Editorial

Recent Advances in Flow and Transport Properties of Unconventional Reservoirs

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Abstract: As a major supplement to conventional fossil fuels, unconventional oil and gas resources have received significant attention across the globe. However, significant challenges need to be overcome in order to economically develop these resources, and new technologies based on a fundamental understanding of flow and transport processes in unconventional reservoirs are the key. This special issue collects a series of recent studies focused on the application of novel technologies and theories in unconventional reservoirs, covering the fields of petrophysical characterization, hydraulic fracturing, fluid transport physics, enhanced oil recovery, and geothermal energy.

Keywords: unconventional reservoirs; petrophysical characterization; fluid transport physics

1. Introduction

Unconventional reservoirs, such as shale, coal, and tight sandstone reservoirs, are complex and highly heterogeneous, generally characterized by low porosity and ultralow permeability. Additionally, the strong physical and chemical interactions between fluids and pore surfaces further lead to the inapplicability of conventional approaches for characterizing fluid flow in these porous reservoir rocks [1]. Therefore, new theories, techniques, and geophysical and geochemical methods are urgently needed to characterize petrophysical properties, fluid transport, and their relationships at multiple scales for improving production efficiency from unconventional reservoirs.

Petrophysical characterization covers the study of the physical and chemical properties of rock and its interactions with fluids, which has many applications in different industries, especially in the oil and gas industries. The key parameters studied in petrophysics are lithology, porosity, water saturation, permeability, and density. Petrophysical characterization is the basis for understanding the special properties of unconventional reservoirs.

Fluid transport physics in micropore structures and macro-reservoirs covers a wide range of research studies including hydrocarbon extraction, geosciences, environmental issues, hydrology, and biology. Implementing reliable methods for the characterization of fluid transport at multiple scales is crucial in many fields, especially in unconventional reservoirs and rocks.

Hydraulic fracturing is currently considered as one of the most important stimulation methods in the oil and gas industry, which significantly improves the productivity of the wells and the overall recovery factor, especially for low-permeability reservoirs, such as shale-gas and tight-gas reservoirs. Problems that are associated with unconventional oil and gas production in hydraulic fracturing

operations include aqueous phase trapping, diversion mechanisms of fracture networks, and fluid incompatibility with the formation.

This collection associated with the special issue in *Energies* emphasizes fundamental innovations and gathers 21 recent papers on novel applications of new techniques and theories 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 studies are classified into five categories.

The first category focuses on petrophysical characterization. By means of a set of experiments including scanning electron microscopy, mercury intrusion capillary pressure, X-ray diffraction, and nuclear magnetic resonance measurements, Xu et al. [2] characterized the pore structure of a tight oil reservoir in Permain Lucaogou formation of Jimusaer Sag and further performed a consecutive prediction for its pore structures. The pore types of this formation were mainly divided into four categories, and the capillary pressure curve and the T2 distribution data were analyzed in depth.

A matrix–fracture interaction model was developed by Liu et al. [3] to investigate the transient response of coal deformation and permeability to the temporal and spatial variations of effective stresses under mechanically unconstrained conditions. The impacts of fracture properties, initial matrix permeability, injection processes, and confining pressure were separately evaluated through the developed model.

Base on a low-pressure nitrogen adsorption experiment and fractal theory, Li et al. [4] studied the characteristics of nanopore structure in shale, tight sandstone, and mudstone, with an emphasis on the relationships between pore structure parameters, mineral compositions, and fractal dimensions. The relationships among average pore diameter, Brunner–Emmet–Teller specific surface area, pore volume, porosity, and permeability were also discussed.

Ma et al. [5] introduced the local force to define the interactions between the matrix and the fracture and derived a set of partial differential equations to define the full coupling of rock deformation and gas flow both in the matrix and fracture systems. Permeability evolution profiles during unconventional gas extraction were obtained by solving the full set of cross-coupling formulations.

A comprehensive experiment, including petrophysical measurements (porosity and permeability), pore structure measurements (low-field nuclear magnetic resonance and carbon dioxide/nitrogen adsorption), geochemical measurements (vitrinite reflectance, pyrolysis, and residual analysis), and petrological analysis (X-ray diffraction, thin section, scanning electron microscopy, and isothermal adsorption measurement), was designed by Fan et al. [6] to explore the influential and controlling factors of the gas adsorption capacity.

By using the data from casting thin section and mercury intrusion capillary pressure experiments, Sha et al. [7] investigated the pore structure characterization, permeability estimation, and fractal characteristics of Carboniferous carbonate reservoirs.

The second category focuses on fluid transport at multiple scales. Based on Swartzendruber equation and conformable derivative approach, as well as the modified Hertzian contact theory and fractal geometry, Lei et al. [8] developed a novel nonlinear flow model for tight porous media, which manifests the most important fundamental controls on low-velocity nonlinear flow. According to this model, the average flow velocity in tight porous media is a function of microstructural parameters of the pore space, rock lithology, and differential order, as well as hydraulic gradients and threshold hydraulic gradients. Moreover, the relationships between average flow velocity and effective stress, the rougher pore surfaces, and rock elastic modulus were further discussed.

Chen et al. [9] proposed a novel model for characterizing boundary layer thickness and fluid flow at microscales, which has a wide range of applications proved mathematically. Based on this model, the effects of fluid–solid interaction on flow in microtubes and tight formation were analyzed in depth.

Two different productivity models, the steady-state productivity model of shale horizontal wells with volume fracturing and the transient productivity calculation model of fractured wells, were derived by Zeng et al. [10]. The former considered the multiscale flowing states, shale gas desorption, and diffusion, while the latter combined the material balance equation. Furthermore, the horizontal well productivity prediction and the analysis of influencing factors were carried out.

In order to describe the pressure-transient behaviors in shale gas reservoirs in a way that considers the stimulated reservoir volume region with anomalous diffusion and fractal features, an improved analytical model was established by Tao et al. [11] through introducing the time-fractional flux law. Base on this model, the influences of relevant parameters, such as fractal-anomalous diffusion, stress sensitivity, absorption, and Knudsen diffusion, on the pressure-transient response were further analyzed through sensitivity analysis.

By introducing an improved pseudopotential multirelaxation-time lattice Boltzmann method, Wang et al. [12] simulated the fluid flow in a microfracture. The effects of contact angles, driving pressure, and the liquid–gas density ratio on the slip length were discussed.

Based on the dual-media theory and discrete-fracture network models, Ren et al. [13] built a mathematical flow model of a stimulated reservoir volume fractured horizontal well with multiporosity and multipermeability media. The differences of flow regimes between triple-porosity, dual-permeability and triple-porosity, triple-permeability models were identified. Moreover, the productivity contribution degree of multimedium was analyzed.

Tang et al. [14] summarized the flow law in shale gas reservoirs and established a three-dimensional composite model, which uses dual media to describe matrix-natural microfractures and utilizes discrete media to describe artificial fractures. The production of multisection fractured horizontal wells in a rectangular shale gas reservoir was described, considering multiscale flow mechanisms in the matrix, such as gas desorption, the Klinkenberg effect, and gas diffusion.

The third category focuses on hydraulic fracturing. By means of the extended finite element method, Wang et al. [15] investigated the diversion mechanisms of a fracture network in tight formations with frictional natural fractures. The effects of some key factors, for example, the location of natural fracture, the intersection angle between natural fracture and hydro-fracture, the horizontal stress difference, and the fluid viscosity on the mechanical diversion behavior of the hydro-fracture, were analyzed in detail.

Kamal et al. [16] developed a new smart fracturing fluid system mainly consisting of a water-soluble polymer and chelating agent, which can be either used for proppant fracturing (high pH) or acid fracturing (low pH) operations in tight as well as conventional formations. The optimal conditions and concentration of this fracturing fluid system were determined by performing thermal stability, rheology, Fourier transform infrared spectroscopy, and core flooding experiments.

By measuring the solution viscosity, Tang et al. [17] investigated the effects of hydrophobic chain, spacer group, concentration, temperature, and addition of nano-MgO on the viscosity of sulfonate Gemini surfactant solution. Moreover, their micellar microstructures were observed by Cryo-SEM. Further, the thickening mechanism of sulfonate Gemini surfactant was investigated by correlating the relationship between solution viscosity and its microstructure.

The fourth category focuses on enhanced oil recovery. A novel depletion laboratory experimental platform and its evaluation method for a tight oil reservoir were developed by Chen et al. [18] to effectively measure the oil recovery and pressure propagation over pressure depletion. On this platform, under different temperatures, formation pressure coefficients, and oil property conditions, the recovery factor as well as the real-time monitoring of the pressure propagation in the process of reservoir depletion were measured to reveal the drive mechanism and recovery factor of tight oil reservoir depletion.

Lyu et al. [19] applied the nuclear magnetic resonance technique to explore the spontaneous imbibition mechanism and the oil displacement recovery by imbibition in tight sandstones under all

face open boundary conditions. The distribution of remaining oil and the effect of microstructures on imbibition were analyzed.

Through three groups of core displacement experiments with cores containing different clay mineral compositions, Jiang et al. [20] studied the effect of different clay mineral compositions on low-salinity water flooding. Additionally, the properties of the effluent were determined in different flooding stages, and the mechanism of enhanced oil recovery effect of low-salinity water flooding was analyzed.

The fifth category focuses on geothermal energy. Based on hydrogeochemical and isotopic constraints, the deep circulation of the groundwater flow system was surveyed by Long et al. [21] to elucidate the origin of the geothermal fluids and the source of solutes and to discern the mixing and hydrogeochemical alteration. The conceptual models and mechanisms for the deep circulation of the groundwater flow system were further discussed.

Combining the fracture continuum method and genetic algorithm, a well-placement optimization framework was proposed by Zhang et al. [22] to address the optimization of the well-placement for an enhanced geothermal system. The optimization efficiency and effect of this framework were further analyzed.

3. Conclusions

Many researchers around the world from different areas, ranging from natural sciences to engineering fields, have been working on the characterization of petrophysical properties for unconventional reservoirs, fluid transport at multiscales, and technologies for the efficient development of unconventional resources. The aim of this special issue is to provide new technologies and theories of characterizing petrophysical properties, fluid transport, and their relationships at multiple scales in unconventional reservoirs. Clearly, the studies covered by this special issue will be helpful to the economic and effective development of unconventional oil and gas resources.

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