Journal of Petroleum Science and Engineering 171 (2018) 919–927

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

Analytical interference testing analysis of multi-segment horizontal well

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ARTICLE INFO

Keywords:
Interference testing analysis
Multi-segment horizontal well
Pressure-transient behavior
Well interference
Water injection
Type curves

ABSTRACT

Most interference-testing analysis of horizontal well ignores fluid flow in and out of the horizontal observation well and represent it by a point. Moreover, even if the observation well is considered to produce fluids during the field test, the production distribution is assumed to be uniform along horizontal wellbore. In fact, production logging tests have shown that only partial horizontal segments are productive and the production contribution is non-uniform along horizontal wellbore.

The aim of this paper is to develop a novel interference testing model of a multi-segment horizontal well (MSHW). Analytical solutions are derived to incorporate the interference of injection wells and consider the effect of non-uniform production on pressure response of the MSHW. There is no need to shut in the horizontal observation well, and the horizontal well is composed of multiple segments with arbitrary rate, length, skin, etc. The type cures of the interference testing model are developed to discuss the effect of both active wells and observation well on pressure behavior (e.g., injection rates, well spacing, rate distribution of horizontal observation well, number and length of horizontal producing segments, permeability anisotropy, horizontal wellbore location in vertical and horizontal plan). Results indicate that the pressure and pressure derivative curves move down during the middle and late flow regime due to the effect of surrounding injectors. The pseudo-radial flow regime may disappear due to the interference caused by adjacent wells. The interference flow regime (IFR) may stabilize at 0.5*(1-Σq_{jD}) on pressure derivative curve when the total injection rates are less than the production rates. The pressure-derivative curve shows the similar characteristic with bottom-water drive when injection rates are much higher than the production rates.

The proposed model is more realistic and enables us to better understand the interference of injection wells when the horizon observation well is open to produce. With the help of interference tests, this model can be applied to evaluate the communication between wells, diagnose the water-inflow direction, and optimize well pattern, which ensure the success of a secondary or an enhanced recovery process.

1. Introduction

The application of horizontal wells contributes a big increase of hydrocarbon productivity especially in low-permeability, tight, and unconventional reservoir (Doan and Ali, 1995; Denney, 2004; Yildiz, 2006; Tang et al., 2017; Safari et al., 2017; Qin et al., 2019; He et al., 2018a; Rui et al., 2018a,b,c). Field tests and performance evaluation are necessary to improve the well performance (Kuchuk et al., 1998; Rui et al., 2017; Qin et al., 2018a). Well testing analysis has been acknowledged as an effective approach to estimate parameters, to understand the reservoir characteristics, and to evaluate dynamic well performance (Ozkan and Raghavan, 1990; Kuchuk, 1995; He et al., 2017a; Wang et al., 2017a, 2017b; Qin et al., 2018b).

During the past three decades, researchers have developed numerous well testing models of horizontal wells (Clonts and Ramey, 1986; Goode and Thambynayagam, 1987; Ozkan et al., 1989; Kuchuk, 1995; Yildiz, 2006). Due to the non-uniform formation damage, selective completion, heterogeneity along horizontal wellbore, only partial horizontal wellbore are productive and the production contribution is non-uniform. The well-testing models have been further proposed to

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https://doi.org/10.1016/j.petrol.2018.08.019
Received 16 April 2018; Received in revised form 19 July 2018; Accepted 7 August 2018
Available online 09 August 2018

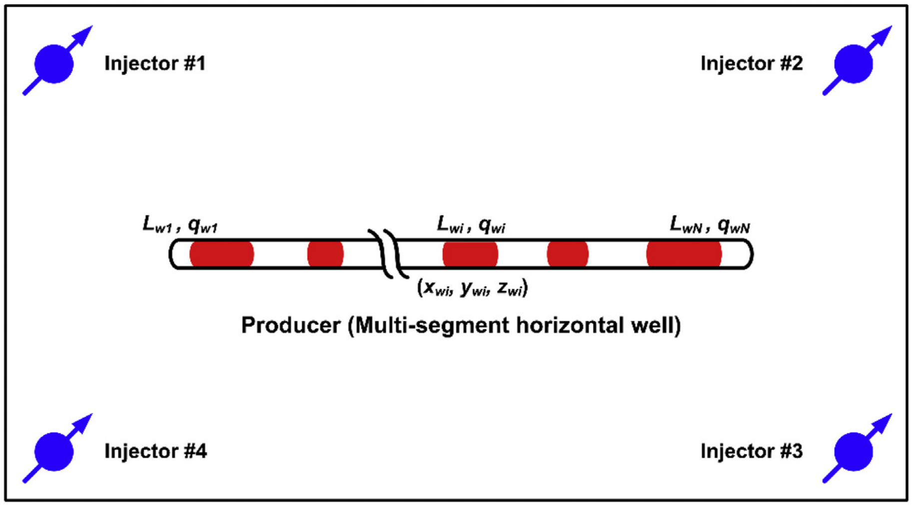

Fig. 1. Physical model of interference-testing model of the MSHW.

investigate the transient pressure response of multi-segment horizontal wells (MSHW) (Kamal et al., 1993; Yildiz and Ozkan, 1994; Frick et al., 1996; Al Rbeawi and Tiab, 2011; He et al., 2018b). All of them above are only available for single horizontal well. However, each well group is composed of multiple wells (production wells and injection wells). The interference from adjacent wells should be considered.

There are two main approaches to investigate the transient pressure performance of multiple wells. Firstly, numerical method can be used to simulate the pressure behavior of horizontal wells with considering the interference, called numerical well testing analysis. Except for analyzing the pressure transient response, it can also be applied to investigate interwell connectivity (Tiab and Dinh, 2008) and estimate water flooding direction (He et al., 2017b). Secondly, the interference testing analysis becomes a novel method to incorporate the effect of surrounding wells (production wells or injection wells) on the observation well through multi-well well-testing models. By adjusting the production/injection schedule of one or more active wells, the effect of interference on pressure response of the observation well can be received through the bottom-hole gauge. By using the corresponding interference testing models, the recorded pressure data can provide valuable information about reservoir properties such as transmissibility, storativity, formation heterogeneity and communication between wells (Obge and Brigham, 1989; Syed and Al-Hashim, 2007).

With the increase of horizontal wells in oil/gas fields, the interference testing of horizontal wells have received higher attention during the past two decades. Malekzadeh and Tiab (1991) firstly presented the solution and type curves for interference test analysis between a horizontal well and a vertical well or two horizontal wells. Houali and Tiab (2004) analyzed the interference testing response of horizontal wells in the anisotropic formation. For the interference testing analysis of horizontal wells, Al-Khamis et al. (2005) discussed the locations of the observation point if horizontal observation well is assumed to be a point. Kutasov et al. (2008) provided solutions for interference tests under a variable rate at the active well. The above models are only available for single-layer reservoir. Syed and Al-Hashim (2007) applied numerical simulation to the interference testing analysis of two horizontal wells in layered reservoir. Later, Adewole (2013) conducted the interference testing analysis of vertical and horizontal wells in a laterally infinite layered formation.

However, many interference-testing models of horizontal well ignored fluid flow in and out of the horizontal observation well and represent it by a point (Malekzadeh and Tiab, 1991; Malekzadeh, 1992; Erwin et al., 2002). In other word, the observation well needs to be shut-in during the test, which may influence the production. Later, Al-Khamis et al., 2005) presented a less complicated model as opposed to a more rigorous model with two horizontal wells, which considered the fluid flow in the horizontal observation well. The investigation about productive horizontal observation well should be further conducted. Furthermore, even if the observation well is considered to produce fluids during the field test, the production distribution is assumed to be uniform along horizontal wellbore. In fact, production logging tests have shown that only partial horizontal segments are productive and the production contribution is non-uniform along horizontal wellbore.

Therefore, these reasons motivate us to develop a novel interference testing model of horizontal well to incorporate the interference of injection wells and consider the effect of non-uniform production on pressure response. There is no need to shut in the horizontal observation well, and the horizontal well is composed of multiple segments with arbitrary rate, length, skin, etc. The type cures of interference testing models are developed to discuss the effect of both active wells and observation well on pressure behavior. The proposed model is more realistic and enable us to incorporate the interference of injectors, evaluate the communication between wells, and optimize well pattern, which ensure the success of a secondary or an enhanced recovery process.

2. Interference-testing model of an MSHW

2.1. Physical model

An MSHW (producer) and multiple vertical wells (injectors) locate in a horizontal-slab reservoir, shown in Fig. 1. The MSHW acts as the observation well, and the vertical wells are the active wells. The reservoir is bounded by impermeable strata in the vertical direction, and it is infinite in the horizontal direction. The formation has constant thickness (h), porosity (ϕ), permeability (k_h) in horizontal direction and k_v in vertical direction, compressibility (c_t), and initial reservoir pressure (p_e). The horizontal wellbore is divided into N segments, and the length, flow rate of the ith segment are L_{wi} and q_{wi} respectively. The production rate of the MSHW equals to q, and the injection rates of vertical wells equal to q_j. The effects of gravity and capillary can be negligible.

2.2. Mathematical model

The governing equation to characterize the fluid flow in the 3D reservoir is:

$$\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2} + \frac{\partial^2 p}{\partial z^{*2}} = \frac{1}{\eta}\frac{\partial p}{\partial t} \tag{1}$$