Thermodynamic properties of gas-condensate system with abnormally high content of heavy hydrocarbons

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Abstract. Gas-condensate systems (GCS) with an abnormally high content of heavy hydrocarbons are characterized by a sharp change in both phase and component compositions with an insignificant decrease in pressure below the start pressure of the phase transitions (the beginning of condensation). Calculation methods for describing the phase behavior of such systems are very sensitive to the quality of the initial information. The uncertainty of the input data leads not only to significant errors in the forecast of phase compositions, but also to an incorrect phase state estimation of the whole system. The research presents the experimental thermodynamic parameters of the GCS of the BT reservoirs on the Beregovoye field, obtained at the phase equilibrium facility. The data contribute to the adaptation of the calculated models of the phase behavior of the GCS with a change in pressure.

1. Introduction

The extraction of crude hydrocarbons from gas condensate deposits is associated with constant phase transitions occurring in a wide range of pressures and temperatures during the fluid movement through the system “reservoir-well-gathering station”. The change in the thermobaric parameters leads to a change in the phase and component composition of the gas-condensate mixture (GCM). Upon that, the higher the content of heavy hydrocarbons (HC C5 +) in the formation GCS is, the greater the influence of the change in thermobaric parameters on the phase addition of a reservoir hydrocarbon system [1] is. The uncertainty of the input data not only leads to significant errors in the forecast of phase compositions, but also often to an incorrect state estimation of the whole system [2].

2. Materials and methods

Under these conditions, a key role in studying the properties of a reservoir hydrocarbon system is played by experimental research methods that are aimed at determining the phase relation under different thermobaric conditions. To avoid significant errors, the design schemes should be oriented towards the use of information obtained from the results of actual measurements.

The gas-condensate system of the BT reservoir of the Beregovoye field under initial conditions is characterized by an abnormally high content of heavy hydrocarbons (over 400 g / m³). The component composition (Table 1) and the properties (Table 2) of the gas-condensate mixture were used to calculate, according to the equation of state [3], the phase diagram (Figure 1), which shows that the
temperature at which the system is located at the depth of the deposit is close to the critical temperature of the mixture. This allows us to classify the GCS as "near-critical" fluids.

A peculiarity of the phase behavior of such systems is a sharp change in properties with a slight decrease in pressure below the pressure of the beginning of condensation (phase transition) [4]. Moreover, in conditions of a significant excess of the critical saturation in the reservoir, problems associated with the combined filtration of the gaseous and liquid phases arise [5].

Experimental data on the change in the potential content of HC C5 + in the composition of the gaseous phase with a decrease in pressure (Fig. 2) show that when the pressure decreases by 6 MPa below the pressure at the start of condensation, the gaseous phase loses half of the initial "liquid" component. Such conditions arise in the operation of wells, even with a small production output [6].

Taking into account the relevance of studying the parameters of the GCS of the Beregovoye field, special experiments were performed within the framework of this research, and a set of experimental data was organized, which in future will allow specialists in hydrodynamic modeling to create an adequate PVT model adapted in the extended data range.

| Table 1. The initial composition of the GCM |
|-------------------------------------------|
| Component, group | Molar content, % |
|------------------|------------------|
| He               | 0.011            |
| H₂               | 0.005            |
| CO₂              | 0.002            |
| N₂               | 0.908            |
| CH₄              | 74.579           |
| C₂H₆             | 6.426            |
| C₃H₈             | 5.587            |
| i-C₄H₁₀          | 1.284            |
| n-C₄H₁₀          | 2.546            |
| i-C₅H₁₀          | 0.824            |
| n-C₅H₁₀          | 1.006            |
| C₆               | 1.087            |
| C₇+              | 5.737            |
| Sum              | 100.000          |

| Table 2. The initial properties of GCM |
|----------------------------------------|
| Parameters | Parameter value |
|------------|----------------|
| Molar mass, g/mol | 28.63 |
| Density, kg/m³ | 1.191 |
| HC content C₅+, g/m³ | 407.2 |
| Degassed condensate density, kg/m³ | 730.0 |
Figure 1. Calculated phase diagram of the GCS (Beregovoye OGCF, BT reservoirs)
Cipher is the volume fraction of the gas phase

Figure 2. Change in the content of HC C5 + in the gaseous phase with a decrease in pressure.

To carry out the experimental studies, the measuring equipment included in the phase equilibria unit "PVT 3000GL System (Chandler Engineering)" with additional auxiliary equipment was used. The technical characteristics of the unit make it possible to carry out studies of hydrocarbon systems in a wide range of pressures and temperatures. The limits of the permissible pressure measurement errors are ±0.1%, temperature is ±0.5 °C, density is ±0.75%. Accuracy of measuring the volume of the LF - hundredths of a cubic centimeter [8, 9, 10, 11].

The disadvantage of this type of units is the impossibility of turning over the measuring cell, which makes it impossible to provide reliable mixing of the system and establish thermodynamic equilibrium in the study of GCS [7]. In order to ensure the establishment of thermodynamic equilibrium of the phases, the experimental unit was modernized. An additional line was included in the circuit, which allowed the phases to be stirred by recycling ("bubbling") the gas through the precipitated liquid phase.
As an auxiliary equipment, a recombination cell is used to carry out the studies, which allows preparing the necessary hydrocarbon mixtures in a wide range of pressures (up to 100 MPa) and temperatures (up to 150 °C). To measure the viscosity of the liquid and gaseous phases, the EV-1000 Vinci piston electromagnetic viscometer is used - a licensed analogue of the SPSL 440 Cambridge Electromagnetic Viscometer with an inaccuracy of 2.5% of the range of the value measured [12].

During the experimental studies, a clear dependence between the density and viscosity of the gaseous phase of the BT reservoir of the Beregovoye field on the pressure and content of HC C5 + in the composition (Fig. 3) was established. Studies were performed in the pressure ranges of 21 - 36 MPa, under conditions of single-phase formation gas at a reservoir temperature of 78 °C.

![Graph showing dependence of density and viscosity on pressure and content of C5+](image)

**Figure 3.** Dependence of the density and viscosity of the gaseous phase on the pressure and HC content of C5 + at a temperature of 78 °C.
In the thermobaric conditions of the coexistence of two phases, that is, at a pressure below the condensation start pressure, the properties of the gaseous phase depend not only on the pressure, but also on the amount of the released liquid phase. So, Fig. 4 shows the dependences of the relative volume of the liquid phase on the initial content of HC C5 + in the formation HC system at different pressures. The maximum saturation of the liquid phase under thermodynamic equilibrium conditions with a C5 + content of more than 400 g / m³ was about 16% of the volume of the system at reservoir pressure.

Figure 4. Dependence of the relative volume of the liquid phase (Beregovoye OGCF, BT reservoirs) on the content of hydrocarbon C5 + and pressure at a temperature of 78 °C
Figure 5. Dependence of the density of the gaseous phase in the two-phase area (Beregovoye OGCF, BT reservoirs) on pressure and content of HC C5 + at a temperature of 78 °C

3. Conclusion

Experimental studies have established that the density of the gaseous phase with a pressure drop below 14 MPa in the two-phase area is slightly dependent on the initial content of HC C5 +, but depends only on the change in pressure (Fig. 5).

As a result of the study, experimental data were obtained, which can form the basis of the adapted thermodynamic PVT model of formation fluid. The dependences created on the basis of the experimental data can also be used to characterize similar gas-condensate deposits with a C5 + hydrocarbon content close to 400 g / m$^3$ and a density of degassed condensate in the range of 720-750 g / m$^3$.

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