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RESEARCH PAPER

Determination of dynamic reserves of fractured horizontal wells in tight oil reservoirs by multi-region material balance method

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Abstract: To overcome the deficiencies of the material balance method, according to strong heterogeneity of tight oil reservoirs, the flow region of fractured horizontal well is divided into high permeable zone and low permeable zone, which are equivalent to radial composite percolation model. Based on parallel plane theory, multiple media of each zone are equivalent as a continuous medium, and with the integral method, the multi-region material balance to calculate the dynamic reserves for the fractured horizontal well of tight oil reservoirs is proposed base on the nonlinear seepage mechanism of tight oil reservoirs, and the corresponding pressure distribution equation and material balance equation for the two zones have been established. In view of the actual production performance, this method considers the pressure mutation and fluid exchange at the interface of two zones. The computational results of an example show that this method can work out the dynamic reserves within a single well control, the dynamic reserves of high permeable zone and low permeable zone, and the recharge rate from the low permeable zone to the high permeable zone in different production time accurately, which provides a basis for selection of well production and appropriate working system, and deployment and adjustment of development well pattern.

Key words: tight oil; fractured horizontal well; pressure distribution; dynamic reserves; multi-region; material balance method

Introduction

Dynamic reserves are the total fluid volume under standard conditions which can effectively flow in the reservoir pore volume using the existing developing technologies of the present stage[1]. For an oil and gas reservoir already put into development, dynamic reserve is one of the key indicators to evaluate development situation. Currently, the methods[1−7] calculating dynamic reserves mainly include transient well testing, production decline, production cumulating and material balance methods. Among these methods, the material balance method is more effective and accurate. Conventional material balance method[8] assumes that rock and fluid properties do not change with space, the flow state of fluid in porous media reaches equilibrium in no time and the producing degree of the reservoir is even. Under these assumptions, the amount of output at different formation pressures can be calculated, according to the balance of underground oil and gas volume. This method is suitable for the reservoirs with high permeability and conductivity, but for highly heterogeneous complex low permeability reservoirs, the reserves calculated by this method often can't reflect the dynamic reserves of a single well or the whole reservoir[8−9]. For such reservoirs, in recent years, many researchers have modified the conventional material balance method[2−7], and proposed the zoning material balance concept and idea, but their studies were mostly based on gas reservoirs.

Now the development mode of "horizontal well + staged fracturing" is widely used to achieve effective production of tight oil resources at home and abroad. When using this mode, fractures of different scales are formed in the tight oil reservoirs, and multi-scale fractures couple with the matrix, making the percolation mechanism very complex, the reservoir heterogeneity is very strong in the control area of a single fractured horizontal well, so the conventional material balance can't accurately predict the dynamic reserves. Existing partition material balance method also can't accurately predict the dynamic reserves of a single fractured horizontal well under the control of multi-coupling media in tight oil reservoirs.

Based on nonlinear percolation mechanism in the multi-media of tight oil reservoirs, considering the effect of starting pressure gradient, stress sensitivity and other factors, a new method, that is, material balance of two-zone recharge

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is proposed to calculate the dynamic reserves of a single fractured horizontal well in tight oil reservoirs. Taking a single well as a study object, we can divide the percolation zone into high permeable zone and low permeable zone, take the multi-media of each zone as a continuous medium, and build the relevant nonlinear percolation model of each zone. Considering the pressure mutation and fluid exchange at the interface of two percolation zones, the pressure distribution equation of each zone can be built using integration method. The type of reservoir can be determined according to formation pressure, and thus, material balance equation of each zone for saturated and unsaturated reservoirs have been built. Therefore, the dynamic reserves of each zone, and the recharge rate from low permeable zone to high permeable zone at different time can be determined. Finally, the dynamic reserves of the fractured horizontal well in tight oil reservoirs can be calculated.

1. The dynamic reserves model of fractured horizontal well

1.1. Research ideas

For tight oil reservoirs, wells are often placed in sweet spots with abundant natural fractures, so when staged fracturing is implemented, natural fractures would open and connect with artificial hydraulic fractures into a complex fracture network, allowing the fluid in the matrix to flow to the fractures in the shortest distance, and then flow into the wellbore along the fracture network, which improves the total permeability in the zone controlled by a single well, and greatly increase the effective producing degree of the reservoir[10–12].

Based on the complex fracture network produced by hydraulic fracturing, MONGALVY and others divided the drainage area of a single well into two parts, namely, effective stimulated reservoir volume including the fracture network (ESRV) near the wellbore and the unstimulated volume in the surrounding of the effective stimulated reservoir volume (UnSRV)[13]; and the whole fracture network was divided into two sets of fracture systems: the fracture network with high conductivity around the wellbore, the fracture network unsupported or poorly supported in ESRV.

When there is limited data available, it is generally difficult to get accurate ESRV border. Therefore, in this study, the partitioning model of the single well drainage area has been built based on the rectangular area formed by the end faces of the horizontal well and tip of artificial hydraulic fractures (Fig. 1). In the rectangular area, Zone 1 mainly consists of high conductivity fracture network (supported fracture network) near the wellbore in the ESRV and matrix, with high permeability, it is named as high permeable Zone 1. Outside the rectangular area, Zone 2 contains the unsupported or poorly supported fracture network in the ESRV and relevant matrix, low in permeability, it is named as low permeable Zone 2.

As the pore and fracture media in the two zones are different, and the relevant parameters are various, so the area con-

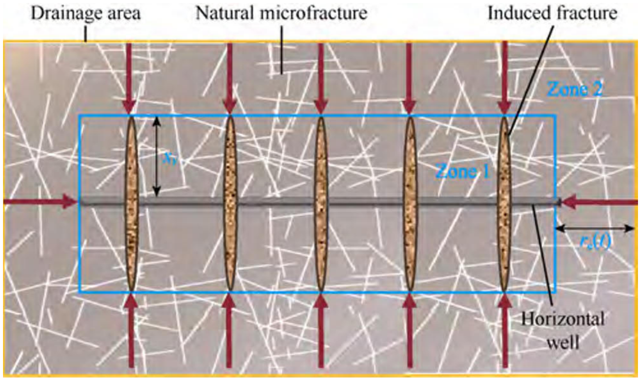

Fig. 1. Sketch map of drainage area of a fractured horizontal well.

trolled by a single well has strong heterogeneity. But in the same percolation zone, the average physical property parameters are similar, and in the interface between the two zones, the physical property parameters change drastically. The drainage area of a single well is theoretically the rectangular area, so it is difficult to establish the corresponding unstable percolation model. In order to make the model building and solving easier, the two percolation zones are equivalent to a corresponding radial flow area based on the equivalent of multi-media (Fig. 2), and the drainage area of a single well is also equivalent to a radial flow area, with the oil well located in the center of high permeable Zone 1.

In the early stage of development, reserves in the high permeable region is first produced. As development goes on, the pressure wave propagates to the border of the high permeable Zone 1 (time T0), and the fluid in the low permeable Zone 2 begins to flow. Under the driving of pressure gradient, fluid in Zone 2 begins to recharge and flow to Zone 1, and the reserves in Zone 2 is started to produce. With the propagation of the pressure wave, the produced area in Zone 2 gradually increases too, but the produced area in Zone 1 remains unchanged. In the actual typical production performance curve, the production in the early stage is higher and then declines sharply, with a rapid output of fluid in high permeable zone and slow recharge in low permeable zone. At the late stage of production, the production keeps stable with the continuous

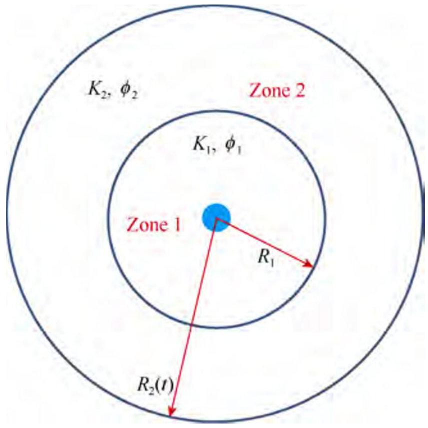

Fig. 2. Sketch map of equivalent radial percolation model of single well.