BIN NIE
and
ER-PENG LI

Phase behaviour and development scheme of near-critical gas condensate reservoir

Combined with fluid data of J gas reservoir in Africa, the phase characteristics of near-critical gas condensate reservoir were studied, and the applicable development technique were analyzed using reservoir numerical simulation. The results show that the near-critical gas has the following characteristics. It has a high content of condensate oil, the sensitivity of phase is strong, and the degree of retrograde condensation is high. Depletion type of recovery results in great loss of condensate oil and poor production, the method of water-oil alternating recovery could control the level of condensate effectively and get a high oil production rate. In addition, it avoids the rising up of water cut too early and quickly in the method of water flooding. Water-oil alternating recovery is the best producing method which combined the advantages of water injection and gas injection. Further study on sensible factors in water-oil alternating recovery indicates that the water/ gas ratio (WGR) has the greatest impact on production effect. When the WGR is too high, injected water will rush into the well bottom too early; when the WGR is too low, the advantage of water injection to displace and provide pressure is lost, and condensate oil production rate cannot be enhanced.

Keywords: *Gas condensate reservoir, near-critical, phase behaviour, water-oil alternating recovery.*

Introduction

It refers to the region's T_r during 0.95 T_c and 1.05 T_c as the near-critical area generally (where T_c is the critical temperature; T_r is the formation temperature). In the near-critical region, the fluid will have some special properties: fluid property between the liquid and the gas, and the density near the liquid while viscosity close to gas. The growth rate of gas-liquid two-phase density difference is faster than interfacial tensions between isothermal phase change process; the phase changes violently as the thin oil rim shows frequently. The particularity of the near-critical condensate gas reservoir has brought greater difficulties for the development of condensate gas. In recent years, many researches on near critical condensate gas reservoir phase change were the experimental research, and for the type of the actual gas reservoir development characteristics. Development is less investigated; the authors analyzed the development mode of J gas reservoir which is a near-critical condensate gas reservoir in Africa through the reservoir numerical simulation method.

Messrs. Bin Nie, Petroleum Engineering College of Yangtze University, Hubei. E-mail: niebin19880918@163.com and Er-peng Li, Research Institute of Exploration and Development, PetroChina Tarim Oilfield Company 1, Korla 841 000, China. E-mail: 382655437@qq.com

General situation of gas reservoir

J gas reservoir belongs to the delta front sedimentary environment, with multiple sets of stable interlayer, top-down development of multiple sets of oil and gas water system, for all of this just as the typical structure of stratified reservoir. The buried depth of gas reservoir is 1700~2500 m, the effective thickness of reservoir is 1 ~ 12 m, the porosity range is 11% ~ 22%, the permeability is 0.07 ~ 1246*10^{-3} μm^2 (average as 12.02*10^{-3} μm^2). The reservoir heterogeneity is strong, which belongs to the medium porosity and low permeability reservoir. It belongs to the normal pressure system when the original reservoir pressure is 25.1 MPa and the pressure coefficient is 0.96. The middle depth temperature is 80ºC and the temperature gradient is 3ºC/100 m. The gas reservoirs is a condensate gas reservoir with most of raw material cause methane content is 67.3% ~ 72.5%, propane of the raw material is more than 20% and carbon dioxide content is between 0.86% ~ 1.02%.

Phase behavior

The gas reservoir formation fluid sample is getting from composite stabilizer of the condensate and dry gas sample, and its components are shown in Table 1.

TABLE 1: GAS RESERVOIR FLUID COMPONENT

Component	Mole fraction /%	Component	Mole fraction /%
N_2	0.712	NC_4	5.414
CO_2	0.8962	IC_5	1.362
C_1	71.036	NC_5	1.046
C_2	5.375	C_6	2.3405
C_3	1.967	C_7	1.1562
IC_4	4.851	C_8^+	3.8441

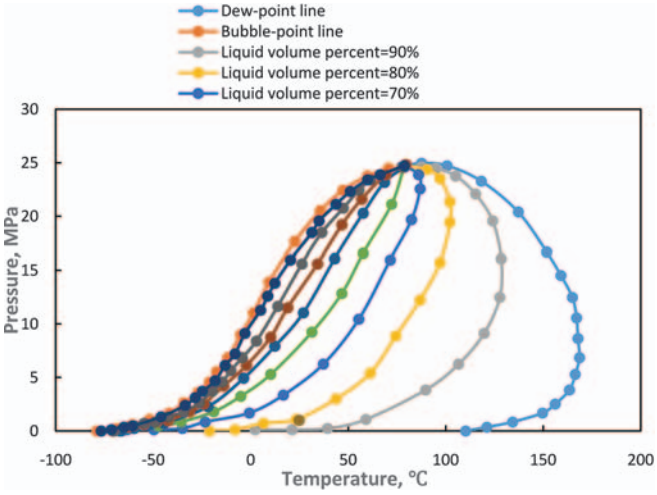

Fig.1 Gas reservoir fluid phase diagram

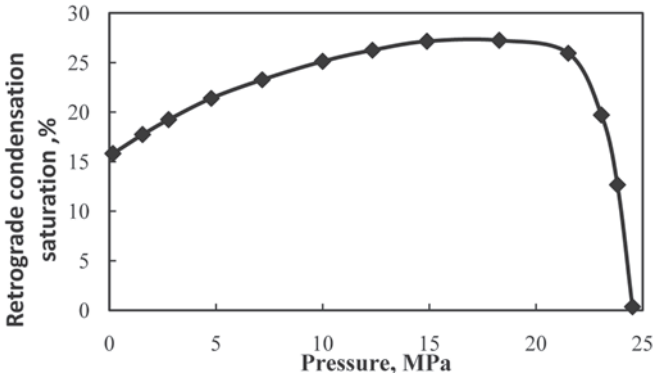

Fig.2 Variation curve about condensate quantity

Fig.1 signifies the liquid phase diagram of the condensate gas reservoir and Fig.2 presents the retrograde condensate volume curve. Combined with the other relevant experimental data, the phase characteristics of the gas-condensate reservoir are analyzed. And then it mainly shows the following characteristics:

(1) High content of condensate oil: condensate oil content of the near-critical condensate gas reservoir is generally higher, the content of condensate oil J gas reservoir is 462 g/m^3. According to the fluid phase diagram of Fig.1, the liquid volume lines are mostly concentrated in the low temperature region, and the volume of the liquid is relatively low, but the liquid volume is large while in the reservoir temperature range.

(2) Phase change sensitivity is strong, as shown in Fig.2, the retrograde condensate liquid phase volume with pressure reduce sharply increased and pore anti condensate saturation moment to maximum in the near-critical region when the reservoir pressure below the dew point pressure, so that J gas reservoir of retrograde analysis of pressure in 15 to 22 MPa.

(3) The degree of retrograde condensation was serious. In the experiment of the equal volume depletion, the condensate saturation was high, and the average condensate oil saturation was 21.14%.

Development mode research

The central problem of developing condensate gas reservoir reasonably and effectively is the choice of development mode. Based on the numerical simulation method, this paper establishes a multiphase fluid flow model of the multi-phase fluid in the near-critical condensate gas reservoir of J gas reservoir and studies its development mode. There are two main types of condensate gas reservoirs exploration way, namely the depletion type mining and the pressure mining.

(1) The depletion mining is also called buck mining, which is based on the formation of natural energy displacement of the mining. The biggest advantage of this method is less investment and easy to operate, but the disadvantage is the formation pressure drop quickly, when it downs to the dew point pressure, the layer of retrograde condensation shows. The retrograde condensation liquid is accumulated in the near well area which is blocked by the oil and gas channel and that can affect the recovery of condensate oil. The method is more suitable for condensate gas reservoirs with low condensate content (below 100 g/m^3) or poor reservoir connectivity.

(2) The pressure mining is using injection agent displacement of moisture rich in condensate which can effectively maintain the formation pressure and avoid or reduce the retrograde condensation amplitude, so it is the main method to improve the condensate oil recovery.

Dry gas, nitrogen and water are commonly used as injection agents in the pressure mining, and there are three main methods, which are cycle gas injection, water injection and water gas. As the nitrogen gas shortage in J gas reservoir, and the effect of dry gas on the recovery of condensate is better than that of other non-hydrocarbon gases in general, so the injection gas is used to remove the dry gas after condensate oil.

Then it can forecast the production of each development with the design of single well gas production is 7 * 104 m^3 /d and the injection production ratio was 1: 1.

Mining effect comparison

Fig.3 shows the development effect of each mining method. The production effect of failure mining is the worst, and the condensate oil recovery degree is only 10.8%. Using packing methods can be achieved very good results, a high degree of condensate recovery which can reach more than 30% and recovery degree of condensate oil is 44.7% of which the best effect is WAG.

The condensate gas reservoir with high content of condensate oil and condensate phenomenon is serious, but the condensate saturation maximum value is 27.24%, lower than the critical flow saturation (38%), condensate oil in the

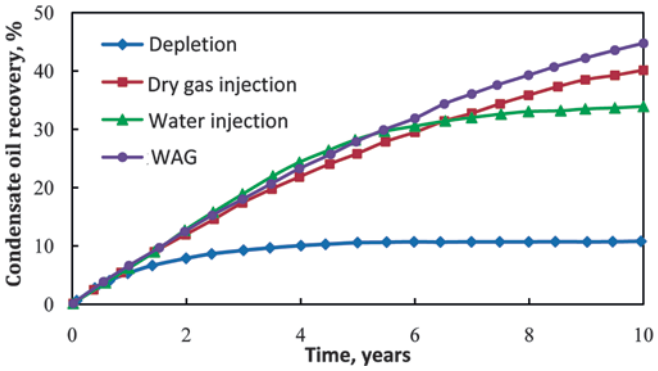

Fig.3 Comparison of recovery with different producing method

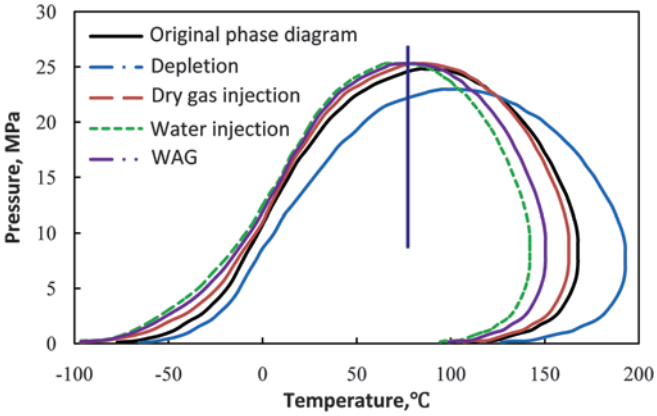

Fig.4 Comparison of phase diagram with different producing method

stratum cannot flow, but can increase the resistance of the gas flow, so when we choose the depletion of near-critical condensate gas reservoir it can only cause condensate loss serious and also can affect the gas production capacity to get a poor development effect.

The pressure mining effectively controls the degree of retrograde condensation, so that condensate oil can be extracted in a gaseous state which can effectively improve the development effect.

The cost of water injection production is lower than gas injection and can achieve a good effect of pressure retaining effect, while the viscosity of water is large and the sweep coefficient is larger than the gas injection, so the oil recovery rate is the highest in the early stage. However, only choose the simple water injection development can make gas condensate reservoir see the water early; even the water rising is faster and associated gas production at the same time produces a lot of water, at the same time reservoir pressure begins to drop, so the final production level is low. Compared to the gas injection, the WAG can more effectively ensure the reservoir pressure and control retrograde condensate, and it also avoids the water rise early and water injection alone too quickly, so the effect is better than that of conventional water injection and gas injection development.

Fluid phase change analysis

Fig.4 signifies the phase diagrams of different producing methods in which the formation fluid composition data are got by 10 years later after J gas reservoir had produced. Compared the phase change characteristics of these phase diagrams to the original phase diagram which is got before the gas reservoir is put into development.

(1) Depletion development causes overall liquid line downward, maximum critical condensate pressure decreases, maximum critical condensate temperature rises, reservoir isotherm has deviated from the retrograde condensate area and have a trend of gradually transformed to the reservoir, the whole things below show the condensate gas reservoir in dry gas recovery ratio as high, heavy content on the rise and fluid anti condensate as high degree in the formation fluid composition, so most of condensate oil are in the strata.

(2) Dry gas and WAG development cause fluid liquid line generally offset to the left, maximum critical condensate pressure increases, reduces the maximum critical condensate temperature, reservoir isotherm gradually deviates from the near critical region; these reflect the formation of fluid heavy content decreases; reservoir fluid retrograde condensation degree is low, condensate produces high degree.

(3) Water injection development cause liquid flow line slightly to the left, the critical point location is very small, the overall change of the phase diagram is small, which shows that the formation of oil and gas composition has basically no change.

Comprehensive analysis of the development effect of J gas reservoir and the phase change of formation fluid, the effect of the near-critical condensate gas reservoir is the best.

WAG parameter sensitivity analysis

According to single factor analysis method, the sensitivity analysis of various parameters such as alternating water injection period, injection production ratio, WAG ratio and so on in the WAG mining process was carried out.

Alternating water injection cycle

Fig.5 shows the calculation results of the condensate oil recovery in different alternating periods. The WAG cycles respectively 20, 30, 40, 50, 60 d. Fixed injection-production ratio and water gas ratio all are 1:1, gas production is $7*10^4$ m^3/d.

It presents that water or gas injection may play the role of good pressure in the WAG injection process, the cycle of the WAG is a weak effect on the development of condensate gas reservoir;only in the case of water injection time is too long, easily caused by injecting water then leads to premature water wells, the impact is of development effectiveness. The alternating cycle is too short, replacement of injected medium frequently only increased operating costs, so the best alternate cycle is 30 ~ 40 d.

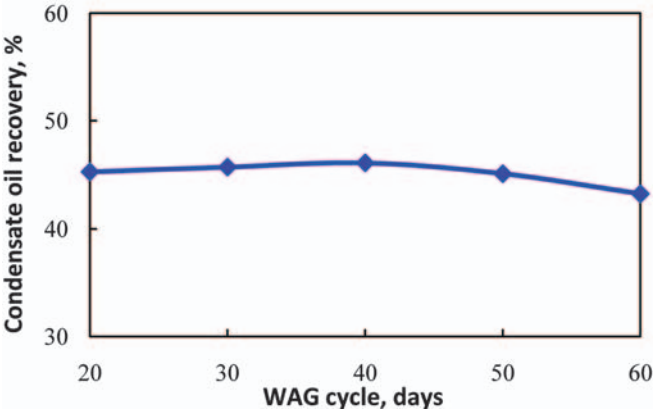

Fig.5 Recovery of condensate oil with different alternate cycle

INJECTION-PRODUCTION RATIO

When the injection production ratio is too low, the formation pressure cannot be effectively added and the retrograde condensation degree gets high in the WAG development process; so the development effect is poor. When the injection production ratio is too high, the injection of water will soon break into the bottom of the production wells resulting in gas wells flooded.

Fig.6 presents the simulation results of the production of the condensate gas reservoir under different injection-production ratio when the WAG fixed period is 40 d, the water gas ratio is 1: 1 and the gas yield is $7*10^4$ m^3 /d. WAG can play a good role in maintaining the pressure from analyzing the result, it can be appropriately reduced injection production ratio, when the injection production ratio is 0.9, better development effect can be achieved. When the injection production ratio reaches 1.1, the recovery degree of condensate oil decreases sharply, which is caused by the excessive injection of water into the bottom of the gas well, in turn the condensate gas recovery channel is blocked and the recovery degree is reduced.

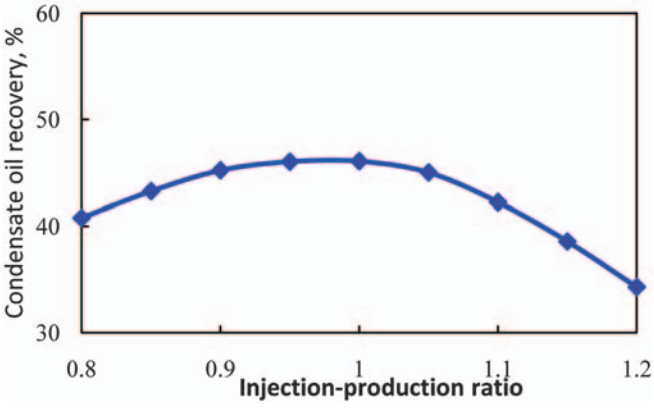

Fig.6 Recovery of condensate oil with different injection-production ratio

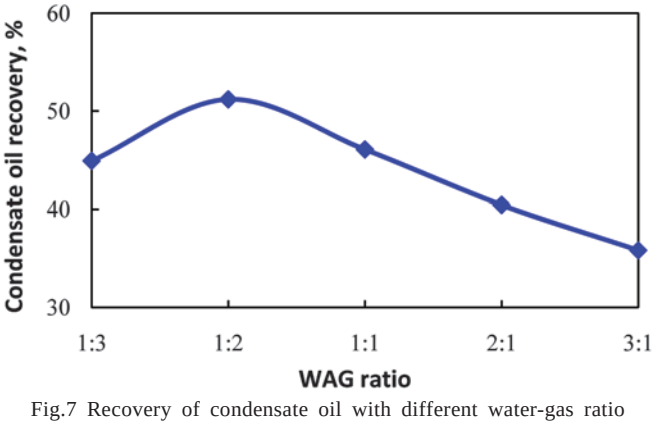

Fig.7 Recovery of condensate oil with different water-gas ratio

WAG RATIO

WAG fixed period of 40 d, injection-production ratio was 0.95, the gas production of $7*10^4$ m^3/d, water gas ratio of 1 to 3 were selected, 1:3, 1:2, 1:1, 2:1, 3:1, water gas ratio calculation of different degree of condensate recovery, the results are shown in Fig.7. With the reduction of water gas ratio, it can be more effective to control water and condensate oil recovery degree gradually increases in the control of retrograde condensation; when the water gas ratio is lower than 1:2, the condensate recovery is not up but down, this is because of the low water gas ratio, cannot effectively play the water injection flooding for the pressure and improve the productivity.

Conclusion

(1) Compared to general condensate gas reservoir, the near critical condensate gas reservoir has the characteristics of high condensate content, more severe phase change and serious retrograde condensate phenomenon.

(2) Using the pressure mining near-critical condensate gas reservoir and effectively control the retrograde condensation and improve the development effect. The recovery degree of condensate can reach more than 30%.

(3) Compared to conventional water injection and gas injection, the development of WAG can effectively maintain the formation pressure, obtain a higher production rate, and can control the rising of water content, and is the best way of development.

(4) In the process of alternation of WAG, the effect of water gas ratio is the most, with the decrease of water gas ratio, the recovery degree of condensate oil increases first and then decreases. The results show that the gas reservoir development effect is best when the water gas ratio is 1: 2.

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