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Development and exploitation of oil and gas fields**ABOUT THE PHYSICAL NATURE OF THE RETROGRADE CONDENSATION
PRESSURE OF GAS-CONDENSATE SYSTEMS IN THE POROUS MEDIA CONDITION****Corresponding Member of NAS of Azerbaijan Z.Y.Abbasov, V.M.Fataliyev**

In this paper, we have investigated the effect of porous media on phase behavior of gas-condensate systems. The results of experimental studies of phase transformations in gas-condensate systems were analyzed and found that the reservoir fluid goes into the two-phase state at pressures significantly exceeding the retrograde dew point pressure which was found in the porous media free cell. That is to say it occurs when the pressure in the interval creates the formation of liquid phase micro-embryos. On the basis of these results, new judgments were formed about the physical nature of the dew point pressure at reservoir condition. The results were used to explain the dynamic processes taking place within and, influencing the operating characteristics of the gas-condensate wells. Thus, some features are given for oil-gas field development.

Keywords: retrograde, fog up pressure, porous media, PVT bomb, gas-condensate phase behavior, PVT characteristics

The effect of porous media on gas-condensate phase behavior has been studied since 1949 [4, 8, 10]. Investigators studied some PVT characteristics of the gas-condensate systems in the reservoir model and identified that the retrograde dew point pressure (RDPP) of gas condensate systems is higher in the porous media than in the porous media free (empty) PVT cell. In the paper [11] authors gathered all experimental research results on this matter and carried out systematic analysis. They confirmed that the effect of porous environment on phase transition of hydrocarbon systems is definite. It can be even more significant in special circumstances depending on chemical and physical features of the systems, connate water in the reservoirs and lithological characteristics of formations. It was found that porous media can increase the system dew point or retrograde condensation pressure by 3 MPa in special cases. These investigations were developed in the experimental work [12]. Here experimental studies have been carried out in parallel in the free PVT cell and also in the porous media or reservoir model with the same gas-condensate systems. Differential condensation method was implemented on both vessels. Pressure depleted from 28 MPa down to atmospheric step by step. Condensate bearing was 83.6% in the PVT cell but it decreased from 77% to 59.9% when the

specific surface of granules increased from 56300 to 341500 m²/m³ in the porous media model. Also when increasing condensate ratio from 120 to 170 cm³/m³, the difference between cell and model condensate bearing increased from 3 to 11%.

There are many papers related to this subject that have been proposed in the recent years and all of them emphasize the importance of this phenomenon regarding the gas-condensate field exploitation and development [2, 5, 6]. An identical subject was studied by us in the works [2, 3]. We approached this issue in more detail: effected parameters were analyzed and selected, aspects of modeling gas-condensate reservoir were solved by using mathematical criteria and experiments were planned as per rational planning methods. A special method of statement was created for performing these experiments. The outcomes were analyzed in accordance with rational planning methods and obtained the mathematical equation which presented the correlation between the parameters studied (pressure, specific surface and porosity, amount of connate water, condensate density and temperature). Summing up the results of investigation it was confirmed that condensate bearing on the reservoir model is 8-12% less than on the PVT bomb.

Knowledge of the phase behavior of gas-condensate systems is important for predicting

reservoir performance and future processing. For this, one of the most important factors to be evaluated by engineers in planning the development of a gas-condensate reservoir, is the RDPP of the original reservoir fluid. When below this pressure, heavier components form a liquid phase and system goes to the two phase state. In this sense it is very important to understand the mechanism of the retrograde condensation process in the reservoir conditions [1]. Some valuable points of the impact have been explained in works [3, 8], however full explanation has never been given and it requires to be expanded and developed.

In this paper, we have investigated the effect of porous media on phase behavior of gas – condensate systems using experimental data which were provided by us and other investigators. The physical features of the retrograde condensation process in the porous media were studied and also some theoretical aspects were expanded and detailed differently. The conclusions were cross checked and proven on the real gas-condensate well, in accordance with analysis of condensate and gas production trends.

It is known that during changing one of the leading parameters in the given system, it moves to the next thermodynamic state. If this change results in phase transition then at first micro embryos of the new phase appear and, then they slowly grow in accordance with changes in the leading parameters. These phase transition processes were studied by many famous scientists and it has been confirmed that these phase developments can proceed differently (even in the same state) on the dissimilar circumstances as its physical properties change respectively [6]. In line with this conclusion, it can be assumed that it is the reason why a given constant temperature retrograde dew point pressure of the gas-condensate system in the porous media is higher than in the free cell. In other words retrograde condensation can happen when the liquid phase is in the early or embryotic state. This could be a very suitable condition for Intermolecular forces around a molecule in the liquid embryos and formation granular surfaces to dominate liquid to be dropped out at the pressure higher than it was identified in the free cell.

In order to learn more deeply the process of the forming liquid phase in the gas-condensate mixture, some physical and thermodynamic characteristics of the phase behavior were experimentally investigated by us [2]. Experiments have been carried out on YKT-3 type PVT bomb which is standard apparatus designed for determining thermodynamic characteristics of gas condensate systems. As with other PVT cells this bomb is also equipped with a camera for visual observation. Samples were taken from Azerbaijan gas-condensate field “Bulla-deniz”. The reservoir fluids were then prepared in the laboratory by recombining the separator condensate with the separator gas according to the gas/condensate ratio data, based on a standard analytical method for condensate gas properties [2]. The composition of the gas was C_1 - 91.61, C_2 - 4.79, C_3 - 1.41, C_4 - 1.64, C_5 - 0.53, C_6 - 0.02% and gas density was 0,7322 kg/m³. Condensate density is 745,7 kg/m³ and condensate/gas ratio of recombined gas-condensate system was 250 g/m³. A constant composition expansion (CCE) test was performed to determine the RDPP and liquid dropout behavior of the fluid.

As an example, here is the description of our observations when we introduced the process at a temperature of 75 deg. C during the CCE test. The prepared sample was pressurized to above the RDPP (28 MPa) at a temperature of 75⁰ C as per procedure. The fluid was a single phase that was transparent and pale yellow in color. As the CCE test proceeded and the pressure dropped, the color of the reservoir fluid also changed gradually from pale yellow to pale red. When the pressure was decreased to close to 25.6 MPa the fluid began to fog up (FUP), and the fog thickened with decreasing pressure. The convective phenomena of the thick fog could also be observed by the naked eye through the PVT cell window. With a continuous drop in pressure, a tiny liquid drop precipitated, and the corresponding pressure (24.6 MPa) was then assumed to be the RDPP of the investigated gas-condensate fluid. In this group of experiments, the FUP and RDPP were determined at the different temperatures. In accordance with this data the correlation between pressures (FUP and RDPP) and temperature was

identified. It was acknowledged that, there is a significant difference between FUP and RDPP, also the deference is increasing with the increase of temperature.

It is known that microscopic particles of one phase dispersed in another are generally called colloidal solutions or dispersions [9]. We can assume that gas-condensate system is dispersion when it is above the RDPP. In this case the gas is dispersion medium and condensate is dispersed phase, also condensate is atomized condition in the system. When pressure decreases isothermally, surface energy of dispersed phase increases and creates an environment for coalescing fine condensate particles. These sub-micron-sized particles grow following pressure drop and turn into the aerosol-colloidal state which can be seen as the fogging up process. Such as it was explained above and in the work [8] an aerosol state of the gas-condensate is a good favorable condition for surface forces to lead to adsorption processes between condensate particles and rock granules surfaces. This environment contributes to the system starting to occur condensate earlier, in the reservoir condition. Here is the conclusion that FUP is equal to a retrograde condensation pressure in the porous media. If this hypothesis is correct then retrograde dew point pressure can be identified very easily in the free PVT cell.

In order to test this hypothesis, we used experimental data which is provided in the paper [3]. This work is detailed above. In that paper an intention was to identify the impact of porous media on the reservoir condensate-bearing, but some useful information was determined that allowed a comparison of a couple of experiments that were carried out in parallel on reservoir model and porous media free PVT bomb. The procedure for general differential condensation (DC) in isothermal condition was applied to model the depletion regime of gas-condensate reservoir.

The prepared sample was pressurized up to 30 MPa at a temperature of 100⁰ C which is above the RDPP and then DC proceeded at this constant temperature. System pressure depleted isothermally with a constant pressure step and gas phase composition was identified at each pressure step, as per procedure. FUP and RDPP values

were identified 26,4 MPa and 24.3 MPa respectively in the PVT bomb. After applying empirical and graphical analysis the gas-condensate system RDPP has been identified as 29 MPa in the reservoir model [3]. This confirms the retrograde condensation pressure in the reservoir model is higher than in the PVT bomb. Analyzing other experimental data in the work [2, 3] we can prove that the theory which is given above and in the work [8] is not so true. Retrograde condensation of gas-condensate mixture can start above the aerosol state of the system in porous media condition. One interesting point noted in this work, it was that retrograde condensation process accelerates in the reservoir model when pressure is below RDPP identified in the PVT bomb. That evidences that in this pressure interval gravitational force starts to lead retrograde condensation progress.

It is known that there are three fundamental forces that operate on fine particles in solution: a gravitational force, tending to settle or raise particles depending on their density relative to the solvent; a viscous drag force, which arises as a resistance to motion, since the fluid has to be forced apart as the particle moves through it; the 'natural' kinetic energy of particles and molecules, which causes Brownian motion [9]. In porous media, we can add here surface energy and force between rock surface and dispersed phase which dominates the adsorption process. If we take all these into account then we can summarize that retrograde condensation in porous media can be caused by two effects.

1. Absorption process between sub-micron-sized condensate particles and formation rock granular surfaces when even gas-condensate system is above FUP, which is identified in the PVT bomb.

2. If system pressure is continuously depleted, the condensate particles grow larger, it will at some stage, break off the Brownian motion and will correspond to the maximum weight of the droplet that can hang in the dispersion medium which is gas. Also vertical filtration can occur due to gravity force being stronger than the surface tension in the reservoir model at some stage when pressure is around or below RDPP

(which was identified in the PVT bomb). That is reason why retrograde condensation was accelerated at that point.

This phenomenon can cause condensate blockage or condensate banking on the early stage of reservoir development, results from a combination of factors, including fluid phase properties and nature of compositions, formation flow characteristics and differential pressure between formation and wellbore. If these factors are not analyzed or studied correctly at the beginning of field development sooner or later production performance can suffer. However as it is seen the results of this research was obtained from experimental studies and because of some toleration on the modeling of formation conditions and also, all experiments have been carried out in thermodynamic equilibrium condition, there is a for need this conclusion to be tested in real reservoir condition.

With this in mind, we analyzed the performance of the couple of wells on "Bulla-deniz" gas-condensate field. These wells are first-drilled wells and that is why we could obtain relevant information about formation flow characteristics in the downhole zone of the wells at early stages of field development. As an example well number 20 average daily condensate/gas ratio per

month in first two years is given in the figure. This well was drilled on April 1976, depth is 5443m which is block-5 horizon VII. Initial reservoir pressure of block-5 horizon VII was 71 MPa, reservoir temperature 102°C and condensate density 800 kg/m^3 .

As it is shown in the fig. condensate/gas ratio was increasing in the first 5 months after the well started. In this period of time condensate/gas factor even exceeded the condensate/gas ratio of this block 5 which was 362 g/m^3 . It seems clear that, two phases were flowing to the well in this period but it can be expected that this is just stabilization well flow characteristics after drilling. There is a visible decrease over the next few months but then this continues in a cyclic trend. It can be seen from empirical trend of condensate/gas ratio which is shown in this picture. It should have been seen as a linear dependence of condensate/gas ratio after some period of time from first start up because initial reservoir pressure identified (71 MPa) is above the retrograde dew point pressure ($62,5\text{ MPa}$) which means fluid was on single gas phase state. We should point out this here that thermodynamic characteristics of this field were analyzed in laboratory condition in YKT-4 PVT bomb in 1976.

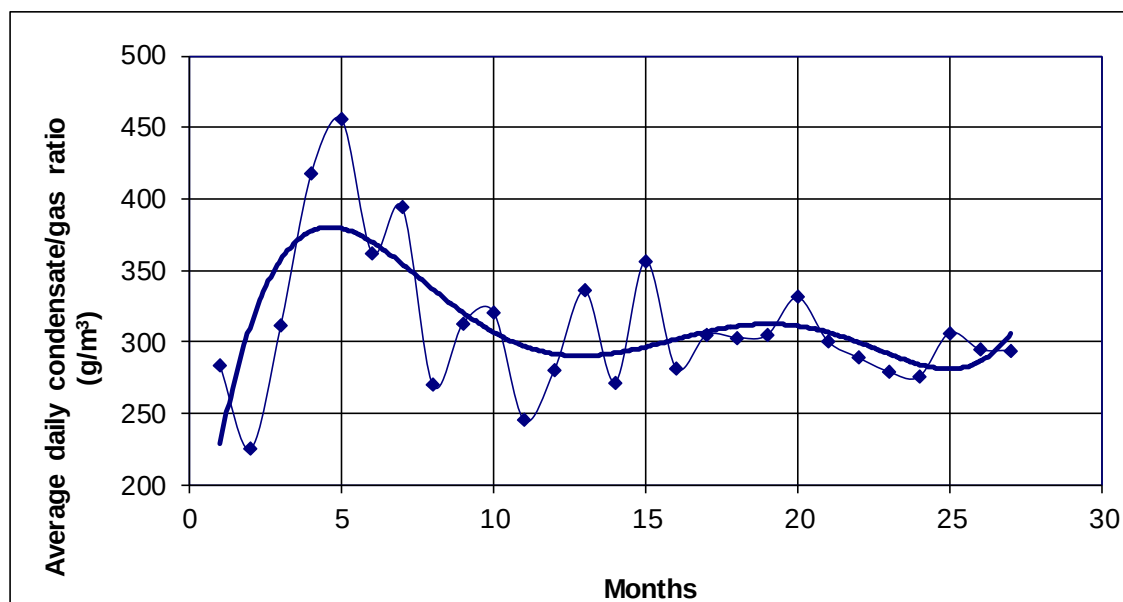


Fig. Average daily condensate/gas ratio characteristic including empirical trend of well 20 in first two years on "Bulla-deniz" gas-condensate field of Azerbaijan

This experimental study was carried out based on gas and condensate samples from this well (well 20) [2]. Investigators confirmed that even with two phases - gas and condensate flowing to the well the reservoir pressure was above fluid RDPP. Reason for this phenomenon was explained that there are free condensate pools existing at some areas in the reservoir. These condensate pools can join the filtration process and flow to the well during a drawing-down condition. This theory can explain the physical mechanism of the process but as it is well known that the reservoir has been for many years under the influence of gravity. In this case it looks unlikely that moveable condensate pools exist in some areas of the gas region of the reservoir. We tried to explain the physical mechanism of the process differently as an example of well 20 scenario, taking into account the results obtained above.

A gas condensate is a single-phase fluid at original reservoir condition. As it was explained above, microscopic particles of heavy compositions-condensate disperse in a short chain, or gas components. Reservoir fluid is in thermodynamic equilibrium condition in the initial condition. When a reservoir produces, formation temperature usually doesn't change, but pressure decreases. The largest pressure drop occurs near producing wells or near the bottom hole zone. When the pressure in a gas-condensate reservoir decreases to a certain point, it can be higher than FUP, the heavier compositions of the fluid drop out of solution due to surface forces. In other words retrograde condensation starts at an earlier stage because of contacting condensate particles with formation rock granules. Condensate saturation can build up near a well because of drawdown pressure, ultimately restricting the flow of fluid. The near well choking can reduce differential pressure and down hole pressure increases. This in turn increases the amount of saturated condensate in the formation, weaken the forces of contact or link with the surface rocks and after that, the mass of condensate begins to move to the wellbore under drawdown pressure. So down hole zone washes up, then it repeats again and cycling.

Conclusion

Experimental investigations on groups of gas-condensate fluid from Azerbaijan natural gas-condensate reservoir confirmed that two phases - gas and condensate can be flowing to the well even when reservoir pressure is higher than RDPP of reservoir fluid. This phenomenon can cause condensate blockage or condensate banking on the early stage of reservoir development, results from a combination of different factors. Summarizing all obtained theoretical and experimental data, the gas-condensate system was analyzed as a colloidal – dispersion solution and identified that retrograde condensation in porous media can be caused by two effects:

Absorption process between sub-micron-sized condensate particles and formation rock granular surfaces when gas-condensate system is above FUP which is identified in the PVT bomb. Break off the Brownian motion under gravity when system pressure continuously depletes, the condensate particles grow larger, and at some stage it will correspond to the maximum weight of the droplet that can hang in the dispersion medium which is gas. Also vertical filtration can occur due to gravity force being stronger than the surface tension in the reservoir model at some stage when pressure is around or below RDPP (which is identified in the PVT bomb). The performance analysis of the couple of wells on "Bulla-deniz" gas-condensate field confirmed that two phases - gas and condensate were flowing to the well even when reservoir pressure was above fluid retrograde dew point pressure (which is identified in the PVT bomb) due to retrograde condensation in reservoir condition.

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Institute of Geology and Geophysics of ANAS
zohhak@lan.ab.az.

QAZKONDENSAT SİSTEMİNİN RETROQRAD KONDENSASIYA TƏZYİQİNİN MƏSAMƏLİ MÜHİT ŞƏRAİTİNDƏ FİZİKİ MAHİYYƏTİ HAQQINDA

Z.Y.Abbasov, V.M.Fətəliyev

Qazkondensat sistemlərində baş verən retroqrad faza çevrilmələrinin laboratoriya şəraitində eksperimental tədqiqi nəticəsində əldə edilmiş məlumatlar təhlil edilmiş və müəyyən edilmişdir ki, qazkondensat sistemi ikifazlı hala retroqrad kondensasiya təzyiqinin boş PVT bombasında tapılmış qiymətindən böyük təzyiqlərdə, yəni maye fazasının mikrorüşeymlərinin – aerosolun yarandığı zonada keçir. Məqalədə, alınmış bu nəticələr əsasında retroqrad kondensasiya təzyiqini məsaməli mühit şəraitində fiziki mahiyyəti haqqında mülahizələr irəli sürülmüş və bu mülahizələr real qaz-kondensat yatağının istismar dinamikası üzrə baş verən proseslərin izah edilməsində istifadə edilmişdir.

Açar sözlər: qazkondensat, retroqrad, mikrorüşeym, PVT bombası, məsaməli mühit, kondensasiya təzyiqi

О ФИЗИЧЕСКОЙ СУЩНОСТИ ДАВЛЕНИЯ РЕТРОГРАДНОЙ КОНДЕНСАЦИИ ГАЗОКОНДЕНСАТНЫХ СИСТЕМ В УСЛОВИЯХ ПОРИСТОЙ СРЕДЫ

З.Я.Аббасов, В.М.Фаталиев

Проанализированы результаты лабораторных экспериментальных исследований фазовых превращений в газоконденсатных системах. На основании этих результатов установлено, что газоконденсатная система переходит в двухфазное состояние при давлениях, превышающих принятые значения давления ретроградной конденсации, то есть в зоне давлений образования микророзродышей аэрозолей конденсата.

Таким образом, сформированы новые суждения о физической сущности давления начала конденсации в пластовых условиях, что было использовано в объяснении процессов, имеющих место при изучении динамики эксплуатационных показателей газоконденсатной залежи.

Ключевые слова: газоконденсат, микророзродыши, бомба PVT, пористая среда, давления конденсации