PORE-SCALE CHARACTERIZATION OF CARBONATE ROCK HETEROGENEITY AND PREDICTION OF PETROPHYSICAL PROPERTIES

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ABSTRACT

Carbonate reservoirs, accounting for majority of the world's hydrocarbon reserves, are well known for their heterogeneity and multiscale pore characteristics. The pore sizes in carbonate rock can vary over orders of magnitudes, the geometry and topology parameters of pores at different scales have a great impact on flow properties. A relatively simple way to integrate a set of digital pore space images of different resolutions is to superpose these images into one single large image by matching the resolutions of the individual images.

In this paper, a series of 2D thin section carbonate images with different resolutions are collected with scanning-electron microscopy (SEM). The lower resolution image shows macro pore properties, while the higher resolution shows micro pore properties. With two different scale resolution images, a Markov Chain Monte Carlo (MCMC) method is used to construct 3D macro pore and micro pore digital rocks respectively. Basing on the macro pore and micro pore digital rocks, superposition method is introduced to construct multiscale digital rock. Then, pore analysis tools (PATs) are used to generate macro pore, micro pore and superposition network respectively; and flow calculation is performed on a pore-network model extracted from the combined image. At last, geometry-topology and flow properties are compared among the three different scale networks. Results show that, the superposition network could capture the important pore scale properties of both macro pore network and micro pore network. More importantly, different contributions to flow properties of certain scale pore structures are recognized, in particular, the potential impact of the micro porosity on the pore connectivity and the interconnectivity between different scale porosities is investigated and highlighted, which could describe the carbonates in a better way and has a dramatic effect on permeability and higher recoveries.

1 INTRODUCTION

Although a number of 3D reconstruction method and pore network models are available for sandstones, developing a similar model for carbonates has been difficult. In carbonate rocks, a wide range of pore sizes from sub-μm to mm scale are produced during the processes of sedimentation and diagenesis. Many carbonate rocks have a bi- or tri- modal pore size distribution with organisms playing an important role in forming the reservoirs. Due to these reasons it is difficult to fully classify and characterize the pore scale microstructure of carbonate rocks, and it is challenging to predict petrophysical and multiphase flow properties in carbonates. In recent years, for more complex rocks, such as carbonates, several authors have studied the multiscale pore characteristics[1-7]. With distinctive macropore (pore size in 10s μm to mm) and micropore (pore size in sub-μm to μm) systems, our 3D Markov random field models can be used to reconstruct representative systems at each scale. For a carbonate sample, thin section images have been obtained under different microscope magnifications, allowing Pore Architecture Models (PAMs) reconstructions from which we extract networks for the coarse and fine scales[8]. A method is proposed to combine the reconstructions from the coarse and fine scales. We extract networks for the coarse, the fine and the combined scales and then we compare the predicted relative permeabilities at each scale.

This paper describes a new approach to make predictions of the transport characteristics of porous media that possess multiple-scales of pore systems. We additionally set out to: (i) develop an approach to link quantifiable measures of porous media to an accurate mapping of the pore morphology at different scale; (ii) develop a methodology for using detailed information on pore morphology and topology as an input to investigate the multiphase flow properties at each scale; (iii) quantify the characterization of pore connectivity and topology then combine all the scaled images into a single imbedded multiscale image and (iv) predict the flow response for that combined part of the medium. We illustrate the comparison results of single phase and multiphase flow simulation.

2 METHODOLOGY

2.1 Multiscale Image Analysis And 3D Digital Rock Reconstruction

Two-dimensional SEM images are used here as we cannot obtain 3D images with the required resolution to image the microstructure of carbonate rocks. Figure 1 shows the carbonate thin section at two different resolutions using scanning electron microscopy. The low resolution image pixel size is 1424×968 with a resolution of 1.34μm (Figure 1(a)); the high resolution image pixel size is 1424×968 with a resolution of 0.335μm (Figure 1 (b)), and the two image resolution ratio factor is 4.

The 2D binary images above are input into an algorithm developed by Wu et al.[8, 9]

that uses Markov Chain Monte Carlo (MCMC) method to construct 3D macro pore and micro pore digital rocks respectively. Since only one direction images are available, it is assumed that the image is isotropic. The resultant 3D digital rocks have the volume of 100^3 to 400^3 voxels. Both the macro pore digital rock and micro pore digital rock have the same physical size (0.134mm×0.134mm×0.134mm). Meanwhile, the porosity of macro pore digital rock (Figure 2(a)) is 0.254366, voxel size is 100×100×100 with a resolution of 1.34μm; the porosity of micro pore digital rock (Figure 2(b)) is 0.354643, voxel size is 400×400×400 with a resolution of 0.335μm.

2.2 Multiscale 3D Digital Rock Superposition Method

The data of digital rock are stored in the form of 0 and 1, and 0 represents pore space while 1 represents skeleton. Basing on the macro pore and micro pore digital rocks, superposition method is introduced to construct superposition digital rock[10]. The superposition procedures are shown as follows: At first, each voxel in macro pore digital rock is refining into $i \times i \times i$ voxels, i the resolution ratio of macro pore digital rock and micro pore digital rock and i equals 4 in this paper. The voxel refinement could make the macro pore digital rock and the micro pore digital rock have the same physical size (0.134mm×0.134mm×0.134mm) and voxel size (400×400×400).Then, the superposition operations of binary data between two digital rocks are as follows: $0+0=0$, $1+0=0$, $0+1=0$, $1+1=1$. The superposition digital rock is constructed to capture both the properties of macro pores and micro pores, as seen in Figure 2(c). The porosity of superposition digital rock is 0.518967, voxel size is 400×400×400 with a resolution of 0.335μm.

3 RESULTS AND DISCUSSIONS

3.1 Geometry And Topology Analysis

Pore analysis tools (PATs) are used to extract pore network model from 3D digital rock. This analysis tools were developed by Jiang et al[11]. Based on macro pore, micro pore and superposition digital rocks, PATs is used to generate macro pore, micro pore and superposition network respectively. Geometry-topology properties are important criterion to evaluate the accuracy of pore network models. Geometry parameters include pore size distribution and shape factor etc.; topology parameters include network connectivity function and coordination number etc[12]. In this paper, a specific Euler number which is developed by Vogel[13], is used to quantify the network connectivity. Figure 3 illustrates the geometry and topology parameters comparison among the three networks. As can be seen in the figure, the curves of superposition network distributes between that of macro pore and micro pore network, which shows that superposition network could capture the geometry and topology properties of both macro pore and micro pore network.

3.2 Flow Analysis

Based on percolation theory in pore network modeling[14], flow calculations have been performed on a pore-network model extracted from the combined image. The parameters to be calculated from pore network flow simulation include absolute permeability and relative permeability etc. Flow processes are simulated according to invasion-percolation principles. All three network models are simulated in the same water-wet condition. The flow parameters, such as absolute permeability and relative permeability curves, are shown as follows: The absolute permeability of superposition network is 15.168mD, which is higher than that of macro pore network 9.56115 mD and micro pore network 4.44805 mD. This is due to the potential impact of the micro porosity on the pore connectivity and the interconnectivity between different scale porosities, which improves the superposition network connectivity and the absolute permeability. Oil flooding drainage and water flooding imbibition process are simulated in water wet condition, as can be seen in the comparison of relative permeability curves in three networks (Figure 4), the more reliable superposition network has a higher water isoperm saturation than both that of macro pore and micro pore network, while the isoperm water saturation describes the reservoir wettability, the superposition network could give a better reservoir description. Especially, during imbibition process, the residual oil saturation of superposition network is 0.14, which is much lower than that of macro pore network 0.28 and micro pore network 0.20.

4 CONCLUSIONS

In this work, based on multiscale image analysis and 3D digital rock reconstruction, a multiscale digital rock was constructed through the superposition of macropore and micropore digital rocks. The geometry-topology and flow properties were compared among the three extracted networks. It showed that the superposition network could capture the important pore scale properties of both macro pore network and micro pore network, the potential impact of the micro porosity on the pore connectivity and the interconnectivity between different scale porosities improved the total network connectivity. The more reliable superposition network with higher water isoperm saturation and less residual oil saturation described a better carbonate reservoir description and had a dramatic effect on permeability and higher recoveries.

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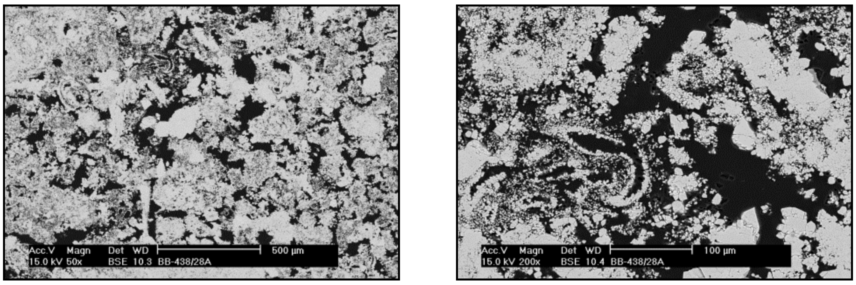
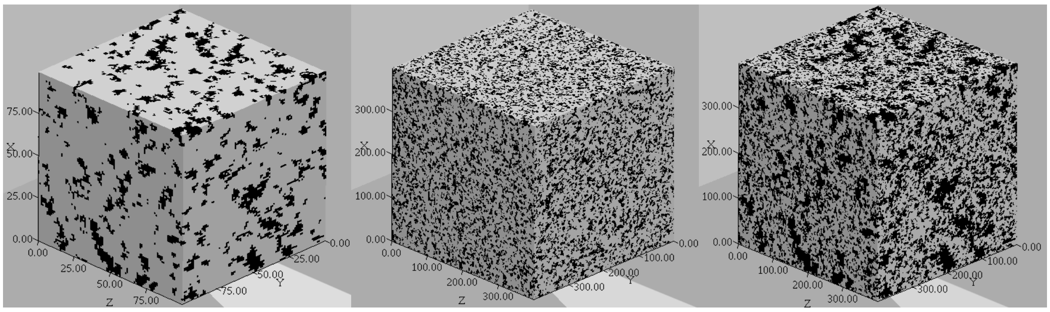


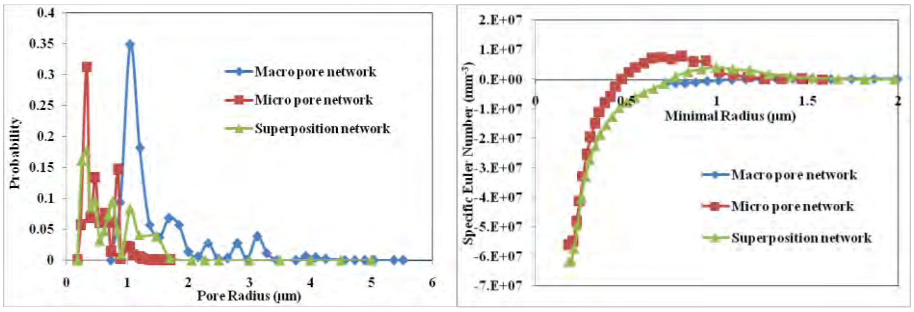
(a) Low resolution image (b) High resolution image

Figure 1. SEM images at different resolutions taken from a carbonate core plug



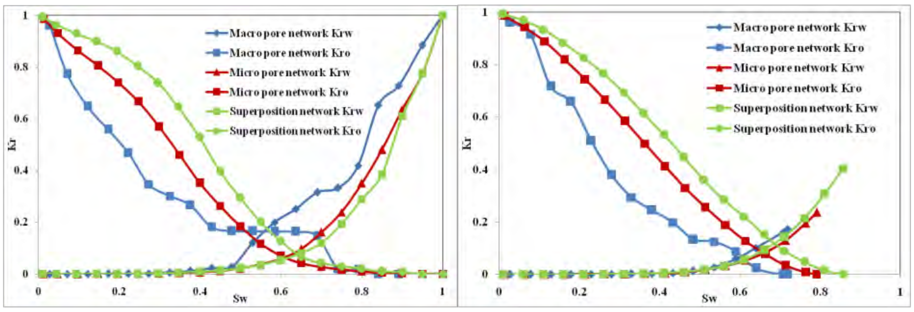
(a) Macro pore digital rock (b) Micro pore digital rock (c) Superposition digital rock

Figure 2. Different digital rocks



(a) Pore size distribution (b) Connectivity function distribution

Figure 3. Geometry and topology parameters comparison of pore network models



(a) Drainage process (b) Imbibition process

Figure 4 Relative permeability curves comparison of pore network models