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Editorial

Emerging Advances in Petrophysics: Porous Media Characterization and Modeling of Multiphase Flow

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Abstract: With the ongoing exploration and development of oil and gas resources all around the world, applications of petrophysical methods in natural porous media have attracted great attention. This special issue collects a series of recent studies focused on the application of different petrophysical methods in reservoir characterization, especially for unconventional resources. Wide-ranging topics covered in the introduction include experimental studies, numerical modeling (fractal approach), and multiphase flow modeling/simulations.

Keywords: petrophysics; fractal porous media; unconventional reservoirs; multiphase flow

1. Introduction

A subsurface reservoir, as an important natural porous media, usually has a complex pore/fracture structure. Several key parameters such as pore-throat size distribution, pore connectivity, and micro-scale fractures strongly affect transport, distribution, and residual saturation of fluids in porous media.

Petrophysics, defined as the study of the physical and chemical properties of rock and its interactions with fluids, has many applications in different industries, especially in the oil and gas industries. Key parameters studied in petrophysics are lithology, porosity, water saturation, permeability, and density. Petrophysics is closely related to different areas such as petroleum engineering, geology, mineralogy, and exploration geophysics. Petrophysicists work closely with reservoir engineers and geoscientists to understand different phenomena in subsurface reservoirs, i.e. how pores are interconnected in a subsurface reservoir, and how this connectivity affects the migration and accumulation of hydrocarbon.

From a broader point of view, petrophysics, especially in terms of characterization of and multiphase flow in porous media, covers a wide range of research studies including hydrocarbon extraction, geosciences, environmental issues, hydrology, and biology. The relevant stakeholders in this issue are authorities and service companies working in the petroleum, subsurface water resources, air and water pollution, environmental, and bio-material industries. Implementing reliable methods for the characterization of multiphase flow in porous media is crucial in many fields, including the characterization of residual water or oil in hydrocarbon reservoirs and long-term storage of supercritical CO_2 in geological formations.

This collection associated with the special issue in *Energies* emphasizes the fundamental innovations and gathers together 15 recent papers on novel applications of petrophysics in unconventional reservoirs.

2. Overview of Work Presented in This Special Issue

The papers published in this special issue present new advancements in the characterization of porous media and the modeling of multiphase flow in porous media. These research studies are divided into four categories.

Studies in the first category focus on the experimental approaches for the characterization of porous media. Through selecting 12 rock samples from the Bakken formation, Liu et al. [1] conducted a set of experiments including X-ray diffraction analysis, total organic carbon analysis, vitrinite reflectance, and low-temperature nitrogen adsorption experiments to study pore structures and the main controlling factors in this formation. The Bakken formation has micro-, meso-, and macro-pores. Total organic carbon and maturity are the main parameters controlling the pore structure of the upper and lower Bakken formation. However, clays and quartz are the controlling parameters for the middle Bakken formation.

Using pressure-controlled mercury injection, casting sheet images and scanning electron microscopy analysis, Wang et al. [2] studied the pore structure of the mouth bar sand bodies in Guan195 area, China. Three types of pores exist in this area, including intergranular pores, dissolution pores, and micro fractures. Pore structure heterogeneity of single mouth bar sand bodies in the short-, middle- and long-terms base-level were respectively analyzed and compared.

By employing a computer-controlled creep setup, Zhou et al. [3] conducted a set of creep tests on salt rock under a constant uniaxial stress. They studied the acoustic emission space–time evolution and energy-releasing characteristics. A new creep-damage model was proposed based on a fractional derivative of combined acoustic emission statistical regularities. This could provide a precise description of full creep regions in salt rock. The acoustic emission data in the non-decay creep process of salt rock could be divided into three stages: the initial transient creep period, the steady-state period, and the tertiary stage.

Based on the functional relationships between porosity, true density, and bulk density, Zhang et al. [4] proposed a new experimental method for characterizing the porosity of loose media subjected to overburden pressure. This method was used to test the total porosity of loose coal particles including the influence of pressure and particle size. The total porosity and pressure obey an attenuated exponential function, while the total porosity and particle size obey a power function. The sensitivity of total porosity and particle size to pressure were also analyzed.

Studies in the second category focus on a fractal-based approach for the characterization of porous media. In addition to pores, fractures can be characterized by fractal geometry [5–8]. Gong et al. [9] utilized the fractal method to evaluate the behavior of fractures in tight conglomerate reservoirs. Three types of fractures were identified in these reservoirs: intra-gravel, gravel edge, and trans-gravel fractures. The fractal dimension of the fractures is in the range of 1.20–1.50. The fractal dimensions are exponentially correlated with the fracture areal density, porosity and permeability. The cumulative frequency distribution of both fracture apertures and areal densities obeys the power law distribution. The fracture parameters at different scales could be predicted by extrapolating their power law distributions. Jiang et al. [10] used mercury injection capillary pressure (MICP) data to characterize the heterogeneity of pore structures. The multifractal analysis based on the MICP data was conducted to investigate the heterogeneity of tight sandstone reservoirs. The relationships among physical properties, MICP data and multifractal parameters were analyzed in detail. Tao et al. [11] presented an efficient fractal-based approach to investigate the effects of initial void ratio on the soil–water characteristic curve (SWCC) in a deformable unsaturated soil. This approach included only two parameters: fractal dimension and air-entry value. The SWCCs are mainly controlled by the air-entry value, while the fractal dimension can be assumed constant.

Studies in the third category focus on the modeling of multiphase flow in porous media. To accurately find flow patterns in high-yield wells with different inclined angles, Qi et al. [12] conducted multiphase pipe flow tests in mid–high yield and highly deviated wells under different: (i) inclined angles; (ii) liquid flow rates; and (iii) gas flow rates. A pressure prediction model with new coefficients and higher accuracy for wellbores in selected blocks was developed. In addition, the effects of inclination, output, and gas flow rate on the flow pattern, liquid holdup, and friction during multiphase flow were comprehensively analyzed. Six types of classical flow regimes were verified with the developed model.

Microfractures (natural and induced) have a great significance on reservoir development. Yang et al. [13] utilized the Lattice Boltzmann method to calculate the equivalent permeability of artificially induced three-dimensional fractures. The fractal dimensions, geometrical parameters and porosity of induced fractures in Berea sandstone were calculated based on digital cores of fractures. The relations between permeability and fractal dimension, geometrical parameters and the porosity of factures were summarized and discussed.

To evaluate the producing degree of commingled production, Shen et al. [14] presented a one-dimensional linear flow model and a planar radial flow model for water-flooded multilayer offshore heavy oil reservoirs based on the Buckley–Leverett theory. A dynamic method was used to evaluate seepage resistance, sweep efficiency, and oil recovery factor. An analysis with field data was also presented.

Scientifically determining a heating scheme requires an understanding of the behavior of oil when the temperature declines during tanker transportation. Yu et al. [15] investigated the free liquid surface movement and the temperature drop characteristics of crude oil in cargo when the tanker was subjected to rotational motion. It was found that the oscillating motion significantly enhanced the temperature decline rate and it was positively related to the rotational angular velocity.

The behavior of flow resistance with velocity is still poorly defined for post-laminar flow through coarse granular media. Banerjee et al. [16] investigated the effect of flow resistance on independently varying media size and porosity subjected to parallel post-laminar flow through granular media. They then simulated the post-laminar flow conditions with the help of a computational fluid dynamic model. Their output advocated the importance and applicability of computational fluid dynamic modelling in better understanding post-laminar flow through granular media.

Zhang et al. [17] developed a generalized method to determine the diffusion coefficient for supercritical CO_2 diffusing into porous media saturated with oil under reservoir conditions. They established a mathematical model to describe the mass transfer process. The results showed that oil with lower viscosity and lighter oil components can enhance the mass transfer process.

Studies in the fourth category focus on marine gas hydrates. Molecular and isotopic analysis of marine gas hydrate samples and potential hazards are associated with their production and development. Ye et al. [18] analyzed the isotopic gas composition of 300 samples from China's first gas hydrate production test in the South China Sea. All gas samples were predominated by methane. However, no H_2S was detected. The methane in all samples was of microbial origin and derived from CO_2 reduction. Moreover, Wang et al. [19] analyzed the potential hazards associated with the production and development of marine gas hydrates. Marine geo-hazards, greenhouse gas emissions, marine ecological hazards, and marine engineering hazards are four reported hazard categories. They proposed the concept of life-cycle management for the prevention of hazards during the development and production from marine gas hydrates. This concept was divided into three steps including preparation, production control, and post-production protection. A production test in the Shenhu area of the South China Sea showed that marine gas hydrate exploration and development could be planned using the three-step methodology.

3. Conclusions

Many researchers around the world from different areas, ranging from natural sciences to engineering fields, have been working on: (i) the characterization of petrophysical properties for unconventional resources; and (ii) simulating multiphase flow in these resources. The aim of this special issue is to provide new ideas related to petrophysics, and then to advance this multidisciplinary effort. Clearly, the modeling of multiphase flow in porous media continues to be helpful for oil and gas reservoirs. Moreover, the molecular and isotopic analysis of gas hydrates in marine fields are beneficial for minimizing the hazardous and polluting gas emissions.

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