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Pressure transient behavior of a fractured well in multi-region composite reservoirs

Qi Deng[a,**], Ren-Shi Nie[a,*], Yong-Lu Jia[a], Quan Guo[b], Kai-Jun Jiang[b], Xiong Chen[c], Bao-Hua Liu[b], Xiao-Fang Dong[d]

[a] *State Key Laboratory of Oil & Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu 610500, Sichuan Province, People's Republic of China*
[b] *Well Testing and Perforating Company of Daqing Oilfield Co., Ltd, Petrochina, Daqing, 163412, Heilongjiang Province, People's Republic of China*
[c] *Guangxi Colleges and Universities Key Laboratory of Beibu Gulf Oil and Natural Gas Resource Effective Utilization, Qinzhou University, Qinzhou 535000, People's Republic of China*
[d] *Well Logging and Technology Service Company of Daqing Oilfield Co., Ltd, Petrochina, Daqing, 163412, Heilongjiang Province, People's Republic of China*

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ABSTRACT

Although there has been some research on the pressure transient behavior of fractured wells in radial composite reservoirs, the analysis and modeling of such systems remain limited. Most existing solutions only consider the case of a fractured well located at the center of an infinite bi-zonal radial composite reservoir. In addition, corresponding research on a partially penetration fractured well in a radial composite reservoir is also rare. In this paper, we present an analytical three-dimensional solution for a point source located at an arbitrary position in the first circular region of a multi-region radial composite reservoir with three side boundary conditions. Then, using the principles of discretization and superposition, a general pressure transient solution of a fully penetrating fractured well or a partially penetrating fractured well in reservoirs is obtained. The standard log–log type curves of the transient pressure are plotted. Sequentially, the main flow regimes are identified and the effects of relevant parameters are analyzed. There is a special flow regime (the first transition flow regime) in the type curves due to the well not being at the center of the circular region. The well location has a significant effect on the mid-term response of the transient pressure. The presented solution can also be used in well testing to obtain reservoir parameters.

1. Introduction

Radial composite systems, which represent a wide variety of reservoir configurations, exist in reservoirs due to variations in either the reservoir rock or fluid properties. In the former case, two-region radial composite systems can serve as reasonable approximations of heterogeneous reservoirs (Rosa et al., 1996; Zhao et al., 2015). Changes in fluid properties may be caused by fluid injection, which is widely used in the early stages of a secondary or tertiary recovery project (Olarewaju and Lee, 1989) or by edge-water drive. In this case, two-or multi-region radial composite systems can serve as reasonable approximations of reservoirs with a region of variable saturation around the injection or production well (Abbaszadeh and Kamal, 1989; Ambastha and Ramey, 1990; Su et al., 2015). In addition, a combination of different variations in rock or fluid properties may also lead to multiple composite regions in reservoirs.

Pressure transient analysis is an effective method to understand the characteristics of reservoirs and wells. The pressure transient behavior of a vertical well in radial composite reservoirs has been studied since the early 1960s. Hurst (1960) first developed a two-dimensional analytical point-sink solution for a vertical well in an infinite two-region composite reservoir. Based on Hurst's solution, Satman et al. (1980) and Olarewaju and Lee (1989) conducted research on the pressure transient analysis of a two-region composite model considering the external boundary conditions, skin factor and wellbore storage. Several authors (Novakowski, 1989; Yeh et al., 2007; Pasandi et al., 2008) had also studied the two-region composite model for a vertical well in consideration of the finite skin region. In view of fluid injection case, several authors (Tang and Ambastha, 1988; Abbaszadeh and Kamal, 1989; Ambastha and Ramey, 1992; Nie et al., 2011; Su et al., 2015) had studied the pressure transient analysis of a multi-region radial composite model. Abbaszadeh

* Corresponding author.
** Corresponding author.
E-mail addresses: dengqigiggs@163.com (Q. Deng), nierenshi2000@126.com (R.-S. Nie).

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and Kamal (1989) presented injection and falloff solutions for a vertical well considering the effect of saturation gradient by assuming that the reservoir is a multi-region radial composite system. Based on their analysis, it was concluded that the single-phase injectivity solutions of a two- or multi-region radial composite reservoir with stationary interfaces can be used by superposition to analyze the falloff test in practice. Tang and Ambastha (1988), Ambastha and Ramey (1992) and Su et al. (2015) established a three-region radial composite model of a vertical injection well for CO2 flooding. They concluded that a three-region radial composite model was believed as more accurate pattern for transient pressure analysis during CO2 flooding. Nie et al. (2011) first developed a three-dimensional analytical solution for a horizontal well in a multi-region radial composite reservoir.

The above-mentioned models are all assumed that the well is at the center of a circular region. Nevertheless, the well may not always be just at the center of a circular region in many cases. Given a vertical well producing from an arbitrary position within a circular composite reservoir, Rosa et al. (1996) developed a two-dimensional analytical solution for an infinite two-region radial composite model with an eccentric well location. By analyzing typical curves, they concluded that the pressure transient behavior is different between the central well location case and the eccentric well location case in the radial composite model. However their solution is two-dimensional which can only be applied to analyzing the pressure-transient response of a fully penetrating vertical well. In addition the solution only considered the infinite side boundary conditions.

Hydraulic fracturing has been widely used to improve the productivity of damaged wells or wells producing from low-permeability reservoirs. Almost all tight hydrocarbon reservoirs have to be fractured before they can be productive. These reservoirs are often produced with fully penetrating hydraulic fractures. However, a hydraulic fracture may not penetrate the entire formation thickness, even when it is supposed to do so (Anderson and Stahl, 1967); furthermore, the final fracture height through which a fluid is produced may not be equal to the created height (Tinsley et al., 1969). In addition, to prevent unwanted fluid at the wellbore in a hydraulic fracture, partially penetrating hydraulic fracturing is generated (AIgbokoyi and Tiab, 2008).

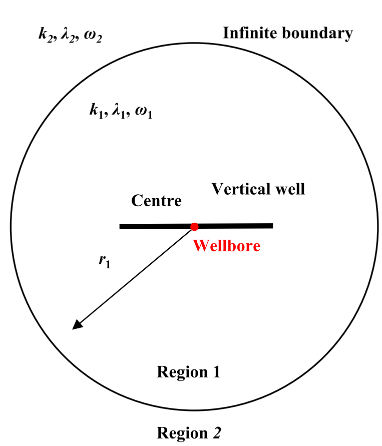
Fractured wells are also used to produce oil or gas in composite low-permeability reservoirs. However, as compared with a vertical well case, the pressure transient behavior of a fractured well in composite reservoirs is seldom studied. Several authors (Stanislav et al., 1987; Chu and Shank, 1993; Chen and Raghavan, 1995; Feng et al., 2009) developed two-dimensional analytical solutions for fluid flow in a fully penetrating fractured well in infinite two-region radial composite reservoirs. In their studies, the pressure transient behavior of the systems was analyzed. There have been few studies that consider the pressure transient behavior of a partially penetrating fractured well in radial composite reservoirs. Zhao et al. (2015) recently developed a three-dimensional analytical solution of gas flow for a partially penetrating fractured well in infinite two-region radial composite reservoirs. They analyzed the transient pressure response and relative sensitivity of both a fully and partially penetrating fractured well in a bi-zonal gas reservoir.

In the above-mentioned solutions that were developed for assessing fluid flow in a fractured well in radial composite reservoirs, the reservoir is assumed to be an infinite two-region radial composite, and the fractured well is assumed to be located at the center of a circular region. In this case, like the schematics (see Fig. 1) of Zhao's model (Zhao et al., 2015), the reservoir is a symmetrical radial composite system and the fluid flows only in the radial direction in a horizontal plane in this system. The well may not always be located at the center of a circular region in some cases, such as in an edge-water drive reservoir.

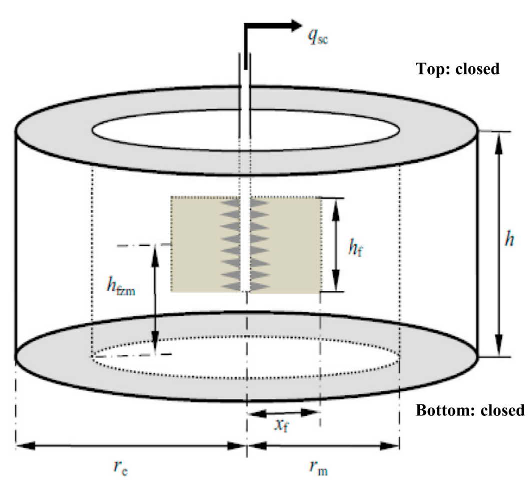
To our knowledge, no solution or pressure-transient analysis has been found for the case of a fractured well located at an arbitrary position in a circular region even in two-region radial composite system with different external boundary conditions. In view of this, this paper presents a general solution for fluid flows to a fully or partially penetrating fractured well in radial composite reservoirs. In the present solution, the reservoir can be a multi-region radial composite and the fractured well can be located at an arbitrary position in the first circular region. Three types of external boundary conditions, wellbore storage and skin effects are considered. The transient pressure response and relative sensitivity of the general solution are analyzed using the type curves.

2. Conceptual model

Figs. 2 and 3 show the schematics of the conceptual model for a fractured well at an arbitrary position in the first circular region of a multi-region radial composite reservoir. Fig. 2 is the plan view of the physical model, and Fig. 3 is the profile of it. All of the regions are circular homogeneous and composed of anisotropic media having uniform thickness, and the physical properties of each region differ from others. A vertical fractured well production or injection occurs at a constant rate at an arbitrary position in the first circular region (region 1). The hydraulic fracture can be a fully penetrating or partially penetrating fracture and is assumed to be infinitely conductive. The external boundary of the side may be infinite or closed or at a constant pressure, and the external boundaries of the top and bottom are closed. The effects of wellbore storage and the skin are considered. The initial formation pressure



A—plan view of the symmetrical bi-zonal model



B—profile of the symmetrical bi-zonal model

Fig. 1. Schematics of the plan view and profile of the symmetrical bi-zonal model for a partially penetrating fractured well (Zhao et al., 2015).