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An approach to calculating snake well productivity under steady-state flow

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ABSTRACT

A snake well is a complex well type and meanders in a sinusoidal pattern through multiple drainage areas provided by multiple isolated production zones. Conventional productivity calculation methods for horizontal wells could not be applied directly for snake wells because the production segments in the wellbore have large vertical fluctuation and wellbore pressure drop is noticeable.

Starting from the distribution of velocity potential produced in an infinite reservoir by one snake well, this paper uses mirror image and the principle of superposition to obtain velocity potential and pressure distributions in bottom water drive reservoirs with and without gas cap, and edge water drive reservoir. Flow characteristics along the wellbore are then investigated and a pressure drop model is developed. Coupling the flow inside wellbore and in the reservoir, we developed and further solved a productivity prediction model for the snake well. The proposed approach to calculating well productivity better meets the reality and results in more accurate prediction.

Case studies in bottom water drive reservoir with and without gas cap, and edge water drive reservoir show that snake wells with small fluctuation rates yield higher productivities than horizontal well. Also, permeability anisotropy has less impact on the productivity of snake well than that of horizontal well. For the reservoir with low vertical permeability, snake well can perform better than horizontal well.

1. Introduction

Horizontal wells have been occupying an ever-increasing share of oil and gas production since the 1980s. Analytical and semi-analytical productivity equations for single-phase oil flow in a horizontal well under steady state and pseudo-steady state have been widely studied (Giger et al., 1984; Joshi, 1988; Babu and Odeh, 1989; Dikken, 1990; Economides et al., 1991; Norris et al., 1991; Renard and Dupuy, 1991; Economides et al., 1996; Penmatcha and Aziz, 1998; Ozkan et al., 1999; Baba and Tiab, 2001; Lu, 2001). Some researchers investigated productivities in fractured horizontal wells (Wan and Aziz, 2002; Medeiros et al., 2008; Guo et al., 2009), horizontal well performance in naturally fractured reservoirs (Al-Kobaisi et al., 2006; Lu et al., 2009), wellbore pressure drop caused by formation damage (Furui et al., 2003; Hill and Zhu, 2008) and wall friction factor (Seines et al., 1993; Ouyang et al., 1998; Yalniz and Ozkan, 1998; Yuan et al., 1998; Cho and Shah, 2001; Archer and Agbongiator, 2005).

In the areas of productivity calculation, well testing, and reservoir modeling, a key parameter is flowing bottomhole pressure. It can be obtained by installing memory gauge or permanent downhole gauge. However, prediction has been widely used through modeling multiphase flow in oil and gas wells. Many researchers have contributed to this topic, ranging from early empirical correlations (Ros, 1961; Hagedorn and Brown, 1965; Orkiszewski, 1967) which came from curve fittings of experimental data and have been successfully used for many decades, mechanistic modeling (Taitel et al., 1980; Xiao et al., 1980; Gomez et al., 2000) which emerged in the early 1980's and predicted through flow patterns, to drift-flux model (Mishima and Ishii, 1984; Shi et al., 2005a, 2005b) which considers slippage between fluid phases, and transient flow model (Bendiksen et al., 1991; Veeken et al., 2010; Shirdel and Sepehrnoori, 2012).

In a real world, horizontal segments in horizontal wells are not straight. Azar-Nejad et al. (1996) studied potential distributions in a curved well that has a quarter of a circle. A slab reservoir and uniform potential of inner boundary conditions were assumed. The

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results showed that especially in anisotropic reservoirs, pressure and pressure derivative responses of a curved well could not be approximated through a straight horizontal well with an equal drilled length. In a simple approximation, Deliu et al. (1996) adapted Babu and Odeh (1989) productivity model to multiple reservoir slices cut by vertical plates along the horizontal length in order to consider the snake-like shape of horizontal well deviated from perfectly designed horizontal route. Göktas and Ertekin (2003) discussed the effect of horizontal well undulation on pressure-transient behavior. They used 20 feet as the maximum undulation and observed that pressure-transient responses could be closely approximated from a straight horizontal well for practical windows of undulations in field practices. Al-Mohannadi et al. (2007) studied the effect of curved wells. The curve in their studies is small (the undulations have the maximum amplitude of 10 feet) and no significant differences between straight and curved horizontal wells were found.

A snake well meanders in a sinusoidal pattern through multiple drainage areas provided by multiple isolated production zones. In summary, snake well can be drilled under the following circumstances:

(1) To develop layered reservoir with poor vertical connectivity, or multiple small faulted reservoirs or small isolated oil sand bodies which are not in the same plate, vertical or horizontal wells are not economical because the reserve controlled by a single well is small and a large number of drilling wells are needed. However, snake wells can reduce overall cost and obtain a high return.
(2) Snake well could yield economical production for high-angle thin layer reservoirs while it is difficult for vertical or horizontal wells to have sufficient production length.
(3) Prior geology recognition has large bias and the designed horizontal well is changed to snake well in order to track reservoir.
(4) Initially designed horizontal well can also be changed to snake well if drilling technology fails to meet the requirements or significant mistake occurs.

Snake wells have been reported mainly in Champion West, offshore Brunei (Johan and Schrader, 2004; Obendrauf et al., 2006; al-Araimi and Srisa-ard 2007; Bacarreza et al., 2008; Mitchell and Skarsholt, 2008; Bakker et al., 2009). However, we have not seen theoretical calculation on its productivity. On the basis of the distribution of velocity potential produced in an infinite reservoir by one snake well, this paper uses mirror image and the principle of superposition and obtains velocity potential and pressure distributions for several common types of reservoirs. Then, coupling wellbore flow with fluid flow in the reservoir, we developed a steady-state productivity model for snake well.

2. Potential distribution in an infinite reservoir

Suppose one snake well has open hole completion in a homogeneous, constant thickness, isotropic, infinite and horizontal reservoir. Suppose the well has constant production rate Q and horizontal production length L. The fluid is incompressible. The flow is steady state and meets Darcy's law. From the beginning (toe) to the end (heel), the production length L can be divided into n intervals. When n is large enough, each interval is sufficiently small and can be treated as a uniform-distributed line sink (see Fig. 1). The length and production rate for the i-th interval are L_i and Q_i ($i = 1, 2, \ldots, n$) respectively. A_i (x_{i1}, y_{i1}, z_{i1}) and B_i (x_{i2}, y_{i2}, z_{i2}) are two end points for the i-th interval. Formation potential influenced by the production of this i-th interval is calculated first and then potential distribution in the whole infinite reservoir with one producing snake well can be obtained according to the principle of superposition.

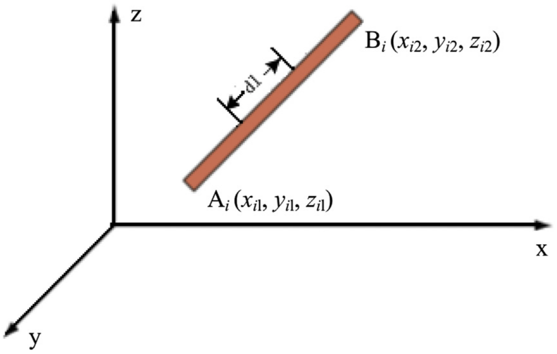

Fig. 1. Schematic of the i-th production interval of a snake well in an infinite reservoir.

Lu (2001) gave the potential at any point caused by one producing horizontal well in a homogeneous, isotropic, infinite reservoir:

$$\Phi = \frac{q}{4\pi L}\ln\frac{R-L}{R+L} + C. \tag{1}$$

Eq. (1) illustrates that the potential at any point M in the reservoir with one horizontal production well depends only on well production length, production rate and the distances between M and two end points of the wellbore. Because velocity potential is a scalar and independent on the coordinate systems, the generated potential by the i-th interval can be expressed in a 3-dimensional space as:

$$\Phi_i = \frac{Q_i}{4\pi L_i}\ln\frac{R_i-L_i}{R_i+L_i} + C. \tag{2}$$

Using the principle of superposition, we get the potential at any point M in an infinite reservoir with one producing snake well

$$\Phi = \sum_{i=1}^{n}\Phi_i + C. \tag{3}$$

3. Potential distributions in several common types of reservoirs

3.1. Bottom water drive reservoir

As shown in Fig. 2, a reservoir has a sealed top, water–oil-

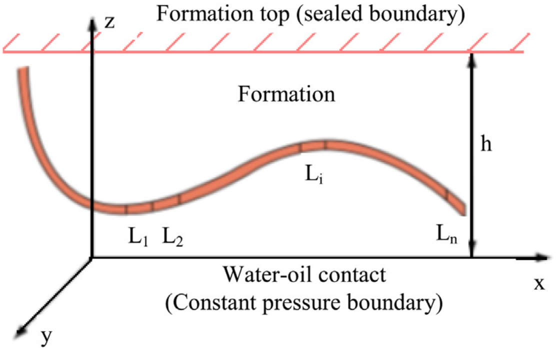

Fig. 2. Schematic of a snake well in a bottom water drive reservoir.

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