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STUDY OF STRUCTURAL CHANGES IN MULTIFACETED GAS PIPELINES

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A B S T R A C T

The study and generalization of the collection and transportation of multifaceted hydrocarbon mixtures produced in operating fields, as well as the acceptance of energy-efficient and resource-saving operational solutions, and the development of new approaches and methods for improving technological processes, are key conditions for the successful resolution of the posed issues. Complications occurring during the collection and transportation of hydrocarbon mixtures are often related to their multifaceted nature. In the preparation for transportation, if natural or associated gases are not dried to the required levels, it results in harmful phase transitions in the multifaceted mixtures within the transportation system. This, leads to the formation of harmful pulsations and causes the equipment and elements in the collection-transportation system to operate in a vibration mode. In practice, it is sometimes possible to encounter the transportation of gases with different quality indicators through a single pipeline. In such cases, natural gases may mix with each other or with associated gas. Studying the technological condition of the gas pipeline, examining quality changes in gas mixtures, diagnosing difficulties arising in the operation of the pipeline, and timely forecasting potential accident scenarios are significant issues. The paper investigates the variations in individual components of gas mixtures, mechanical impurities, gas humidity, and other indicators that do not conform to their initial values. The research demonstrates the possibility of diagnosing structural changes occurring during the transportation of natural and associated gases, as well as their mixtures, based on the component composition of the gas and certain physical-chemical indicators.

Keywords: natural gas; associated gas; gas mixture; gas component composition; density; dew point; phase transitions; structural changes; classification function; expert evaluation.

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Introduction

Modern requirements for the rational use of hydrocarbon resources highlight the need for effective management and regulation of technological processes in the oil and gas industry. This involves complex control-diagnostics issues to enhance the efficiency of these processes. In this context, the efficiency of natural and associated gas transportation through pipelines depends significantly on the level of perfection of the implemented technological processes [1-3]. Imperfect execution of the gas preparation for transportation can result in pressure pulsations, blockage, hydrate formation, erosion-corrosion wear, and other issues within the pipeline system due to residual liquid particles in the gas mixture. The presence of mechanical impurities in gas mixtures can also lead to premature failure of various elements in the transportation system [4-7].

There are both gas-dynamic and thermodynamic reasons for the separation of the liquid phase in gas pipelines. The gas-dynamic reasons arise from the failure to consider certain factors in the physical model of the separation process or their simplification [8-10]. The thermodynamic reason for the liquid phase drop in a gas pipeline is related to the failure of the separator to maintain stable thermobaric conditions (pressure and temperature). When the pressure and temperature are below the maximum condensation pressure, the gas-liquid flow in the pipeline becomes a two-phase liquid-gas flow instead of a single-phase gas flow. A subsequent drop in temperature leads to renewed condensation, meaning that the gas phase becomes saturated with liquid, and condensation of the moisture occurs again. In high-pressure zones and under certain conditions for gas-liquid mixtures, retrograde processes such as «back-condensation» and «back-evaporation» can also occur. Thus, during the isothermal movement of the mixture, a decrease in pressure in the pipeline causes the liquid phase to evaporate and transition to the gas phase, like a separation process occurring within the pipeline. However, the accumulated liquid mass in the pipeline is not expelled, and the process repeats as thermobaric conditions change [11-13].

Research methodology

The efficiency of technological processes during the extraction and transportation of oil and gas is complicated

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by the diversity and complexity of the internal structure of the transported product, leading to sharp increases in pressure and the occurrence of harmful pulsations. The separation of the liquid phase in a gas pipeline causes several technological problems [14-16]. Research has shown that the flow characteristics of a gas-liquid environment in a pipeline, accompanied by phase transitions, can be unstable, and this instability may manifest as localized pressure loss in the pipeline. Therefore, modeling the flow characteristics of gas-liquid mixtures in multiphase pipelines and diagnosing complications presents significant challenges. The entry of the liquid phase into the gas pipeline also creates favorable conditions for hydrate formation. Changes in thermobaric conditions can intensify the formation of gas hydrates. Although several innovative methods have been developed and applied recently to prevent the formation of hydrates or to eliminate existing hydrate compounds, the best method for combating hydrate formation is the drying of the gas [21-24]. On the other hand, the presence of the liquid phase facilitates internal corrosion in multiphase gas pipelines. Mechanical impurities in the gas mixture further accelerate corrosion-erosion wear, leading to premature failure of the pipes [25, 26].

When the depth of gas processing does not allow for single-phase transportation, the condensation of gas occurs. In marine pipelines, the hydraulic characteristics of vertical ascents and descents are complex, often resulting in pipelines filling with water and condensate. Consequently, the pipeline cross-section narrows, pressure increases, and the accumulation of condensed gases creates serious problems. It has been established that when liquid ingress occurs during the flow of gas, structural changes characteristic of liquid systems take place. Studying the dynamics of such structural changes plays an important role in diagnosing the formation of liquid phase cores in gas pipelines [5, 27-29].

Methods and discussion

Experiments conducted with the aim of investigating the thermodynamic reasons for the drop of the liquid phase in gas pipelines determined the amount of precipitated liquid phase depending on the pressure values (P=2.0; 4.0; 6.0; 8.0; 10.0; and 12.0 MPa). The experiments were carried out at a temperature of -10 °C, and the amounts of components C_3H_8, C_4H_{10}, C_5H_{12}, C_6H_{14}, C_7H_{16}, C_8H_{18} in the initial gas mixture (Mole/100 Moles) were determined (see fig. 1).

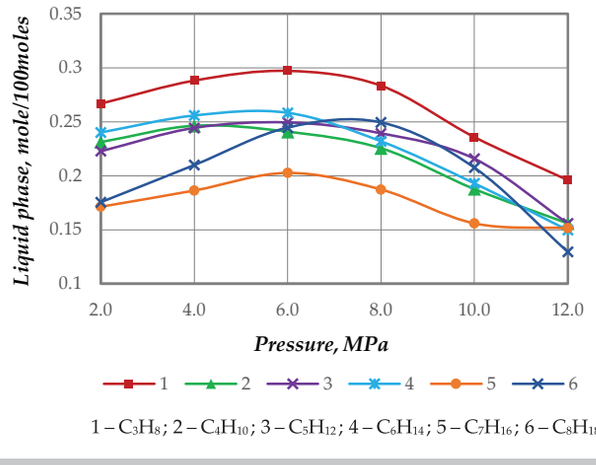

Fig. 1. Pressure dependence of gas components transitioning to the liquid phase in a gas mixture (T=-10 °C)

As seen in figure 1, the maximum amount of condensed liquid hydrocarbons corresponds to a pressure of 6.0 MPa. This pressure value is referred to as the «maximum condensation pressure.» In the graphs, «normal condensation» and «normal evaporation» are located to the left of this pressure value, while the «retrograde zone» is on the right. It is evident from the dependence that the amount of the precipitated liquid phase increases at higher pressures. This indicates that gases such as methane, ethane, nitrogen, and carbon dioxide in the gas mixture transition to the liquid phase at higher pressures.

From the above, it follows that the presence of water and gas vapors transported in a gas pipeline later condenses and causes the formation of various complex phenomena. Currently, various mobile laboratories investigate phase changes and liquid phase precipitation in natural gas transportation systems. Various devices and equipment are extensively used to determine the amount of separated liquid phase and to remove it from the transportation system. However, while it is possible to monitor liquid accumulation in the system with such devices and equipment, predicting phase changes remains challenging. Therefore, ensuring effective flow options in gathering and transportation systems and selecting justified regime parameters can help prevent additional difficulties and extra costs during gas gathering and transportation. It should be noted that the complex phenomena occurring during transportation are also related to the multiphase nature of the gases [30]. Specifically, the mixing of different gases in transportation systems alters their quality indicators.

Predicting phase transitions in multiphase gas pipelines with various sources of natural gas or mixtures of natural gas and associated gas is an important practical issue. Numerous studies have shown that the dynamics of changes in the composition of natural gas can serve as a diagnostic criterion for assessing its main parameters and technological processes [31-33]. It has been determined that the separation of water in producing wells leads to significant changes in the amounts of $C0_2$, C_1, C_5 and C_6 components. For example, before water separation in a well, the amounts of C_5, C_6, and $C0_2$ components increase, while the percentage of C_1 decreases, indicating that the gas component changes can serve as diagnostic indicators of well water influx [19, 34-36].

During the exploitation process of wells, the evaluation and ranking of the classification function based on the obtained data regarding the gas component composition have allowed monitoring of the water influx process in gas wells. Analysis of the dynamics of the changes in the ranking function during the exploitation process has provided insight into the presence of excess water in the well at certain values. This indicates structural changes in hydrocarbon mixtures [11, 30, 37].

Given these considerations, diagnosing structural changes in pipelines transporting mixed gases has become a point of interest. To this end, the study has examined how the quality indicators of natural gas, arriving from the preparation unit to the gas pipeline and mixed with associated gas from the compressor station, change during the transportation process (see fig. 2).

As shown in figure 2, natural gas from the gas preparation station is combined with the associated gas from the compressor station before being transported to the AGDS via the natural gas pipeline. For the studies, gas samples were collected from the following junctions: from natural gas (Junction 1), from associated gas (Junction 2), and from their mixture (Junction 3). The results of the laboratory analysis of the gas samples taken from Junctions 1, 2, and 3 are presented in table 1.

For natural and associated gases, as well as their mixtures, calculations have been performed based on the additivity rule for four model gas samples with different ratios: Model M-1 (30% natural gas + 70% associated gas), Model M-2 (50% natural gas + 50% associated gas), Model M-3 (70% natural gas + 30% associated gas), and Model M-4 (80% natural gas + 20% associated gas). The deviations from the actual values have been calculated by comparing the calculated values based on the additivity rule with the actual values (table 2).

The chromatographic analysis results of gas samples taken from various locations are presented. These results include

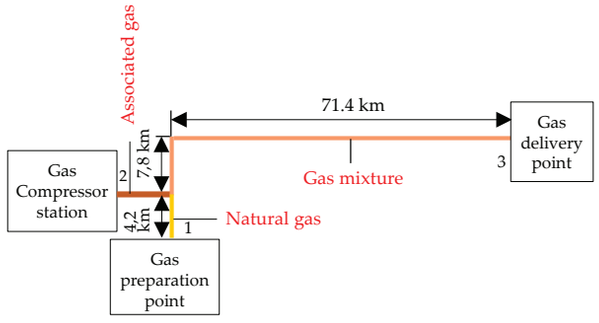

Fig. 2. Schematic of the junctions where samples were collected for analysis

Table 1

Key physical-chemical ındicators of transported natural gas, associated gas, and their mixture

№	Quality indicators			
	Title	Location 1	Location 2	Location 3
1	CH_4, %	92.0752	81.0170	88.6936
2	C_2H_6, %	0.6310	5.7403	1.7729
3	C_3H_8, %	1.1823	2.9122	1.5933
4	C_4H_{10}, %	0.0131	3.0575	0.7167
5	C_5H_{12+}, %	0.0829	3.5078	1.7145
6	O_2, mol	0.0288	0.0270	0.0257
7	CO_2, %	0.1883	1.3085	0.4035
8	N_2, %	5.7984	2.4297	4.8997
9	Gas density (20 °C), kgg/m^3	0.6941	0.7550	0.7130
10	Dew point for water,°C	-10	35	-12
11	Humidity,mg/l	0.2230	4.7994	0.3539
12	Mechanical impurities, mg/l	0.5733	0.0788	0.6453

Table 2

Comparison of calculated values based on additivity rule with actual values for the main physical-chemical indicators of natural and associated gases and their mixtures at various ratios

№	Calculated values based on additivity rule					Error (%) observed during comparison of actual gas mixtures with various compositions			
	Adı	M-1	M-2	M-3	M-4	XM-1	XM-2	XM-3	XM-4
1	CH_4, %	84.3345	86.5461	88.7577	89.8636	4.91	2.42	0.07	1.32
2	C_2H_6, %	4.2075	3.1857	2.1638	1.6529	137.32	79.69	22.05	6.77
3	C_3H_8, %	2.3932	2.0473	1.7013	1.5283	50.21	28.49	6.78	4.08
4	C_4H_{10}, %	2.1442	1.5353	0.9264	0.6220	199.18	114.22	29.26	13.21
5	C_5H_{12+}, %	2.4803	1.7954	1.1104	0.7697	44.67	4.72	35.23	55.11
6	O_2, mol	0.0275	0.0279	0.0283	0.0284	7.16	8.56	9.96	10.66
7	CO_2, %	0.9724	0.7484	0.5244	0.4123	141.00	85.48	29.95	2.19
8	N_2, %	3.4403	4.1141	4.7878	5.1247	29.79	16.03	2.28	4.59
9	Gas density (20°C), kgg/m^3	0.7367	0.7246	0.7124	0.7063	3.33	1.62	0.09	0.94
10	Dew point for water,°C	21.5	12.5	3.5	-1	279.17	204.17	129.17	91.67
11	Humidity,mg/l	3.4265	2.5112	1.5959	1.1383	868.21	609.58	350.95	221.64
12	Mechanical impurities, mg/l	0.2272	0.3261	0.4250	0.4744	64.80	49.47	34.15	26.48

the component composition and some physical-chemical quality indicators of the gases, and are compared with the values calculated using the additivity rule (fig. 3-8).

Figures 3, 4, 5, 6, 7, and 8 show that the study investigated the dynamics of changes in the component composition and some key physical-chemical indicators of gases such as O_2, CO_2, N_2, CH_4, C_2H_6, C_3H_8, C_4H_{10}, and C_5H_{12+}. Along with the component composition of the transported gases, their key quality indicators (number of mechanical impurities, gas density, relative density, humidity, and dew point) were also investigated. It is evident that both the component composition and the key quality indicators of natural and associated gases differ significantly from each other. For example, the weight percentage of methane and mechanical impurities, as well as the density, humidity, and dew point of the gases, are as follows: for natural gas, the average values are 92.1% weight %, 0.57 mg/l, 0.694 kg/m³, 0.2230 mg/l, and -10 °C, while for associated gas, the corresponding values are 81.0% weight %, 0.08 mg/l, 0.755 kg/m³, 4.80 mg/l, and 35 °C.

Based on the sample taken at the AGDS entrance (point 3), the analysis of the component composition and physical-chemical indicators (actual indicators after mixing natural and associated gases) shows that the parameters of the gas mixture are as follows: 88.69%, 0.64 mg/l, 0.713 kg/m³, 0.354 mg/l, and -12 °C. Taking into account that the actual mixture ratio of transported natural and associated gases is 80:20%, the values of the component composition and quality indicators for mixtures at ratios of 30:70 (M-1), 50:50 (M-2), 70:30 (M-3), and 80:20 (M-4) were compared with those calculated using the additivity rule.

The comparison of the calculated values of these parameters using the additivity rule with the actual values obtained from samples taken at point 3 showed that the component composition and quality of the gas mixtures change signif-

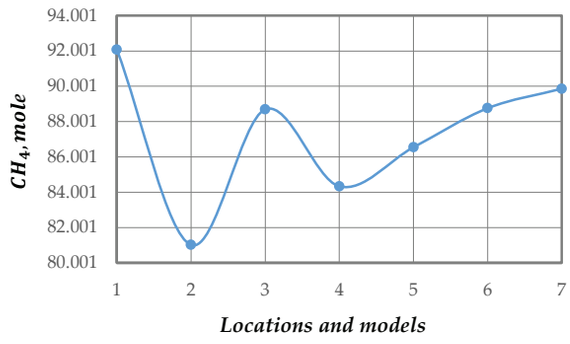

Fig. 3. Dynamics of changes in CH4 values by locationsand models

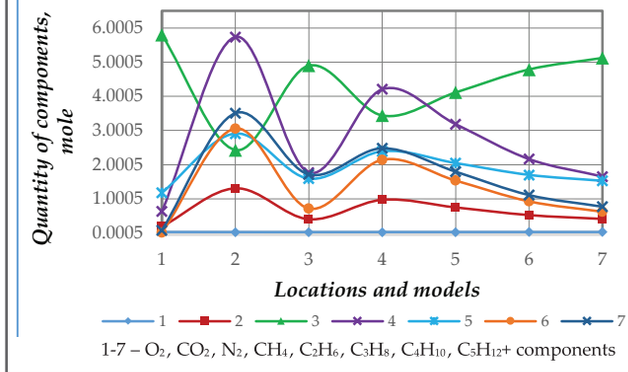

Fig. 4. Dynamics of changes in the values of other gas components by locations and models

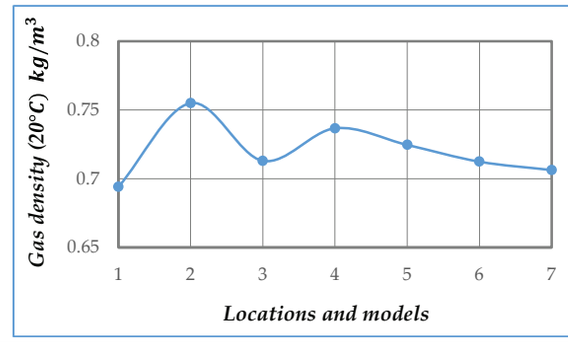

Fig. 5. Dynamics of density changes by locations and models

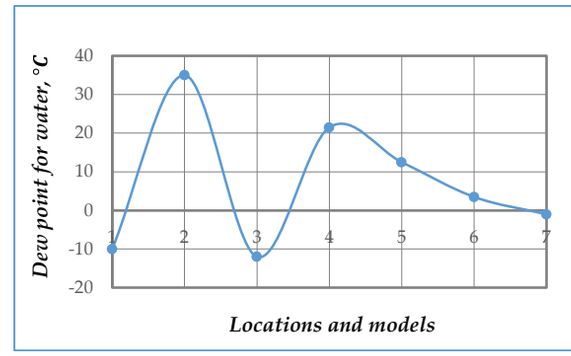

Fig. 6. Dynamics of dew point temperature changes with respect to water by locations and models

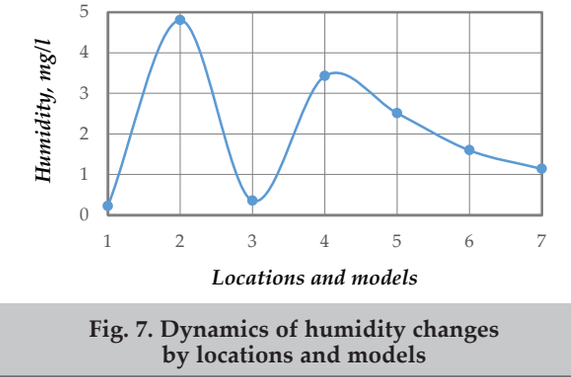

Fig. 7. Dynamics of humidity changes by locations and models

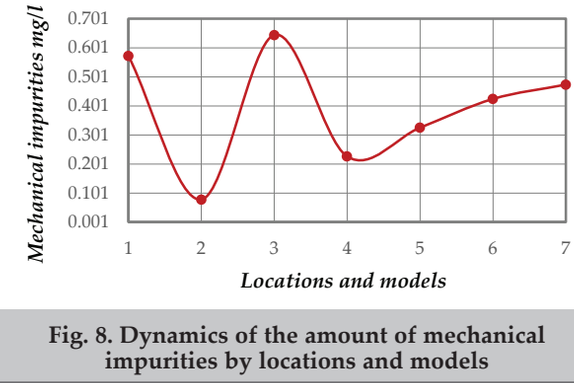

Fig. 8. Dynamics of the amount of mechanical impurities by locations and models

icantly when transported through the pipeline from point 1 to point 3. The analysis revealed that, in comparison to the values obtained by the additivity rule at a ratio of 80:20%, the actual values of heavy fractions (C_{5+}), mechanical impurities, and humidity undergo greater changes. This indicates that during the transportation of the natural and associated gas mixture, the number of heavy fractions, gas humidity, and dew point decreases towards the end of the pipeline, which signifies the separation of the liquid phase (water and heavy fractions) in the pipeline.

Conclusions

1. The conducted research has shown that the quality indicators of natural and associated gases, as well as their mixtures, undergo non-additive changes from their initial values due to the accumulation in reservoir conditions or structural changes during the transportation process through gas pipelines.
2. The component composition and other quality indicators of natural and associated gas mixtures can serve as diagnostic indicators for the formation of liquid phases.
3. Diagnosing the separation of liquid phases, which is one of the main causes of intensive corrosion of individual sections of multifaceted gas pipelines, can enable the prediction of internal corrosion and other technological complications.

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