Periodicals of Engineering and Natural Sciences ISSN 2303-4521
Vol. 8, No. 4, October 2020, pp.2029 - 2034

Study of the effect of formation water during reserves estimation and designing hydrocarbon recovery of oil and gas condensate fields

Mohammed Jawad Zeinalabideen[1], Rozaliya Kirillovna Katanova [2], Ekaterina Ivanovna Inyakina[3], Ivan Ignatyievich Krasnov[2]
[1] University of Kirkuk, College of Engineering, Al-Sayada St., Kirkuk, 36001, IRAQ
[2] FSBEI HE North-Eastern Federal University M.K. Ammosov, Polytechnic Institute (branch), 14 Oyunskogo Str., Mirny, 678175, Republic of Sakha (Yakutia)
[3] Federal State Budget Educational Institution of Higher Education « Industrial University of Tyumen», IUT, 36 Volodarskogo Str., Tyumen, 625000, Russia

ABSTRACT

Currently, exploratory thermodynamic studies of the PVT reservoir fluids properties to assess the effect of condensate water on reserves estimation, design and development of the fields are carried out on Russian National and international oil companies. Such PVT ratios settings allow a wide range of pressures and temperatures to be used to study phase transitions of hydrocarbon systems. Conducted experimental studies of gas condensate systems showed a negative effect of formation water on the amount of condensate extraction during development. The studies were conducted on recombined samples of gas separation, formation water and saturated condensate taken from the wells during the pilot development of the Srednetyungskoe field in Western Yakutia. Wherein, a pattern was found of increasing the loss of high molecular hydrocarbons at the stage of the onset of condensation with increasing water vapor content in the gas condensate system. As a result of studies of the dependence of hydrocarbon losses during the increasing in the water vapor content in the system, certain parameters are the initial ones when calculating the reserves of hydrocarbon and non-hydrocarbon components in natural gas, the development of designing and field development. The aim of thermodynamic investigations was to determine the effect of formation and condensation water vapors on the condensate recovery rate during the isothermal condensation process, which manifests itself when the pressure decreases in the oil and gas condensate field.

Keywords: Condensate; PVT; Temperature; Reservoir pressure; Hydrocarbons; Thermodynamic studies; Gas reservoir.

Corresponding Author:

Mohammed Jawad Zeinalabideen,
Petroleum Engineering Department,
University of Kirkuk,
Al-Sayada St., Kirkuk, 36001, IRAQ
E-mail: mohammed.jawad@uokirkuk.edu.iq

1. Introduction

The difficulty of studies at the stage of pilot development is represented by gas condensate deposits with low permeability reservoir properties. In this case, to obtain the required flow rates, it is necessary to create large depressions on the reservoir. The effect of formation water on hydrocarbon production leads to a significant differentiation of the current composition of raw materials extracted from various parts of the field. To determine the characteristics of the produced gas and its practical interest during the design development, field development and processing of gas condensate, it's necessary to use some methods with the lowest possible error rate. The results of field studies showed that the gas condensate reservoir opened by thirteen wells, and only three from them which made the possibility to determine the position of the gas-water contact (GWC). The gas-water contact is determined using well logging in the well №.225 at a depth of 2821.6 m (True vertical depth 2620.1 m) and obtaining 100 liters of gas-water mixture through 10 minutes using wireline formation tester the same depth. The formation was tested in the column slightly higher than the GWC in the interval 2805-2815 meters (True vertical depth 2603.4 m, True vertical depth2613.4 m). The studies in the gas condensate reservoir were carried out in well No. 222 (interval 2690-2718 m, True vertical depth 2550.8-2578.8 m). For more than 20 days of trial operation, more than 16 MMm^3 of gas was flared, with stable

operation of the well. Wellhead parameters during operation remained constant. No drop in reservoir and bottomhole pressures, formation and fluid flowback has not been observed.
According to thermodynamic studies of the formation fluid at the PVT lab equipment, graphs of changes in the current condensate content in gas reservoir during the isothermal process are constructed. This graphical dependence showed a change in the condensate content in the presence of water vapor in the gas phase of the multicomponent mixture at the stages of field development. In repeated experiments using the method of differential condensation at a constant volume with gas sampling, it was determined that the initial reservoir pressure matches with the initial condensation pressure. In the process of selection gas-condensate mixture in the presence of formation water in the system, the nature of the curve of "hydrocarbon losses" indicates an increase in the condensation of heavy component fractions at the initial stage of field development.

2. Results and discussion

The considered topic is relevant due to the fact that productive rocks of the Lower Triassic age in the Srednetyungskoe field are characterized by a rather high degree of heterogeneity. In the same reservoir and when the wells drilled not far from each other, a different number of permeable layers are allocated. The reservoir rocks by area and section are often replaced by impermeable deposits, wedge out, their filtration-capacitive properties gradually deteriorate from the center of the structure in the mainly northeast direction. The effective thickness is 25.65 meters with an average value of the total thickness of the T1-A layer equal to 49.59 meters. The sandiness coefficient reaches 51.72%, despite the fact that in the reservoir are numbered from 4 to 19 permeable layers. T1-B layer is characterized by approximately the same sandiness coefficient as T1-A layer which is 51.33%. Although, the average thickness of the reservoir does not reach even (7 m) with an average effective of 3.29 m and a number of permeable intervals of 1.21. The T1-B layer has an average thickness of 40.26 m, an average effective thickness of 19.31 m, and a sand coefficient of 47.96%.
The study of the gases composition in the reservoir of the Lower Triassic and Upper Permian productive complexes showed that the gases of all the deposits have a close physicochemical characteristic. This circumstance may indicate the geochemical unity of the above deposits, and their comparison with the gases of the deposits of the central part of the Vilyui hemisyneclise (Srednevilyuyskoye, Tolonsky, Mastakhsky, Sobolokh-Nejelinsky, Badaransky and Nizhnevilyuiysky) allows us to talk about the genetic connection of gases of different age deposits. From the Lower Triassic deposits, qualitative and quantitative characteristics of gases and condensates were obtained in reservoir and surface conditions. About 30 analyses of free and dissolved gases were analyzed for the deposits of the complex. The gas samples taken into the pressure vessels were given great attention during storage and transportation.
The results of studying the thermodynamic and physicochemical properties of gas reservoir of deposits showed that the density of stable condensate ranges from 0.7539-0.7544 g/cm^3. During establishing the reliability of the studied samples of separation gases and condensates, their conformity was primarily determined by comparing the results of the analysis of samples taken under various conditions, while obviously low-quality were rejected. The methane content in the gases of the deposits ranges from 90.53-92.06%, the amount of fuel exceeds 97%. Practically, in the gases, there is no hydrogen (0.004-0.0023%), the carbon dioxide content is from 0.04 to 0.68%, and helium is about 0.008-0.01%. The ratio of the total hydrocarbon content to the nitrogen content in gases varies from 60 to 100. Generally, they are of the hydrocarbon type with a very low content of nitrogen and carbon dioxide. The content of heavy hydrocarbon fractions in the natural gases of the Lower Triassic and Upper Permian deposits is not very different and varies within very narrow limits of 7.09-7.87%, and the ratio of the components of the heavy hydrocarbons in these gases is almost identical. The content of pentanes plus higher in free gases is 0.18-0.48%. The coefficient of "dryness" of the gas (the ratio of methane to the sum of heavy hydrocarbons) of the deposits of both complexes is about 12, which indicates the presence of condensate in the gases. The gas-condensate reservoir system of the lower Triassic productive horizon is characterized by the following parameters (% mol.): Methane 90.72-91.12, ethane 4.42-4.94, propane 1.25-1.63, butane 0.42-0.60 pentane plus higher 1.04-1.10, carbon dioxide 0.30, nitrogen 1.00-1.03 and helium 0.01. The measured molecular weight is up to 108 units, fractional distillation showed that the boiling point is 38-420 °C, and the end of boiling does not exceed 3600°C. Therefore, a detailed study of the composition of reservoir systems is of practical interest in the development of fields and the rational processing of condensate. According to the content of commodity

fractions, condensates are characterized as follows: the gasoline fraction (NK – 200 °C) is 75-81% by volume, white spirit (150-200 °C) is 15-21% by volume, the diesel fraction (200-300 °C) is about 13-16% volume [8]. By comparing the water-soluble gases of the Srednetungskoe field with free gases are characterized by high methane content and, conversely, a decrease in heavy hydrocarbons, and the amount of heavy hydrocarbons in them decreases with distance from the contacts of gas deposits. Thus, an analysis of the gas compositions of deposits of the Lower Triassic and Upper Permian productive complexes shows that the gases of all deposits have a close physicochemical characteristic. This circumstance may indicate the geochemical unity of the above deposits. In isoprenoid hydrocarbons of these oils, the main share falls on the prystane (prystane-phytane equal 4.50-5.86). In the hydrocarbon composition of the resinous part, aromatic cycles are dominant. The resulting oils are close in composition and properties to coeval oils of the Hapchagai uplift. Table 1 shows the results of well test analysis of gas condensate.

Table 1. The Results of Gas Condensate Well Test Analysis of the Srednetyungskoe Field

Parameters and Units	Significance		
Well Number	226	226	226
Productive horizon	T_1-A	T_1-B	T_1-C
Perforation interval, m	2744-2755	2690-2718	2720-2745
Production Tubing, m	2744	2692	2728
Production Inner Tubing Diameter, м	50	50	63
Separator type	GSV-100	GSV-100	GSV-100
Reservoir pressure (abs.), kgf/cm^2	276	276	277
Annular pressure, kgf/cm^2	210	212	216
Tubing pressure, kgf/cm^2	198	210	201
Separation pressure, kgf/cm^2	58	58	63
Reservoir temperautre, °C	+58	+58	+61
Separation temperature, °C	-3	+7	+19
Gas outflow	According to tubing	According to tubing	According to tubing
Gas flow rate, 1000.m^3/day	164.1	154,0	138.0
Water flow rate, m^3/day	-	-	19.7
The content of degassed condensate, cm^3/m^3	76.2	66.2	63.0
Crude condensate content, cm^3/m^3	100.3	81.8	76.4

The data on the performed job in the wells is made it possible to determine the yield of degassed condensate obtained using the measured tank in atmospheric conditions, shrinkage factor - with a calibrated high-pressure container filled with crude condensate with equal temperatures of the container and the separator. The flow rate of the separated gas was measured by a diaphragm device of static flow. The crude condensate content (gas condensate factor in cm^3/m^3) was determined as the ratio of the volume (output) of the crude condensate to the volume of the separated gas from which the crude condensate was separated. The modeling of hydrocarbon losses in the presence of water vapor in the gas condensate system was carried out according to the approved methodology of Gazprom VNIIGAZ LLC, which allows the study of phase processes in the isothermal process and the development of deposits in the depletion mode. Structural features The Chandler Engineering PVT unit allows accurate measurement of the volume of produced fluid with the least error. The built-in digital video system allows measuring automatically the amount of condensate and water that has precipitated. The volume of saturated condensate and water loaded into the PVT cell was calculated by the formula: $V_{load\ k-t}$ = Vg / 1000 x Condensate Gas ratio. The basis of thermodynamic studies of gas condensate systems was the determination of development indicators at different stages of reservoir pressure reduction in the reservoir. Predicted development indicators for the operating conditions of the Srednetugskoye field are shown in Figure 1.

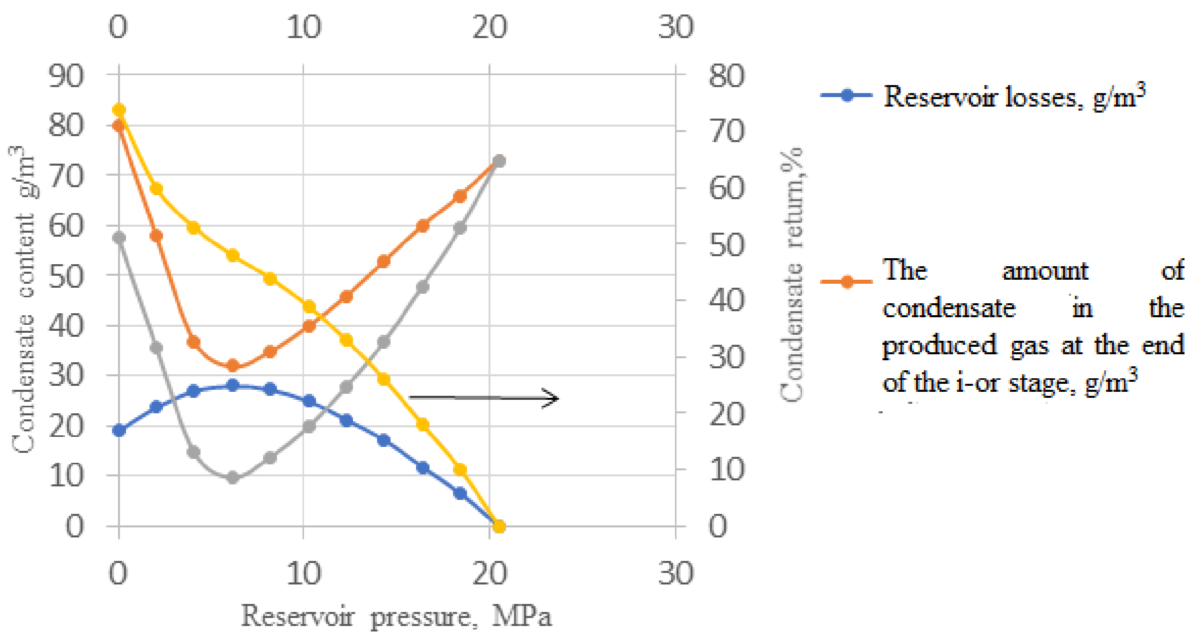

Figure 1. Forecast indicators of the Srednetyugskoye field development

The creation of a representative recombined sample to justify the effect of formation water on the coefficient of condensate recovery was carried out taking into account measurements under the conditions of development of the Srednetugskoye field of gas, condensate and water flow rates. The essence of the experiments was to determine the loss of condensate under conditions of varying degrees of saturation of the formation system with water vapor by differential condensation. The graphic curves obtained by this method for the dependence of reservoir condensate losses on pressure for the gas-condensate system of the Srednetyugskoye field are shown in Figure 2.

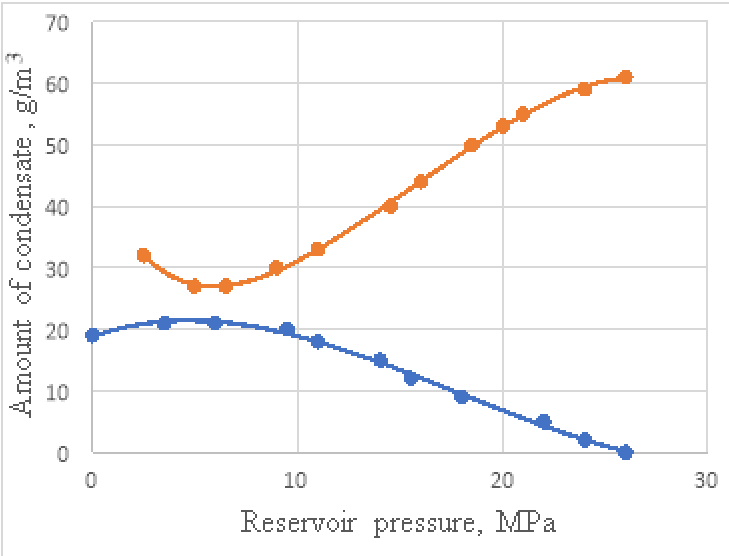

Figure 2. Dependence of hydrocarbon losses on the proportion of pressure reduction gas condensate system of the Srednetungskoye field

So, from the graphical dependence it is seen that the condensation onset pressures determined by the contact and differential method are equal to the current reservoir pressure, and amounted to 25.90 MPa. The gas condensate factor of the analyzed system is 110 cm^3/m^3, the density of the stable condensate is 0.765 g/cm^3, the molecular weight of the condensate is 119, and the reservoir temperature is 59.3 °C. After creating a recombined sample of the separation gas, saturated condensate and water in the PVT cell under reservoir conditions, the thermodynamic properties were studied. Figure 3 shows a graphical distribution of the condensate of the T1-A deposit in the presence of formation water in the system.

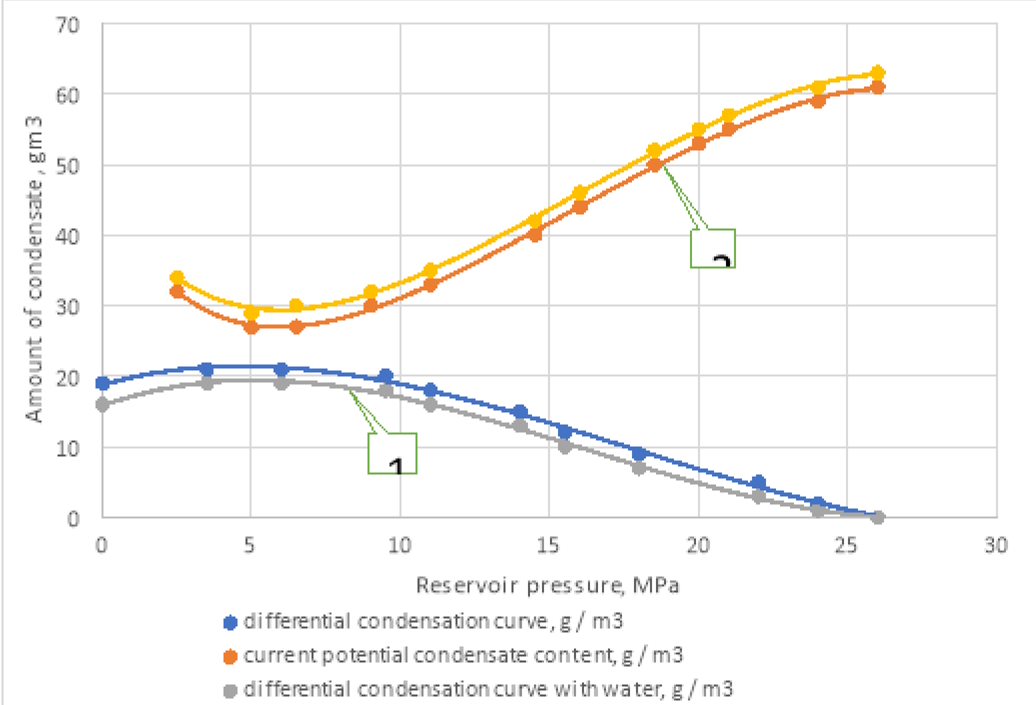

Figure 3. Graphic dependence of the distribution of the condensate of the reservoir in the presence of water vapor in the formation system with a gradual decrease in pressure
1. condensate loss with and without water g/m^3,
2. potential condensate content with and without water, g/m^3

During the study, a change in the volume of the gas-vapor mixture was observed by differential condensation and the conditions for the transition of the gas mixture to the liquid phase were determined. The experiment on differential condensation is essential, and then in subsequent experiments the formation system was released after the gas-condensate mixture was saturated with condensation water in the PVT cell. The experiment was repeated in a thermostatic cell of the PVT-ratios at different degrees of water saturation of the reservoir mixture by differential condensation.

3. Conclusion

The results of experimental studies of the phase processes of gas condensate systems of the Srednetyungskoe field showed that there is an effect of water vapor on the reservoir loss of hydrocarbons. The negative effect of water vapor on condensate loss has been established, i.e. there is an increase in reservoir condensate loss in the deposit. The comparison of the obtained data showed that the magnitude of the effect of condensation water on the phase transformations of gas condensate systems depends on the thermobaric conditions of occurrence of the deposit and the hydrocarbon composition of the condensate. In the hydrocarbon composition of the resinous part, aromatic cycles are dominant. Based on this, we can conclude:

- The condensation onset pressure determined as a result of the studies by the contact and differential method is equal to the reservoir pressure, and amounted to 25.90 MPa.
- The stabilization time of the vapor-liquid equilibrium at the points of the staged pressure reduction was established during the test. Then, the density of the stable condensate precipitated in the equilibrium cell at the end of the experiment at a pressure of 0.1 MPa and at a temperature of + 20 °C, which was 0.7560 g/cm3, was determined. The volume of condensate discharged in the PVT cell from the gas mixture in the reservoir at the end of the experiment was: 2098.14 - 1843.94 = 254.2 or 252 liters, which matches with the volume of gas loaded into the PVT cell at the beginning of the experiment. It can be observed from the graphical dependence that in the presence of water in the gas reservoir-condensate system, the pressure of the onset of condensation increased by 0.4 MPa, the pressure of maximum condensation shifted towards the beginning of condensation. The nature of the "reservoir loss" curve indicates an intensification of the

condensation process in the presence of water vapor in the well production. Loss of condensate in the reservoir and, accordingly, the final amount of condensate extraction decreased to 4% in the presence of water in the gas-condensate system. Consequently, the obtained results of thermodynamic studies can be the starting ones for assessing the balance reserves of condensate in the gas reservoir, the development of fields and the further processing of hydrocarbon raw materials.

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