Estimation of the Influence of Oil Flows on the Formation Losses of Condensate During the Development of Multi-Layer Deposits

R K Katanova, E I Inyakina, M D Z Alsheikhly, I I Krasnov

1 Mirny Polytechnic Institute (branch) of North-Eastern Federal University, 14 Oyunskogo Str., Mirny, 678175, Republic of Sakha (Yakutia)
2 Federal State Budget Educational Institution of Higher Education « Industrial University of Tyumen»/ IUT, 36 Volodarskogo Str., Tyumen, 625000, Russia
3 Kirkuk University, Faculty of Engineering, Al-Sayada St., Kirkuk, 36001, IRAQ

E-mail: rose941101@mail.ru

Abstract. During the development of multilayer oil and gas condensate fields, the production of condensate is influenced by the associated oil. Analysis of field data showed that the cause of oil flows is the outstripping decrease in reservoir pressure in the gas condensate section in comparison with oil zones. Thus, incoming heavy oil fractions into a gas condensate reservoir have a negative impact on reservoir losses of hydrocarbons, including the final condensate recovery factor. Many years of experience in the development of such fields showed that the bulk of the presence of associated oil in well production is explained by the following reasons: the relationship between the reservoirs through lithological windows, the residual oil saturation of the reservoirs, and the presence of lenticular layers. Determination of the quantitative content of oil in the reservoir mixture was determined by infrared spectrometry using a Perkin-Elmer Fourier transform spectrometer, which makes it possible to assess changes in the component composition of gas condensate systems. In the course of the research, selected samples of the gas and liquid phases were analyzed directly from the production facilities of the development. The analysis of IR spectrometry showed that in most of the samples of gas condensates, the effect of displacement is recorded, which is characteristic of fluids with the manifestation of oil impurities. The purpose of these studies is to study the influence of the produced oil on the dynamics of hydrocarbon production and the final condensate recovery factor.

1. Introduction

When calculating hydrocarbon reserves and designing the development of multilayer fields, data on the change in the degree of condensate recovery at different contents of scattered oil in the reservoir gas condensate system are of interest. Based on the results of theoretical and experimental PVT studies, it was revealed that with a decrease in reservoir pressure during the development of oil and gas condensate deposits, a significant difference arises between the design and actual production of condensate. As a result, a special integrated approach is required in their development. Since the process of retrograde isothermal condensation, with a decrease in pressure in the reservoir, condensate losses in the reservoir additionally increase. Therefore, for the efficient development of condensate reserves, it is necessary to
predict its reservoir losses and change the composition of reservoir gas, taking into account the influence of oil flows during the operation of the development object. [1,2].

2. Relevance
Studies to determine the effect of heavy oil fractions of hydrocarbons on reservoir condensate losses for gas condensate facilities characterized by residual oil saturation. Modeling the process of implementing the method of developing a reservoir system “condensate-oil” with the subsequent achievement of the percentage of oil in the system. The revealed patterns show that the presence of scattered oil in the mixture has an increased value on the partial pressure of the reservoir system and negatively affects the process of gas condensate production. To study the thermodynamic properties, samples of separation gas and saturated condensate were taken during the operation of the wells of the studied development object. Experiments on the effect of residual oil on the CFC were carried out on the Vinci Technologies unit, on recombined samples taken from the wells of the Botuobinsky, Ulakhansky and Talakhsky horizons of the Srednebotuobinsky field. The properties of formation gases and condensate were studied using the studied deposits of the productive complex in reservoir and surface conditions [3,4].

3. Formulation of the problem
To study the thermodynamic properties of gas condensate, 64 samples were taken from wells that penetrated the Botuobinsky, Ulakhansky and Talakhsky productive horizons of the Northern dome of the Srednebotuobinsky field. Sampling of separation gas and saturated condensate was carried out in accordance with the instructions of Gazprom Vniigaz. Sampling conditions are as follows: during gas condensate studies before separation and after separation, during trial operation, etc. Experimental studies were carried out on the condensation of the reservoir system on a PVT installation to determine the effect of associated oil on the amount of condensate recovery. The study was carried out on recombined samples of separation gas and a mixture of saturated condensate and oil from real development objects under study. The formation of a reservoir sample in the PVT cell was carried out in accordance with the condensate-gas factor (CGF) measured during field tests. The technique of the experiment consists in the fact that a series of loadings of samples with different contents of oil impurities was made. The system was brought into equilibrium for each load, then, with a stage-by-stage pressure reduction, formation condensate losses were determined. Based on the data obtained, the oil recovery factory value was calculated [5,6].

4. Theoretical part
Based on the experimental modeling of the field development process in the mode of natural depletion of reservoir energy, the negative influence of oil on the predicted dynamics of condensate production was revealed. Along with fairly good results, in some cases the predicted value during the process of differential condensation diverges from the predicted values. In order to identify the patterns that affect the change in reservoir losses of hydrocarbons during the implementation of the adopted system of field development, a series of PVT experiments were performed. The experiments were carried out on the condensation of the reservoir system on a PVT unit to determine the effect of associated oil on the amount of condensate recovery. Modeling of the development process of a reservoir with an admixture of associated oil was carried out by the method of differential condensation. Samples for study were taken from wells operating the Botuobinsky, Ulakhansky and Talakhsky horizons under normal well operating conditions.

The quality of surface samples largely depends on the drawdown, gas flow rate at the bottomhole, pressure, separation temperature, and study time. The complex of studies of the phase processes of a multicomponent system consisted in a sequential increase in the oil concentration in the PVT cell from 5%, 10% to 15% of the mass of the volume of condensate contained in the formation gas. The experiments were carried out on recombined samples of saturated condensate and separation gas in accordance with the condensate-gas factor (CGF) measured during field tests [7].
5. Practical significance

In the context of the development of gas condensate fields, data on the change in the magnitude of reservoir condensate losses at different residual oil content in the reservoir hydrocarbon system are of interest. The solution to this issue was carried out experimentally by the method of differential condensation of the "gas condensate-oil" reservoir system with different percentage of oil in the system. The obtained patterns show that the presence of scattered oil negatively affects the condensate production process. Within the Northern block of the Srednebotuobinskoye field, oil and gas content was revealed in four horizons - Botuobinsky, Ulakhansky-I, Ulakhansky-II, Talakhsky. The Botuobinsky productive horizon is distributed over the entire area of the North I, II and East III blocks of the field. The Botuoba gas condensate reservoir is complicated by two faults, which are the boundary of the block, dividing the reservoir into two blocks - North I and North II. The properties of reservoir gases of the Botuobinsky productive horizon in terms of methane content ranges from 71% to 87%. The nitrogen content is relatively high up to 15.84% with a low carbon dioxide content up to 0.50% and hydrogen up to 0.08%. The ratio of the total hydrocarbon to nitrogen content in the gas varies from 9 to 22. On average, the hydrocarbon content in the reservoir gas is 12 times higher than the nitrogen content. The average composition of free gas in gas condensate deposits in volume percent is: methane up to 82.8%, ethane up to 5.19%, propane up to 1.68%, isobutane up to 0.28%, butane up to 0.44%, pentane + higher up to 0.648%, helium up to 0.39%, carbon dioxide up to 0.50%, nitrogen up to 7.86%. The Ulakhan gas condensate reservoir is traced in the Northern Block II and the northern part of the Northern Block I. The largest total thickness penetrated by well No. SBt74 was 16.2 m, the smallest in well No. SBt-48 was 4.5 m. Complicated by two faults, which are the boundary of the Northern Block II. Average gas inflows for wells in the volume from 64.66 thousand m3 / day (# SBt-99) to 117 thousand m3 / day (# SBt-163). The Talakhsky productive horizon is widespread in the Northern block I. During reservoir testing, inflows were obtained from wells No. SBt-160, No. 159 and No. 41, the gas rates of which were in the range from 40.1 to 123.6 thousand m3 / day.

The properties of the botuobinsky horizon condensate are based on the interpretation of the materials of physical and chemical studies of separation samples from wells No. SBt-27 and No. 44. It is light (density up to 0.7835 g / cm3) and low boiling point; when distilled to 200 ° C, it boils off on average up to 90% of condensate. In practice, they consist only of the gasoline fraction. The content of resins and asphaltenes is insignificant, sulfur 0.29%, paraffins - 0.1%. In terms of hydrocarbon composition, the condensate is of the methane type: the content of methane is 81.42% by weight, naphthenic is 9.76%, and aromatic is 8.82%. The stable condensate content in the reservoir system is 16.1 g / m3, the relative molecular weight is from 80.0 to 94.0, the potential condensate content in the reservoir gas is 30.9 g / m3. The density of the gas-condensate mixture under standard conditions is 0.763, the relative density of the mixture in air under standard conditions is up to 0.634. The reduced pressure to the initial reservoir pressure is 3.08, the reduced temperature is 1.44. Based on the above composition and physicochemical properties of hydrocarbons, a curve of reservoir losses of saturated condensate was obtained with a decrease in pressure in the Botuoba gas condensate reservoir.
When predicting the production of stable condensate, its residual content in the separation gas was taken into account when the pressure at the inlet to the GPP is not lower than 8.0 MPa and the pressure in the main gas pipeline is 5.60 MPa. The gas supercompressibility factor calculated by the Redlich–Kwong equation in reservoir conditions is 0.76. On the example of the Sbt-44 well (Botuobinskaya deposit, perforation interval 1903-1908 meters), it can be seen that the separation gas and saturated condensate samples were taken at reservoir pressure equal to 12.79 MPa, temperature -130°C, total operating time in exploration modes 39 hours from them 24 hours in sampling mode. The gas velocity at the bottom hole is 5.3 m/sec, the drawdown is 2.4%. at separator pressure, $P_{sep} = 39.3 \text{ kgf/cm}^2$ and separator temperature, $T_{sep} = -30 \, ^\circ\text{C}$. The gas composition of the Botuobinsky and Ulakhansky horizons is significantly similar, and the average methane content is 87%. The gas from the Talakh horizon is less "dry" with an average methane content of 83%. It is noted that in gas samples taken during the period of geological exploration, the methane content in the samples is 2-3% lower than in the samples taken at the present time. The main reason for the "drainage" of reservoir gas is the transition of hydrocarbon components into the liquid phase and precipitation in the reservoir with a decrease in reservoir pressure.

**Figure 1.** Condensate loss curves in the Botuobinsky horizon.

**Figure 2.** Change in the condensate-gas ratio from the gas flow rate.
The analysis of the performed gas condensate studies indicates that the condensate yield varies in the range from 66.7 to 78.5 cm$^3$ m$^{-3}$. Such a significant difference is explained by the fact that the Northern block of the Srednebotuobinskoye field operates in the mode of a gas consumption regulator, which leads to a change in the well operation mode, both on a seasonal and daily basis. It is also worth noting that the error in determining the potential condensate content in reservoir gas for values less than 60 g / m$^3$ is significantly greater than for higher values. Nevertheless, it is possible that not the most optimal operating modes of the wells were selected for the study to ensure maximum condensate removal. In the course of the upcoming studies in order to determine the gas condensate characteristic, it is recommended to take samples of condensate and separation gas during well development in a steady state for at least 24 hours.

![Figure 3. Dependence of the condensate-gas ratio on the drawdown.](image)

The composition of the recombined reservoir gas samples generally correlates well with the composition of free gas.

**Table 1.** Calculation of the deviation from the Boyle-Mariotte law due to supercompressibility of formation gas.

| Reservoir          | Reservoir pressure atm | Reservoir temperature K | Critical pressure atm | Critical temperature K | Ghost pressure atm | Ghost temperature K | Z    | α    |
|--------------------|------------------------|--------------------------|-----------------------|------------------------|------------------|---------------------|------|------|
| Botuobinskiy + ulakhanskiy | 144.8                  | 284.1                    | 46.09                 | 198.77                 | 3.14             | 1.43                | 0.756 | 1.32 |
| Talakhskiy         | 140.5                  | 284.1                    | 45.15                 | 195.64                 | 3.11             | 1.45                | 0.770 | 1.30 |
|                    | 1.0                    | 284.1                    | 45.15                 | 195.64                 | 0.02             | 1.45                | 0.998 | 1.00 |

In laboratory conditions, studies were carried out to predict the process of development of the deposit. Based on this, curves of changes in the potential content of hydrocarbon components in the formation gas were calculated as the formation pressure decreased. Sketched curves are similar in shape, but slightly different in absolute values. This dispersion of results is probably related to the accuracy of determining the potential content of liquid hydrocarbon fractions. The condensate recovery ratio
calculated for each sample varies from 0.71 to 0.73, with an average value of 0.720. Condensates belong to the group of gas condensates of preferential gasoline fractional composition with boiling point from 60 to 150 °C. In terms of sulfur content, the analysed condensate refers to low-sulfur ones, the content of paraffins and resinous-asphaltenes in it is noted. Group hydrocarbon composition of condensates of naphthene-methane type.

![Figure 4](image-url)  
*Figure 4.* Forecast and actual formation losses in deposits of the Srednebotuobinskoye deposit.

In well No. SBT-156, when testing the Ulakhan horizon, the gas flow rate at the nozzle of 6 mm was 83 thousand m³/day, with a depression of 2.65 MPa. Currently, the discrepancy between the design and actual levels of gas extraction in the licensed area of ALROSA-Gaz company is due to the presence of residual oil in the well products. A series of PVT experiments was performed in order to identify the patterns affecting the increase in hydrocarbon formation losses during the implementation of the adopted development system of the Srednebotuobinskoye deposit.
Studies were carried out at the Vinci Technologies plant manufactured by France to condense the formation system to determine the effect on the amount of condensate extraction of oil vapors. The forecast of the development of the deposit with an admixture of scattered oil was carried out using the differential condensation method. The results of the study of samples of the formation mixture of the Central Botuobin NGCM are shown in Figure 6.

**Figure 5.** Change of potential condensate content in reservoir gas at reduction of pressure in deposits of Srednebotuobinskoye deposit.

**Figure 6.** The dependence of condensate losses in the deposit on the presence of oil vapors in the formation gas condensate system.
The complex of studies consisted in sequential increase of oil concentration of multi-component system in PVT-cell from 5%, 10% to 15% by weight of condensate volume contained in formation gas. Experiments were carried out on recombined samples of saturated condensate and separation gas in accordance with the condensate gas factor (CGF) measured during field tests. Change of condensate recovery factor value from oil impurity fraction in gas condensate system by results of PVT-studies is given in Table 2.

| Name field               | Change of value to from oil impurity fraction in the gas condensate system |
|--------------------------|--------------------------------------------------------------------------------|
|                          | No oil content in gas condensate mixture | oil content in gas condensate mixture up to 5% | oil content in gas condensate mixture up to 10% | oil content in gas condensate mixture up to 15% |
| Srednebotuobinskoye field| 0.72                                      | 0.65                                             | 0.63                                           | 0.62                                           |

Based on the obtained PVT-studies, it can be seen that the presence of residual oil in the gas condensate system reduces the condensate recovery factor. In this regard, an intensive decay process occurs, which has a significant impact on condensate formation losses.

6. Conclusion

Thus, experiments were carried out on samples of the gas condensate system taken from wells operating the Srednebotuobinskoye oil and gas condensate field using the contact and differential condensation method. From the obtained graphical dependence, it can be seen that in the presence of scattered oil, the nature of the "formation loss" curve changed. During the analysis of samples, the density of the formation gas of Botuobinsky and Ulakhansky horizons under standard conditions is 0.7736 kg/m³, the relative density of the mixture through air under standard conditions is 0.642. For the gas of the Talakhsky horizon, these parameters correspond to 0.7834 kg/m³ and 0.650. The supercompressibility coefficient of gas calculated by the Newton method in formation conditions is 0.756 for Botuobinsky and Ulahansky horizons and 0.770 for Talakhsky. According to the experiment, it was found that an increase in the content of oil impurity in the gas condensate system is accompanied by a decrease in condensate recovery. Thermodynamic studies have shown that the presence of oil in the gas condensate mixture increases the loss of hydrocarbons when the pressure decreases, and, therefore, the condensate recovery coefficient decreases. The maximum condensation pressure is shifted to the higher pressure region. According to the results of the test at concentration of oil impurity up to 5 wt%. from the volume of the gas condensate system, losses increased to 35%, the condensate recovery coefficient decreased and amounted to 0.65.

7. References

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