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Application of the unstructured grids in the numerical simulation of fractured horizontal wells in ultra-low permeability gas reservoirs

Jiaoni Chen [a,*,1], Tiantai Li [b], Yi Zhang [b]

[a] College of Petroleum Engineering, China University of Petroleum, Beijing 102249, China
[b] College of Petroleum Engineering, Xi'an ShiYou University, Xi'an 710065, China

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ABSTRACT

Given the impermeable lithological boundary problem of the Sulige Gas Field in China, this study validates the dynamic characteristics of this reservoir through a radial model of the vertical well and proposes an unstructured grid refinement technology using a perpendicular bisector, while considering the horizontal well fracturing model. The vertical fractures and impermeable lithological boundary around the horizontal well can be accurately simulated using the unstructured grid refinement technology. This study also investigates the influence of stress sensitivity on the development indices of an ultra-low permeability gas reservoir. Results show that an impermeable lithological boundary in a horizontal well can effectively decrease the production rate of the working system of intermittent open wells. For ultra-low permeability gas reservoir with different stress sensitivities, important aspects, such as stabilization period, economic benefits, and ultimate recovery, should be considered in the early production allocation of gas wells.

1. Introduction

Ultra-low permeability gas reservoirs are important in the natural gas industry in China. These reservoirs have low natural productivity because they possess low permeability. Horizontal wells can greatly improve the effectiveness of the development of ultra-low permeability gas reservoirs. (Hegre, 1994; Giger, 1985; Renard and Dupuy, 1991; Joshi, 1991; Muskat, 1937; Weiyang and Xiaoping, 2012) Horizontal wells in ultra-low permeability gas reservoirs should be fractured to form artificial fractures with unequal lengths, improve the bottom seepage environment of the reservoir, and increase the deliverability of horizontal wells.

Stress sensitivity refers to damages to reservoir permeability and porosity caused by effective stress change. Research shows that both high- and low-permeability reservoirs have different stress sensitivity degrees, and the effect of low permeability is more significant than that of high permeability. Vairogs J indicated through experimentation that high-pressure and low-permeability reservoirs exhibit obvious stress sensitivities during fluid flow. (Vairogs et al., 1971) Ostensen R W showed that stress sensitivity can be reduced by as much as 30% of the initial capacity of a typical tight sandstone gas reservoir. (Ostensen, 1983) Pedrosa O. A. Jr. and Zhang M. Y studied the dynamic characteristics of stress sensitivity in oil and gas reservoirs, which are confined in the infinite radial flow of inhomogeneous systems. (Pedrosa, 1986; Kikani and Pedrosa, 1991; Zhang and Ambastha, 1994) An experimental study on ultra-high pressure gas reservoirs in western China also showed that low-permeability gas reservoirs possess stress sensitivity. (Xinwei et al., 2004) The rock compaction degree in low-permeability oil and gas reservoirs is high; as a result, given an increase in effective, both the changing scale of a pore volume, and the porosity reduction become small. The pore throat can be easily deformed because of its arched shape, which causes a sharp decrease in the throat radius, thereby seriously affecting the permeability.

The largest ultra-low permeability gas reservoir in China is the Sulige Gas Field. Some of the reservoir conditions in this field are complex. The reservoir is cut by an irregular impermeable lithological boundary along the plane, and the effective gas-bearing area of the reservoir is less than 0.2 km^2 with an east–west width ranging from 300 m to 400 m, as is the case in certain small

* Corresponding author. East section of Shanxi Xi'an Electronic 2 18, Xi'an Shiyou University Zip code: 710065, China.
E-mail address: 46129968@qq.com (J. Chen).

[1] Writer Introduction: Jiaoni Chen, female, born in May 1982, PhD student, currently studying in China University of Petroleum, Beijing, specializing in oil and gas field development projects.

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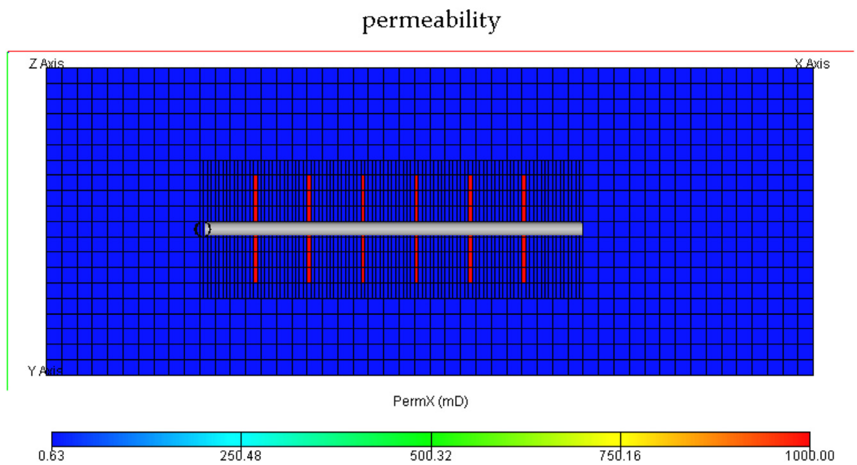

Fig. 1. Method of Cartesian grid refinement to simulate the horizontal well fracture.

reservoirs.

Grid technology serves an important function in the numerical simulation of reservoirs. In some cases, the Cartesian grid has severe grid orientation effects. In the process of grid division, the general numerical simulation software uses a row of grids to represent the fracture. The maximum fracture width is only 5 cm near the wellbore formation. In practical computation, fracture permeability and flow are large; hence, the problem of calculation convergence and stability often occurs when fractures are treated as separate rows of grids. Therefore, numerical simulation must be focused on expressing the character of the fractures and on achieving the ideal simulation effect.

Through the analysis of several methods of hydraulic fracturing numerical simulation, this study proposes using the perpendicular bisector (PEBI) unstructured grid refinement function of the large commercial simulation software Eclipse and simulating the multi-

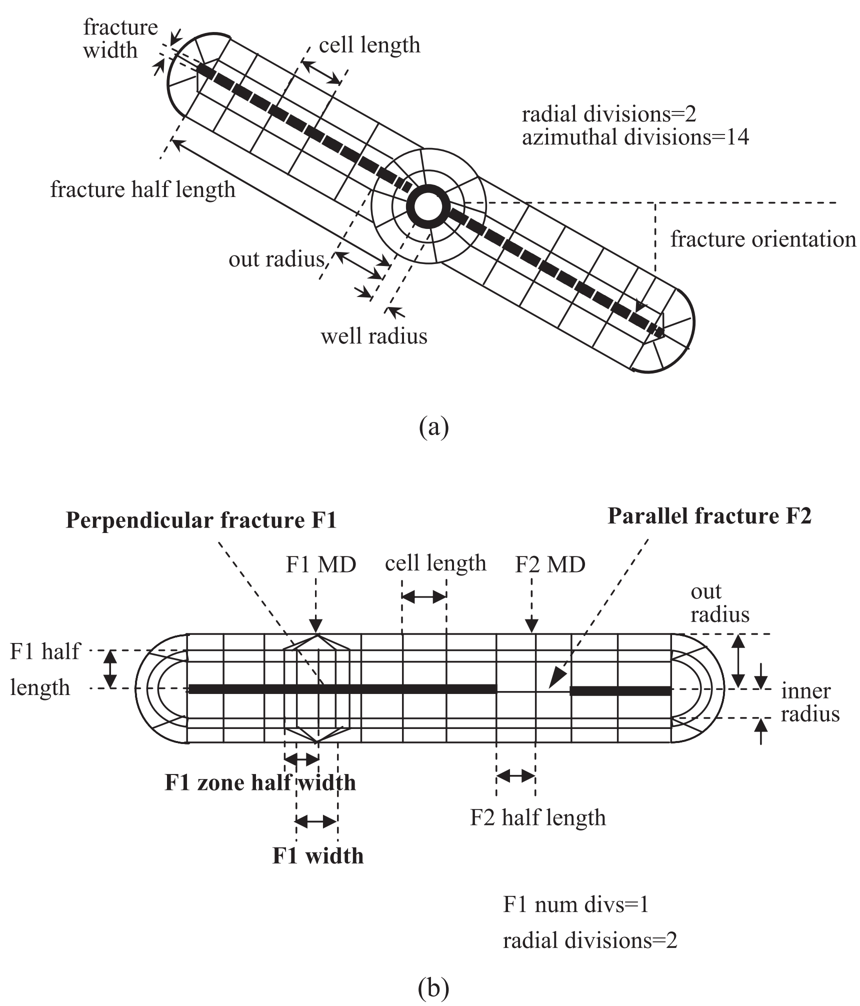

Fig. 2. PEBI unstructured grid simulation of vertical- and horizontal-well fractures (a) Hydraulic features of the vertical well (b) Vertical fracture in the horizontal well.