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Editorial

AN INTRODUCTION TO FRACTAL-BASED APPROACHES IN UNCONVENTIONAL RESERVOIRS — PART I

JIANCHAO CAI,[*,||] LIEHUI ZHANG,[†] YANG JU,[‡] GIORGIO PIA,[§] and ZHIEN ZHANG[¶]

[*]*Hubei Subsurface Multi-Scale Imaging Key Laboratory*
Institute of Geophysics and Geomatics
China University of Geosciences
Wuhan 430074, P. R. China

[†]*State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation*
Southwest Petroleum University
Chengdu, Sichuan 610500, P. R. China

[‡]*State Key Laboratory of Coal Resources and Safe Mining*
China University of Mining & Technology (Beijing)
Beijing 100083, P. R. China

[§]*Dipartimento di Ingegneria Meccanica, Chimica e dei Materiali*
Università degli Studi di Cagliari, Piazza d'Armi
09123 Cagliari, Italy

[¶]*School of Chemistry and Chemical Engineering*
Chongqing University of Technology
Chongqing 400054, P. R. China

[||]*caijc@cug.edu.cn*

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[||]Corresponding author.

Abstract

In recent years, unconventional reservoirs have drawn tremendous attention worldwide. This special issue collects a series of recent works on various fractal-based approaches in unconventional reservoirs. The topics covered in this introduction include fractal characterization of pore (throat) structure and its influences on the physical properties of unconventional rocks, fractal characteristics of crack propagation in coal and fluid flow in rock fracture network under shearing, porous flow phenomena and gas adsorption mechanism, fractal geophysical method in reservoirs.

Keywords: Fractal; Unconventional Reservoirs; Modeling.

1. INTRODUCTION

Unconventional reservoirs include shale oil and gas, tight oil and gas, coalbed methane, and natural gas hydrate, etc. In recent years, unconventional reservoirs have received a great deal of attention from reservoir engineers, geologists, geophysicists, physicists, and energy economists. Unconventional natural gas and oil systems have tremendous complex microstructure. A three-dimensional pore network modeling of tight sandstone with a porosity of 0.144 is depicted in Fig. 1. A better understanding of the nano- and micro-scale structures of these reservoir rocks, and their transport properties are critical for improving the efficiency of these natural oil and gas systems. Due to the complexity of unconventional rock microstructures, and the strong interactions between fluids and pore surfaces due to the reduced dimensionality, conventional approaches and theories (equations) are typically not applicable to quantify and characterize fluid flow in these porous reservoir rocks.

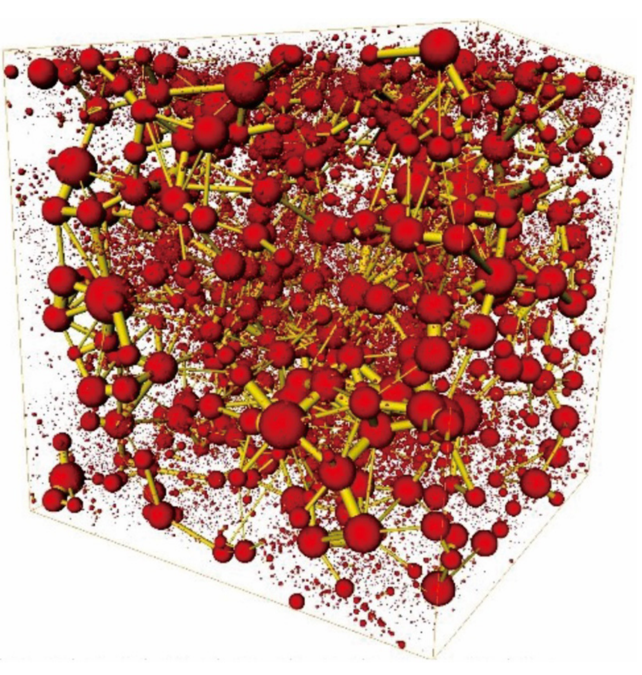

Fig. 1 Three-dimensional pore network modeling of tight sandstone.

Fractal geometry offers a quantitative evaluation on the heterogeneity and complexity of reservoir rocks, such as pore surface structure, pore size distribution and fracture networks, which significantly affects fluids flow and transport in these porous systems.[1–6] The fractal-based approaches have been widely and successfully used in unconventional reservoirs. This special issue emphasizes the fundamental innovations and gathers together a number of recent papers on new applications of fractal theory in unconventional reservoirs.

2. OVERVIEW OF WORKS PRESENTED IN THIS SPECIAL ISSUE

The papers published in this issue of *Fractals* represent Part I of a special topic covering fractal-based approaches in unconventional reservoirs. They can be clearly divided into the following four groups.

The first group of papers focuses on fractal theory applied to pore (throat) structure characterization and its influences on physical properties of rocks. Fractal dimension offers a quantitative evaluation on pore (throat) structure. In order to better understand the impact of fractal features of pore-throat structures on effective physical properties of tight gas sandstones, Huang *et al.*[7] carried out a series of measurements and analyzed 20 sandstone samples of the Shihezi Formation from 16 wells of the Sulige Gas Field in the Ordos Basin, China. The fractal dimensions of pore-throat structures were calculated and its influences on the physical properties of sandstone samples were investigated. Combining low-pressure N_2 adsorption and other technologies, fractal dimensions of pore surface with Frenkel–Halsey–Hill model were obtained to investigate the fractal characteristic of pores shale from Taiyuan formation by Kunjie Li *et al.*,[8] Yanchang Formation from the Ordos Basin by Yang Wang *et al.*,[9] and Biyang Depression of Henan Oilfield by Jijun Li *et al.*[10] The controlling factors for fractal dimensions, including pore morphology, total organic carbon content, and mineral content, were analyzed accordingly. To compare the fractal characteristics between marine and continental shales, Liu *et al.*[11] also characterized the reservoir properties and fractal dimensions of 18 shale samples. Weiming Wang *et al.*[12] studied the morphological characteristics and size distribution of nanoscale pores in the volcanic rocks of the Haerjiawu Formation using the results of low temperature nitrogen adsorption experiments and fractal geometry theory. Considering the relationship between the porosity of rocks and the fractal characteristics of pore structures, Lin *et al.*[13] proposed a new improved image segmentation method, which used the calculated porosity of core images as a constraint to obtain the best threshold.

The second group of papers focuses on fractal characterization of fractal network and crack propagation. Huang *et al.*[14] studied the size effect on the permeability and shear induced flow anisotropy of fractal rock fractures. In their work, the effect of model size on fluid flow through fractal rough fractures under shearing was investigated using a numerical simulation method. The shear behavior of rough fractures with self-affine properties was described using an analytical model. Fluid flow through fractures in the directions both parallel and perpendicular to the shear directions was simulated by solving the Reynolds equation using a finite element code. Zhao *et al.*[15] studied the fractal characteristics of crack propagation in coal containing beddings under the impact loading condition. The image processing method and fractal dimension calculation software were combined to further analyze the effects of bedding and loading rate on the fractal characteristics of crack propagation in coal.

The third group of papers focuses on the porous flow and gas adsorption mechanism by means of fractal geometry. Lei *et al.*[16] conducted laboratory tests on the stress-dependent relative permeability in porous media and developed a corresponding fractal model. The predictions from the proposed analytical model exhibited similar variation trends to the experimental data. Shen *et al.*[17] established an analytic equation of spontaneous imbibition by considering slip effects in capillaries with nanoscale and built a spontaneous imbibition model by coupling the analytic equation based on fractal theory. In addition, Xiao *et al.*[18] derived an analytical model for the capillary pressure and water relative permeability in unsaturated porous rocks by taking into account the fractal distribution of pore size and tortuosity of capillaries. Integrating the fractal theory and molecular dynamics simulation, Liehui Zhang *et al.*[19] investigated the adsorption phenomenon in shale kerogen. In their work, the adsorption of methane in 2, 5 and 10 nm slit-like pores was simulated at different temperatures and pressures, and the simulation results were analyzed using the multilayer fractal adsorption model. Xu and Li[20] proposed a fractal model for erosion threshold of bentonite flocs, in which cohesion forces, the long-range van der Waals interaction between two clay particles are taken as the resource of the erosion threshold.

The fourth group of papers focuses on combining of fractal geometry and (rock) geophysical method in reservoirs. Using nuclear magnetic resonance (NMR) and mercury intrusion porosimetry (MIP), Fuyong Wang *et al.*[21] presented an advanced fractal analysis of the pore structures and petrophysical properties of the tight oil sandstones. The relationships between the fractal dimensions of different size pores calculated from NMR T_2 spectrum and petrophysical properties of tight oil sandstones were analyzed. Micro-seismic diagnostic has been introduced into petroleum fields to describe the distribution of hydraulic fractures. Furthermore, Kai Zhang *et al.*[22] integrated micro-seismic technology with history matching to predict the hydraulic fracture parameters. By considering the fractal feature of hydraulic fracture, a fractal fracture network model was established to evaluate this method in numerical experiment. Magnetotelluric was an electromagnetic-based exploration method, which has been widely used to identify the distribution of underground geoelectric structure. Jin Li *et al.*[23] proposed a new technique for signal-noise identification and targeted de-noising of Magnetotelluric signals based on fractal-entropy and clustering algorithm.

3. CONCLUSIONS

The use of fractal theory to characterize and model structure and transport properties of unconventional reservoirs is an extremely new field of research. Seventeen papers collected in this special issue focus on the characterization of pore (throat) structure, fractal network and crack propagation as well as its influences on physical properties of porous media, porous flow and gas adsorption mechanism, and modeling approaches by combining of fractal geometry and (rock) geophysical. The aim of the special issue is to further advance this multidisciplinary endeavor.

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