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Transient pressure test analysis of horizontal wells in gas condensate reservoirs: Evaluation of conventional multi-phase pseudo-pressure solutions

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ABSTRACT

Transient pressure test analysis, as a tool to well and reservoir characterization, is not well developed in two-phase horizontal wells. As our best knowledge, potential of conventional multiphase pseudo-pressure solutions in horizontal well test analysis of gas condensate reservoirs below dew-point pressure has not been demonstrated yet. The most challenge is that flow regime around horizontal wells is not constant. Also, high velocity effects near wellbore are the other main conflict which need more investigation.

The objective of this paper is to express encountered challenges in transient pressure test analysis of horizontal wells in gas condensate reservoirs below saturation pressure. For this purpose, based on simulated models, potential of the conventional multiphase pseudo-pressure solutions to interpret pressure behavior of these wells is examined. Also, their potential to estimate well and reservoir properties is investigated. After that, the reason for inability of these solutions in well test analysis of horizontal wells is explored. Furthermore, the effects of near wellbore phenomena on two-phase horizontal gas wells are studied.

The results show that, during early radial flow, once bottom-hole pressure falls below dew-point, pressure data shows a composite behavior; however, two phase pseudo-pressure responses calculated by both steady-state and 3-zone solutions, can accurately correct the effect of liquid saturation. In the result, reservoir permeability is estimated with a good accuracy. The study also expressed that, during other flow regimes, deviation from single phase flow due to condensate accumulation cannot be corrected using conventional solutions of two-phase pseudo-pressure function. The reason is that fluid composition is not constant during any of the flow regimes except radial flow. Though, constant fluid composition is the basic assumption for the conventional solutions. Moreover, the result shows that non-Darcy effect in two-phase flow is less than single-phase. Also, positive coupling effect around horizontal wells is not as much significant as vertical wells.

1. Introduction

In recent years, due to depletion of many giant reservoirs, tendency to develop small and thin reservoirs is dramatically increasing. Horizontal drilling as one of the best completion methods in thin reservoirs, naturally fractured reservoirs and reservoirs with gas or water coning problems is more interesting in gas condensate fields; because pressure maintenance is crucial to achieve optimum recovery of valuable fluid components in gas condensate reservoirs.

Although there are many studies on gas condensate well test around vertical wells, gas condensate well test analysis around horizontal wells needs more investigation. A few published literatures in this area mostly focus on well performance rather than on well test. Muladi and Pinczewski (1999), Dehane et al. (2000), Boualem and Tiab (2006) and Jamiolahmady et al. (2007) worked on the performance of horizontal wells in gas condensate reservoirs. They conducted numerical simulations on horizontal wells and performed sensitivity analysis on relevant parameters. Hashemi and Gringarten (2005) conducted a series of sensitivity

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Nomenclature

c_t	total compressibility, psi^{-1}
h	reservoir thickness, ft
x_r	reservoir length
y_r	reservoir width
k	permeability, md
L_w	length of the well
$\psi(p)$	pseudopressure
q	volumetric flow rate, Mscf/day
r_w	wellbore radius, ft
S	skin
t	time, day
x, y, z	coordinate, ft
z	gas compressibility factor
ϕ	porosity, fraction

Subscripts

r	reservoir
w	well

studies to compare the well productivity of horizontal, hydraulically fractured and vertical wells in a lean gas condensate reservoir. Ghahri et al., (2011) also conducted a sensitivity analysis to evaluate the impact of a number of pertinent parameters on productivity of horizontal and deviated wells.

Harisch et al. (2001) performed an experimental work and expressed how multiphase flow would affect test interpretation and how liquid dropout would affect the long-term production performance of the well. They concluded that multiphase flow had no effects on their particular horizontal well test with pressure drawdown just below dew point. The test is not conducted under significant pressure drawdown below dew point. This result is not consistent with Hashemi et al. (2004). Hashemi et al. (2004) performed some case studies to understand near wellbore well test behavior in horizontal wells in gas condensate reservoirs and demonstrated how horizontal well flow regimes are affected by condensate accumulation, and how this modifies the derivative curves. It is noticeable that, they used only single phase pseudo-pressure function.

However, as our best knowledge capability of the conventional multiphase pseudo-pressure solutions in horizontal well test analysis in gas condensate reservoirs has not been demonstrated yet; consequently, there is no approach to use transient well test data to estimate well and reservoir parameters.

In the following, a brief description of main features of flow behavior in two-phase gas condensate reservoirs is presented, and the methods to analyze well test data in gas condensate reservoirs below dew point are explained. Then, flow regimes around horizontal wells and related analytical equations are briefly expressed. After that, synthetic models of vertical and horizontal wells in gas condensate reservoirs above and below saturation pressure are simulated by a compositional simulator. Based on simulator output, numerical responses calculated from single-phase pseudo-pressure and multiphase pseudo-pressure functions are compared with analytical solution. Before studying horizontal wells, a vertical well model is analyzed to confirm that numerical solutions are applied correctly. Next, two single-phase horizontal well models are analyzed to confirm that analytical equations are applied correctly in gas systems. Then, two-phase gas condensate horizontal wells are studied. After that, the reason for deviation between analytical and numerical responses during different flow regimes except radial is expressed. At last, the effect of non-Darcy flow and capillary pressure on two-phase horizontal gas wells are examined.

2. Background

Flow behavior of gas condensate reservoirs is much more complicated than dry gas reservoirs. Because there are many special features that affect the performance of gas-condensate reservoir during the exploitation process. In a typical gas condensate reservoir, until pressure is above dew point, there exists only single-phase gas. During isothermal production when bottom-hole pressure falls below dew-point, hydrocarbon liquid dropouts. Condensate buildup around the wellbore leads to a significant decrease in gas effective permeability. The retrograde condensate phase first forms near the wellbore and propagate circularity around the well. Condensate buildup may create three regions with different liquid saturations around the well[2,12,17]:

- Region-1: Farthest away from the well, pressure is still above saturation pressure. This outer region contains single phase reservoir gas. Fluid composition is constant and is equal to the original reservoir gas. This region exists only when reservoir pressure is greater than dew-point pressure of the original fluid.
- Region-2: Closer to the well, there is an intermediate region with a rapid increase in condensate saturation and accordingly a decrease in gas relative permeability. However in this region, liquid is immobile and single-phase gas is flowing; so, fluid composition is not constant. In this region, the outer boundary pressure is equal to the saturation pressure of the original gas if $P_r > P_d$, or it is equal to the average reservoir pressure if $P_r < P_d$. The inner boundary pressure is the saturation pressure of the produced well stream fluid. This pressure is named P^*. P^* is also defined as pressure in critical oil saturation.
- Region-3: Near the well, an inner region forms where liquid saturation reaches to a critical value and both gas and liquid flows simultaneously at different velocities. Flowing composition throughout this region is constant and it is equal to the composition of the produced well stream mixture. Outer boundary pressure of this region is equal P^* and inner boundary pressure is equal well flowing bottom hole pressure, P_{wf}.

Existence of these regions and their extent depends on reservoir pressure and fluid richness. There may also exist a fourth region in the immediate vicinity of the well where low interfacial tensions (IFT) at high rates yields a decrease in liquid saturation and an increase in gas relative permeability[2,21].

2.1. Near wellbore effects

In gas condensate reservoirs, two rate-dependent phenomena influence on flow behavior within a few feet of the wellbore. These phenomena act in opposite direction. A balance between various phenomena occurring near wellbore region controls flow and pressure behavior of the well[2,19].

2.1.1. Positive coupling

High velocity leads system to the near critical condition; therefore the IFT (Interfacial Tension) decreases. The high velocity and low IFT effects are modeled in term of a single parameter