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Laboratory experiments of well testing for fracture-cave carbonate gas reservoirs

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ABSTRACT

It is well known that the flowing of oil and gas in fracture and cave does not obey Darcy law, which makes it unable to interpret parameters correctly when doing well testing for those kinds of formation for having no flowing test used to correct corresponding flowing equations. Based on similarity criterion, a physical experimental method for gas flowing from cave to wellbore through fracture has been built up. The characteristics of fluid flowing in fracture and cave can be seen clearly according to log–log curves with the measured data, which was obtained from the experimental model test and dealt with Savitzky-Golay filtering method. In addition, a new mathematical model reflecting those transient-flow behaviors as well as its solution has been presented in this paper. Log–log curves obtained from our new model could reflect the characteristics of flowing in fracture and cave. The results showed that test experiments can reflect the influence of large-scaled cave and fracture on the flowing characteristics and the new model can be applied to explain parameters of fracture and cave for similar cases.

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1. Introduction

It was complex for well testing of carbonate reservoirs, which had generated great scientific interest and significant challenges [1,2]. Vugular porosity can be subdivided into two kinds, namely, connected and disconnected types [3]. The effect of vuggs on permeability was related to their connectivity [4]. It had been observed in the literature that vugular zones could strongly influence the production performance [5,6]. Well testing interpretation model could not explain those kinds of fractured-cave reservoirs effectively [7,8]. For the fractured-vuggy reservoir, the double [9,10] or triple-continuum [11,12] model was widely used in well testing interpretation. But the syntagmatic relationship for large scale of fracture and cave or the fluid exchange mechanism between them was still not been observed. Most of the existing theories were based on the linearly flow theory and there was no more sophisticated theory to explain the sophisticated flow in fractured-vuggy reservoir. It is in need of experiment to study the flow characteristics of fractured-vuggy reservoir to guide the production of field.

Lots of studies had been done about the flow in fractured-vuggy reservoir. In 2008, Peng et al. [13] regarded the cavity as a equipotential body neglecting the flow from the reservoir to the large vug and had created a model of drilling directed into the cavity. In 2009, Cheng et al. [14] proposed a model of single well drilling in isolated cavity, in which the pressure of outer boundary was steady and the cave was regard as the expand of the wellbore. In addition, the flow mechanism between the matrix and the cave was also studied in their paper. In 2010, Zhang et al. [15] established a model of well drilled in big vug and had gained the analytic solution in Laplace space. In addition, the main factors affecting the bottom hole dynamic pressure were also analyzed in their paper. In 2011, Xiong et al. [16] regarded the cave as the expansion of wellbore and had analyzed the flow mechanism between bedrock and isolated cave. In 2014, Lin et al. [17] put forward a suitable model for fractured-vuggy reservoir and the well testing model was classified into four types, namely,

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a single large-scale vug, a large-scale vug with a connected large-scale fracture, two connected large-scale vugs in series through a large-scale fracture and two connected large-scale vugs in parallel with a large-scale fracture. In 2015, Omotayo et al. [18] presented an analytic technique for interpreting pressure falloff tests of non-Newtonian Power-law fluids in wells that were located near boundaries in dual-porosity reservoirs. In 2016, Yao et al. [19] used a multiscale mixed finite element method for fluid flow in fractured-vuggy media using the discrete fracture–vug model. Gao et al. [20] developed an efficient well testing analysis model, which was suitable for naturally fractured reservoirs with a well drilled into a large-scale cavity. However, all of those methods were just of theoretical studies and there was no experimental study about them. Based on the previous researches, this paper has studied the influence of fracture and vug on the well testing curves with laboratory experimentation. Furthermore, the gas well of JY401 in Tarim Oilfield was analyzed with the proposed model in this paper.

2. Typical geology model in tarim oil field

Lost circulation, one of the most severe problems in drilling fractured formations, caused the most serious formation damage and remained a crucial issue in drilling engineering. Lost circulation problems associated with drilling in fractured and caved zones were linked with the nature of fractures and caves. Dominated by the large-scale Tazhong No. 1 fault zone, a fault system extends across central uplift of the Tarim basin. Many wells are drilled on the fractures next to a big cavity in Tarim Oil field. As can be seen in Fig. 1, JY401 is a typical fractured-vuggy well and the log–log curve is shown in Fig. 2. The well depth is 7068 m and the finished lawyer is the limestone in Ordovician system. The build-up well testing began at November 3 in 2014 and was finished at November 9 in 2014 lasting for 182.4 h. History plot and semi-log plot were shown in Figs. 3 and 4, respectively. Classical radial uniform compound interpreting model in Saphir does not match actual situation of gas reservoir making the results colliding to actual geology conditions. It could not explain the volume of the vug or the fracture length. A way to solve this kind of reservoir parameter by experiment has been proposed in this paper.

3. Physical model and the experimental procedure

3.1. Physical model design

A large number of geological research results showed that in fractured-vuggy reservoir, karst cave is the main space for storage while the fractures are mainly used as the flow channel. There are many kinds of reservoir space in fractured-vuggy reservoir. The effective reservoir space for storage includes eroded pores, large caves and fractures. The matrix only has little capability of permeability and the reservoir space has obvious multi-scale properties. The characteristic size of the eroded pores is usually measured by millimeter while the characteristic scale of large caves is usually measured by meter. When it comes to the caves, the radius of some caves is as long as hundreds of meters. The forming mechanism of the fractures is very complicated and the width of fracture ranges from several microns to a few centimeters while the length can even reach thousands of meters. In view of the phenomena of drill pipe discharge, slurry leakage during drilling operation and the beads-shaped reflection in geological exploration, this paper simulated the situation that the well is located at the large scale of fracture connected to the big carve with experimental measurement. The experiment device was shown in Fig. 5. The high-pressure vessel is used to simulate the cave, the thin tube filled with sand simulates the fracture and the empty pipeline is used to simulate the wellbore. The device is designed to test the influence of characteristics of fracture and cave on the well testing curves.

3.2. The establishment of similarity criterion

There are some certain defects in the existing mathematical equations describing the flow mechanism in the carbonate reservoir. Then, it is in need of similarity analysis to ensure the correctness and applicability of the results in the experiment.

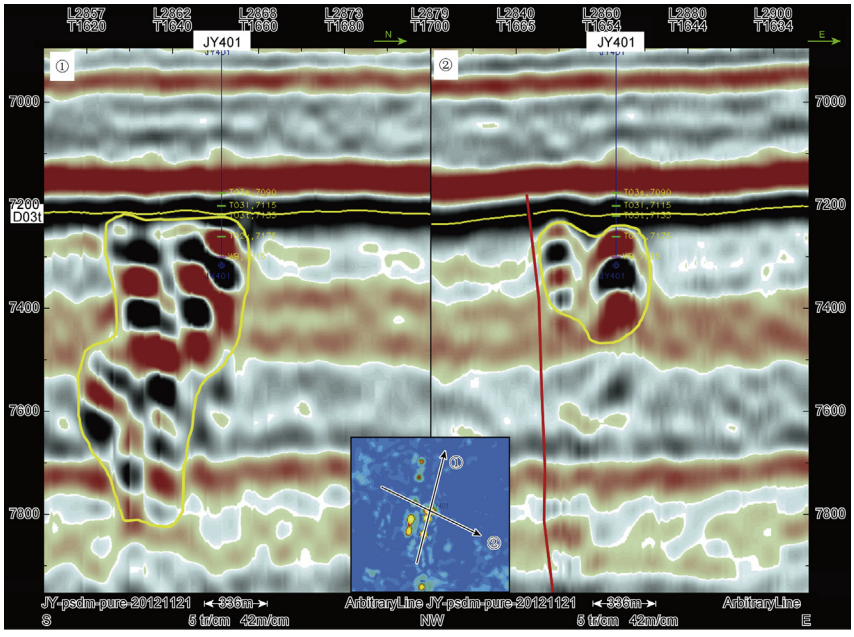

Fig. 1. Seismic profile plot of JY401.

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