The Discrete Numerical Models and Transient Pressure Curves of Fractured-Vuggy Units in Carbonate Reservoir

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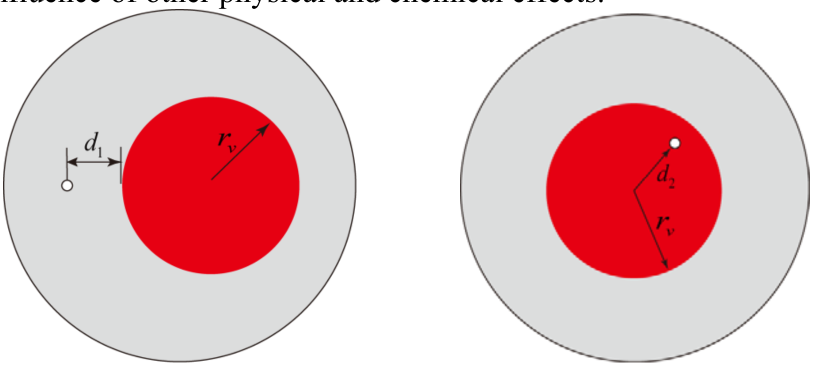
Abstract. Fractured-vuggy carbonate reservoirs have various types of units, and making full use of the well test data to study reservoir characteristics is quit important to enhance oil production. However, conventional analytical well test model cannot consider the positional relationship of well and fractured-vuggy units. According to the distribution of well and fractured–vuggy units, two kinds of discrete numerical models of WIC and WOC are given, and these models are solved by the finite element method. The influence of cave volume and the distance between cave center and well are analyzed. The measured data of 65 Wells in Hala Hatang oilfield is summarized and interpreted, and the classification of the reservoir units and identification methods are analyzed. Their well test double logarithmic curves are divided into five types corresponding to different reservoir units characteristics. Ⅰ: The oil well is not drilled in any fractured-vuggy unit, but abundant fractured-vuggy units exist in the reservoir. Ⅱ: The oil well is drilled in the fractured-vuggy units, and many fractured-vuggy units exist in the reservoir. Ⅲ: The oil well is drilled in multiple connected caves. Ⅳ: Carbonate reservoirs contain primarily matric. Ⅴ: The oil well is drilled in some individual caves, but the fractured-vuggy units do not develop.

1. Introduction

Carbonate reservoirs have a wide distribution in Tarim basin, and their reservoir spaces mainly contain caves, fractures and matrix. One fractured-vuggy unit is composed of one or more interconnected reservoir bodies, and has a uniform pressure and fluid system of reservoir. Well test is widely used to obtain reservoir parameters. According to the study of the relationship between gas field static characteristics and well test curves, these curves can be divided into several different types. Classification has the role of two aspects: On the one hand, we can use classification to find out the laws governing the process of well test interpretation, so the uncertainty of well test interpretation is reduced. On the other hand, corresponding relationship between the well test curve and reservoir geological characteristics is established, intuitive judgment of the test curve is given. Many scholars study a lot of work on the well test model of carbonate reservoir in recent years, R.C Amacho (2002) proposed a triple porosity model for describing the seam hole carbonate reservoir. Z. H. kang (2003) summarized carbonate reservoir well test model, and the existing carbonate well test models are divided into three kinds of model: double porosity model, double and triple medium permeability model. All kinds of well test curves' shape and affecting factors are analyzed. J. Yang (2006) established a three-dimensional double bottom water carbonate reservoir pore medium oil-water two phase numerical well test model, in order to solve the limited bottom water carbonate reservoir of well test interpretation. Z. S. Wang (2007) [7] established a fractured-vuggy type single-phase flow well test interpretation model of triple medium reservoir, according to the actual geological data in Tahe oil field, and automatic fitting well test interpretation method is proposed for fractured-vuggy type reservoir by using the genetic algorithm. H. D. Sun (2008) has carried on the comprehensive analysis of well test theory according to the fractured-vuggy type carbonate research data, and main characteristics of this reservoir well test curve are summarized. L. Yang (2012) through the analysis of characteristics of well test curve, combined with the single-well static data and production characteristics, the reservoir percolation medium types can be divided into initial matrix, constant volume cavity, double medium and beaded reservoir. Y. W. Liu and Y. Z. Wan (2015) put forward a kind of composite discrete model describing fractured-vuggy carbonate reservoir. These existing well test model are lack of consideration of relative position between cave and well, and the relationship of well test curves shape and the reservoir geologic characteristic is studied less. According to the geological characteristics of fractured-vuggy reservoir, this paper established two discrete numerical well test models for these two conditions: well drilling in fractured-vuggy reservoir cave (WIC) and well drilling outside the fractured-vuggy reservoir cave (WOC). These models are applied to 65 wells' pressure response curve analysis in Tarim Hala Hatang oil field, the pressure response curve characteristics and the relationship with fractured-vuggy reservoir characteristics are studied.

2. Physical models and assumptions

According to the relative position relationship between the fractured-vuggy unit and the well, two kinds of physical models, such as the WIC and WOC, are established, as shown in **Fig. 1**. The basic assumptions: ① single-phase weak compressible fluid in the horizontal, thick, top and bottom of the formation of seepage in the formation; ② formation in the formation of one or more seam hole reservoir, regardless of drilling or not drilling holes; ③ considering the effect of wellbore and epidermis, ignoring the influence of gravity and capillary pressure, the temperature is constant, regardless of the influence of other physical and chemical effects.



(a) Wells not drilled in the fractured-vuggy reservoir model
(b) Wells drilled in the fractured-vuggy reservoir model
Fig. 1 Schematic diagram of the physical model of the fractured-vuggy unit and well

3. Mathematical Model and Solution

Matrix area:

$$\frac{\partial^2 p_{1D}}{\partial x_D^2}+\frac{\partial p_{1D}}{\partial y_D^2}=\frac{1}{C_D e^{2S}}\frac{\partial p_{1D}}{\partial T_D} \tag{1}$$

Fracture-vuggy reservoir area:

$$\frac{\partial^2 p_{2D}}{\partial x_D^2}+\frac{\partial p_{2D}}{\partial y_D^2}=\frac{1}{C_D e^{2S}}\frac{\omega}{M}\frac{\partial p_{2D}}{\partial T_D} \tag{2}$$

Initial conditions:

$$p_{1D}\left(x_D, y_D, 0\right)=0,\; p_{2D}\left(x_D, y_D, 0\right)=0 \tag{3}$$

Wellbore boundary conditions:

$$\sum_{j=1}^{N} L_j \left. \frac{\partial p_{\mathrm{D}}}{\partial \mathrm{n}} \right|_{\Gamma_{\mathrm{i}}} = 2\pi \left(-1 + \frac{dp_{\mathrm{wD}}}{dT_{\mathrm{D}}} \right) \tag{4}$$

Cave and matrix interface conditions:

$$p_{1\mathrm{D}}\left(T_{\mathrm{D}}\right)\Big|_{\Gamma_{\mathrm{v}}} = p_{2\mathrm{D}}\left(T_{\mathrm{D}}\right)\Big|_{\Gamma_{\mathrm{v}}} \tag{5}$$

$$\left. \frac{\partial p_{1\mathrm{D}}}{\partial n_{\mathrm{v}}} \right|_{\Gamma_{\mathrm{v}}} = M \left. \frac{\partial p_{2\mathrm{D}}}{\partial n_{\mathrm{v}}} \right|_{\Gamma_{\mathrm{v}}} \tag{6}$$

Reservoir boundary conditions:

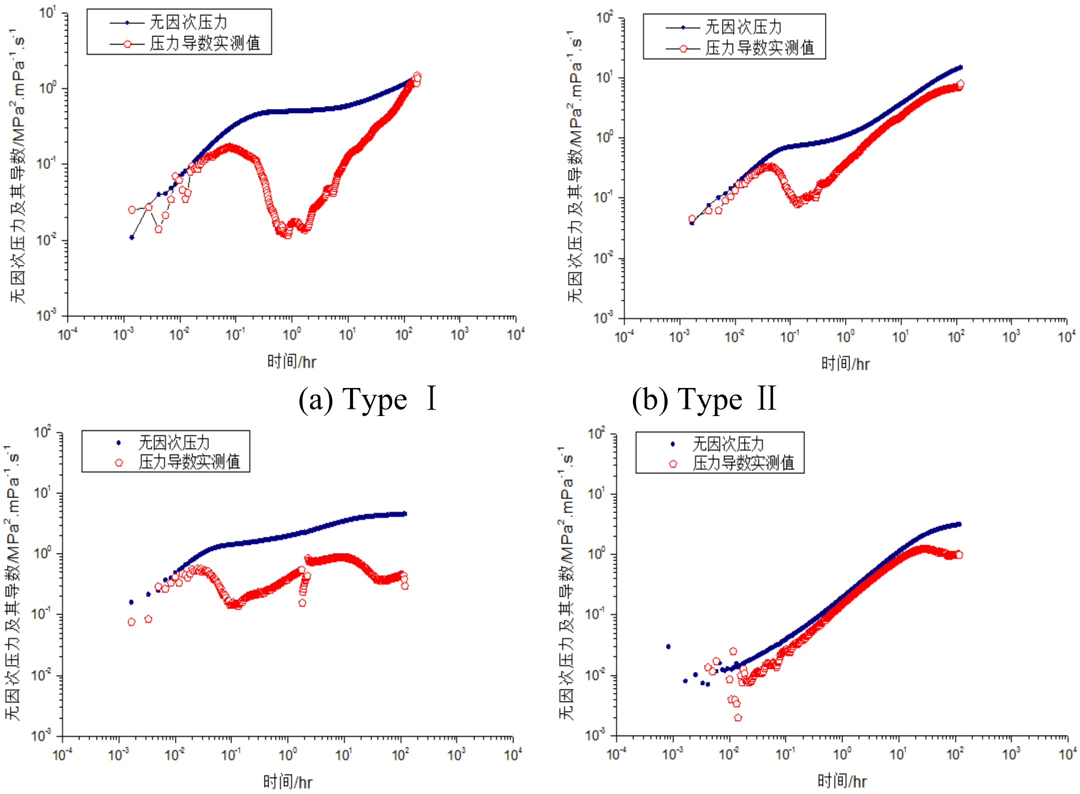
$$\left. \frac{\partial p_{\mathrm{D}}}{\partial \mathrm{n}} \right|_{\Gamma_{\mathrm{e}}} = 0 \tag{7}$$

Constant pressure boundary condition:

$$p_{\mathrm{D}}\Big|_{\Gamma_{\mathrm{e}}} = 0 \tag{8}$$

4. Field Application

The Karah Basin in the Tarim Basin is characterized by a gentle structure in the southwest, with a tectonic structure that is relatively gentle and is affected by the effect of fracture modification. Experimental Core flooding test and well logging test will get a matrix porosity of between 0.1% and 1% and a permeability of less than $1\times10^{-3}\mu m^2$. The characteristics of seismic reflection are "strong bead", strong reflection, flaky reflection and clutter reflection, and the phenomena of drilling cave drift and drilling fluid leakage are often reflected in the drilling process.



(a) Type Ⅰ (b) Type Ⅱ

(c) Type Ⅲ (d) Type Ⅳ

Fig. 2 Different types of pressure response curves

The pressure test data of 65 wells in this block are tested by the discrete fracture model proposed in this paper. Some explanations are shown in Table 1. According to the morphological characteristics of the pressure response curve and the results of the parameter interpretation, it is divided into five different types: Ⅰ "Cave development, no drilling cave or drilled in the side of the cave", Ⅱ "Cave development, Drilling cave", Ⅲ "Drilling Connected to the cave ", Ⅳ" Matrix-based, fracture is not developed "and Ⅴ" Fracture is not developed, drilling individual cave ", as shown in **Fig. 2**.

By summing up the correspondence between different types of pressure response curves and reservoir characteristics, we can not only use the laws of classification to constrain the well test interpretation process, reduce the multi-solution of well test interpretation, but also intuitively through the test curve Determine the basic characteristics of the reservoir.

The main reason for the different types of curves is the main reason for the different types of curves, which is mainly composed of type Ⅰ (26.2%) and type Ⅱ (53.8%). The location of the reservoir is different. It can be seen that the large-scale seam reservoirs determine the seepage regularity of the reservoir. In addition, the proportion of pressure response curve (type Ⅲ, Ⅳ) corresponding to the development of reservoir fractures is 14%, which indicates that there is some mutual interference between the reservoirs.

5. Conclusion

The relationship between the pressure response curve and the characteristics of the reservoir development is summarized, and five types of pressure response curves are summarized: Ⅰ " , "Not drilled in the trap hole reservoir", " Ⅱ" crevice development, drilling seam hole storage group ", Ⅲ" drilling a number of connected cave ", Ⅳ" matrix-based, crevice is not developed "and Ⅴ" seam Holes are not developed, drilling individual cave ", the oil field single well pressure response curve to type Ⅰ and type Ⅱ mainly. The single well pressure response curve of oil field is dominated by type Ⅰ and type Ⅱ.

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