DOI: 10.5604/01.3001.0014.4088
Volume 101 • Issue 1 • July 2020
Journal of Achievements in Materials and Manufacturing Engineering
International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Developing a set of measures to provide maximum hydraulic efficiency of gas gathering pipelines

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ABSTRACT

Purpose: The purposes of this article are to study the effective ways of increasing the hydraulic efficiency of gas gathering pipelines of the Yuliivskyi oil and gas condensate production facility (OGCPF); to calculate the operation efficiency of gas gathering pipelines of the Yuliivskyi OGCPF and develop a set of measures to monitor their condition and improve their hydraulic characteristics; to investigate the technology of cleaning the inner cavity of flowlines of gas-condensate wells with foam, to perform the feasibility study on the prospects of its application in practice.

Design/methodology/approach: The technology of cleaning the inner cavity of flowlines of gas-condensate wells with foam was investigated to objectively evaluate its application and determine the effectiveness of this measure. The research was carried out within the framework of research and development work by the specialists of the Ukrainian Scientific Research Institute of Natural Gases.

Findings: The results of production studies showed that due to cleaning the flowlines of gas-condensate wells (No.85 and No.60) from the accumulation of liquid, the coefficients of their hydraulic efficiency increased by 12% and 7%, respectively. Measures taken to clean the inner cavity of the flowlines from liquid have proven their efficiency and can be recommended for other flowlines of wells at other production fields.

Research limitations/implications: Based on the characteristics of gas gathering pipelines, it is reasonable to conduct experimental studies on the use of the proposed technology of cleaning the inner cavity with foam in the case of increasing its multiplicity.

Practical implications: Using the wells of the Yuliivske oil and gas condensate field as case studies, the operating parameters were measured and the pressure losses along the length of the flowlines were calculated. According to the results of calculations at two wells (No.85 and No.60), a significant excess of the actual value of the flow friction characteristic over the theoretical value was established. To reduce excessive pressure losses due to the presence of liquid and improve the hydraulic characteristics of the wells, their inner cavities were cleaned using foam with the expansion ratio from 40 to 100.

Originality/value: It is important to note that the advantages of foam piston include: ease of use, no occurrence of hydraulic shocks and preventing stuck during movement in the gas pipeline, application in both straight and inclined sections, no wear of the elements of the cleaning equipment, a rather efficient cleaning of gas pipelines.

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

Reference to this paper should be given in the following way:

V.B. Volovetskyi, A.V. Uhrynovskyi, Ya.V. Doroshenko, O.M. Shchyrba, Yu.S. Stakhmych, Developing a set of measures to provide maximum hydraulic efficiency of gas gathering pipelines, Journal of Achievements in Materials and Manufacturing Engineering 101/1 (2020) 27-41. DOI: https://doi.org/10.5604/01.3001.0014.4088

ANALYSIS AND MODELLING

1. Introduction

Nowadays PJSC "Ukrgasvydobuvannya" owns and develops a large number of fields. Most of them are already depleted and at the final stage of development. However, PJSC "Ukrgasvydobuvannya" provides over 70% of the total natural gas production in Ukraine. This positive result is obtained due to the hard and coordinated work of all the branches of PJSC "Ukrgasvydobuvannya" (hereinafter referred to as the Company). Thus, the Company's specialists develop many administrative and technical measures aimed at stabilizing the production of hydrocarbons. It should be mentioned that without different activities it would be impossible to maintain a stable production of hydrocarbons from gas and gas condensate fields, which naturally deplete. This process is accompanied by the decrease in the formation and working pressures, and, subsequently, well production rates. However, the Company's specialists provide the planned production of hydrocarbons using a comprehensive approach to defining the production capacities of wells by means of analysing their operation and taking into consideration the peculiarities of field development. Based on the feasibility study results, a decision is taken on the prospects of implementing actions to ensure stable production of hydrocarbons and, subsequently, investments.

Taking the above into account, the issue of obtaining maximum production rates of gas condensate from the fields still remains relevant. It requires a comprehensive approach. First of all, it is necessary to analyse gas flow from formation to gas treatment unit (GTU), which may include the following stages: formation – bottomhole zone (BZ) – well – flowline – gas gathering station (GGS) – gas gathering pipeline – complex gas treatment unit (CGTU). It is obvious that at each of these stages it is necessary to increase the well operation efficiency for the rational use of formation energy. One of the mentioned stages refers to ensuring a reliable transportation of natural gas through gathering pipelines. The reliable transportation of domestic natural gas requires the improved hydraulic efficiency of gas gathering pipelines.

2. Literature review

PJSC "Ukrgasvydobuvannya" has accepted for execution an ambitious and extremely important task of ensuring the energy independence of Ukraine – "Program 20/20", i.e. increasing the domestic production of natural gas up to 20 billion m^3 per year by 2020. To achieve the set goal the equipment is upgraded, the scopes of prospecting, exploratory and production drilling are increased, modern methods of well completion, workover and maintenance of wells and hydraulic fracturing are used [1].

To accomplish the assigned tasks of increasing the production of hydrocarbons PJSC "Ukrgasvydobuvannya" should consider all alternative solutions to this issue. One of the important directions of the Company's further development concerns its gas production from depleted fields. These conditions lead to the problems of maintaining the operation of wells with low working pressures, natural gas treatment at CGTU and delivering gas to the gas gathering line, in which the pressure varies (increases or decreases) throughout the year. Nowadays the Company's gas production divisions supply gas to the gas transmission system in abnormal operating conditions.

In view of the fact that the gas production divisions in the eastern and western regions of Ukraine are the largest gas suppliers, consideration should be given to dividing the gas transmission system into the pipelines transporting domestic gas, pipelines transporting export high-pressure gas and pipelines transporting both export and domestic gas flows [2].

It is obvious that the current system of gas pipelines of the Company's divisions, which supply natural gas to consumers through high-, medium- and low-pressure systems, needs detailed analysis. Therefore, the alternative ways of supplying gas to consumers should be considered, for example, by means of constructing additional gas pipelines to low-pressure networks, as this supply would require less capital investment.

The current state of gas transmission system of PJSC "Ukrgasvydobuvannya" plays an important role in accomplishing both the tasks of stabilization and increase of hydrocarbons production. To study this issue it is necessary to perform the numerical calculations and studies. Their results can be illustrative of the state of gas field pipelines and gas gathering pipelines that at normal design capacity carry a smaller volume of natural gas.

Hydrocarbon condensate, formation water, rock particles, products of inline corrosion, etc., flowing from GTU, can accumulate in the inner cavity of gas gathering pipelines, which are in operation for many years. Such contaminations lead to a decrease in the hydraulic efficiency of gas pipelines and an increase in energy consumption for transportation. If the flow rate is high, these contaminations cause two-phase flows [3], which in their turn result in the increased losses of hydraulic energy in the shaped elements of the pipelines [4], and higher intensity of their erosive wear [5]. Erosive wear affects the stress-strain state of shaped elements [5,6] and is extremely dangerous, because it can cause a large-scale accident. In order to avoid accidents, repairs should be performed in a timely manner. One of the latest effective technologies of trenchless pipeline repair in hard-to-reach areas is drawing a new polyethylene pipe into a defective steel pipeline using a piston [7].

To increase the reliability of gas pipelines that are in operation for more than 30 years, it is necessary to take into account the peculiarities of their laying and optimize their operating parameters [8], thoroughly inspect the pipes and detect corrosion defects in a timely manner [9], and minimize natural and technology-related risks [10].

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

Among the above-mentioned methods, special attention should be paid to cleaning gas pipelines with foam, gel and viscoelastic cleaning pigs.

Using foam is one of the effective methods for cleaning gas pipelines. In [11] the results of an experimental study of cleaning the inner cavity of gas pipelines from liquid contaminations are presented. The experimental unit simulated the ascending and descending sections of the pipeline. For this purpose, glass and plastic tubes of different lengths were connected at different angles. The effect of surfactant concentration on foam quality was determined experimentally. For the effective cleaning it is necessary to provide a high-quality and stable foam depending on the composition of liquid contaminations.

E. Tuna [12] recommends determining the foam quality by means of analysing the average size and texture of the foam bubbles. It was determined experimentally that the larger the average size of the foam bubble is, the better the foam cleans the inner cavity of the pipeline.

In [13] the influence of surfactants on the flow rate and the pressure drop magnitude in the ascending sections of the pipeline was studied by means of electric tomography. For 0°, 2.5° and 5° pipe inclinations, the surfactant has obvious effect on the transition from the stratified wavy flow to the annular flow, and the range of the stratified smooth flow regime is also extended to higher gas velocities. For 10° pipe inclination, no stratified flow regime is observed in the air/water flow. In the air/surfactant solution system, however, the stratified flow regime can be found in the range of U_{SG} = 10 m/s-28 m/s and U_{SL} = 0.07 m/s-0.2 m/s. For all inclination angles, the changes of the pressure gradient characteristics are accompanied by the flow pattern transitions. Adding surfactant to a two-phase flow would reduce the pressure gradient significantly in the slug flow and annular flow regimes. In the annular flow regime, the pressure gradient gradually becomes free of the influence of the upward inclined angle, and is only dependent on the property of the two-phase flow.

In [14] 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 influence of surfactant addition on the flow regimes, the corresponding pressure gradients, and the bubble sizes and velocity. At low Reair, the bubble sizes of the surfactant solution are 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 become greater than those of pure water which is attributed to the effect of surface tension.

Many studies on the use of foam for cleaning gas pipelines were carried out by the specialists of 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 [15].

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 Lviv Gas Vydobuvannya Gas Production Division. 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 [16].

The article [17] 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 of 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 (AS) with higher fatty alcohols in the ratio of 10:1 used stabilizers double the cleaning efficiency as compared with non-stabilized foams. Stabilizers increase the structural and mechanical properties of the foam and damage tolerance to dynamic loading [17].

The paper [18] 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 another important factor.

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

$$ER = \frac{V_f}{V_{fs}} = \frac{V_g + V_{fs}}{V_{fs}} \quad (1)$$

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

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

As part of the research, development, and engineering, the specialists of UkrNDIgaz developed and implemented in practice new methods of cleaning gas pipelines. For instance, they got Patent of Ukraine No. 94194 "Method of cleaning the inner cavity of pipelines" [19], which consists in the formation of pig by means of mixing the components until a homogeneous mixture is obtained, the decontamination by moving the pig inside the pipeline and the dissolution of the pig. The peculiarity of this method is that first the corrosion inhibitor solution is injected, and the pig is formed as an elastic-polymer compound in an elastic membrane that dissolves when moving. The dissolution time of the pig should not be less than the time it needs to clean the pipeline.

Due to that the pig is made as an elastic-polymer compound it can easily pass through the raised and curved sections of the pipeline without losing the sealing contact with the inner wall of the pipeline. Besides, as the pig moves, its components contact with the pipe surface through elastic membrane pores, dissolve and push the contaminants off the walls and bottom of the pipeline.

When the pig reaches the CGTU, it looks like a muddy mixture that passes to the first stage separator, in which the contaminants are removed from natural gas and discharged.

The article [20] deals with the experimental investigations of the way the elastic-polymer compound (EPC) behaves inside the flowline. The formula was developed to determine the passage time of EPC used as a cleaning pig from the wellhead to the gathering manifold at the CGTU, taking into consideration the flowline route profile, the extent and type of contamination of its interior and the well operation conditions. The efficiency of flowline cleaning with EPC is assessed with the cleaning ratio by means of comparing the hydraulic efficiency data for the flowline before and after the cleaning operations.

In the course of research and development activities, the researchers of the Ivano-Frankivsk National Technical University of Oil and Gas (IFNTUOG) developed a number of recommendations for increasing the hydraulic efficiency of gas pipelines. They obtained Patent of Ukraine No. 78315 "Viscoelastic cleaning pig" [21]. The proposed cleaning pig contains a water-soluble polymer and water and is special as it additionally contains a foaming surfactant. As a water-soluble polymer, carboxymethylcellulose is used in the following mixture proportion, expressed in terms of mass:

- carboxymethylcellulose – 4-8%;
- foaming surfactant – 1-2%;
- water – the rest.

The composition of the viscoelastic cleaning pig is prepared in the following sequence. A foaming surfactant and carboxymethylcellulose are added to fresh water and mixed until a homogeneous mixture is obtained. The mixture is treated with methyl alcohol (methanol) for 5-10 minutes at a volume ratio of 1:2 and shaped as a cylinder with a diameter close to that of the pipeline.

The interaction of the homogeneous mixture, containing the foaming surfactant and the carboxymethylcellulose with methanol, is followed by the desalting process of carboxymethylcellulose and the generation of a foamy solid. In this case, during the interaction of methanol with the foam, formed from the foaming solution in the desalting process, the interfilm liquid is turned into the elastic film, which substantially strengthens the foam structure and increases foam stability.

The main positive properties of the viscoelastic cleaning pig are:

- resistance to dissolution when it passes through the pipelines of different cross-sections;
- resistance to dissolution in case of pipeline shutdown;
- low adhesion to metal;
- the pig takes on the shape of the pipeline and fills its whole interior;
- after the completion of pipeline cleaning the pig dissolves in water.

The article [22] provides the results of the pilot testing of cleaning the well flowlines in the Khidnovytske gas field (GF). The operation of wells in the Khidnovytske GF is characterized by the accumulation of liquid in the lower sections of the flowline. The performed calculations of hydraulic pressure losses in the gathering system show that the actual hydraulic resistance coefficients significantly exceed the theoretical coefficients in the flowlines of most wells. This results in the reduced production capacities of wells and even may cause wells shutdown. A water-soluble viscoelastic pig was proposed to be used for cleaning the well flowlines. This technology for cleaning well flowlines from the accumulation of liquid involves two options: passing a viscoelastic pig from the wellhead to the CGTU or in the reverse direction.

3. Methods and materials

During the development of the Yuliivske, Skvortsivske, Narizhnianske, Nedilne fields of the Yuliivskyi OGCPF there can arise problems that lead to complications in the production of hydrocarbons. 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.

Taking the above into account, the construction of additional gas pipelines in the structural units of the Company's gas production divisions is topical nowadays, since there is a need to supply gas not only to the main gas pipeline, but also to other production sites, to different consumers, etc. For example, the Yuliivskyi OGCPF (Fig. 1) benefits from the optimization of wells operation and the rational use of hydrocarbon raw materials due to the construction of gas pipelines between production sites [23,24].

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

- 1 is the gas gathering pipeline from the GGS of the Narizhnianske oil and gas condensate field (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 Central block of the Yuliivske OGCF, which is used for supplying the hydrocarbons to the first and second separation stages and removal of liquid from the flowline;
- 8 is the gas gathering pipeline from the COTU of the Central block 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-2 to the CGTU-1 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.

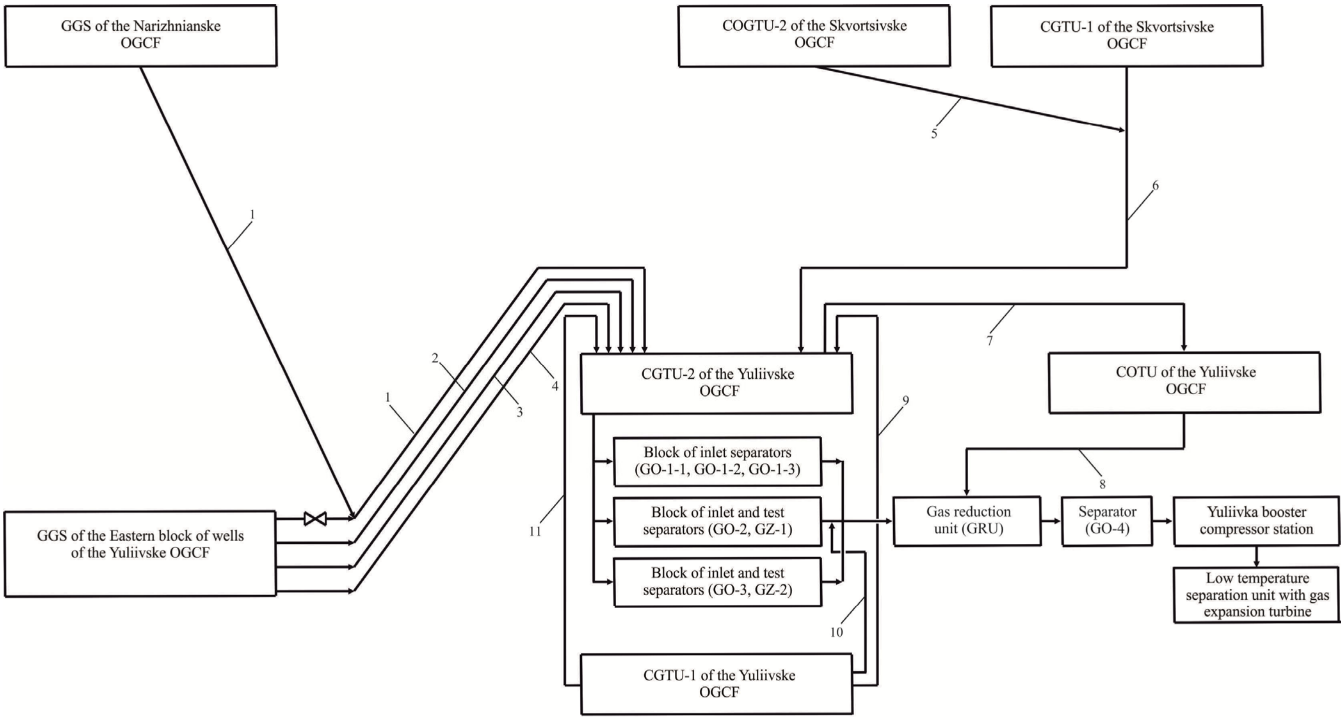

Fig. 1. Connection scheme of gas pipelines between the production sites of the Yuliivskyi OGCPF

Thus, the construction of gas pipeline systems between gas treatment units and generally within the Yuliivskyi OGCPF helps to ensure a stable operation of wells, increase the extraction of liquid hydrocarbons, hydrocarbon condensate and propane-butane fraction and supply the treated gas to consumers.

During the operation of gas gathering pipelines 1-6 of the Yuliivskyi OGCPF there can arise complications associated with liquid accumulation and hydrate formation. Below are the main reasons for liquid accumulation inside the gas pipeline [25]:

- one-stage gas separation, which does not provide qualitative gas treatment;
- reduction in the efficiency of separation equipment caused by the violation of the design operation modes, i.e. insufficient separation of the liquid phase;
- non-compliance with the temperature profile along the pipeline route, which causes liquid condensation;
- decrease in gas velocity. If gas velocity is over 12-15 m/s, the liquid does not accumulate and the process of self-cleaning of gas pipeline takes place. If gas velocity decreases to 5-11 m/s, an aperiodic wave motion of the liquid occurs, that is accompanied by its ejection from the pipe elbow. If the velocity falls below 5 m/s, this leads to the gradual accumulation of liquid contaminants.

It should be noted that the considerable length of gas gathering pipelines, the presence of local restrictions (valves, reducers, tees, bends, welding joints, ascending and descending sections) and their route profile are the main reasons for decreasing temperature conditions, which may lead to the condensation of heavy fractions from the two-phase flow. Besides, liquid accumulations in the lower sections of gas pipelines may be additional local restrictions too. The accumulation of liquid inside gas pipelines may cause the hydraulic resistance in some sections, which ultimately leads to the decrease in gas production and transportation.

Hydrate deposition can occur in different sections of the gas gathering pipeline and may change its operating parameters, in particular, the increase or decrease in pressure and decrease in the volume of transported gas. Different methods are used to overcome this complication.

Thus, nowadays it is important to improve the hydraulic efficiency of gas gathering pipelines. This issue is closely related to the influence of gas-liquid mixture on the pipeline throughput. Obviously, the quality of cleaning the inner cavity of gas pipelines affects their hydraulic efficiency. It is known that the hydraulic efficiency index (E) is within the range of $0 < E \leq 1$. That is, if $E \rightarrow 1$, the decrease in the volume of accumulated liquid contaminants in the gas pipeline is observed. If $E \sim 1$, there is a small volume or even absence of the accumulated liquid contaminants in the pipeline. As a result, measures should be taken so that the hydraulic efficiency index is 1.0, i.e. 100%, after gas pipelines cleaning.

The calculation procedure for the hydraulic efficiency coefficient of the gas pipelines at Yuliivskyi OGCPF is provided below. First, the molecular weight, gas density, relative density and critical temperature and pressure are determined for gas composition. Further calculations are done to determine the following parameters [26,27]:

1. Average gas pressure in the pipeline:

$$P_{av} = \frac{2}{3} \cdot \left(P_i + \frac{P_o^2}{P_i + P_o} \right). \tag{2}$$

where: P_i – gas pressure at the pipeline inlet, MPa;
P_o – gas pressure at the pipeline outlet, MPa.

2. Average gas temperature in the pipeline:

$$T_{av} = T_{soil} + \frac{T_i - T_o}{\ln \frac{T_i - T_{soil}}{T_o - T_{soil}}}. \tag{3}$$

where: T_i – gas temperature at the pipeline inlet, K;
T_o – gas temperature at the pipeline outlet, K;
T_{soil} – soil temperature, K.

3. Gas compressibility factor for the average values of pressure and temperature:

$$Z_{av} = 1 - 5.5 \cdot 10^6 \cdot \frac{P_{av} \cdot \Delta^{1.3}}{T_{av}^{\ 3.3}} \tag{4}$$

where: P_{av} – average pressure, MPa;
Δ – specific gravity of gas;
T_{av} – average temperature, K.

4. Average gas velocity in the pipeline:

$$V_{av} = \frac{4 \cdot Q \cdot 10^6}{\pi \cdot D_i^2 \cdot 86400} \cdot \frac{Z_{av}}{Z_{ref}} \cdot \frac{P_{ref}}{P_{av}} \cdot \frac{T_{av}}{T_{ref}} \tag{5}$$

where: Q – transported gas, mcm/day;
Z_{av} – gas compressibility factor for P_{av} and T_{av};
P_{ref} – reference pressure in the pipeline, MPa;
T_{av} – average gas temperature in the pipeline, K;
D_i – internal diameter of the pipeline, m;
Z_{ref} – gas compressibility factor for P_{ref} and T_{ref};
P_{av} – average pressure in the gas pipeline, MPa;
T_{ref} – reference gas temperature in the pipeline, K.

5. Theoretical value of the hydraulic resistance coefficient:

$$\lambda_t = 0.067 \cdot \left(\frac{158}{\mathrm{Re}} + \frac{2 \cdot k_e}{D_i} \right)^{0.2}. \tag{6}$$

where: Re – Reynolds number;
k_e – equivalent pipe roughness coefficient, mm;
D_i – internal diameter of the pipeline, mm.

6. Reynolds numbers:

$$Re = 17.75 \cdot \frac{Q \cdot \Delta}{D_i \cdot \mu}. \tag{7}$$

where: Q – transported gas, mcm/day;
Δ – specific gravity of gas;
D_i – internal diameter of the pipeline, mm.
μ – dynamic viscosity coefficient of gas, Pa·s.

7. Actual value of the hydraulic resistance coefficient:

$$\lambda_a = \frac{(105.087)^2 \cdot D_i^5 \cdot \left(P_i^2 - P_o^{\ 2}\right)}{\Delta \cdot Z_{av} \cdot T_{av} \cdot L \cdot Q^2}. \tag{8}$$

where: D_i – internal diameter of the pipeline, m;
P_i – gas pressure at the pipeline inlet, MPa;
P_o – gas pressure at the pipeline outlet, MPa;
Δ – specific gravity of gas;
Z_{av} – gas compressibility factor for P_{av} and T_{av};
T_{av} – average gas temperature in the pipeline, K;
L – gas pipeline length, km;
Q – transported gas, mcm/day.

8. Hydraulic efficiency coefficient E:

$$E = \sqrt{\frac{\lambda_t}{\lambda_a}}. \tag{9}$$

where: λ_t – theoretical value of the hydraulic resistance coefficient;
λ_a – actual value of the hydraulic resistance coefficient.

Calculation results of the operating efficiency of gas gathering pipelines at the Yuliivskyi OGCPF are represented in Table 1.

The analysis of the above results shows that the lowest values of the hydraulic efficiency coefficient are for gas gathering pipelines 2, 3, 4. In this regard, it is necessary to choose their optimal operation modes in order to prevent the accumulation of liquid and propose an effective method for cleaning the interior of gas pipelines.

It should be noted that the hydraulic efficiency was calculated for gas gathering pipelines 1-6 at different periods of the year. Thus, according to the results of experimental studies, the amount of accumulated contaminations in gas gathering pipelines was 6-15% bigger than the calculated amount.

One of the ways to increase the throughput of gas pipelines is to reduce their hydraulic resistance. For this purpose, it is necessary to monitor the hydraulic efficiency of pipelines and develop measures to improve their operational efficiency [28].

Taking the above into account, it is reasonable to consider the possibility of installing the control and measuring devices at the inlets and outlets of gas gathering pipelines that measure pressure and temperature in real time. This will ensure a continuous monitoring of the operating parameters of gas gathering pipelines and will help to look through the archival data on computer in the GTU control room of the gas treatment unit. The implementation of the above measures will help to monitor the operating parameters of gas pipelines and take timely responsive measures.

Based on the above information, we propose the measures for monitoring gas gathering pipelines at the Yuliivskyi OGCPF and improving their hydraulic efficiency. These measures are presented in Tables 2, 3.

Table 1.
Operating efficiency of gas gathering pipelines at the Yuliivskyi OGCPF

Pipeline name	Outer diameter, mm	Wall thickness, mm	Average gas velocityin the pipeline V_{av}, m/s	Hydraulic efficiency coefficient E,%
1	114	12	10.9	98
2	114	12	3.9	65
3	114	12	3.9	65
4	159	6	3.9	65
5	114	10	3.2	76
6	159x114	8x12	9.2	96

Table 2.
Measures for monitoring gas gathering pipelines at the Yuliivskyi OGCPF

Pipeline name	Gas outlet pipeline from GGS, CGTU (gas pipeline inlet)	Gas inlet pipeline of CGTU-2 (gas pipeline outlet)	Control room at the Yuliivskyi OGCPF
Gas gathering pipelines 1-6	Installation of control and measuring devices: • pressure gauge; • temperature gauge; • (data should be transmitted from converters to computer display devices); • gas flow metering system.	Installation of control and measuring devices: • pressure gauge; • temperature gauge; • (data should be transmitted from converters to computer display devices).	1. Development and implementation of software and creation of the automated workstation for monitoring pressure and temperature in gas pipelines with measurement parameters displayed on the mnemonic circuit and shutdown setpoints (control and signalling of the abnormal parameter values). 2. Remote transmission and display of the data on pressure and temperature from gas treatment units to the control office for monitoring the operating parameters of gas pipelines in real time. 3. Archiving the data on the measured pressure, temperature and transmittion capacity in an electronic database in order to trace the dynamics of parameter changes and calculate the operating efficiency of gas pipelines. 4. Development and implementation of the program for calculating gas flow velocity and hydraulic efficiency of gas gathering pipelines in real time. 5. Installation of the “Programming and computing complex”, developed by UkrNDIgaz to define the conditions for hydrate formation in gas pipelines and flowlines.

Table 3.
Measures to improve the hydraulic efficiency of gas gathering pipelines

Pipeline name	Gas outlet pipeline from GTU, CGTU (gas pipeline inlet)	Gas inlet pipeline of CGTU-2 (gas pipeline outlet)	Methods of improving the hydraulic efficiency of gas gathering pipelines
Gas gathering pipelines 1-6	Setting up the line with a valve and a quick nut and plug for connecting the pumping unit and feeding: • a surfactant solution; • gel pigs; • foam pigs; • hydrate formation inhibitor, etc.	Repiping the existing utilities so that several gas pipelines could transport hydrocarbons to the measuring line of the CGTU-2, CGTU-1 and COTU.	1. Feeding the surfactant solution to gas pipelines. 2. Creating the high-speed gas flow in gas pipelines by means of shutting them down and increasing well pressure and then resuming the gas flow. 3. Purging gas pipeline in the direction of gas flow. 4. Purging gas pipeline in the direction opposite to gas flow. 5. Increasing gas flow velocity by means of decreasing the operating parameters of the booster compressor station (BCS) for a certain period of time. 6. Using foam pigs. 7. Injecting the hydrate formation inhibitor by means of pumping unit or dosing pumps. 8. Feeding the gas-nitrogen mixture into the gas pipeline by means of special equipment. 9. Installation of expansion tanks on the gas pipeline. 10. Using gel pigs. 11. Increasing the efficiency of separation equipment (upgrading or replacement). 12. Optimizing the operation parameters of gas pipelines by means of constructing BCS at the GGS of the Eastern block of wells at the Yuliivskyi OGCPF and the CGTU-1 of the Skvortsivske OGCF.

Table 3 shows different methods for increasing the hydraulic efficiency of gas gathering pipelines 1-6. Undoubtedly, their use in practice has both advantages and disadvantages. Therefore, before applying any method, it is necessary to take into account different criteria, for example, not only the ease of use and efficiency, but also the cost and environmental impact. Thus, the alternative methods with the minimal losses of hydrocarbons, ease of use, low cost, and minimal environmental impact [29] should be preferred.

4. Results and discussion

At the Yuliivskyi OGCPF, the workers at the facility and the specialists of UkrNDIgaz conducted the industrial research on the technology of cleaning the flowline with foam. The experiments were conducted on two gas condensate wells 85 and 60 of the Yuliivske field, connected to the CGTU-1. The length of flowlines on well 85 was 2960 m, on well 60 – 2884 m, and their internal diameters were 90 mm. These wells were selected on the basis of the following criteria:

- a relatively large length of the flowline (about 3 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 flowlines, which are usually a multicomponent mixture, which includes formation and condensation water, hydrocarbon condensate, mechanical impurities, salts, methanol, etc.);
- the existence of ascending and descending sections;
- the presence of many local restrictions (bends).

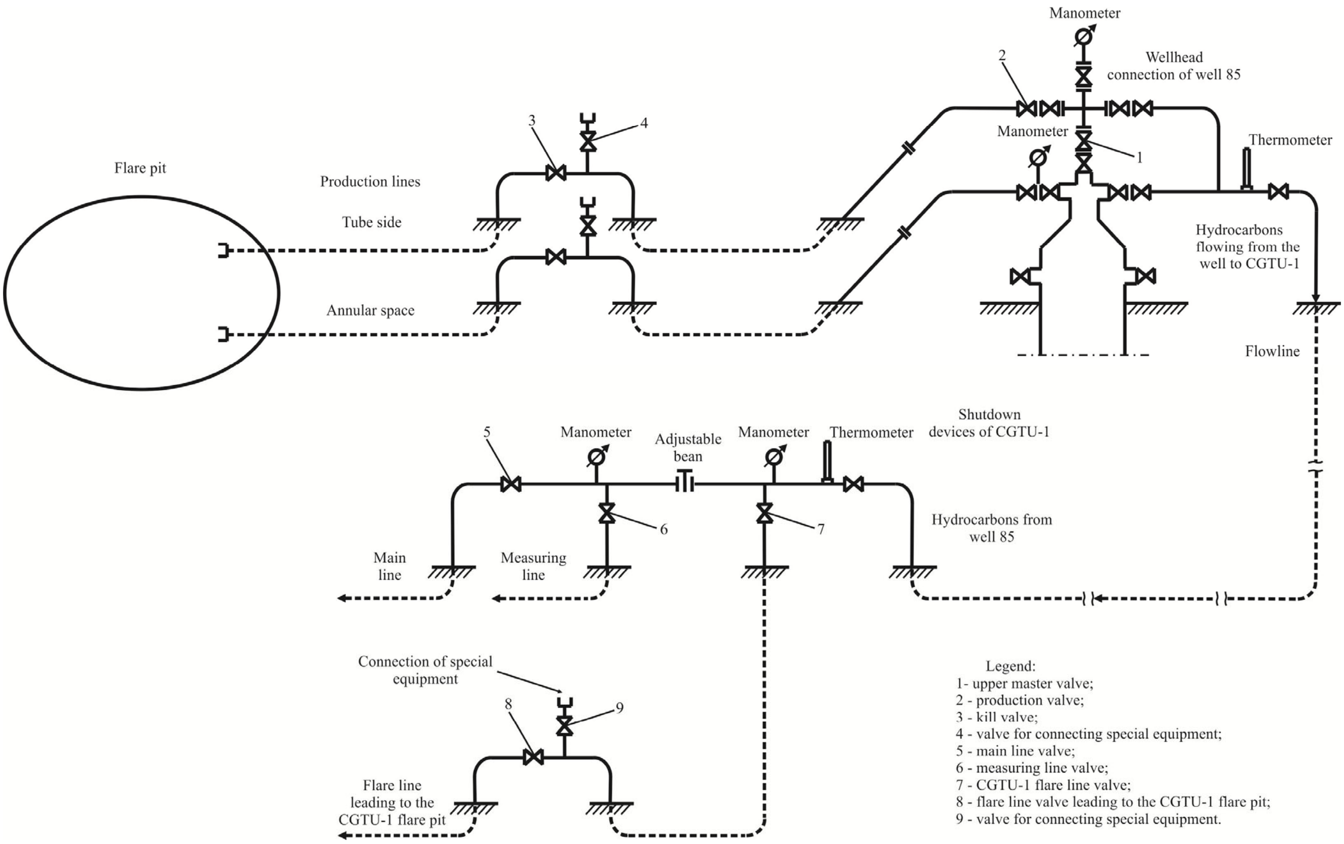

Fig. 2. Connection scheme of well 85, flowline and the shutdown devices of CGTU-1

Before the experiment, 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 calcium chloride ($CaCl_2$) and 100 g/l sodium chloride (NaCI), with a density from 1.075 g/cm^3 to 1.087 g/cm^3 at a temperature of 20°C and surfactant solution concentrations of 0.5%, 1%, 1.5% and 2%. In addition, a stable condensate with a density 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.

The first experiment was carried out on well 85. Before cleaning the flowline, the well operating parameters were measured and the hydraulic efficiency coefficient was calculated to be 80%. The research was performed in the following order:

1. The pressure and temperature at the wellhead of well 85 and at the inlet of the CGTU-1 and the well production rate were measured.
2. The well was shut down by closing the upper master valve on the Christmas tree.
3. The pressure in the flowline was reduced to the pressure of the first separation stage on the CGTU-1 and the necessary valves were closed on shutdown devices.
4. The production valve on the Christmas tree and the kill valve were opened in order to reduce pressure to the atmospheric level in the flowline leading to the flare pit.
5. At the CGTU-1, special equipment (a mobile pumping unit, two mobile nitrogen compressor stations, and a device [30]) were connected to the flare line valve and the back valve was installed on the downstream line (Fig. 2).
6. The downstream line was pressure tested with the 1.5 times expected working pressure.

7. The valves on the flare line and on the series of shutdown devices of the CGTU-1 were opened and the inert gas mixture (composition by volume: nitrogen – not less than 90%; oxygen – not more than 10%) was injected inside the flowline by means of two mobile nitrogen compressor stations. The rate of outward flow of the inert gas mixture directed to the flare pit and, consequently, the pressure in the flowline, were regulated by opening and closing the kill valve. The pressure was controlled according to the readings of manometers installed at the inlet of the CGTU-1 and at the wellhead.
8. After the inert gas mixture appeared in the flare pit, the 2% solution of surfactants Solpen-10 T was supplied in the device [30] by means of the pumping unit and the foam was injected into the flowline, the consumption of surfactants was monitored. After injecting the foam, generated from the 0.250 m^3 solution of surfactants, the pumping unit was stopped, but the injection of the inert gas mixture was carried on by the mobile nitrogen compressor station. After a certain period of time the injection of foam was resumed.
9. The outflow of foam was controlled by means of the visual inspection of the flare pit.
10. After the experiment was finished, the valves on the flare line and on the series of shutdown devices of the CGTU-1 were closed, the downstream line was depressurized and removed.
11. The production valve on the Christmas tree and the kill valves were closed.
12. The upper master valve on the Christmas tree was opened to let the hydrocarbon raw materials flow and increase pressure in the flowline.
13. The well was put into production to the measuring line of the CGTU-1 and its operating parameters were monitored.
14. The pressure and temperature at the wellhead, at the inlet of the CGTU-1 and the well production rate were measured.

During the experiment the foam expansion ratio was between 90 and 100. The experiment resulted in flowline cleaning 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%.

The second experiment was carried out on well 60. Before cleaning the flowline, the well operating parameters were measured and the hydraulic efficiency coefficient was calculated to be 78%. The research was performed in the following order:

1. The pressure and temperature at the wellhead of well 60 and at the inlet of the CGTU-1 and the well production rate were measured.
2. The well production was changed from the main line to the measuring line of the CGTU-1.
3. At the wellhead, special equipment (mobile pumping unit, a mobile nitrogen compressor station, and a device [30]) were connected to the valve for connecting special equipment and the back valve was installed on the downstream line (Fig. 3).
4. The downstream line was pressure tested with the 1.5 times expected working pressure.
5. The valve for connecting special equipment and the production valve on the Christmas tree of tubing were opened and the inert gas mixture was injected inside the flowline by means of the mobile nitrogen compressor station. The pressure was controlled according to the readings of manometers installed at the wellhead and at the inlet of the CGTU-1.
6. Five minutes after the injection of inert gas mixture, the 2% solution of surfactants Solpen-10 T was supplied in the device [30] by means of the pumping unit and foam was injected into the flowline, the consumption of surfactants was monitored. After injecting the foam, generated from the 0.200 m^3 solution of surfactants, the operation of pumping unit and mobile nitrogen compressor station was stopped. After a certain period of time the injection of foam was resumed.
7. Based on the results of the first experiment, the outflow of foam was controlled by the periodic opening of the manometer valve at the inlet pipeline in the CGTU-1.
8. On the measuring line of the CFTU-1, in the separator and segregator the flow of pollutants from the flowline was monitored and their volume was determined.
9. After finishing the experiment, the valve for connecting special equipment and the production valve on the Christmas tree of tubing were closed, the downstream line was depressurized and removed.
10. The well was put into production to the measuring line of the CGTU-1 and its operating parameters were monitored.
11. The pressure and temperature at the wellhead, at the inlet of the CGTU-1 and the well production rate were measured.

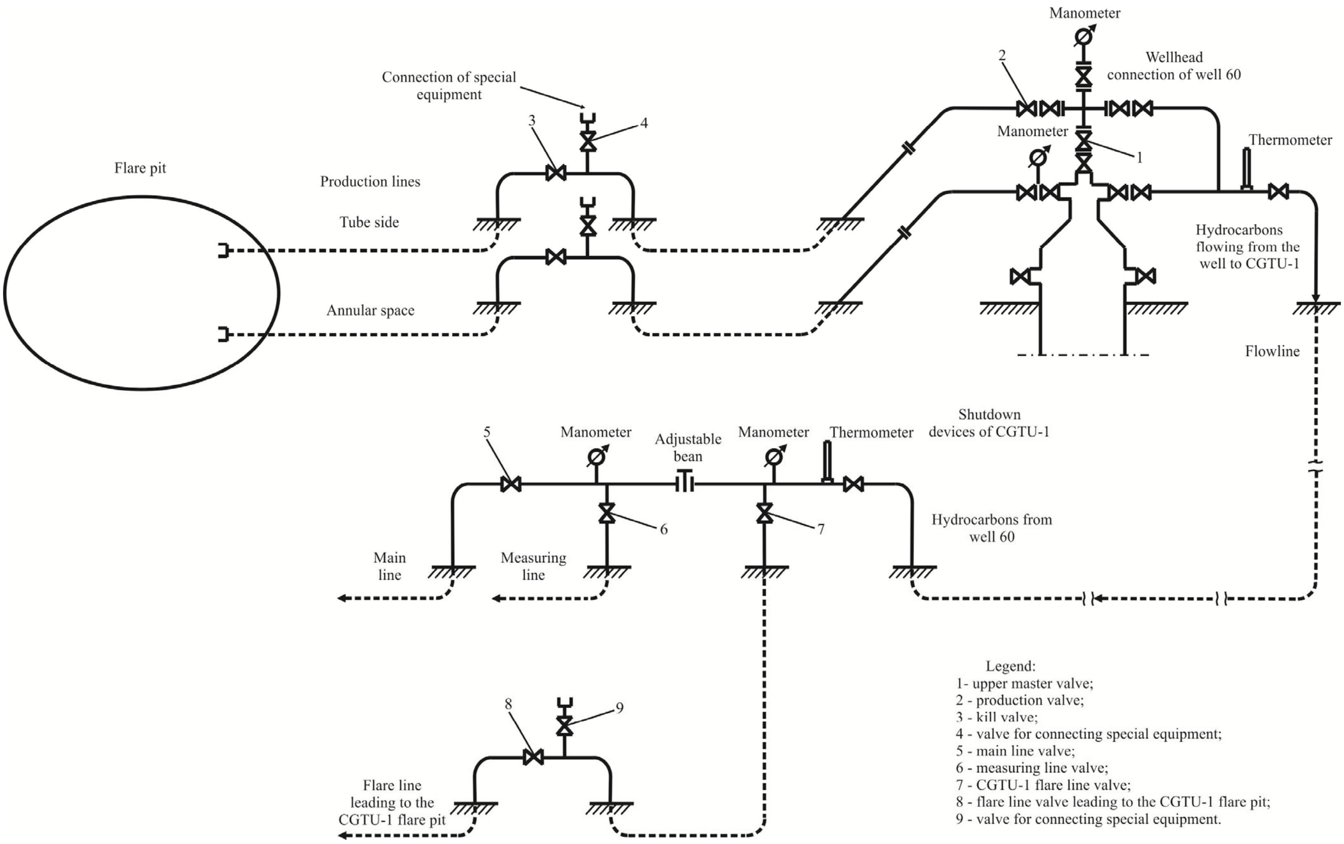

Fig. 3. Connection scheme of well 60, flowline and the shutdown devices of CGTU-1

During the experiment the foam expansion ratio was between 40 and 50. The experiment resulted in flowline cleaning 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%.

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

- the first experiment involves well shutdown and, therefore, the absence of hydrocarbon production over the period of experiment. In the course of the experiment the velocity of gas-nitrogen mixture could be regulated in the flowline by means of closing or opening the kill valve. It is important that the actual process duration can be defined based on the visual inspection of the outflow of contaminants. The advantages of this process include the following: no need to take special machinery to the wellhead (which may be complicated by the absence of access road and by weather conditions); duration of the process; the possibility of performing the process on other wells without special machinery relocation; the possibility of using a conventional compressor to inject air instead of gas-nitrogen mixture. The disadvantages of this process are the shutdown of well and, consequently, the decrease in the volume of produced hydrocarbon raw materials for the process performance period;
- the second experiment involves well operation and transferring gas to the measuring line of the gas treatment unit. The velocity of gas flow depends on the individual well operation parameters. An important thing is that it is difficult to control foam movement in the flowline and therefore define the actual process duration. The advantages of this process include hydrocarbons production and control of the well production capacities during flowline cleaning. The disadvantage of this process is the possible flow of high-expansion and stable foam to the gas treatment

unit, which may negatively affect the operation of gas separation and purification equipment.

Thus, taking into account the characteristics of gas gathering pipelines 2 and 3, which have the same diameter as the flowlines of gas condensate wells 85 and 60, it is advisable to perform the industrial research on the application of the foam cleaning technology.

5. Conclusions

1. The article considers the current state of gas gathering pipelines of the Yuliivskyi OGCPF. The results of the calculations, made to determine the operational efficiency of gas gathering pipelines, show the accumulation of liquid inside pipelines and low hydraulic efficiency coefficient (from 65% to 76%) of gas gathering pipelines 2, 3, 4, 5.
2. The authors proposed a set of measures to monitor the gas gathering pipelines of the Yuliivskyi OGCPF and ways to increase their hydraulic efficiency. In practice these proposals can help to provide constant control over the operation of gas gathering pipelines and apply the effective methods of cleaning the inner cavity of pipelines.
3. The calculations were carried out to determine pressure losses along the length of flowlines of the Yuliivskyi OGCPF. The calculations results show that the actual hydraulic resistance coefficient significantly exceeds the theoretical coefficient in the flowlines of wells. This causes the increase in wellhead pressure and decrease in the production capacities of wells.

   To eliminate the defects, the authors of the article proposed to clean the inner cavity of flowlines using foam with the expansion ratio from 40 to 100. This method can be used both for straight sections and for sections with many local restrictions.

   The results of the industrial research on cleaning the flowlines of wells 85 and 60 of the Yuliivskyi OGCPF from liquid accumulation showed that their hydraulic efficiency coefficients increased by 12% and 7%, respectively. The measures taken to clean the interior of gas pipelines from liquid have proved their efficiency and can be recommended for other well flowlines of the Yuliivskyi OGCPF.
4. In the future, it is advisable to study cleaning of the inner cavity of gas gathering pipelines using medium- and high-expansion foam. The results of experiments will help to make conclusions on using this technology in gas pipelines with different diameters and working pressures.

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