on the discharge line. A non-explosive gas mixture (composition by volume: nitrogen – not less than 90% and oxygen – not more than 10%) and foam were injected into the inner cavity of the gas gathering pipeline and flowed in the direction opposite to that of the gas flow;
10) the discharge line was pressurized to one and a half times the expected operating pressure;
11) 2% aqueous surfactant solution was prepared in the measuring tank of the pumping unit;
12) the valvings No. 6 and No. 5 on the flare line on the shutdown devices at the CGTU-2 were opened and a non-explosive gas mixture was supplied into the inner cavity of the gas gathering pipeline until it appeared in the separator S-1-3. The flow of non-explosive gas mixture was monitored and, accordingly, the pressure was controlled in the gas gathering pipeline by manometers (No. 3, No. 8, No. 10, No. 14), and the outflow intensity was regulated by opening and closing the valving No. 9 at the inlet of the separator S-1-3, as a result the pressure in the gas gathering pipeline was changed;
13) after the non-explosive gas mixture appeared in the separator S-1-3 (pressure increase up to 1.0 MPa on the manometers No. 8, No. 10, No. 14), the aqueous surfactant solution was supplied into the device [29] by the pumping unit and the foam was injected into the inner cavity while monitoring the consumption of solution. After injecting the foam, created from 0.350 m^3 of the aqueous surfactant solution, the pumping unit was stopped while the non-explosive gas mixture was still being pumped by the mobile nitrogen compressor stations. After a certain period of time the injection of foam was resumed;
14) during the experiment, the pressure in the gas gathering pipeline was controlled according to the readings of manometers No. 3, No. 8, No. 14. To control the liquid flow in the separator S-1-3, the pressure was maintained at a level not higher than 1.5 MPa;
15) the foam flow was monitored by visual inspection by removing the manometer No. 10, periodic opening of the valve on the line through which the gas-liquid mixture flowed to the separator S-1-3 and in the measuring tank EZ-1;
16) the liquid flow from the gas gathering pipeline to the measuring tank EZ-1 was monitored;
17) after the cleaning of the gas gathering pipeline at the CGTU-2 was completed, the operation of special equipment was stopped, the valvings No. 6 and No. 5 on the flare line on the shutdown devices were closed, the discharge line was depressurized to the atmospheric level and removed. Thereafter, at the GGS of the Eastern block, the valvings No. 20 were closed on the liquid removal line from the separator S-1-3 to the measuring tank EZ-1 as well as on the flare line of the measuring tank EZ-1. The valvings on the shutdown devices on the GGS of the Eastern block and No. 15 were opened to supply hydrocarbons from well 83 to the separator S-1-3 and to gradually increase pressure in the gas gathering pipeline to the specified level according to the operation mode. Thereafter, the valvings were opened to supply crude hydrocarbons from wells 84 (23), 70, and 14 to the separator S-1-3 and then to the gas gathering pipeline. When increasing pressure to the required value, the gas gathering pipeline was commissioned by opening the valving No. 1 on the shutdown devices of the CGTU-2;
18) the operating parameters of the gas gathering pipeline and their compliance with the operating mode were monitored.

During the experiment the foam expansion ratio was between 80 and 90. The experiment resulted in the appearance of liquid contaminants and dirty foam at the GGS of the Eastern block of wells, in particular in the separator S-1-3 and the measuring tank EZ-1. After cleaning the gas gathering pipeline, gas transportation was resumed

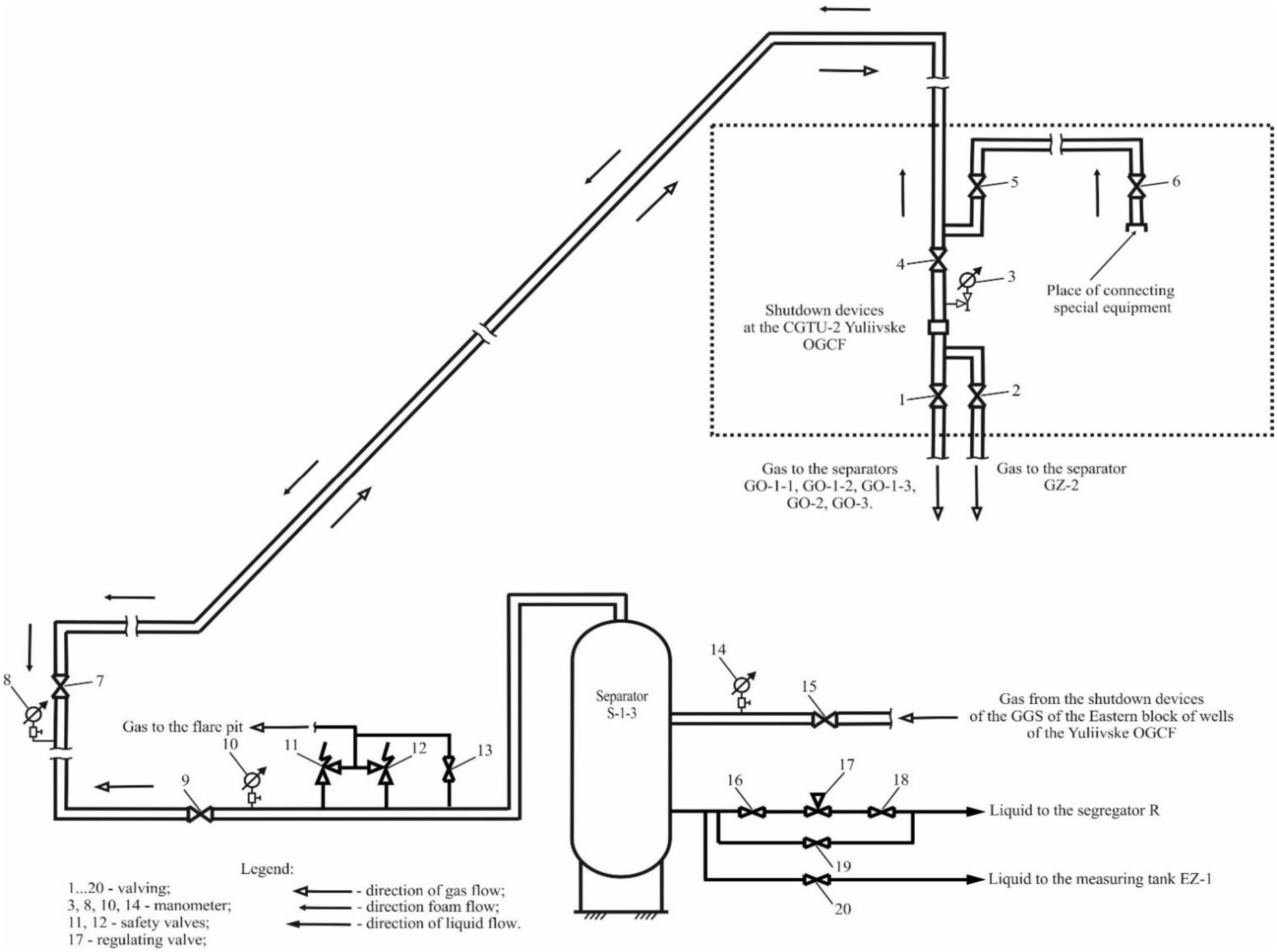

Fig. 5. Scheme of foam cleaning of the gas gathering pipeline from the CGTU-2 to the GGS of the Eastern block of wells in the Yuliivske OGCF

and as soon as the set mode was achieved, the actual operating parameters were measured and the hydraulic efficiency was defined, which increased by 10.5 %. The second experiment was carried out on the gas gathering pipeline from the CGTU-1 of the Skvortsivske OGCF to the CGTU-2 of the Yuliivske OGCF (Fig. 6).

Before cleaning, the operating parameters of the gas gathering pipeline were measured and the hydraulic efficiency coefficient was calculated to be 82%. The studies were performed as follows:

1) the pressure and temperature at the inlet and outlet of the gas gathering pipeline and the volume of gas transported to the CGTU-1 of the Skvortsivske OGCF were measured;
2) the actuation of control valves on the automated liquid purging line from the separators at the CGTU-1 of the Skvortsivske OGCF was checked;
3) the pumps supplying the hydrate formation inhibitor to the gas gathering pipeline from the CGTU-1 of the Skvortsivske OGCF were switched off and the valves were closed;
4) at the CGTU-2 of the Yuliivske OGCF, the separator GZ-1 and segregator RZ-1 on the measuring line were checked for the presence of liquid and the found liquid was removed into the drainage tank ED-1 (Fig. 7);
5) the operation of automated liquid purging from the separator GZ-1, the control valve, level gauge and other equipment were checked;

6) at the CGTU-2 of the Yuliivske OGCF, gas flowing from the gas gathering pipeline from Skvortsivske OGCF to the inlet separators GO-1-1, GO-1-2, GO-1-3, GO-2, GO-3 was directed to the measuring line, in particular to the separator GZ-1 and CGTU-1 of the Yuliivske OGCF. At the same time, the valving No. 8 was closed and the valvings No. 9, No. 10, No. 14 were opened;
7) the pressure and temperature at the inlet and outlet of the gas gathering pipeline and the volume of gas transported to the CGTU-2 of the Yuliivske OGCF were measured;
8) at the CGTU-1 of the Skvortsivske OGCF, special equipment (a mobile pumping unit, two mobile nitrogen compressor stations, a device [29]) was connected to the gas gathering pipeline and the back valve was installed on the discharge line. A non-explosive gas mixture and foam were injected into the inner cavity of the gas gathering pipeline and flowed in the same direction as the gas flow;
9) the discharge line was pressurized to one and a half times the expected operating pressure;
10) 2% aqueous surfactant solution was prepared in the measuring tank of the pumping unit;
11) the valving No. 2 at the CGTU-1 of the Skvortsivske OGCF was opened and a non-explosive gas mixture was supplied into the inner cavity of the gas gathering pipeline;
12) five minutes after the non-explosive gas mixture had been injected into the gas gathering pipeline, the aqueous surfactant solution was supplied into the device [29] by the pumping unit and the foam was injected into the inner cavity while monitoring the consumption of solution. After injecting the foam, created from 0.300 m^3 of the aqueous surfactant solution, the pumping unit and the mobile nitrogen compressor stations were stopped. After a certain period of time the injection of foam was resumed;
13) during the experiment, the pressure in the gas gathering pipeline was controlled according to the readings of manometers No. 3, No. 7, No. 11, No. 12;
14) the foam flow was monitored by visual inspection by the periodic opening of the angle three-way valve on the manometer No. 7 of the gas inlet pipeline of the CGTU-2 shutdown devices and on the separator GZ-1;
15) in the separator GZ-1, the presence of liquid was controlled, which was periodically removed into the segregator RZ-1;
16) upon completion of the gas gathering pipeline cleaning at the CGTU-1 of the Skvortsivske OGCF, the special equipment was stopped, the valving No. 2 was closed, the discharge line was depressurized to the atmospheric level and removed. Thereafter, the valvings No. 9, No. 10, No. 14 were closed at the CGTU-2 of the Yuliivske OGCF to stop the flow of transported gas from the gas gathering pipeline from the Skvortsivske OGCF to the separator GZ-1 and to the CGTU-1 of the Yuliivske OGCF, and then the valving No. 8 was opened for gas supply to the separators GO-1-1, GO-1-2, GO-1-3, GO-2, GO-3;
17) the operating parameters of the gas gathering pipeline and their compliance with the operating mode were monitored.

During the experiment, the foam expansion ratio was between 50 and 60. The experiment resulted in the appearance of liquid contaminants and foam at the measuring line of the CGTU-2, in particular in the separator GZ-1 and segregator RZ-1. After the gas gathering pipeline had been cleaned and the set mode had been achieved, the actual operating parameters were measured and the hydraulic efficiency was defined, which increased by 5.7 %.

Based on the results of two experiments, the following conclusions could be made:

- the first experiment involved the shutdown of wells 83, 84 (23), 70, 14 at the GGS of the Eastern block of wells and, as a result, the absence of hydrocarbons production over the period of experiment. During the experiment, the velocity of non-explosive gas mixture could be regulated in the gas gathering line by means of closing or opening the valving at the inlet of the separator S-1-3. It is important that the actual process duration can be defined based on the visual inspection of the outflow of liquid and foam. The benefit of this process is that its performance can be monitored. Its disadvantage is that the wells should be shut down over the period of experiment, which leads to the decrease in the volume of produced crude hydrocarbons;
- the second experiment involved the operation of the wells of the Skvortsivske OGCF on the measuring line of the CGTU-2, in particular the separator GZ-1, and then on the CGTU-1. The gas flow velocity depended on the individual operation parameters of the wells of the Skvortsivske OGCF. It should be noted that during the experiment it is difficult to control the foam flow in the gas gathering pipeline and, as a result, determine the actual process duration. The benefits of this process include no need to stop the wells, and the ability to control the volume of transported gas while cleaning the gas gathering pipeline. The disadvantage of this process is that high-expansion and stable foam can flow to the CGTU-2 together with gas, which may reduce the operating efficiency of separation equipment and, as a result, affect the gas treatment quality.

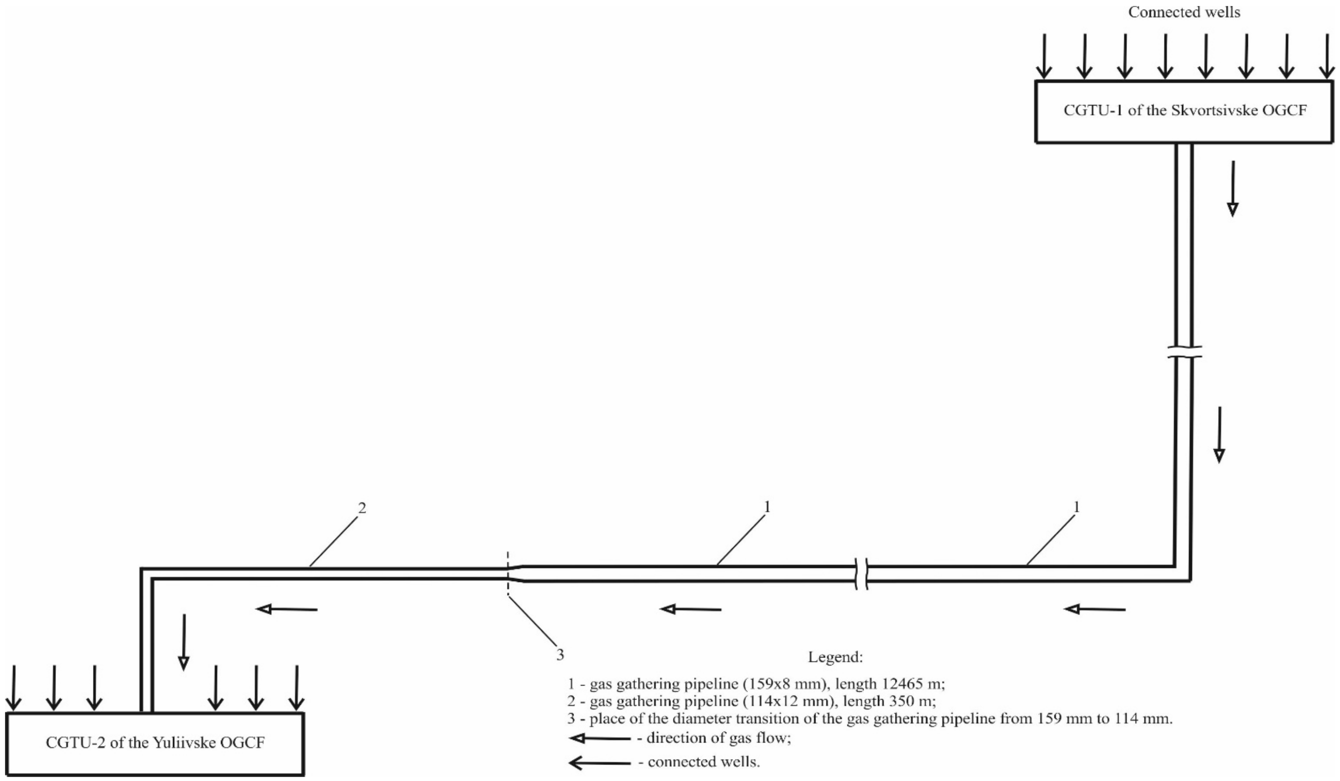

Fig. 6. Connection scheme of the gas gathering pipeline from the CGTU-1 of the Skvortsivske OGCF to the CGTU-2 of the Yuliivske OGCF

The advantages of the foam piston are no stucking while moving through the pipeline, unobstructed passage through local restrictions (lower sections, bends, tees, valvings, etc.), wear resistance of the structural components of the cleaning tool, etc. Considering the research results, it should be stated that:

- surfactants with the best properties in terms of foam stability should be chosen for further use during gas pipelines cleaning only based on the results of laboratory tests;
- before cleaning the gas pipeline, it is important to consider its diameter and length, as every surfactant is characterized by the foam stability over time, so its use for cleaning the inner cavity of the pipeline is limited;
- before using the surfactant, it is necessary to perform laboratory tests of the sample to determine its physicochemical parameters for compliance with the quality certificate provided by the manufacturer;
- using the surfactant solution at different ambient temperatures affects the foaming properties;
- increasing the foam expansion ratio helps to improve cleaning of the inner cavity of gas gathering pipelines from contaminants;
- foam stability increases with the increasing concentration of surfactant solution to a certain limit (maximum saturation of the adsorption layer), and then decreases;
- foam expansion ratio depends on both the foaming properties of the surfactant solution and the method of its generation, in particular the volumetric ratio of gas to the foaming agent solution;
- the efficiency of cleaning the inner cavity of the gas pipeline depends on the physicochemical parameters of the foam and contaminations that should be removed. Thus, the results of laboratory studies have shown that the presence of hydrocarbon condensate decreases the foam stability;
- before cleaning the gas pipeline, it is important to know the amount of accumulated liquid contaminants in the inner cavity that should be removed, as well as their composition. This will help to choose the optimal volume of surfactant solution to generate foam.

Thus, taking into account the characteristics of two gas gathering pipelines, it is advisable to carry out the industrial studies on using the technology of cleaning the inner cavity with foam with higher expansion ratios.

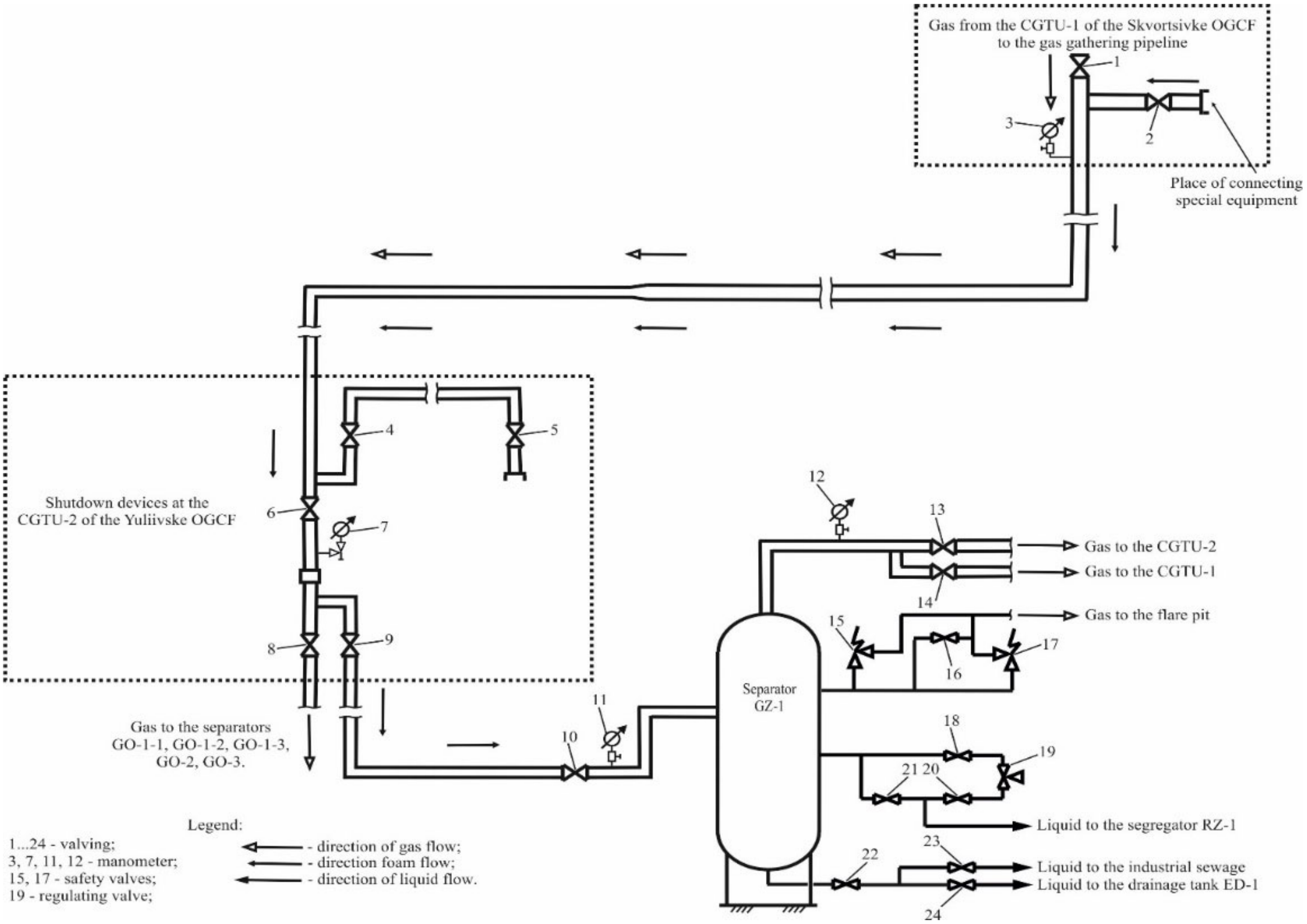

Fig. 7. Scheme of foam cleaning of the gas gathering pipeline from the CGTU-1 of the Skvortsivske OGCF to the CGTU-2 of the Yuliivske OGCF

In view of the above, it is advisable to develop a set of measures to monitor the gas gathering pipelines and improve their cleaning efficiency. They will include:

1) measures for monitoring gas gathering pipelines;
2) measures for cleaning gas gathering pipelines using medium and high expansion foams;
3) measures to increase foam stability;
4) measures for foam destruction in the gas-liquid flow.

Let us analyze these measures in detail.

1) Measures for monitoring gas gathering pipelines:

- to control the pressure, temperature at the inlet and outlet of gas pipelines, as well as the volume of transported gas in real time in the control office of the Yuliivskyi OGCPF;
- to analyze historical data on the pressure, temperature and volume of transported gas within a specified time period with the development of dependency diagrams;
- to develop and implement a software package for monitoring the operating parameters of gas pipelines and in case the values of pressure, temperature and volume of accumulated contaminants in the inner cavity reach the set critical values, give the following signals: “warning of possible emergency” and “emergency”.

2) Measures for cleaning gas gathering pipelines using medium or high expansion foams in two ways:

- to stop transporting gas through the gas gathering pipeline for the period of cleaning; to reduce pressure to the atmospheric level or to partially reduced it, and then to constantly inject the non-explosive gas mixture and periodically inject the foam;
- to switch the gas gathering pipeline to direct the transported gas from the main to the measuring line of the CGTU-2 through the separator and to the CGTU-1 without reducing the pressure under the actual operating

mode. The non-explosive gas mixture and foam are injected periodically.

In both cases, contaminants from the inner cavity of the gas gathering pipeline flow to the gas treatment unit, where they are collected. One of the two methods can be selected as optimal depending on the individual conditions of the gas pipeline and taking into account various factors.

3) Measures to increase foam stability.

   In practice, stabilizers are used to increase foam stability. Their function can be performed by various substances, such as higher fatty alcohols, alkylaryl sulfonates, alkyl sulfates, carboxymethyl cellulose, methylcellulose, polyacrylamide, amines, amino acids, etc.

4) Measures for foam destruction in the gas-liquid flow.

   In the case of using a surfactant solution, foam is formed, which together with the gas-liquid flow and liquid contaminants from the pipelines flows to the gas gathering and treatment system and is completely or partially destroyed in the separators. The remains of undestroyed foam can adversely affect the efficiency of the separation equipment and, consequently, the gas treatment quality.

To solve this problem, the authors have proposed a method of foam destruction in the gas-liquid flow by mixing it with the degassed liquid at the maximum possible distance from the inlet of the separator of the main and/or measuring line of the CGTU-2. A stable hydrocarbon condensate from an additionally installed tank is periodically or continuously added to the gas-liquid flow. This technical solution is based on the results of laboratory tests conducted in accordance with the methodologies in force in Ukraine. It was found that a sharp decrease in the foam stability occurred when the volume of stable hydrocarbon condensate with a density from 0.736 g/cm^3 to 0.757 g/cm^3 increased as it was added to the studied model of mineralized formation water with a density from 1.075 g/cm^3 to 1.083 g/cm^3, which contained 50 g/l of calcium chloride ($CaCl_2$) and 100 g/l of sodium chloride (NaCl), at the concentration of surfactant solution (Solpen-10 T, Stinol-NG, Savinol, Sulfanol, Pinosil-NHI, Fomelit, SE-235-A, Piren-10, etc.) from 1% to 5% at a temperature of 20ºC and 60ºC. The research results showed that adding 10% of stable hydrocarbon condensate reduced the foam stability at least by half, 20% – at least three times, and 30% – at least four times [30].

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

The analysis of many studies showed that the proposed method was effective, but cleaning the inner cavity of gas gathering pipelines with foam did not help to completely remove all liquid contaminants. At present, there is no method that would help to completely remove all liquid contaminants from gas gathering pipelines. Thus, it is reasonable to improve the existing cleaning methods and develop the new ones. The authors proposed to develop a new method of cleaning gas gathering pipelines, which would consist of first using foam and then the gel piston. This method involved first injecting foam and then preparing and inserting the gel piston into the inner cavity of the gas gathering pipeline. This facilitated a more thorough cleaning, as the liquid was pushed by the foam piston in the direction of its flow, and the gel piston would displace its remnants.

Thus, it would be possible to improve the technology of cleaning the inner cavity of gas gathering pipelines from liquid contaminants and achieve their higher hydraulic efficiency.

5. Conclusions

1. During the operation of the gas gathering pipelines of the Yuliivskyi OGCPF, there are complications associated with the accumulation of fluid in their inner cavity, which lead to a reduction in the volume of transported gas and a decrease in hydrocarbons production.
2. The results of calculations showed that the fluid accumulation in the inner cavity of the gas gathering pipelines of the Yuliivskyi OGCPF caused a low hydraulic efficiency coefficient (from 79% to 82%).

   To increase the hydraulic efficiency of these gas pipelines, the authors proposed to clean the inner cavity of the gas gathering pipelines using the foam with an expansion ratio from 50 to 90. This method could be used in straight sections and in the sections with local restrictions.
3. The results of experimental studies showed that the foam cleaning of two gas gathering pipelines of the Yuliivskyi OGCPF from the accumulation of liquid helped to increase their hydraulic efficiency coefficients by 10.5% and 5.7% respectively.
4. According to the results of two experiments, it was found that better cleaning of the gas gathering pipelines of the Yuliivskyi OGCPF could be achieved when using foam with a greater expansion ratio from 80 to 90.
5. Measures for the foam cleaning of the inner cavity of gas gathering pipelines from liquid proved to be efficient and can be recommended for other gas pipelines.

6. To monitor the hydraulic condition of gas gathering pipelines and their efficient cleaning, a set of measures was proposed, which include: control of the operational parameters, cleaning of gas pipelines using medium or high expansion foams, measures for foam destruction in the gas-liquid flow and development of a new method of gas pipeline cleaning. The developed set of measures can provide the maximum hydraulic efficiency of gas gathering pipelines and, consequently, a reliable gas transportation and stable production of crude hydrocarbons.
7. In the future, it is advisable to investigate cleaning of the inner cavity of gas gathering pipelines by other methods, which will help to determine the most efficient ones.

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