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Method for assessing the hydrate formation from a mixture of natural gas flows of varying degrees of moisture content

Metoda oceny powstawania hydratów z mieszaniny strumieni gazu ziemnego o różnej zawartości wilgoci

Elman Kh. Iskandarov, Alovsat N. Baghirov, Lala M. Shikhiyeva

Azerbaijan State Oil and Industry University

ABSTRACT: The article deals with the issues of assessing the conditions of hydrate formation when mixing natural gas flows of various standards. An urgent problem of operation, especially of offshore subsea gas pipelines, is the prediction of the time, place and expected intensity of hydrate formation. Depending on the changing operating mode of the gas pipeline, dispatch service specialists must be able to adjust the process control tactics on their own, as quickly as possible. The predisposition of a particular gas pipeline to hydrate is also important for the dispatching service. Changes in the volumes of gas entering the region under consideration from different sources, due to the constant change in gas production, create the need to mix gases of different standards and pump them into subsea gas pipeline. To avoid hydrate formation, it is important to predict the thermobaric conditions that will be formed in the gas pipeline by considering the characteristics such as a volume in the mixture and the moisture content of the gas. The processes of hydrate formation proceed quickly and if the beginning of the process is overlooked, the problem of significant or complete blockage of the gas pipeline might appear. The paper gives a systematization of the risk of hydrate formation depending on several infrastructural factors – the presence of a preliminary gas drying system and a system for starting and receiving cleaning pistons. A method is proposed for estimating the moisture content and dew point temperature of a natural gas mixture by the condition and the proportion of primary flows. It has been shown that the addition of a small volume of undried gas to the main dried gas significantly increases the risk of hydrate formation. A formula is given for calculations for a mixture of multiple natural gas flows. The advantage of this method is the quick calculations, and the absence of the need for huge mathematical calculations and laboratory studies. This is an important element in the activities of the dispatch service, limited by a lack of time in the process of preventing hydrate formation.

Key words: hydrate formation, natural gas, dew point, pipeline transport, offshore gas pipeline, flow mixing, nomogram, moisture content.

STRESZCZENIE: W artykule podjęto problematykę oceny warunków powstawania hydratów podczas mieszania strumieni gazu ziemnego o różnych standardach. Istotnym problemem eksploatacji, zwłaszcza w gazociągach podmorskich, jest określenie czasu, miejsca i przewidywanej intensywności powstawania hydratów. W zależności od zmieniającego się trybu pracy gazociągu specjaliści służb dyspozytorskich muszą potrafić jak najszybciej samodzielnie dostosować taktykę sterowania procesem. Dla służby dyspozytorskiej istotne znaczenie ma także predyspozycja danego gazociągu do powstawania hydratów. Zmiany objętości gazu docierającego do rozpatrywanego regionu z różnych źródeł, w związku z ciągłą zmianą wydobycia gazu, powodują konieczność mieszania gazów o różnych standardach i wtłaczania ich do gazociągu podmorskiego. Aby uniknąć tworzenia się hydratów, istotne jest przewidywanie warunków termobarycznych, jakie będą panować w gazociągu, biorąc pod uwagę takie cechy jak objętość mieszaniny i zawartość wilgoci w gazie. Procesy powstawania hydratów przebiegają szybko i jeśli zostanie przeoczony początek tego procesu, może pojawić się problem znacznego lub całkowitego zablokowania gazociągu. W pracy usystematyzowano ryzyko powstawania hydratów w zależności od kilku czynników infrastrukturalnych – obecności układu wstępnego osuszania gazu oraz układu startu i odbioru tłoków czyszczących. Zaproponowano metodę szacowania zawartości wilgoci i temperatury punktu rosy mieszaniny gazu ziemnego na podstawie stanu i proporcji natężenia przepływów pierwotnych. Wykazano, że dodatek niewielkiej ilości nieosuszonego gazu do głównej partii gazu osuszonego znacznie zwiększa ryzyko powstania hydratów. Podano wzór do obliczeń w przypadku mieszaniny wielu strumieni gazu ziemnego. Zaletą tej metody jest szybkość obliczeń, brak konieczności wykonywania obszernych obliczeń matematycznych i badań laboratoryjnych. Jest to ważny element w działalności służby spedycyjnej, ograniczonej brakiem czasu w procesie zapobiegania tworzeniu się hydratów.

Słowa kluczowe: powstawanie hydratów, gaz ziemny, punkt rosy, transport rurociągami, gazociąg podmorski, mieszanie przepływów, nomogram, zawartość wilgoci.

Corresponding author: Inglab Aliyev, e-mail: *inglab_aliyev@hotmail.com*

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Introductıon

The main gas pipeline system (MG) is a complex, branched and continuously changing technological structure, the distinguishing feature of which is the ability to manoeuvre gas flows, which requires dispatching services to be precise in their work and understand the processes taking place in the MG. This issue is even more relevant in the operation of offshore subsea main gas pipelines.

One of the most difficult complications in the main gas pipeline is hydrate formation (Makogon, 1974; Istomin and Yakushev, 1992; Thadil et al., 2022). As a result of observation and analysis, it has been established that a temperate climate is more typical for the middle part of the Caspian Sea. Hydrate formation and partial or complete plugging of pipelines of offshore gas pipelines built and operated in this zone occur by two different mechanisms.

The first situation on gas pipelines operated in the Middle Caspian region is observed in October-January, when the ambient temperature drops sharply. This is because during these months of the year a large amount of free water-condensate mass does not accumulate inside the gas pipeline. This is explained by the fact that the high ambient air temperature (35–45°C) established over the past summer creates conditions for gas heating and recondensation of liquefied C3-C5 components along the coast and in onshore pipelines. As a result, most of the liquid collected in the pipeline during the previous winter-spring season is removed from the pipeline. In the specified time interval, gas hydrate is deposited on the inner surface of the gas pipeline.

The second scenario of hydrate formation in existing offshore gas pipelines occurs more often in February-April. In this case, partial or complete clogging of the gas pipeline can be explained by the accumulation of a large amount of free water and condensate in the gas pipeline because of phase transformations in the winter season. Water, condensate, and mechanical deposits (solids entered the pipeline because of corrosion and incomplete separation of the pipeline inner wall), which are denser than gas, form high-density formations in the pipeline slopes along the subsea gas profile. Depending on the length of the gas pipeline and the profile of the seabed, this situation may occur in several places. The decrease in the cross section of the gas pipeline occurs in the lower sections of the gas pipeline, which characterizes the change in thermobaric conditions in the gas flow. Reducing the cross section of the pipeline leads to an increase in the gas flow velocity in this section and a decrease in the gas temperature due to expansion after the section.

For the transportation of natural and associated gases coming from various fields to the Neft Dashlari region, an extensive network of gas pipelines has been created, which makes it possible to reach coastal facilities located at more than a hundred kilometers, which also predetermines the joint use of the infrastructure of subsea main gas pipelines for gas flows of various conditions.

Natural gas produced from the Guneshli field and supplied to the specified region, after separation, is fed directly into gas pipelines for further transportation to the shore. Most of the associated gas with a pressure of 0.5 MPa is compressed to 5.5 MPa at the booster compressor station (CS) by means of centrifugal compressors driven by gas turbines of the Centaurus and Tauras types (manufactured by Solar Turbines) with subsequent dehydration at glycol dryers. The other part of associated petroleum gas is compressed at compressor stations with gas engine compressors of the 10GKNAM2/5-55 type manufactured by RUMO JSC. Due to its lunch several years earlier, there are no gas drying units at these CSs, which affects the quality of compressed gas in terms of moisture content and susceptibility to hydrate formation during further transportation through offshore subsea main gas pipelines.

Theory

Since the mode of operation of the gas pipeline changes dynamically and depending on the condition of the transported gas, the specialists of dispatching services must, in each specific situation, independently, in a short period of time, be able to adjust the process control tactics (Iskandarov and Baghirov, 2022).

The intensity and scale of hydrate formation is influenced by various factors, including:

1. Preliminary drying (dehydration) of the gas supplied to the pipeline. Currently, the gas pumped from the compressor station with gas turbine compressors to the Neft Dashlary-Bahar pipeline is being dried. Gas supplied from other sources (GMSP No. 4 and 14, compressor station with gas engine compressors) is only separated.
2. Availability of the technical possibility of launching a cleaning device into the gas pipeline. In relatively earlier pipelines (Neft Dashlary-Bahar (1st line), Neft Dashlary-Zira, both Bahar-Garadagh gas pipelines), the system for launching and receiving treatment facilities is not provided. For this reason, the liquid that accumulates due to precipitation in the gas pipeline creates additional conditions for hydrate formation.
3. The temperature of the gas supplied to the gas pipeline. The temperature of the gases coming from the gas turbine CS (dried) and the gas engine compressor CS (undried) ranges from 45–50°C. Due to the fact that the water temperature at a depth of 50–100 meters in the Caspian Sea

is 6°C, the cooled gas coming through the underwater gas pipelines from GMPS No. 4 and No. 14 has a much lower temperature. Since the last sections of these gas pipelines pass through the overpass, under abnormally cold weather conditions for this region, the gas temperature can drop to minus values, which creates more realistic conditions for hydrate formation.

Changes in the volumes of gas entering the region under consideration from different sources, due to the constant change in gas production at the fields, create the need to mix gases of different parameters and pump them into subsea gas pipeline. To avoid such a serious complication as hydrate formation, it is important, considering the above characteristics of the flows of the gas injected into the gas pipeline, to predict the thermobaric conditions that will be formed in the gas pipeline.

The processes of hydrate formation proceed quickly, in a very short period of time (1–2 hours), and if the beginning of hydrate formation is missed, a significant or complete blockage of the gas pipeline is possible (Mirzajanzade et al., 2003; Iskandarov et al., 2022).

Iskandarov and Baghirov (2022) and Iskandarov et al. (2022) proposed an analytical method for earlier identification of the beginning of hydrate formation, which consists in calculating the coefficient

$$K = \frac{Q^2}{P_b^2 - P_e^2} \tag{1}$$

where:

Q – is the operational volume of gas injected into the gas pipeline [million m^3/day],

P_b and P_e – are the pressure at the beginning and end of the gas pipeline, respectively, abs. [MPa].

A decrease in the K index is a signal for the beginning of the hydrate formation process. This proven and effective method for predicting the onset of hydrate formation in offshore gas pipelines provides for more frequent measurement of indicators such as P_b, P_e and Q (every hour or half hour) than in the usual mode. However, this method begins to work only after the onset of complications in the gas pipeline.

Information such as the predisposition of a particular gas pipeline to hydrate formation is also important for the dispatching service. For the first time introduced in the technical literature, the term "predisposition" in philosophy, physiology and psychology is understood as a skill, readiness, inclination, or tendency to act in a certain way. Predisposition to a disease in medicine is an increased likelihood of developing a disease due to some features of the organism or environment. Usually, circumstances that predispose to certain pathological changes are called risk factors. The concept of susceptibility is also close to this concept. The gas transportation system as a complex technological system is also subject to various kinds of complications; one of the most difficult is hydrate formation. Thus, the predisposition to hydrate formation is a set of factors and operational parameters that determine the propensity of the system to this complication.

Using only two factors – the presence of a gas pre-drying system and a system for starting and receiving cleaning pistons, it is possible to systematize the degree of risk of hydrate formation, all other things being equal. The results are shown in Table 1.

Results

To prevent hydrate formation, it is necessary to know in advance the condition of the gas supplied to the gas pipeline. Based on the composition of natural gas and the presence of various non-hydrocarbon inclusions in it, the pressure and temperature of the gas, the conditions for the formation of hydrates are determined, and the moisture content parameter is used to calculate the probability of formation of deposits under these conditions (ISO 18453:2004; Zhou et al., 2018).

In contrast to the four situations considered in the table, that are understandable for the dispatching service, in the case

Table 1. Systematization of the risk of hydrate formation depending on infrastructural factors

Tabela 1. Usystematyzowanie zagrożeń powstawania hydratów w zależności od czynników infrastrukturalnych

No.	Drying the gas	Cleaning pistons	Expected predisposition to hydrate formation
1.	Yes	Yes	The system is perfect, there are no risks of hydrate formation.
2.	Yes	No	Hydrate formation is possible with an abnormal decrease in gas temperature below the dew point or with the accumulation of moisture at the lower points of the route. The risk is minimal.
3.	No	Yes	Hydrate formation is possible if the regime for starting the cleaning pistons is not observed, if the regime is not corrected during the abnormal decrease in temperature, and there is no flexibility to change the mode of pouring methanol. The risk is significant.
4.	No	No	Hydrate formation is possible already during the normal operation of the gas pipeline. With the abnormal decrease in temperature, the addition of a gas stream with an increased moisture content to the gas pipeline, the lack of flexibility to change the mode of pouring methanol. The risk is significant.

of mixing gas flows of different conditions, forecasting possible scenarios of hydrate formation is much more difficult (Slobodchikov, 2018). Therefore, to characterise the newly emerged distribution of factors, additional information is needed (Istomin and Kvon, 2004; Thadil et al., 2022). One of the proposed options may be to estimate the moisture content and dew point of a natural gas mixture according to the condition and the proportion of primary flows.

Let's consider the options for mixing gas flows of various conditions using an example.

Option 1. Streams similar in hydrocarbon composition with a density of 0.76 are mixed with the same pressure of 5.5 MPa (800 psi) and a temperature of 37.8°C (100°F), with the difference that 80% of the gas has been dried with a dew point temperature of –15°C (5°F), and 20% of the gas was not dried. According to the nomogram for determining the moisture content of natural gases, we determine the moisture content of each of the streams – 2.8 and 7.2 lb/MMCF or 0.045 and 1.161 g/m³ (ISO 18453:2004).

Let's estimate the moisture content of the created stream:

$$W_{1\text{-}2} = W_1 \cdot 0.8 + W_2 \cdot 0.2 =$$
$$= 0.045\ \text{g/m}^3 \cdot 0.8 + 1.161\ \text{g/m}^3 \cdot 0.2 =$$
$$= 0.036\ \text{g/m}^3 + 0.2322\ \text{g/m}^3 = 0.2682\ \text{g/m}^3$$

Converting to lb/MMCF, we get:

$$W_{1\text{-}2} = 0.2682\ \text{g/m}^3 : 0.016018463\ (\text{g/m}^3)/(\text{lb/MMCF}) =$$
$$= 16.7\ \text{lb/MMCF}.$$

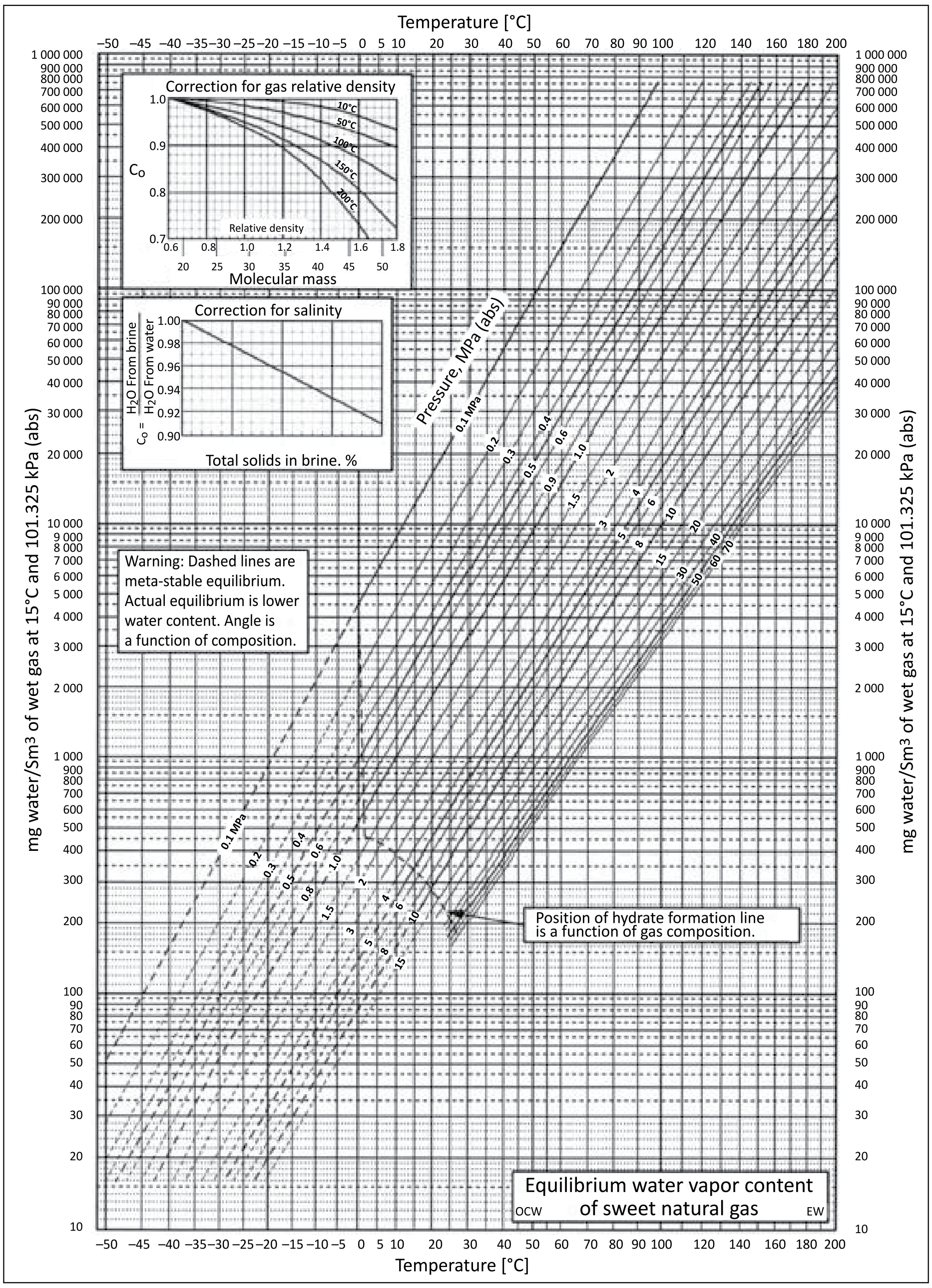

Figure 1. Nomogram for determining the moisture content of natural gases

Rysunek 1. Nomogram dla określenia zawartości wilgoci gazów ziemnych

As can be seen from the nomogram, this indicator corresponds to the moisture content of the undried gas at a temperature of 10°C (54°F). The dew point of the resulting flow is at the same level. Since the temperature of the sea water at the depth of the gas pipeline is much lower at 6°C, by adding only 20% dry gas, the risk of hydrate formation increases significantly and complications in the gas pipeline are likely to be expected, although the situation was favourable with dry gas.

Option 2. Let us consider the situation when, under other identical conditions, 85% of the dried gas is mixed with 15% of the non-dry one.

Let's estimate the moisture content of the created stream:

$$W_{1\text{-}2} = W_1 \cdot 0.85 + W_2 \cdot 0.15 =$$
$$= 0.045 \text{ g/m}^3 \cdot 0.85 + 1.161 \text{ g/m}^3 \cdot 0.15 =$$
$$= 0.0383 \text{ g/m}^3 + 0.1742 \text{ g/m}^3 = 0.2125 \text{ g/m}^3$$

Converting to lb/MMCF, we get:

$$W_{1\text{-}2} = 0.2125 \text{ g/m}^3 : 0.016018463(\text{g/m}^3)/(\text{lb/MMCF}) =$$
$$= 13.3 \text{ lb/MMCF}.$$

As can be seen from the nomogram, this figure corresponds to the moisture content of the undried gas at a temperature of 5.6°C (42°F). Moisture content corresponds to the state of the gas, close to the minimum temperature in the gas pipeline. By adding only 15% raw gas, the risk of hydrate formation is much less, but still there.

Option 3. Let us consider the situation when, under other identical conditions, 90% of the dried gas is mixed with 10% of the undried one.

Let's estimate the moisture content of the created stream:

$$W_{1\text{-}2} = W_1 \cdot 0.9 + W_2 \cdot 0.1 =$$
$$= 0.045 \text{ g/m}^3 \cdot 0.9 + 1.161 \text{ g/m}^3 \cdot 0.1 =$$
$$= 0.0405 \text{ g/m}^3 + 0.1161 \text{ g/m}^3 = 0.1566 \text{ g/m}^3$$

Converting to lb/MMCF, we get:

$$W_{1\text{-}2} = 0.1566 \text{ g/m}^3 : 0.016018463(\text{g/m}^3)/(\text{lb/MMCF}) =$$
$$= 9.78 \text{ lb/MMCF}.$$

As can be seen from the nomogram, this figure corresponds to the moisture content of the undried gas at a temperature of 2.2°C (36°F). The addition of 10% dry gas does not create the risk of hydrate formation since the moisture content corresponds to the state of the gas at a temperature significantly lower than the minimum temperature in the gas pipeline.

Let us consider a similar problem of determining the volume of off-standard gas that can be added to the dry gas flow without the risk of hydrate formation. In this case, we know the following parameters:

- Q_1 – the volume of dried gas (defined as average per day according to the gas meter) [million m^3/day or MMCF/d];
- W_1 – moisture content of the dried gas at operating pressure and temperature (determined by the nomogram considering the dew point of the dried gas) [g/m^3 or lb/MCF];
- W_2 – wet gas moisture content at operating pressure and temperature (determined by nomogram) [g/m^3 or lb/MMCF];
- $W_{1\text{-}2}$ – limiting moisture content by hydrate formation (determined by the nomogram by the minimum temperature along the pipeline route in accordance with the ground temperature or sea water temperature at the depth of the pipeline) [g/m^3 or lb/MMCF];
- Q_2 – volume of undried gas (determined as a static average per day according to gas meter data) [million m^3/day or MMCF/d].

Let's compile the balance of moisture content after mixing the flows: W1-2

$$W_{1\text{-}2} \cdot (Q_1 + Q_2) = W_1 \cdot Q_1 + W_2 \cdot Q_2 \tag{2}$$

After a series of transformations, we obtain a formula for the volume of off-standard gas:

$$Q_2 = \frac{W_{1-2} - W_1 \cdot W_2}{W_2 - W_{1-2}} \cdot Q_1 \tag{3}$$

Formula (3) allows determining the maximum volume of off-spec non-dried gas that can be added to dried gas of a known volume without the risk of hydrate formation.

In the case of mixing multiple natural gas flows, by analogy with (2), we have

$$W_{1\text{-}n} \cdot (Q_1 + Q_2 + \ldots + Q_n) =$$
$$= W_1 \cdot Q_1 + W_2 \cdot Q_2 + \ldots + W_n \cdot Q_n \tag{4}$$

where:

$Q_1, Q_2, \ldots, Q_n$ – volumes of gas flows [million m^3/day or MMCF/d],

$W_1, W_2, \ldots, W_n$ – moisture content of gas flows [g/m^3 or lb/MMCF],

$W_{1\text{-}n}$ – maximum moisture content for hydrate formation [g/m^3 or lb/MMCF].

Having carried out a series of transformations of expression (4), we obtain a formula for the volume of the nth flow:

$$Q_n = $$
$$= \frac{W_{1-n} \cdot (Q_1 + Q_2 + \& + Q_{n-1}) - (W_1 \cdot Q_1 + W_2 \cdot Q_2 + \& + W_{n-1} \cdot Q_{n-1})}{W_n - W_{1-n}}$$

This formula can be used to add the next gas flow to an already available mix of any number of gas flows.

Discussion

Similar calculations can be made for other combinations of mixing natural gas flows. The advantage of this method is the speed of calculations, the absence of the need for long mathematical calculations and laboratory studies, which is an important element in the activities of the dispatch service, limited by the lack of time in the process of preventing hydrate formation.

Conclusion

The issues of assessing the conditions of hydrate formation during mixing of natural gas flows of various standards are considered. The paper gives a systematization of the risk of hydrate formation depending on several infrastructural factors – the presence of a preliminary gas drying system and a system for starting and receiving cleaning pistons. The method for estimating the moisture content and dew point of a natural gas mixture depending on the conditions and proportion of primary flows is proposed.

It has been shown that the addition of a small volume of undried gas to dried gas significantly increases the risk of hydrate formation. A formula is given to determine the maximum volume of off-spec non-dry gas that can be added to a known volume of dry gas without the risk of hydrate formation.

Since the formation of hydrates is influenced by a large number of factors, and the issue of mixing natural gas flows of various conditions has not been studied enough, the issue of developing methods for early recognition of hydrate formation processes remains very relevant.

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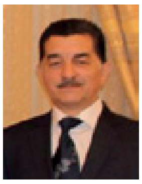
Prof. Elman Kheyrulla ISKANDAROV, Sc.D.
Professor at the Faculty of Oil and Gas Production
Azerbaijan State Oil and Industry University
34 Azadliq Ave, AZ1010 Baku, Azerbaijan
E-mail: *elman.iskandarov@asoiu.edu.az*



Alovsat Nusrat BAGHIROV, Ph.D.
Associate Professor at the Faculty of Oil and Gas Production
Azerbaijan State Oil and Industry University
34 Azadliq Ave, AZ1010 Baku, Azerbaijan
E-mail: *alovsat.bagirov@asoiu.edu.az*

Lala Madat SHIKHIYEVA, M.Sc.
Tutor at the Faculty of Oil and Gas Production
Azerbaijan State Oil and Industry University
34 Azadliq Ave, AZ1010 Baku, Azerbaijan
E-mail: *lala.shixiyeva.ma@asoiu.edu.az*