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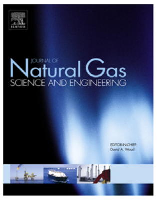

A new changing wellbore storage model for pressure oscillation in pressure buildup test

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ABSTRACT

The early characteristic of the pressure buildup test is usually dominated by wellbore storage effect. These wellbore phase redistribution effects, which are transient in nature, including phase re-injection, bubble flow and hammering effect, sometimes lead to the pressure oscillation in early pressure buildup. And, these phenomena are characterized with the changing wellbore storage effect. But the present changing wellbore storage models vary with time monotonically, which could not describe these periodic processes.

This paper presents a new changing wellbore storage model for analysis of the pressure oscillation process at wellbore or near wellbore region during the pressure buildup test. First, the physical processes of the phase re-injection, bubble flow and hammering effect are analyzed for reasons of the pressure oscillation. Then, a periodic correlation is introduced to describe these processes based on experiments. Finally, a new model is proposed by taking account of the combination of the Fair model and a cosine function.

Then, the Stehfest algorithm and Crump algorithm are used to simulate the process of pressure oscillation. The results show that Stehfest algorithm has a significant error on high frequency pressure oscillation, but Crump algorithm could simulate the whole process of pressure oscillation more accurately than that of Stehfest algorithm.

When the pressure oscillation occurs in the well test, the pressure and pressure derivative of the proposed model could match the experimental data and oil field data very well. With this model, the pressure oscillation in the pressure buildup test can be understood and predicted better. And the proposed model is a supplement to the phase redistribution model and yields an insight into the corresponding impact on well test transient pressure behavior.

1. Introduction

The phenomenon of wellbore phase redistribution occurs in a well which is shut-in with gas and liquid flowing simultaneously in the tubing. Stegemeier and Matthews (1958) firstly proposed the negative impact of phase redistribution on pressure transient analysis. Even though the negative impact of phase redistribution on pressure transient analysis has long been recognized, it was not given serious consideration until Fair (1981) presented the first mathematical model incorporating the phase segregation effects that is:

$$p_\phi = C_\phi\left(1 - e^{-t/\alpha}\right) \tag{1}$$

where, p_ϕ is the phase redistribution pressure, kPa; C_ϕ is the maximum pressure change resulting from phase redistribution effects, kPa; α is the phase redistribution time parameter, h. The Fair's model, known as the increasing wellbore storage model, could be solved analytically in the Laplace space to obtain a dimensionless pressure solution. But when the pressure buildup test showed a decreasing wellbore storage coefficient, Fair's model did not yield a good fit of the field data. Therefore, Hegeman et al. (1993) suggested another model that suits this situation.

$$p_\phi = C_\phi erf(t/\alpha) \tag{2}$$

Then other researchers (Winterfeld, 1989; Almehaideb et al., 1989; Hasan and Kabir, 1992, 1993) tried to offer a physical

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explanation for both Fair and Hegeman's models until Xiao et al. (1996) used a simple mechanistic numerical wellbore model to clarify it. After that, the studies of wellbore phase redistribution can be clarified as follows: (1) Studies on further investigated Fair's work (Thompson et al., 1986; Meunier et al., 1985; Kucuk and Ayestaran, 1985; Thompson and Reynolds, 1986; Nashawi, 1989). (2) Differences between the graphical behavior of the phase segregation effects and other heterogenous systems (Olarewaju and Lee, 1989a,b). (3) New methods to study wellbore phase redistribution, such as Primary Pressure Derivative (PPD) (Mattar, 1992) and nonlinear regression analysis method (Baghdarvazehi et al., 1993).

Ali et al. (2005) experimentally investigated the effects of wellbore phase redistribution and phase re-injection on downhole pressure build-up data. The single-phase and two-phase flow tests were conducted with air and water. The results of experiments showed that the rising gas bubbles impacted on the pressure gauge in bubble flow regime, making the early pressure oscillation which was a wave-type response in the log–log plot. And the pressure oscillation appeared in a shut-in test with single-phase water due to the incompressibility of the fluid and the typical water hammering effect. Though these pressure oscillation phenomena were caused by dominating wellbore effects, but few wellbore storage models studied these phenomena.

This paper is intended to show the pressure oscillation impacted by the changing wellbore storage effect, then a new changing wellbore storage model is proposed to model this process. Finally, the proposed model is applied to well test interpretations.

2. The characteristics of pressure curves in the wellbore or near wellbore

(1) Wellbore phase redistribution

The existence of wellbore phase redistribution is important because it can create derivative shapes which could be easily misinterpreted as they are similar to what would be obtained with double porosity, partial penetration or composite behaviors. Typical derivative shapes of Fair model are shown in Fig. 1. It shows that the typical derivative shapes are classified as the recessive hump (Curve (1)), the small hump (Curve (2)), the complex shape such as more steps (Curve (3)), the big hump (Curve (4)) and the deep canyon (Curve (5)) (Gringarten et al., 2000; Hu et al., 1996; Hu, 1999).

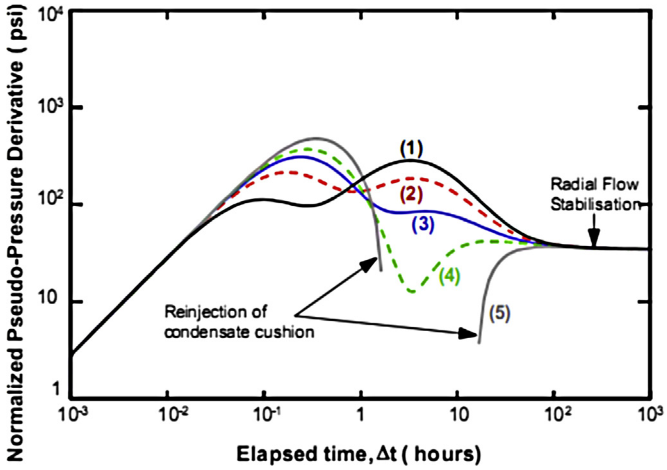

Fig. 1. Log–log derivative plots, increasing wellbore storage due to phase redistribution in the wellbore.

(2) Liquid loading and re-injection

When the liquid loading well is shut-in and the additional pressure drop exceeds the pressure from formation energy supplies (i.e., greater than the pressure buildup rate), the well test curves usually have a V-shape which is the characteristic of re-injection. Re-injection and wellbore afterflow should be a repetitive process due to the inertia and compressibility effects. However, due to the small repeated wellbore afterflow, the pressure oscillation is not very obvious. So the pressure derivative curve only represents a big pressure deep canyon, as shown in the fifth curves of Fig. 1 (Gringarten et al., 2000).

(3) Bubble flow and hammering effect

The water hammering effect also leads to the pressure oscillation in a single water well test shown in Fig. 2, as well as in the bubble flow shown in Fig. 3 (Ali et al., 2005).

3. The new wellbore phase redistribution model

The conventional pressure profile in the near-wellbore region (Fig. 4a) is not suitable to characterize the transient phenomena that take place during liquid loading and re-injection. And the bottomhole pressure changes with time because of the wellbore phase redistribution which occurs during liquid loading and re-injection. When the well is shut in, the simple physical process could be described as follows:

(1) The first bubble rises or drops to the bottom of the liquid column surface leading to two phase redistribution in the wellbore, which makes the expansion of gases and the change of wellbore density;
(2) And the expansion of gases and the change of wellbore density add an additional back pressure making the bottomhole pressure rise. The increased ratio of the wellbore pressure is the largest at the shut-in moments;
(3) Then the increased ratio of the wellbore pressure becomes smaller with time, until some time when the bottomhole pressure is larger than the near wellbore pressure due to the inertial effect;
(4) After this, the fluid in the wellbore flows back into the reservoir. And re-injection not only lowers the bottomhole pressure but also rises the near wellbore pressure;

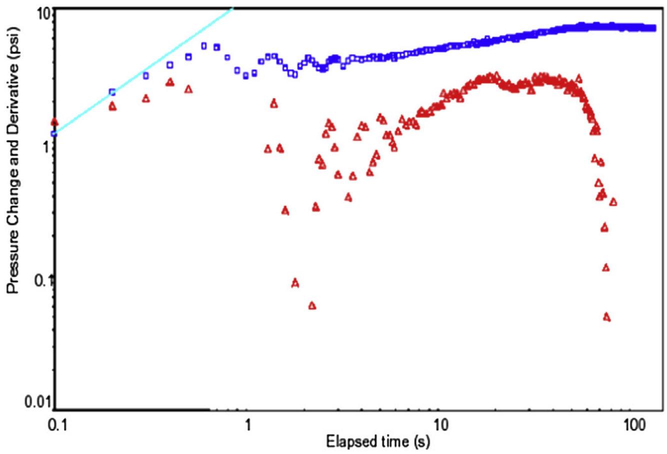

Fig. 2. Log–log plot pressure change and pressure derivative vs. elapsed time. Bubble flow regime, phase redistribution without afterflow effect (Ali et al., 2005).