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Development of foam-breaking measures after removing liquid contamination from wells and flowlines by using surface-active substances

V.B. Volovetskyi [a,*], Ya.V. Doroshenko [b], S.M. Stetsiuk [c], S.V. Matkivskyi [d], O.M. Shchyrba [c], Y.M. Femiak [e], G.M. Kogut [f]

[a] Branch R&D Institute of Gas Transportation Joint Stock Company “Ukrtransgaz”,
16 Koneva str., Kharkiv, Ukraine
[b] Department of Oil and Gas Pipelines and Storage Facilities, Institute of Petroleum Engineering,
Ivano-Frankivsk National Technical University of Oil and Gas, 15 Karpatska str., Ivano-Frankivsk, Ukraine
[c] Branch Ukrainian Scientific Research Institute of Natural Gases Joint Stock Company
“Ukrgasvydobuvannya”, 20 Himnaziina Naberezhna str., Kharkiv, Ukraine
[d] Joint Stock Company “Ukrgasvydobuvannya”, 26/28 Kudriavska str., Kyiv, Ukraine
[e] Department of Well Drilling, Institute of Petroleum Engineering, Ivano-Frankivsk National
Technical University of Oil and Gas, 15 Karpatska str., Ivano-Frankivsk, Ukraine
[f] Department of Energy Management and Technical Diagnostics, Institute of Architecture,
Construction and Power Engineering, Ivano-Frankivsk National Technical University of Oil
and Gas, 15 Karpatska str., Ivano-Frankivsk, Ukraine
* Corresponding e-mail address: vvb11@ukr.net
ORCID identifier: https://orcid.org/0000-0001-8575-5143 (V.B.V.)

ABSTRACT

Purpose: The purpose is to consider the complications that arise during the operation of gas condensate wells, in particular, the accumulation of liquid contamination. Development of new approaches to improve the efficiency of the separation equipment performance of gas gathering and treatment systems when a multiphase flow enters. Development of a foam breaking method in a gas-liquid flow after removal of liquid contaminants from wells and flowlines using surfactants.

Design/methodology/approach: An analysis was made of the complications that may arise when removing liquid contaminants from wells and flowlines using surfactants. Measures have been developed that will make it possible to timely prevent the ingress of foam into the separation equipment of gas gathering and treatment systems. Using computational fluid dynamics (CFD) modelling, an effective foam-breaking device was developed by supplying stable hydrocarbon condensate.

Findings: A method to minimize the negative impact of foam on the operation of separation equipment after fluid removal from wells and gas condensate field flowlines using a surfactant solution was elaborated. A method for its breaking was proposed to prevent the flow of foam into the gas processing unit. This method foresees the application of the technological scheme layout for supplying a stable hydrocarbon condensate to a gas-liquid flow entering the separators of the first of separation, both the main line and the measuring line. CFD modelling was used to study the process of foam breaking by feeding hydrocarbon condensate into it. The influence of the hydrocarbon condensate supplying method on gas-dynamic processes (distribution of pressure, velocity, volumetric particles of phases), and the efficiency of foam breaking was estimated. It was established that the supply of hydrocarbon condensate from one branch pipe to the pipeline through which the foam moved did not ensure its complete breaking. To increase the efficiency of foam breaking, a device with designed four nozzles for supplying hydrocarbon condensate was developed. CFD modelling made it possible to substantiate that in this case, a pressure reduction zone appeared at the place of condensate supply. Because of a sharp change in pressure, a strong improvement in the effect of foam breaking occurred. The understanding of the regularities of foam breaking processes by hydrocarbon condensate was obtained, and the design of a device for the complete foam breaking was developed.

Research limitations/implications: The obtained results of laboratory studies have shown that a sharp decrease in the stability of the foam occurs under the condition of an increase in the volume of stable hydrocarbon condensate added to the studied model of mineralized formation water. Based on the results of CFD modeling, a device for breaking foam by stable hydrocarbon condensate has been worked out, the effectiveness of which will be confirmed experimentally and in field conditions.

Practical implications: The results of the performed laboratory studies and CFD modelling allow a more reasonable approach to using various available methods and measures to prevent the ingress of foam with a gas-liquid flow into the separation equipment of gas gathering and treatment systems. This approach makes it possible to develop new effective ways and measures to prevent this complication.

Originality/value: Based on CFD modelling, it was found that when a stable hydrocarbon condensate is supplied into a gas-liquid flow, foam breaks. A method for breaking foam in a gas-liquid flow has been developed, which is original and can be introduced in practice.

Keywords: Well, Gas, Flowline, Liquid removal, Gas-fluid flow, Foam breaking

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MANUFACTURING AND PROCESSING

1. Introduction

During the operation of gas condensate wells, complications arise associated with the accumulation of liquid (formation, condensate water and hydrocarbon condensate) at the bottom hole, in the wellbore, as well as in low sections of pipelines (flowlines, gathering and field pipelines) [1]. These complications reduce well productivity [2,3], and pipeline throughput, lead to erosion wear of shaped elements [4,5], overtime pressure losses, etc. Also, fluid in the wells gas stream can lead to other negative complication, including hydration [6] and equipment corrosion [7]. Therefore, workers at the production facilities monitor the actual pressure and temperature values to identify possible complications.

Therefore, to ensure the stable operation of both wells and pipelines of the gas gathering and treatment system, to remove liquid contamination, several complex measures were developed, namely: monitoring of wells operating parameters by pressure and temperature sensors installed at the wellhead and inlet gas pipelines of the gas treatment unit; calculation of the accumulated fluid volume in the wellbore and flowlines; installation of a complex for automated supply of surfactants solution both into the annulus of wells and into the pipeline [8,9]. According to the results of experimental studies, it was established that cleaning the internal cavity of flowlines and gathering gas pipelines with foams leads to an increase in their hydraulic efficiency [10-12]. Foams are also effective for developing gas condensate wells to remove liquid contamination from the shafts and restore their productivity.

2. Literature review

To ensure the stable operation of wells and pipelines (flowlines, gathering and field pipelines), the gas gathering and treatment systems remove the accumulated liquid using a surfactant solution [13-15]. In the case of surfactants use, foam is formed, which, together with the gas-liquid flow and liquid contaminants from the wells through pipelines, enter the gas collection and treatment system and is destroyed in the separators completely or partially. Remains of undistracted foam can negatively affect the efficiency of the segregation equipment and, accordingly, the gas purification quality. Consequently, foam can enter the gas treatment unit (GTU) with different characteristics in terms of multiplicity and stability. Therefore, mechanical and chemical methods or their combination are used at GTU to defoam. The foam is mechanically destructed using nets or nozzles installed at the inlet or inside the separators. The chemical method involves using various chemical reagents fed into the gas-liquid flow with foam.

The authors in the publication [16] provided a method for the foam destruction formed due to the use of a surfactant solution for cleaning the internal cavity of gas pipelines. The foam under pressure is fed to the cutter, partially destroyed, and then – into the separation tanks, where the defoamer is supplied. After that, a fluoroplastic filter package captures the remnants of foam and dripping moisture, and the purified gas is fed to the gas pipeline inlet. The disadvantage of this method is its limited operation due to the low manufacturing utility of bulky equipment, which makes it difficult to transport, install and dismantle.

For high-quality foam destruction, [17] an annular nozzle-like device was developed in which the foam is destroyed by a high-speed jet of airflow, supplied to the annular slot. The efficiency of such a device was verified experimentally and by numerical simulation. It was found that the supply of air led to the emergence of a shear force and a low-pressure zone and a strong improvement in the foam destruction effect. Numerical simulation evaluated the influence of various geometric parameters of the device on gas-dynamic processes, particularly the pressure distribution in the internal cavity, which made it possible to develop an optimal design. For even better foam destruction, in the article [18], a two-stage aerodynamic device with two annular slots was presented, operating like a jet ejector. Numerical simulation showed that the supply of compressed air at high speed to such a device led to the emergence of two pressure reduction zones stimulating the foam bubbles to burst due to a sharp change in pressure.

Moreover, the second annular opening provided a wider zone of pressure drop. Also, using numerical simulation, the optimal distance between two annular slots was determined. The annular devices developed in [17,18] were intended for their connection to pipelines from which the foam was planned to be released into the environment, and they were not able to be used if not provided.

Also, numerical simulation was used to study the efficiency of the mechanical device developed in [19] for the destruction of foam based on the action of self-oscillations. Based on the simulation results, it was found that the combined effect of pressure drop, extrusion and displacement into the internal cavity of such a device led to the destruction of the foam.

To increase the efficiency of foam destruction, article [20] provided a developed device containing perforated plates with different holes' diameters and open area ratios. According to the results of studies concerning the influence of the number of perforated plates, the diameter of the plates' holes, and the foam ratio on the destruction effect, it was found that the perforated plate can significantly enhance the coalescence of bubbles and enhance the effect of foam destruction. Also, the results obtained made it possible to create a model to predict the percentage of foam destruction when using perforated plates.

3. Methods and materials

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

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

Considering that most of JSC "Ukrgasvydobuvannya" fields are depleted and at the final stage of development, the problem of removing fluid from wells and flowlines using optimal methods, including the use of a surfactant solution, is still important [21]. Since it is known that such complications negatively affect the possibility of ensuring the operation of wells in accordance with the technological regime and, in general, the reliability of gas supply.

It should be noted that despite using a surfactant solution as one of the effective measures for removing fluid from wells and the flowlines' internal cavity, many complications may arise.

So, if foam enters the gas collection and treatment system along with the gas-liquid flow and liquid pollution from wells through the pipelines, it can adversely affect the efficiency of the separation equipment installed individually to the technological scheme at all stages of separation (first, second, third, etc.), and as a consequence of the deterioration of gas cleaning quality.

Therefore, taking into account the above facts, it is recommended to work on the problem of foam destruction in a gas-liquid flow.

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

To solve this problem, a method of foam destruction in a gas-liquid flow by mixing it with a degassed liquid at a maximum possible distance from the inlet to the separator of the main and/or measuring GTU line has been developed. Stable hydrocarbon condensate is intermittently or continuously supplied in a metered amount to the gas-liquid flow by a pump from an additionally mounted tank. The basis for such a technical solution is the results of laboratory tests conducted according to methods currently applied in Ukraine.

It has been found that a sharp decrease in the foam stability occurs in case of an increase in the volume of stable hydrocarbon condensate with a density of 0.736 g/cm^3 to 0.757 g/cm^3, which is added to the studied sample of mineralised formation water with a density of 1.075 g/cm^3 to 1.083 g/cm^3, containing 50 g/l of calcium chloride ($CaCl_2$) and 100 g/l of sodium chloride (NaCI), with the concentration of surfactant solution (Solpent-10 T, Stinol-NG, Savinol, Sulfanol, Pinosil-NHI, Fomelit, SE-235-A, Pyrene-10, etc.) from 1% to 5% at temperatures of 20ºC and 60ºC. According to the research findings, adding 10% stable hydrocarbon condensate reduces the stability of the foam at least twice, of 20% – at least three times, and of 30% – not less than four times.

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

To explain the essence of the proposed method, a flow chart that provides the feeding of stable hydrocarbon condensate in the gas-liquid flow has been presented in Figure 1.

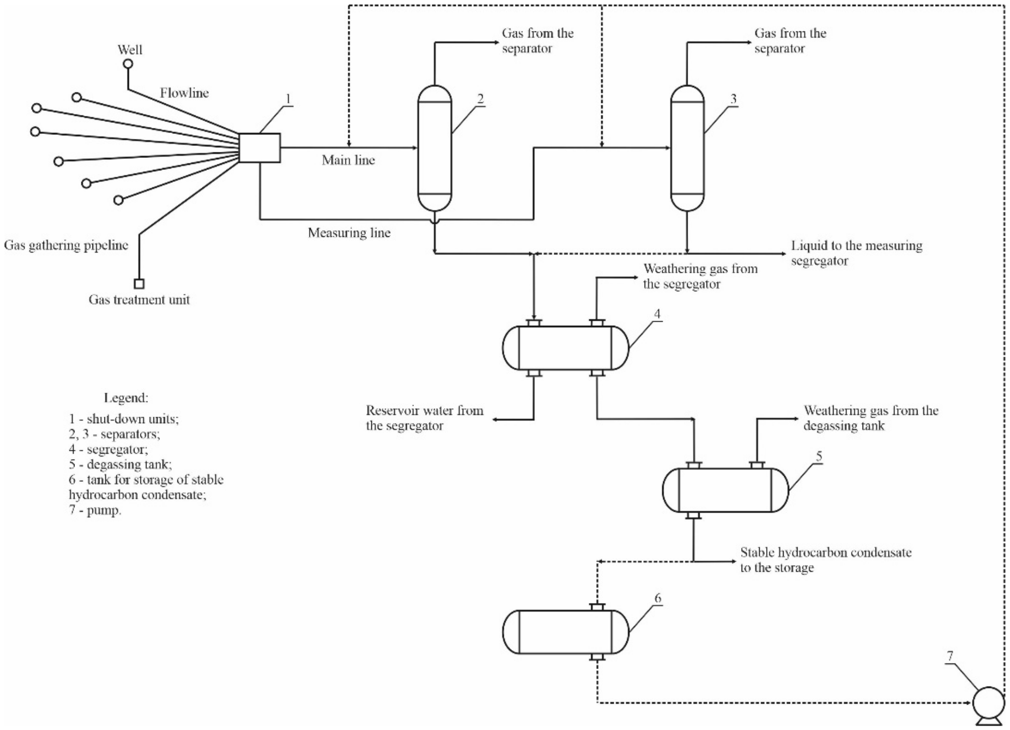


Fig. 1. Scheme of feeding stable hydrocarbon condensate to the main and/or measuring line (separator two and/or 3)

The gas-liquid flow (hydrocarbon feedstock) travels from wells through flowlines, as well as from other GTU through gathering (field) pipelines to the equipment of shut-down units 1, where it passes through the reduction unit (adjustable bean, etc.), with the help of which well operation mode is regulated. Afterwards, the gas-liquid flow enters the separator of the surface infrastructure: separator 2 of the first stage of the main line; or separator 3 of the first stage of the measuring line, or both separators (separator two and separator 3) simultaneously, where a primary purification of the gas from mechanical impurities and liquid takes place. Further on, the gas from separators two and/or three is supplied according to the individual technological scheme of GTU. The liquid from separator 3, which can be supplied to the individual measuring segregator, is supplied into the same segregator four as the one from separator 2. In the process, the entire volume of the liquid from two lines is divided into formation water and unstable hydrocarbon condensate, besides partial gas emission takes place. After that, the unstable hydrocarbon condensate enters tank 5 for degassing (it is possible to use several tanks and/or a unit for stabilising hydrocarbon condensate), where the total separation of gas takes place. Then, the stable hydrocarbon condensate flows to the gas storehouse and, if necessary, to the additional container 6 for stable hydrocarbon condensate, and afterwards, pump 7 supplies it into the gas-liquid flow, in particular, a straight section of the pipeline at the maximum possible distance from the inlet to separators two and/or 3.

The foam destruction method is described below. At GTU, the staff control the parameters of the well and gathering (field) pipelines (pressure, temperature, gas yield, etc.) operating mode. In case of complications related to liquid accumulation in wells or pipelines, the surfactant solution is used to remove it. Before supplying the surfactant solution into wells or pipelines, the condition of separators two and/or three are checked, and they are set up, the operating parameters are measured, and the gas-liquid flow rate is estimated to predict the time of its inflow into GTU. The surfactant solution is fed into wells or pipelines.

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

Foam inflow is visually monitored by periodically opening the valves on the shut-down devices' inlet gas pipelines and piping the separators manifold, taking into account a specified gas-liquid flow rate. After detecting foam in the gas-liquid flow, the appropriate shut-off valve is opened and pump seven is turned on, which intermittently or continuously feeds the stable hydrocarbon condensate from tank six into the gas-liquid flow in pre-measured amounts at the maximum possible distance from the inlet to separators two and/or 3.

The frequency and length of feeding stable hydrocarbon condensate into the gas-liquid flow for the foam destruction are estimated according to the results of the foam presence in the gas production equipment of GTU.

The foam destruction takes place directly in the pipeline starting from feeding stable hydrocarbon condensate into the gas-liquid flow up to separators 2 or 3 and in separators 2 or 3, or simultaneously to separators 2 and 3 and in separators 2 and 3. Application of the suggested method will improve gas purification efficiency. Separators 2 and 3 can also be connected in series to increase gas purification efficiency from foam.

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

Considering the information mentioned above, it is necessary to adapt the presented method of foam destruction in the gas-liquid flow to the conditions of complex gas treatment unit-2 (CGTU-2) of the Yuliivske oil and gas condensate field (OGCF).

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

The Yuliivske OGCF, like many other fields of Ukraine, is being developed for depletion and is now at the final stage of development in the state of declining hydrocarbon production. The difficulty of extracting residual hydrocarbon reserves is associated with low formation pressure, low hydrocarbon rates; high water cut production, accumulation of liquid at the bottom of wells, and corrosion of surface and underground equipment.

It is possible to increase the efficiency of extraction of residual hydrocarbon reserves under such conditions by optimising the existing development system by introducing the latest methods and technologies of production, preparation and transportation of hydrocarbons [22].

Figure 2 shows a general view of the piping of the main and measuring lines at CGTU-2 of the Yuliivske OGCF, where the gas-liquid flow comes from the equipment of shut-down unit 1, which is shown in Figure 1. Figure 3 presents the separators piping of the main lines and measuring lines at CGTU-2 of the Yuliivske OGCF.

Fig. 2. Piping of the main lines and measuring lines at CGTU-2 of the Yuliivske OGCF

Fig. 3. Separators piping at the main line at CGTU-2 of the Yuliivske OGCF

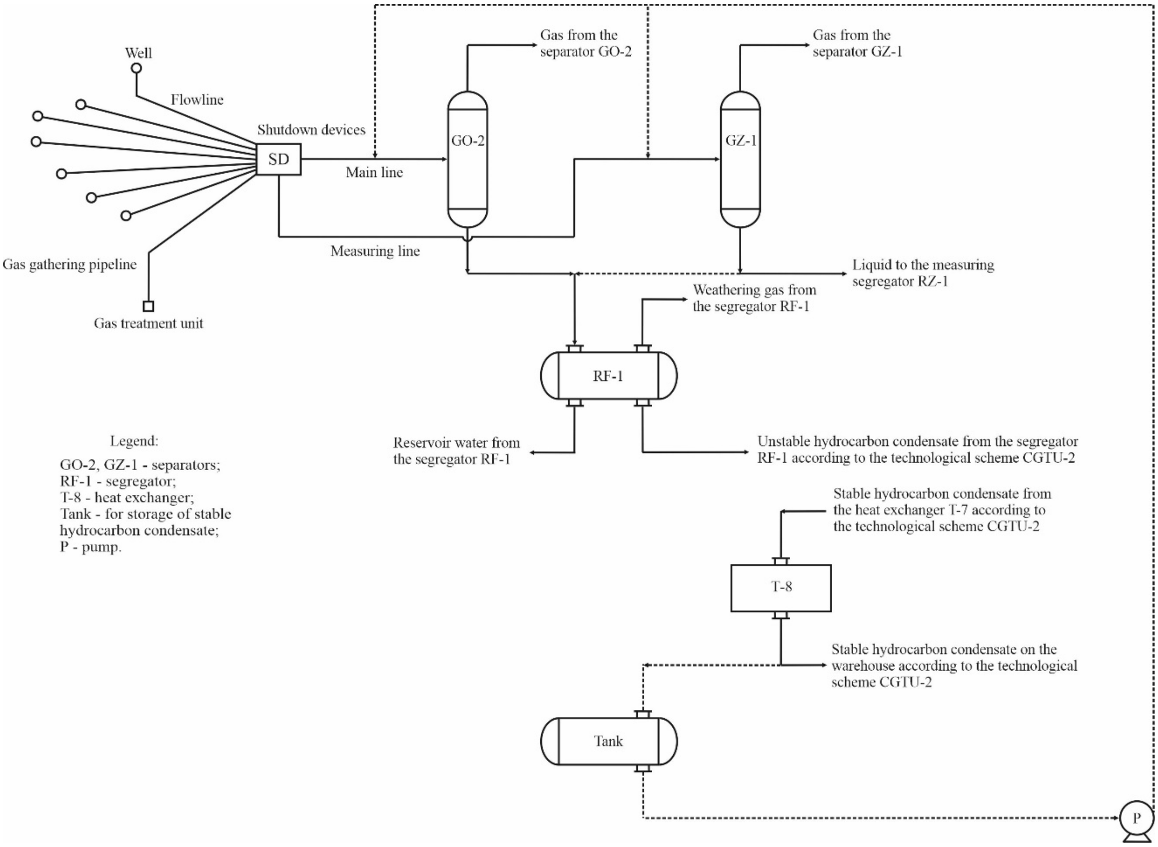


Fig. 4. Scheme of feeding stable hydrocarbon condensate to the main and/or measuring line (separators GO-2 and/or GZ-1) CGTU-2 of the Yuliivske OGCF

To explain the essence of the suggested method, a process flow diagram is given in Figure 4. It provides feeding stable hydrocarbon condensate to the gas-liquid flow, similar to the process flow diagram shown in Figure 1, but for the conditions of CGTU-2 of the Yuliivske OGCF.

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

As tank 1 is emptied from stable hydrocarbon condensate, it is periodically filled. To fill tank 1, shut-off valve five is opened to let the stable hydrocarbon condensate flow from heat exchanger T-8 of CGTU-2.

The way of foam destruction is presented in the following way. At CGTU-2, personnel control the parameters of the well and gathering (field) pipelines (pressure, temperature, gas yield, etc.) operation mode. In case of complications related to the accumulation of the liquid in wells or pipelines, a surfactant solution is used to remove it.

Before feeding the surfactant solution into wells or pipelines, the condition of the separator of the first stage of the main line GO-2 and/or of the first stage separator of measuring line GZ-1 is checked and set up for operation. Operating parameters are measured, and the rate of the gas-liquid flow is determined in order to predict the time of its entry into CGTU-2. The surfactant solution is fed into wells or pipelines.

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

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

The frequency and length of supplying the stable hydrocarbon condensate in the gas-liquid flow for the foam destruction are determined according to the results of studying the presence of foam in the gas field equipment of CGTU-2.

The foam destruction takes place directly in the pipeline starting from feeding stable hydrocarbon condensate in the gas-liquid flow up to separators GO-2 or GZ-1 and in separators GO-2 or GZ-1, or simultaneously to separators

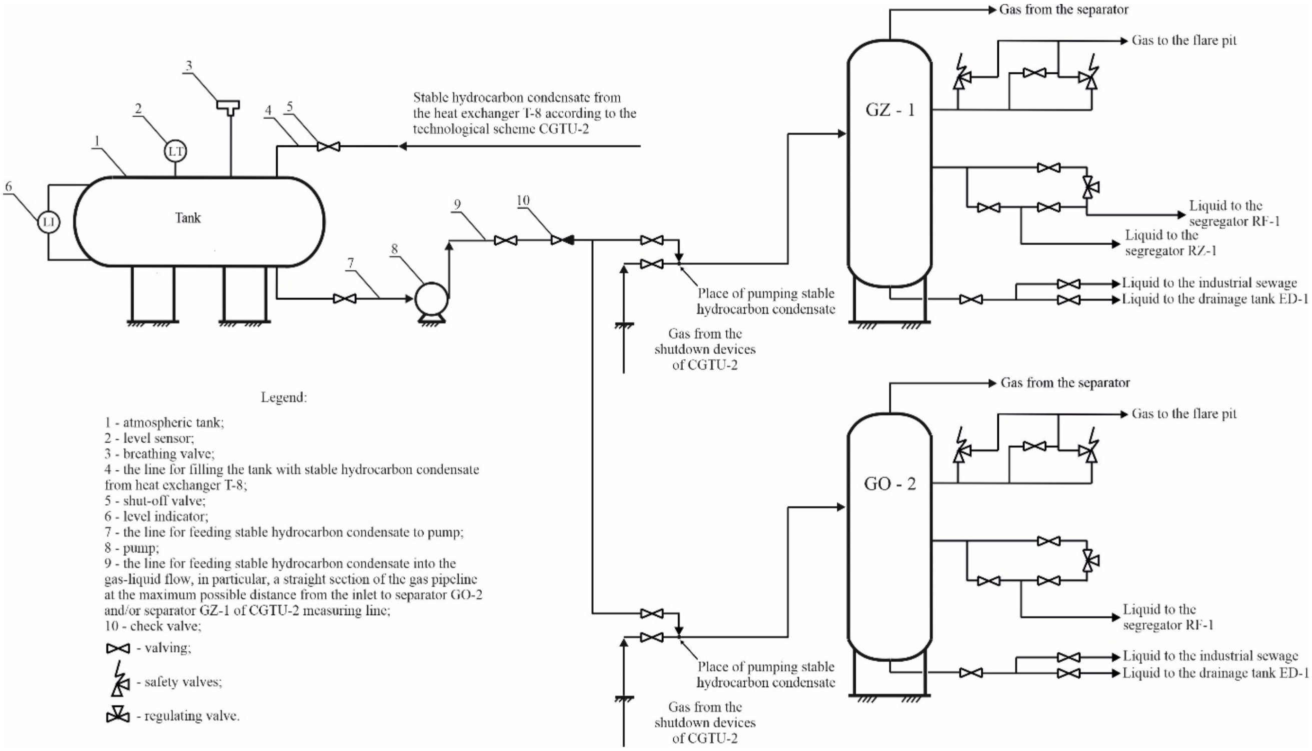


Fig. 5. Scheme of tank connection for feeding stable hydrocarbon condensate to the main and/or measuring line (separators GO-2 and/or GZ-1) CGTU-2 of the Yuliivske OGCF

GO-2 and GZ-1 and in separators GO-2 and GZ-1. The application of the suggested method will improve the quality of gas purification. Separators GO-2 and GZ-1 can also be connected in series to increase gas purification efficiency from foam.

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

4. Results and discussion

To determine the efficiency of foam destruction by hydrocarbon condensate, it is necessary to investigate the gas-dynamic processes occurring in the pipeline at the place of these substances mixing. The process of foam destruction is influenced by the distribution of pressure at the place of mixing, the flow rate, etc. Therefore, CFD modelling is an effective tool for such studies. The results of CFD simulations make it possible to see in detail the three-dimensional multi-phase flow in the pipeline and study pressure losses, phase distribution (volumetric particles), flow velocities, turbulence, kinetic energy, etc. It is also possible to optimise the design to change the initial regime parameters and the geometry of the investigated element and study their influence on the physical picture of multiphase flow movement.

To perform CFD modelling of the investigated processes, the ANSYS Academic 2021 R2 finite element analysis software package was chosen, namely the ANSYS Fluent code. ANSYS Fluent has various complex multiphase models, from which the Mixture model, a multiphase mixture model, was chosen. The Mixture model is designed for two or more simulated phases as mutually permeable continuums. For this purpose, the concept of a volume fraction of a phase is introduced, which is another additional flow parameter. At the same time, the Mixture model allows mutual penetration into the phases. Bulk particles of the continuous phase q and the dispersed phase p can have any value from 0 to 1, depending on how much space they occupy per unit volume. The Mixture model allows the phases to move at different speeds. Considering this, the concept of sliding velocity is introduced. Also, the phases can move at the same speed, and then the Mixture model is reduced to a homogeneous multi-phase model. In the Mixture model, only one of the phases can be compressed.

The main equations used in the simulation were the mixture continuity equation, the momentum conservation and mixture energy, the volume fraction equation for dispersed phases, and algebraic expressions for relative velocities (if the phases move at different velocities).

The mixture continuity equation

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

where

ρ_m – mixture density;

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

By adding the individual momentum equations of each phase, the mixture momentum equations are obtained

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

where

$\bar{F}$ – force acting on the flow;

μ_m – mixture viscosity;

$\vec{g}$ – free fall acceleration;

$\bar{v}_{dr,k}$ – drift rate of the dispersed phase k.

Relative velocity (sliding speed) is the difference between the velocity of the dispersed phase p and the velocity of the continuous phase q

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

where

$\bar{v}_p$ – dispersed phase velocity;

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

The drift rate of the dispersed phase – is the difference between the sliding velocity and the algebraic sum of the products of mass particles and the speed of the dispersed phase.

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

Mixture energy velocity

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

where

k_{eff} – effective conductivity;

h_k – phase k enthalpy;

S_E – energy transfer due to conductivity. Includes any other bulk heat source.

From the equation of continuity of the dispersed phase p, we can obtain the equation of volume fraction for the dispersed phase p

$$\frac{\partial}{\partial t}\left(\alpha_p \rho_p\right) + \nabla \cdot \left(\alpha_p \rho_p \bar{v}_m\right) = -\nabla \cdot \left(\alpha_p \rho_p \bar{v}_{dr,p}\right). \text{ [23]} \qquad (6)$$

CFD modelling was performed by numerical solutions of equations (1-6), which were closed by a two-parameter turbulence model using a wall function with corresponding initial and boundary conditions.

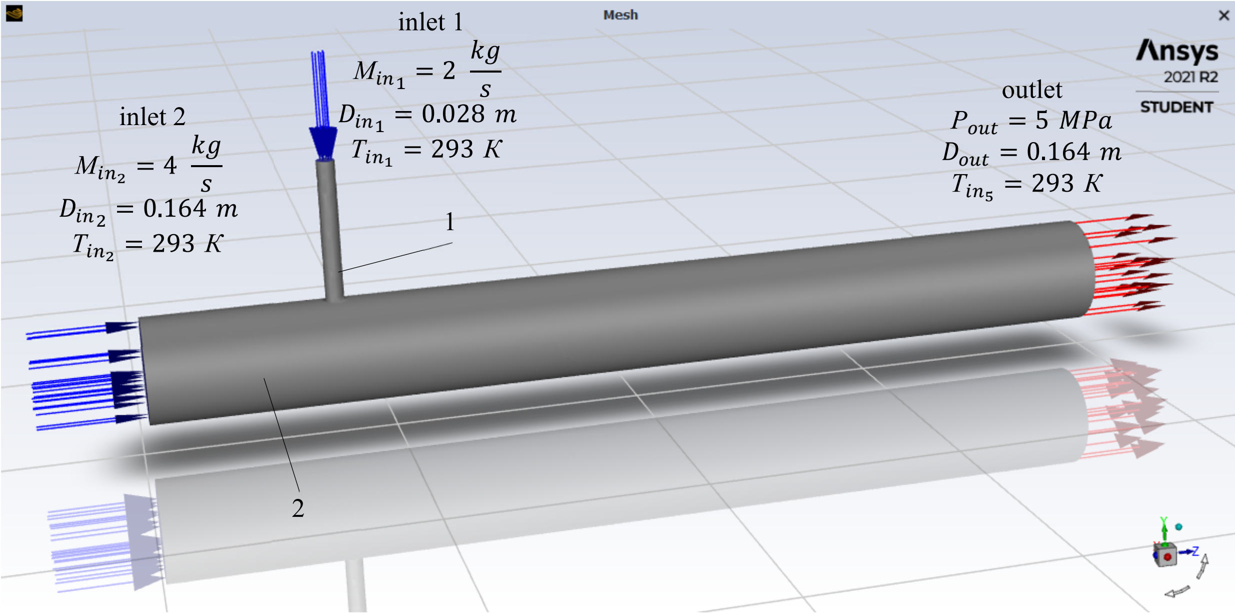


Fig. 6. Calculation diagram of the unit for supplying hydrocarbon condensate to the pipeline through which foam moves 1 – hydrocarbon condensate supply pipe; 2 – the pipeline through which the foam moves

A three-dimensional geometric model of the internal cavity of the unit for supplying hydrocarbon condensate to the pipeline through which the foam moves was drawn (Fig. 6). The inner diameter of the branch pipe, which is supplied with hydrocarbon condensate, is 28 mm, and its length is 200 mm. The inner diameter of the pipeline through which the foam moves is 164 mm, with a length of 1500 mm. The following limiting conditions were set for the studies (Fig. 6). At the inlet to the branch pipe, by which the hydrocarbon condensate is supplied (inlet 1), the medium and their mass flow were set. A condensate was selected from the ANSYS Fluent material database as a medium. The mass flow rate of the condensate was assumed to be 2 kg/s. The medium and its mass flow rate were also given at the inlet to the pipeline through which the foam is moved (inlet 2). The medium was foam. The foam was specified as a compressed medium (it was specified that the density of the foam should depend on the flow parameters). In this case, the energy equation is automatically added to the solved equations. The mass flow rate of foam was assumed to be 4 kg/s.

At the outlet of the resulting mixture from the pipeline's investigated section, the pressure was set, which was assumed to be equal to 5 MPa.

A temperature of 293 K, a turbulence intensity of 5% (for this value, the flow was considered completely turbulent) and a hydraulic diameter were set at the inlets of the media and at the outlet of the mixture. The hydraulic diameter was assumed to be equal to the inner diameter of the pipelines through which the medium is fed.

The results of CFD modeling were visualized in the post-processor of the ANSYS Fluent software package, which made it possible to see the flow structure in the hydrocarbon condensate supplying unit to the pipeline, which moves the foam, and to collect comprehensive data about it. Velocity fields (Fig. 7a), pressure fields (Fig. 7b), fields of the bulk part of the hydrocarbon condensate (Fig. 8a) and fields of the bulk part of the foam (Fig. 8b) are plotted in the plane of the vertical longitudinal section node being studied.

The velocity in the internal cavity of the unit for supplying hydrocarbon condensate to the pipeline through which the foam moves is not uniformly distributed (Fig. 7a). The fastest flow of hydrocarbon condensate is in the branch pipe by which it is supplied. Its speed reaches 5.7 m/s. After flowing from the nozzle into the pipeline through which the foam moves, the jet of hydrocarbon condensate slows down to a speed of 4 m/s and is distorted in the direction of foam movement. As a result, a zone of increased velocity is formed near the lower generatrix of the pipeline. With an increase away from the hydrocarbon condensate supply pipe, the velocity is more and more equalized in the entire cross section of the pipeline. A low velocity zone is formed along the hydrocarbon condensate stream in the upper part of the pipeline, where the velocity decreases to 0.6 m/s.

There is no significant change in pressure in the internal cavity of the pipeline through which the foam moves (Fig. 7b). Only in front of the branch pipe, which is supplied with hydrocarbon condensate, an insignificant zone of increased pressure is formed, and behind the branch pipe (in the zone of maximum speed reduction) a zone of low pressure is formed. Such slight pressure changes lead to the fact that there is no complete destruction of the foam, which is evident from the distribution of bulk particles of both hydrocarbon condensate (Fig. 8a) and foam (Fig. 8b). If in the lower part of the pipeline through the branch pipe, which supplies condensate, the volume fraction of hydrocarbon condensate is significant and there is no foam in this place (Fig. 8a), then in the upper part of the pipeline, on the contrary, the volume fraction of foam is significant (Fig. 8b).

The reasons for the incomplete destruction of the foam, in addition to the fact that the supply of hydrocarbon condensate does not lead to changes in pressure in the pipeline, is also the fact that a small amount of condensate is supplied and, under the action of gravity, it will move in the lower part of the pipeline, and foam will remain in the upper part.

Since in case of hydrocarbon condensate supplying to the pipeline, incomplete destruction of the foam occurs, it is advisable to develop and research further methods allowing it to be completely destroyed. For this purpose, a device for the foam destruction by hydrocarbon condensate was developed (Fig. 9). Such a device consists of a pipe 1, which is connected to four nozzles 2 for supplying hydrocarbon condensate. Flanges 3 are provided for connecting the device to the pipeline.

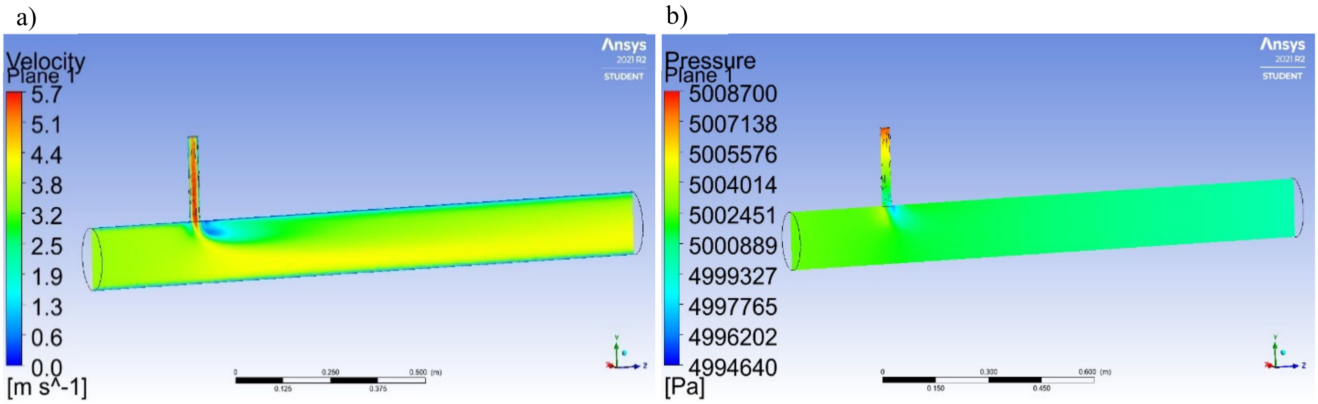


Fig. 7. Distribution of the flow main parameters in the plane of the vertical longitudinal section of the supply unit of hydrocarbon condensate in the pipeline through which the foam moves a) – velocity fields; b) – pressure fields

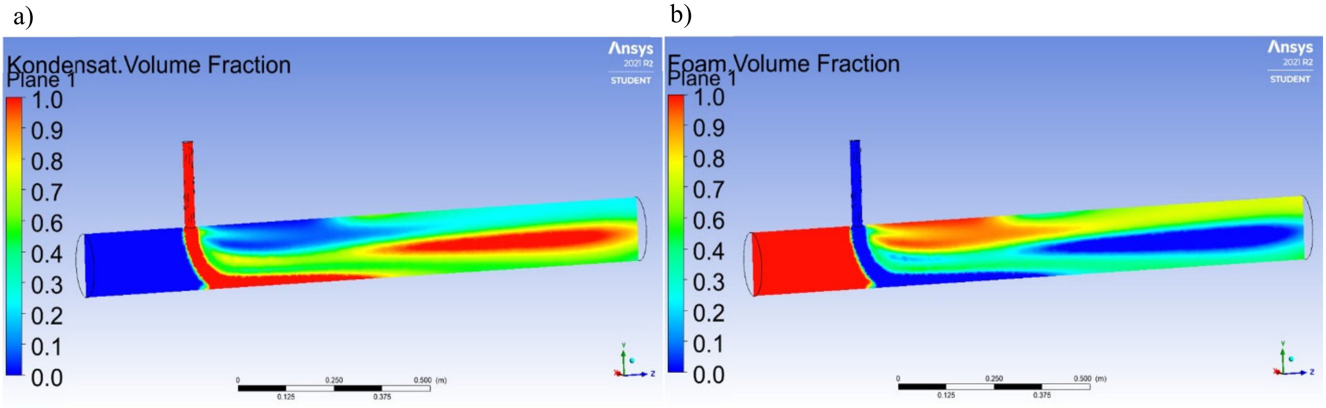


Fig. 8. Distribution of phase volume fractions in the plane of the vertical longitudinal section of the hydrocarbon condensate supply unit in the pipeline through which the foam moves a) – hydrocarbon condensate volume fraction fields; b) – foam volume fraction fields

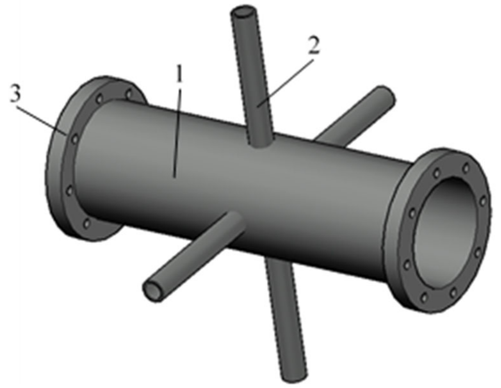


Fig. 9. Scheme of a device for the destruction of foam by hydrocarbon condensate 1 – pipe; 2 – branch pipe; 3 – flange

To determine the efficiency of foam destruction by the proposed device, it is necessary to investigate the gas-dynamic processes occurring in the pipeline at the place of its installation. For this purpose CFD modeling was also applied. A three-dimensional geometric model of the internal cavity of the device for the foam destruction by hydrocarbon condensate was drawn (Fig. 10). The inner diameter of the nozzles, which are supplied with hydrocarbon condensate, is 28 mm, and their length is 200 mm. The inner diameter of the pipeline through which the foam moves is 164 mm, and its length equals 1500 mm. The following limiting conditions were set for the study purpose (Fig. 10). At the inlet to the branch pipes, which supplied the hydrocarbon condensate (inlet 1, inlet 2, inlet 3, inlet 4), the medium and their mass flow were set.

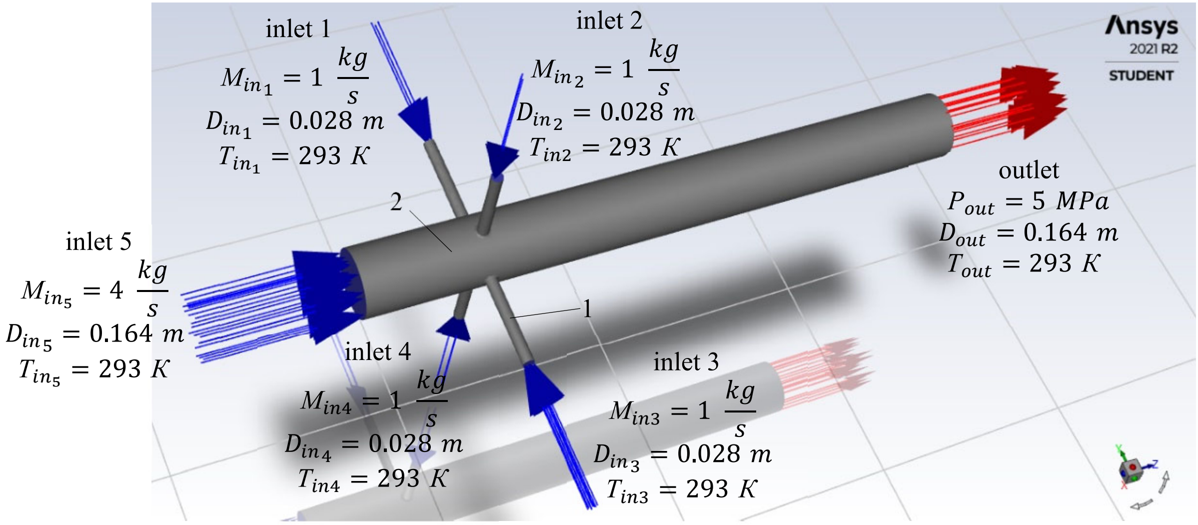
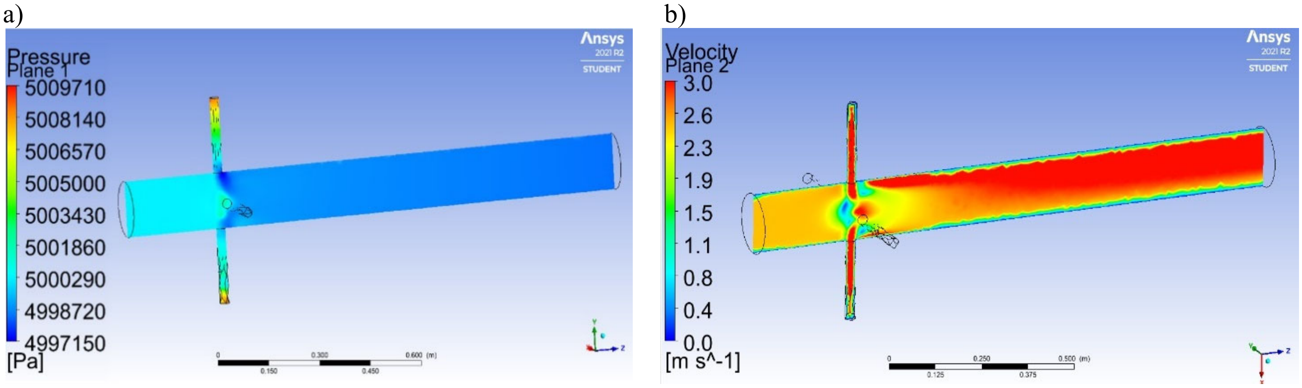


Fig. 10. Calculation scheme of the device for the foam destruction by hydrocarbon condensate 1 – hydrocarbon condensate supply pipe; 2 - the pipeline through which the foam moves


a)

b)

Fig. 11. Distribution of the main parameters of the flow in the plane of the vertical longitudinal section of the device for the foam destruction by hydrocarbon condensate a) – velocity fields; b) – pressure fields

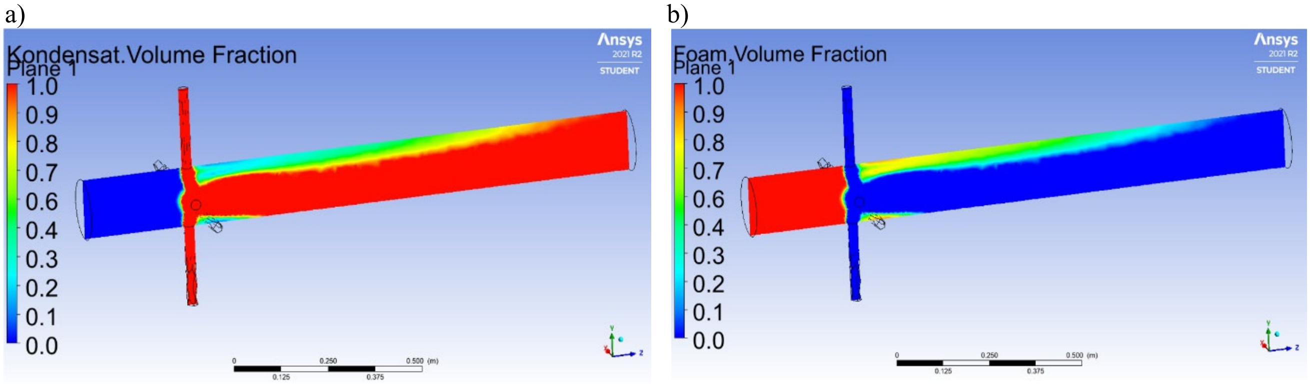


Fig. 12. Distribution of phase volume fractions in the plane of the vertical longitudinal section of the device for foam destruction by hydrocarbon condensate a) – hydrocarbon condensate volume fraction fields; b) – foam volume fraction fields

The mass flow rate of the condensate was assumed to be 1 kg/s. At the inlet to the pipeline through which the foam moves (inlet 5), the medium and its mass flow rate were also given. The mass flow rate of foam was assumed to be 4 kg/s. At the outlet of the resulting mixture from the investigated section of the pipeline, the pressure was set, which was taken equal to 5 MPa.

The supply of hydrocarbon condensate simultaneously from four nozzles leads to a significant change in the velocity fields (Fig. 11a) and pressure fields (Fig. 11b). The simulation results show that before the high-speed jets of hydrocarbon condensate, the foam begins to slow down and a zone of low velocity is formed in the middle part of the pipeline (Fig. 11a). Further, high-speed jets of hydrocarbon condensate enter the pipeline, and the flow begins to accelerate significantly. Also, the supply of hydrocarbon condensate simultaneously from four branch pipes leads to a significant pressure drop in the pipeline at the place of such injection (Fig. 11b). As the foam moves through this area of pressure drop, the bubbles will burst as a result of the rapid change in pressure. The supply of hydrocarbon condensate simultaneously from four nozzles, significant changes in the foam flow rate and pressure lead to the complete destruction of the foam, which can be seen from the distribution of bulk particles of both hydrocarbon condensate (Fig. 12a) and foam (Fig. 12b).

5. Conclusions

1. The method was developed to prevent the ingress of foam in the gas-liquid flow to the GTU, which will minimize the negative impact on the separation equipment. This method includes a technological scheme for the device supplying a stable hydrocarbon condensate to a gas-liquid flow entering the separators of the first separation stage, both the main line and the measuring line.
2. On the basis of the developed measures, the ways of implementing the method of foam destruction in a two-phase flow were given, and it is also adapted to the conditions of CGTU-2 of the Yuliivske OGCF. So, taking into account the existing underground and surface infrastructure of CGTU-2 of the Yuliivske OGCF, a piping of the technological scheme is proposed, which provides the installation of certain equipment for the implementation of this method. It is assumed that stable hydrocarbon condensate is fed into the liquid flow at the maximum possible distance from the inlet to the separators of the first separation stage of the main line GO-2 and/or the separator of the first stage of the measuring line GZ-1. In this case, the destruction of the foam occurs directly in the gas pipeline from the place where stable hydrocarbon condensate is supplied to the gas-liquid flow to the GO-2 or GZ-1 separators and in the GO-2 or GZ-1 separators themselves or simultaneously to the GO-2 and GZ-1 separators. Implementation of the proposed method will improve the quality of gas purification.
3. On the basis of CFD modeling of gas-dynamic processes occurring during the destruction of the foam, it was established by the developed method that in case of hydrocarbon condensate supply from one branch pipe, the complete destruction of the foam does not occur. The reason for this is in no pressure change in the pipeline, and hydrocarbon condensate moves under the action of gravity in the lower part of the pipeline, and foam remains in the upper part. Complete destruction of the foam was observed when the hydrocarbon condensate was supplied from four nozzles. This effect is

significantly affected by the occurrence of a pressure drop zone at the site of such injection. Based on these simulation results, an efficient device for the destruction of foam by hydrocarbon condensate was developed.

The performed studies provide the understanding of the regularities of foam destruction processes by hydrocarbon condensate. The knowledge obtained is useful for gas field operators engaged in improving the efficiency of well operation.

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