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RESEARCH PAPER

Killing fluid loss mechanism and productivity recovery in a gas condensate reservoir considering the phase behavior change

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Abstract: A single well numerical model considering rock capillary pressure and hysteresis was built to study killing fluid loss mechanism and its influence on productivity recovery under different positive pressure differentials based on the gas reservoir characteristics of the gas condensate well by combining the reservoir engineering and oil and gas phase behavior theory. The results show that when reservoir pressure of near wellbore zone increases to the critical pressure of condensate oil, the three-phase (oil, gas, water) flow will change to two-phase (oil, water) flow, the gas block effect will weaken, and water-phase relative permeability will increase, which can be manifested as sharp increase of killing fluid loss rate; and the rising fluid loss into the reservoir can affect the phase of condensate oil and gas and fluid distribution in the storage space near wellbore, and consequently lead to abnormal killing fluid loss. The larger the fluid loss volume, the longer the time is needed to flow back the killing fluid after going into operation again and the lower the fluid flow back efficiency, and the longer the time need to recover stable production of condensate oil and gas will be. Using fluid loss control solution or lowering liquid-column positive pressure differential (by using low-density killing fluid) can effectively avoid abnormal fluid loss during overbalanced well workover and guarantee productivity recovery after well workover.

Key words: gas condensate reservoir; phase behavior change; killing fluid; numerical simulation; loss mechanism; productivity recovery

Introduction

Gas condensate accounts for quite a proportion of oil and gas resources in the world, but its complex physical and chemical properties make it difficult to develop[1–3]. Gas condensate reservoir is usually developed by depletion, when the pressure near wellbore drops to dew point pressure of condensate oil and gas, condensate liquid would occur near well bottom, causing liquid blocking damage, reducing gas phase relative permeability and condensate oil and gas recovery[4–7]. Workover operation is frequent during the middle-late stage of gas condensate reservoir development. Killing fluid could leak easily into formation and remain in the zone near wellbore under the effect of capillary force during workover operation in low pressure gas condensate reservoir, causing liquid blocking damage. In order to reduce the formation damage caused by killing fluid leakage, the reservoir protection technology for low pressure formation workover has been researched and a series of reservoir protection liquid systems have been invented in recent years by China and abroad. In light of the high temperature and high pressure in Yakela-Dalaoba gas condensate field of Xinjiang, TBO-type killing fluid of low damage was developed, solving the problems of workover fluid leakage and formation damage[8]. The solidified water killing fluid was invented, to prevent workover fluid leaking problem in low pressure reservoir layers and protect the oil and gas reservoir layers against damaging[9]. Low damage temporary plugging fluid system was developed for Changqing old gas storage reservoir with low pressure and high water cut, which was effective in sealing water layer[10]. MacPhail et al. developed a micro-foam fluid system, and the oil and gas flowing capacity could quickly recover after workover with this fluid[11]. Vasquez et al. developed a new solid-free and low leakage killing fluid, which could effectively reduce the fluid loss in low pressure formation after well workover[12]. However, as these technologies are often high in cost and have the risk of blocking removal difficulty, the produced water or clean water is still widely used as low cost killing fluid.

Killing fluid loss during workover in low pressure gas condensate reservoir can increase pore pressure in the near

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wellbore zone, affect the phase behavior of oil and gas, induce change of oil, gas and water saturation and seepage flow behavior, which in turn would exacerbate the leakage of killing fluid, and make the oil and gas productivity after workover lower. In this study, taking a gas condensate well as example, numerical simulation was used to find out the killing fluid loss mechanism during workover operation and predict productivity recovery pattern after killing fluid loss, in the hope of providing theoretical support for production of this kind of wells.

1. Building of gas condensate single well model

1.1. Grid setting

A single well model was established in CMG-GEM module based on a gas condensate reservoir. The reservoir has an initial formation pressure of 48 MPa, initial temperature of 136.5 °C, and a critical pressure of 51.5 MPa. The well has a testing radius of about 300 m. According to geologic and logging data, the grid for the reservoir model was 21×21×16. The grids were refined with logarithmic cell densification treatment in plane to capture accurate changes in formation pressure near wellbore and saturation (oil, gas and water). Vertically, grids were unevenly arranged according to geologic horizons and perforation, with the perforated pay processed by local densification treatment. With a top depth of 4963.5 m and bottom depth of 5 163.0 m, the model's grid has a control height of 199.5 m. The gas condensate reservoir has a matrix porosity of 18% and permeability of 50×10^{-3} μm^2, rock compressibility factor of 5×10^{-6} kPa^{-1}, condensate oil relative density of 0.805, condensate gas relative density of 0.661, and initial water saturation of 43.2%. In the center of the grid, a production well and a virtual water injection well were set up in the same perforation section. In order to simplify the killing fluid loss model, Bahrami et al.[13–15] assumed that the volume of drilling fluid loss was equal to water injected volume under positive pressure differential. In this study, we adopted the same method to simulate well killing fluid loss process during workover in the gas condensate well.

1.2. Relative permeability curves and capillary pressure model

Relative permeability curves (oil, gas and water) equations derived by Larsen et al[16] were used in the simulation, which will influence the simulation effect and prediction reliability, the main equations are as follows (with gas permeability curve as an example).

$$S_{\rm gf}=\frac{1}{2}\left[\left(S_{\rm g}-S_{\rm gr}\right)+\sqrt{\left(S_{\rm g}-S_{\rm gr}\right)^2+\frac{4}{C}\left(S_{\rm g}-S_{\rm gr}\right)}\right] \quad (1)$$

$$K_{\rm rg,drain}\left(S_{\rm g},S_{\rm w,start}\right)=\left[K_{\rm rg,input}\left(S_{\rm g}\right)\right]\left(\frac{S_{\rm wi}}{S_{\rm w}}\right)^{\alpha} \quad (2)$$

$$K_{\rm rg,imb}\left(S_{\rm g}\right)=K_{\rm rg,drain}\left(S_{\rm gf,trans}\right) \quad (3)$$

$$p_{\rm cgw}=f\left(S_{\rm g}\right) \quad (4)$$

Equations 1 to 4 represent the free gas saturation formula, curve of gas phase displacement by liquid phase, gas phase imbibition curve and gas-water capillary pressure curve, respectively. In the simulation, iteration was used in calculation. Relative permeability curves and the capillary pressure of oil phase and water phase were calculated by the other formulas in reference 16. The initial input data of oil-water relative permeability and gas-liquid relative permeability are given in Tables 1 and 2.

1.3. Phase behavior equilibrium model

Phase behavior modeling is crucial in numerical simulation, PR (Peng-Robinson) equation of state was taken [17] in this study:

$$p=\frac{RT}{V-b}-\frac{a\alpha(T)}{V(V+b)+b(V-b)} \quad (5)$$

The equation can be used to calculate the thermodynamic parameters of each component of gas condensate, with which the gas condensate can be divided into a few pseudo-components.

Table 1. Input data for oil-water relative permeability

$S_{\rm w}$/%	$K_{\rm rw}$	$K_{\rm row}$	$p_{\rm cow}$/kPa	$p_{\rm cowi}$/kPa
40	0	1.000 0	50.0	50.0
45	0.008 5	0.731 6	32.1	28.1
50	0.021 2	0.533 9	23.9	18.5
55	0.036 7	0.392 7	19.5	14.3
60	0.052 3	0.283 9	17.9	12.8
65	0.069 2	0.210 5	17.0	11.7
70	0.093 2	0.154 0	16.5	11.1
75	0.117 2	0.094 6	16.0	10.6
80	0.152 5	0.052 3	15.5	9.4
85	0.199 2	0.018 4	14.8	6.0
90	0.272 6	0	13.3	0
95	0.368 6	0	8.7	0
100	0.500 0	0	0	0

Table 2. Input data for gas-liquid relative permeability

$S_{\rm l}$/%	$K_{\rm rg}$	$K_{\rm rog}$	$p_{\rm cog}$/kPa	$p_{\rm cogi}$/kPa
40	1.000 0	0	50.0	50.0
45	0.642 7	0.007 1	34.3	31.0
50	0.436 4	0.016 9	22.6	19.0
55	0.302 3	0.026 8	19.5	13.2
60	0.211 9	0.039 5	18.8	11.6
65	0.139 8	0.049 4	18.1	11.0
70	0.086 2	0.077 7	17.7	10.5
75	0.049 4	0.113 0	17.2	9.9
80	0.025 4	0.166 7	16.8	8.1
85	0.011 3	0.245 8	16.4	5.0
90	0	0.382 8	14.8	0
95	0	0.603 1	9.3	0
100	0	1.000 0	0	0