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A pore network model reconstruction method via genetic algorithm

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ABSTRACT

A pore network model could represent the porous medium space to predict rocks' various flow properties. This paper proposes a new method via genetic algorithm (GA) to reconstruct the pore network model with irregular distribution and topologically equivalent based on the real porous medium. Firstly, the properties of pore and throat are based on the Weilbull distribution function. A random pore network model is built by some assumptions and Weilbell parameters. In order to obtain the reliable parameters of pore and throat, the Avizo Fire analysis software is used to analysis the sample's micro-computed tomography (micro-CT) images. The theory of pore network simulation also is introduced simply in this section. Second, two objective functions for GA are given. We build up an objective function to reduce the discrepancy of slices of numerical model with the real micro-CT images, which is controlled by the core porosity. The second objective function makes model much more agreed with the experiment value. Thirdly, according to the characteristics of control parameters, we choose three steps alternating optimization to construct the model via GA. It demonstrates that this method has a quick convergence speed than before experiments. We adopt two kinds of complex geological porous medium to test the validity of our proposed method. One is a rock with high porosity (Sample One). The other is the dense sandstone (Sample Two). After the optimization, two appropriate pore network models are performed excellent of the prediction displacement in primary oil flooding of the target porous medium.

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1. Introduction

Pore-scale modeling has a wide ranging application to describe the macroscopic flow in petroleum engineering and chemical engineering. The relative permeability, water saturation, or capillary pressure as well as the mass transfer coefficient which not actually measured in multiphase flow, can be estimated by the corresponding pore network model. The physical processes occurring on the microscopic pore scale fundamentally provides the direction and clues for significantly improving oil recovery factor. Fatt (1956) firstly proposed a two-dimensional model, which is similar to the circuit network, representing the real porous medium to derive the capillary pressure curves and the distribution of pore size. After that, many researches ((Lopez et al., 2003; Al-Gharbi, 2004; Blunt et al., 2002; Øren and Pinczewski, 1995; Okabe and Blunt, 2004) simulated the multiphase flow using the digital core or the pore network model. They proved that the microscopic mechanism of the flow fluid in porous media, such as wettability and boundary layer, could be quantified by the micro models effectively. Pentland et al. (2010) measured Non-wetting phase capillary trapping in difference pore network model to investigate the influence of the petrophysical properties on capillary trapping in oil-brine system. The study is important for the field scale CO_2 drainage studies and calculation of structure and stratigraphic trapping capacity. Qi et al. (2007) simulated the geological carbon dioxide storage using the pore network model to propose design strategy for CO_2 injection to maximize storage in aquifers. Sochi and Blunt (2008) and Sochi (2010) studied the pore scale modeling the different type of Non-Newtonian rheology in porous media which was compared well to experimental data. The aim of those pore network model researches was to describe the real topological space of porous medium, extent the knowledge of microscopic flow and predict their macroscopic behaviors without any experiment work.

In early works, the porous media reconstruction often depended on the core plane images. Extracting the effective information from rocks' 2D thin section images, the mathematical statistics methods (Hazlett, 1997; Yeong and Torquato, 1998a, 1998b; Wu et al., 2004; Wu et al., 2006) were adopted to construct the digital cores. Those methods can build up models with well pore connectivity. Different from above, Øren and Bakke (2002) proposed the process-based reconstruction method. This method builds a porous medium model by simulating the diagenetic process of geological formation

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(including sedimentary, compaction and diagenesis). Most of these methods assume the porous media was homogeneous. Those reconstructed digital core can only be used to simulate the fluid flow on the images, so it was difficult to carry the further research. The high resolution micro-CT images can be obtained more easily as development continues, which promoted researches on the irregular pore space of rock. Zhao et al. (1994) proposed a multi-orientation scanning algorithm to search the pore (corresponding to the larger void spaces) and throat (the narrow openings connecting the pores) in pore space. Lindquist et al. (1996) extracted the geometrical features of pore and throat from the 3D micro-CT images based on the medial axis of void structure. Silin et al. (2003) introduced the concept of the maximal balls to analyze the pore space and computer the dimensionless capillary pressure curve of rock sample. Then Al-Kharusi and Blunt (2007) extended this conception and extract a complete network. Dong and Blunt (2009) improved the modeling method of Al-Kharusi and Blunt, and describes the relationship between the various spheres by constructing a tree structure and greatly reduces the computer memory.

Random pore network models are mostly built up by a regular lattice with parameters random distribution. Those models are easily to qualitatively study the multi-phase flow and the problem of the wettability in porous media. Valvatne et al. (2005) carried the pore and throat as having a square, circular or triangular cross section to model the pore network with regular distribution to study the flow of power-law fluids in porous media. Piri and Blunt (2005) predicted relative permeability and studied the physically model of wettability alteration in the multiphase flow by using an irregular random pore network. Jivkov et al. (2013) established a pore network with high coordinate number based on truncated octahedral sup, and calculated the relationship between the evolutions of permeability and damage-related pore space change.

The GA is also introduced into modeling the pore network. Unsal et al. (2005) optimized a numerical model representing porous medium with the pores' size distribution and arrangement form the air permeability measurements by genetic algorithm. It can be seen that the pores' size distribution position are important to the pore geometry. Jamshidi et al. (2009) simulated multicellular growth (L-system) to generate random irregular pore network models. The networks are obtained by optimizing the L-system parameters via genetic algorithm and predicted both static and hydraulic information of the target porous medium. Nejad Ebrahimi et al. (2013) extracted a pore network with reasonable coordinate number from the micro-CT images by genetic algorithm. In the Ebrahimi's study, the first objective function was used to reduce the differences of the model and CT images. The GA would be useless with the loosen rules, for the individual fitness does not rise steadily as time goes on. We add the bond of the porosity which is a basic parameter of porous medium in the objective function. It can reduce the computation time and make the individual fitness easily convergence. During the process of optimization, Ebrahimi finds that the optimization process fixed the pore number and position by the first objective function and further optimized other parameters by the second objective function can obtain excellent match. In order to model the porous medium more accurately, we deeply analyze the properties of all parameters and change the optimization process. Three steps are developed to obtain the pore network. GA is used to alternate optimize those parameters about pore radius, the aspect ratio (ratio between radius of the connected pore and throat) and the coordinate number step by step. The first changed objective function was used to optimize the pore numbers and position. Then, we fix pore number and position to optimize all the other parameters via the same objective function, which makes the numerical model more match with CT-images. In the third step, the second objective only decides the aspect ratio distribution and the connecting relationship with fixing all other parameters. After the reconstruction, the models are used to simulate the process of drainage. The experiment proved that this method could reconstruct a better pore network model with less time consumption. In this paper first an irregular network model structure is built with some rules. We also describe the method of solving pore network model's absolute permeability and calculate the wetting phase saturation across the drainage process. Then, the genetic algorithm is simply introduced. After selecting optimization parameters, two objective functions and experiment procedure are given in Section 4. We reconstruct and analyze two types of pore network model, and then simulate the process of displacement under water wetting. Finally, we conclude our work in the last section.

2. The description of pore network model and the theory of pore network simulation

2.1. Network construction

The pore space of porous medium is composed by irregular shaped pores with many small sections. In order to simplify the model, the basic idea of model is to treat the pore space as ideal geometry. The irregular pore space can be described as a certain shape pore (spheres) and throat (cylinder) interconnected. In general researchers, the random pore network is described as the cubes with pore and throat regular arranged. While in this paper we consider the pore network model as the cylinder with the irregular lattice distribution which has the same size with samples' micro-CT images.

The Weilbull distribution function is introduced to describe the prosperities of pore and throat. So the pore radius, coordinate number and aspect ratio are generated by Weilbull distribution. The cylinder is used to represent the throat with ignoring its tortuosity. In order to avoid generating too long throat, the distance of connected pores is limited. The coordinate number is used to control the number of throats in a pore. The throat radius should be smaller than the linked pore radius. The aspect ratio is the ratio of the pore radius with throat radius. This parameter is important for controlling the throat radius to building a reasonable model. A 3D cylinder pore network numerical model is built up with spheres connected cylinders via MATLAB, which is shown in Fig. 1. The properties of the pore and throat are reasonable assumption and

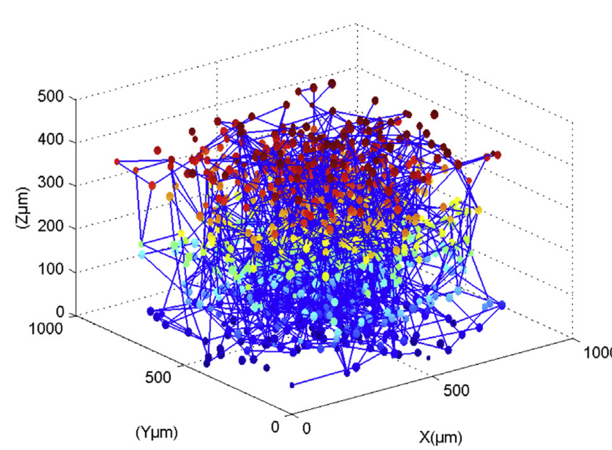

Fig. 1. The cylinder pore network numerical model.

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