Phase characteristics modeling of reservoir gas-condensate mixture of Tegermen group of fields

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Abstract. Taking into account the forthcoming concept, it is proposed to develop Tegermen group of fields with construction of onshore systems for collection, treatment and transportation of natural gas in order to supply the extracted products to the gas treatment point (Samantepe gas treatment unit 2) in a single-phase state. Natural hydrocarbon systems consist of a large number of components, and these are not only hydrocarbons of the paraffin series, but also hydrocarbons belonging to other groups. The phase state of a hydrocarbon mixture depends on its composition, as well as on the properties of individual components. Construction in a wide range of temperature and pressure values of phase diagrams of reservoir fluids with low condensate factor allows to determine with high accuracy the parameters of the beginning of condensate precipitation (dew point) in the system of gas gathering and transportation to supply the produced products of Tegermen group of fields.

1 Introduction

A number of scientific researches are carried out in the world on the most complete utilization of geological potential of fields by finding progressive scientific and technological solutions for maximum separation of natural gas from associated water and gas condensate [1-4]. In this direction, special attention is paid to the creation of effective geological and gas dynamic models of natural gas production, development and improvement of methods and technologies of gas gathering and treatment, increasing the degree of recovery of their reserves, due to the deteriorating conditions of gas production, as well as modernization of the applied systems of field development, which contributes to the increase in reserves and replenishment of the hydrocarbon resource base [5-8].

The world’s research into the development of efficient gas gathering, treatment, compression and transportation systems has resulted in a huge number of variants of these systems designed for specific periods of field operation. Great importance is given to the tasks of designing rational systems of additional development of gas condensate fields, with the provision of relatively high rates of natural gas production.
gas production at the final stage of their operation, with positive technical and economic indicators [9, 10].

The most important task of developing a productive hydrocarbon-bearing reservoir is to achieve the highest possible hydrocarbon yield. Reliability of predictive calculations of hydrocarbon yield value is largely predetermined by knowledge of their state and phase behavior of formation fluids saturating the productive reservoir [1, 2, 5, 7].

The Tegermen group of fields was chosen as an example for the operation of which "Technological solutions for the design of facilities of the gas treatment system of the fields of Tegermen group in order to prevent the ingress of dripping liquid into the gas pipeline-collector "Garbiy Tegermen-GPTP-2 Samantepe" were developed [8-10].

2 Materials and methods

The widely accepted conceptualization of the phase behavior in reservoir gas-liquid systems (RGLS) relies on a generalized phase diagram depicted in the "pressure-temperature" (P-T) coordinates [11]. This diagram serves as a comprehensive representation, illustrating key processes such as the transition of gas-liquid mixtures into either a vaporous or liquid state in response to variations in pressure and temperature [12, 13].

The phase diagram, often referenced in studies of reservoir gas-liquid systems, provides a visual framework for understanding the transformations that gas-liquid mixtures undergo under different thermodynamic conditions. By mapping out the variations in pressure and temperature, the diagram facilitates the identification of critical points, phase boundaries, and the regions associated with distinct phases (vapor or liquid). This foundational understanding is instrumental in predicting and managing the behavior of reservoir fluids, influencing decisions in the oil and gas industry related to exploration, production, and reservoir management.

The phase P-T diagram is based on the isotherms of contact condensation or degassing of GPTP: condensation in the temperature range from the beginning to the critical temperature, degassing in the temperature range from the critical temperature and below, which are used in the design of gas collection and transportation technology of gas condensate fields.

3 Results

Tegermen group of deposits includes Tegermen, Garbiy Tegermen, Shimoliy Tegermen, Uzunshor deposits. The projected facilities of the Tegermenskaya group of fields include:

- construction of a 33 km long Ø426x17mm collector gas pipeline from Tegermen field to the primary gas treatment unit (GPTP-2 Samantepe) field.
- construction of a collector gas pipeline with an approximate length of 15 km (diameter and length of the gas pipeline to be specified by the conducted studies) of the design block of inlet strings (BIS) at Garbiy Tegermen from the 33rd km of Garbiy Tegermen-Samantepa gas pipeline with double-sided purge valve units, flare facilities, UZOU and UPRU;
- construction of BVN for 10 technological strings of Tegermen field and gas pipeline from BVN to the projected gas pipeline (diameter and length of the gas pipeline to be determined by research);
- construction of a 6-strand BIS and a 10-strand BIS at the Garbiy Tegermen field and a gas pipeline from the BIS to the projected gas pipeline (the diameter and length of the gas pipeline should be determined by research);
A typical phase diagram of a multicomponent mixture in pressure-temperature coordinates has a loop-shaped form, i.e. it differs from the corresponding phase diagram of a pure substance, which is depicted as one monotonically increasing, concave to the temperature axis curve with one end (critical) point.

Studies are performed by decreasing the pressure in the PV -T chamber without changing the mass of the filled LPG. The pressure and volume are changed by the piston. When the piston is fully extended, the minimum possible pressure of the given mass filled with LPG is created in the PVT-chamber.

Characteristics of a diagram:
• loop-shaped envelope of the phase diagram, representing boiling point and dew point lines and bounding the two-phase province;
• the existence of a critical point at which the distinction between liquid and vapor phases disappears;
• the existence of areas of retrograde phenomena;
• the presence of a province of complete vaporization of the liquid located below the dew points.

However, the generalized phase diagram does not actually reflect the phase behavior of real LPGs [4]. Let us consider the difference between the phase behavior of the real LCPPs and the phase behavior of LCPPs determined on the basis of the P-T diagram.

Thus, when comparing the nature of two isotherms of contact condensation, one of which is obtained on the basis of real experimental data, and the other is taken from a generalized phase diagram, one can see fundamental differences.

It should be noted that the change of phase characteristics of the reservoir gas condensate system at reservoir pressure reduction in the process of development occurs due to changes in the initial mass of the system in the process of hydrocarbon recovery. Therefore, the peculiarities of the phase behavior of the gas condensate system in the process of pressure reduction are determined on the basis of experimental data obtained during differential condensation experiments, which simulate the development of a gas condensate reservoir in the depletion mode. The experiments are carried out using phase equilibrium setups at a constant temperature corresponding to the reservoir temperature [11]. Pressure reduction is carried out in steps, by releasing a portion of gas. At each pressure reduction step, the volume of precipitated saturated condensate in the PVT cell, the volume of released gas and its composition are determined. To study the composition of the precipitated condensate, a new recombination of the reservoir HC system is performed after each step [12]. The gas released from the PVT cell corresponds to the produced formation gas in the development, and the saturated condensate precipitated out corresponds to the retrograde condensate.

Nevertheless, this problem is relevant due to the need to develop fields with low condensate factor - Tegermen, Garbiy Tegermen, Shimoliy Tegermen and Uzunshor etc. Condensate factor of formation fluids of productive deposits of these fields varies from 11.3 g/m$^3$ in Tegermen (GCF) to 18.2 g/m$^3$ in Uzunshor (GCF). At such condensate factors, standard methods of phase diagrams construction (e.g., PVT bomb) become ineffectual due to low accuracy of visual fixation of the beginning of condensate precipitation. Construction in a wide range of temperature and pressure values of phase diagrams of formation fluids with low condensate factor, allowing to determine with high accuracy the parameters of the beginning of condensate precipitation (dew points), requires the use of new research methods.

Thus, a method of precision adiabatic calorimetry based on the determination of phase transitions by "jumps" of heat capacity and pressure derivative by temperature, measured directly at constant volume, is proposed.

Nowadays, with the development of science and technology, engineering calculations and modeling of processes at oil and gas industry facilities are performed using software products. With an extensive set of tools and specialized working environments, simulation in Aspen...
HYSYS allows optimization of process performance, production conditions and other parameters on the basis of which phase equilibrium plots in the gas mixture are calculated. Graphs illustrating the phase equilibrium dependence in the gas mixture of the Tegermen field in response to changes in temperature and pressure are thoughtfully presented in Figure 1. These graphs serve as invaluable visual tools, offering insights into the intricate relationship between temperature, pressure, and the resulting phase transformations within the gas mixture. The plotted data on the graph delineate how the system responds to variations in these critical parameters, shedding light on the conditions under which transitions from gas to liquid or vice versa occur. This nuanced representation is essential for reservoir engineers and researchers, providing a comprehensive overview of the thermodynamic behavior of the gas mixture in the Tegermen field. The thorough analysis of these phase equilibrium graphs contributes to a deeper understanding of the complex dynamics governing gas reservoirs, facilitating informed decision-making in the exploration and production phases of the oil and gas industry.

The graphical representation in Figure 2 offers a visual exploration of the phase equilibrium dependencies within the gas mixture of the Garbiy Tegermen field, emphasizing the dynamic interplay between temperature and pressure. These graphs serve as indispensable tools for comprehending how the gas mixture undergoes phase transitions in response to variations in these key thermodynamic parameters. Each plotted point on the graph encapsulates crucial information about the intricate relationship between temperature, pressure, and the resulting phase states—providing a clear depiction of transitions between gas and liquid phases. This visual analysis proves vital for professionals in reservoir engineering and research, enabling a nuanced understanding of the thermodynamic complexities inherent in the Garbiy Tegermen field’s gas reservoir. As a result, these phase equilibrium graphs contribute significantly to informed decision-making processes in the exploration, development, and production phases of the oil and gas industry, ultimately enhancing the efficiency and effectiveness of resource extraction in this specific geological setting.
Figure 3 showcases illuminating graphs that depict the phase equilibrium dependence within the gas mixture of the Shimoliy Tegermen field, specifically capturing the nuanced interactions influenced by alterations in temperature and pressure. These graphical representations serve as indispensable tools for unraveling the complex relationships governing phase transitions in the gas mixture. Each data point on the graph intricately illustrates how the system responds to variations in temperature and pressure, providing valuable insights into the conditions under which transitions between gas and liquid phases occur.

This visual analysis is of paramount importance for professionals in reservoir engineering and research, facilitating a comprehensive understanding of the intricate thermodynamic behaviors inherent in the Shimoliy Tegermen field's gas reservoir. By presenting a clear visualization of phase equilibrium dependencies, these graphs contribute significantly to decision-making processes in the exploration, development, and production phases of the oil and gas industry. The insights garnered from these graphs are pivotal for optimizing resource extraction strategies and enhancing overall operational efficiency in the unique geological context of the Shimoliy Tegermen field.

The phase equilibrium dependence within the gas mixture of the Uzunshor field is vividly illustrated in Figure 4 through graphs delineating the intricate interplay of temperature and pressure changes. These graphs serve as invaluable visual tools, capturing the dynamic relationships that govern phase transitions in the gas mixture. Each point on the graph signifies a critical juncture, revealing the system's response to varying temperature and pressure conditions and providing essential insights into the transitions between gas and liquid phases.

For professionals in reservoir engineering and research, these graphical representations offer a nuanced understanding of the Uzunshor field's gas reservoir's complex thermodynamic behaviors. By presenting a clear visualization of phase equilibrium dependencies, Figure 4 plays a pivotal role in decision-making processes throughout the exploration, development, and production phases of the oil and gas industry.
Fig. 3. Graph of phase equilibrium dependence in the gas mixture of the Shimoliy Tegermen field on changes in temperature and pressure.

Fig. 4. Graph of dependence of phase equilibrium in the gas mixture of Uzunshor field on changes in temperature and pressure.

The insights derived from these graphs contribute significantly to optimizing resource extraction strategies, enhancing operational efficiency, and advancing the overall comprehension of the Uzunshor field's geological characteristics.

The natural gas is then directed to a gas pretreatment unit (GPU). Gas pretreatment is a technological process designed to separate hydrocarbon condensate, reservoir liquid and mechanical impurities from the gas stream under field conditions at actual process parameters.
4 Discussion

The main task of gas treatment is purification of produced gas from formation liquids and mechanical impurities, taking into account at gas metering stations.

In accordance with the proposed gas treatment technology, the projected gas treatment unit includes:

1. Gas separation unit:
   - vertical separators C1/1 and C1/2 units.
2. Purified gas metering unit.
3. Condensate treatment unit:
   - separator P1 unit;
   - weatherizer B1 unit;
   - condensate collection tanks E1a/b units;
   - pumps for liquid transfer H1,2 units;
   - degasser D1 unit;
   - reservoir water collection tank E2a/b units;
   - pumps for water injection to the well H3,4 units.

It is also necessary to construct a wellhead compressor station (WCS) to achieve the necessary conditions for gas transportation. The Garbiy Tegermen Wellhead Compressor Station (WHCS) is designed to increase gas pressure at the Garbiy Tegermen field, which is part of the Tegermen group of fields.

Based on the results of hydraulic calculation, the volume of accumulated liquid on the gas pipelines-collectors in the gas transportation systems of the fields of Tegermen group before and after the commissioning of the projected GPTP of Tegermen group was determined. The results are presented in Table 1.

Table 1. Results of hydraulic calculation of the volume of accumulated liquid on gas pipelines-collectors before and after commissioning of the projected "Tegermen" gas gathering station

<table>
<thead>
<tr>
<th>Name</th>
<th>Diameter, mm</th>
<th>Length, km</th>
<th>Liquid volume in gas pipelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas pipeline-collector from the Tegermen GPTP to Samantepe GPTP</td>
<td>168</td>
<td>20</td>
<td>4.4</td>
</tr>
<tr>
<td>Gas pipeline-collector from the Tegermen GPTP to Samantepe GPTP</td>
<td>426</td>
<td>20</td>
<td>4.4</td>
</tr>
<tr>
<td>Gas pipeline-collector from the Tegermen GPTP to Samantepe GPTP</td>
<td>530</td>
<td>15</td>
<td>2.0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>66.0</td>
</tr>
</tbody>
</table>

The WCS inlet will be supplied with gas from the Tegermen, Garbiy Tegermen and Shimoliy Tegermen fields, which are part of the Tegermen group of fields.

The conducted research provides for the construction of a WCS with two reciprocating compressor units (RCU) with a gas piston engine with a unit capacity of 0.3 MW. The operating mode of the WCS is two RCU units in operation without reserve.

Hydraulic calculation of the gas transportation system of Tegermen group fields was performed in order to compare the parameters of the gas transportation system operation before and after commissioning of the designed gas transportation system.

The results of hydraulic calculation of the gas transportation system of the fields of Tegermen group show that the hydraulic losses of field operation with gas pretreatment plant (GPTP) have decreased.
5 Conclusions

In order to reveal the contribution of individual components to the general character of the behavior of a multicomponent hydrocarbon mixture, mixtures represented as individual components have been investigated. It is shown that when modeling the phase behavior of hydrocarbon fluids with a low condensate factor, the representation of mixtures as three-component mixtures allows to reveal the conditions of stratification of the system into phases, identify the phases by composition and determine the contribution of individual components to the overall behavior of the system. The obtained data contribute to optimization of the process of experimental studies of multicomponent mixtures.

This approach allows to build phase diagrams of reservoir fluids, including fluids with low condensate factor, and to determine thermobaric parameters of the beginning of condensate precipitation (dew point) with higher accuracy. Increasing the accuracy of dew point parameters determination creates prerequisites for increasing the efficiency of low condensate factor field development and increasing hydrocarbon production.

Studies have shown that phase behavior of formation fluids with low condensate factor qualitatively differs from traditional concepts. Their phase state is characterized by significant uncertainty of measurements, cannot be studied by traditional methods and the more so predicted theoretically requires application of new research methods.

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