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OpenFOAM: Pore-scale modeling of water-gas two-phase flow in hydrate-bearing sediments

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Natural gas hydrate (NGH) is an ice-like crystalline substance formed at low temperature and high pressure with water molecules as the host and methane molecules as the guest. Natural gas hydrate is considered to be an important energy source in the future due to its large resources and large energy storage capacity, and has been valued by many countries (the United States, China, Japan, Canada, India, etc.). In the past few decades, in order to explore the production of reservoir fluids, Japan, China and other countries [1, 2] have carried out several field production tests, among which the commonly used gas hydrate extraction methods include pressure reduction, thermal Exciting method. The exploitation of natural gas hydrate is a heat-fluid-chemical-mechanical (THCM) coupling process of multi-component (CH_4, H_2O, NaCl) heat and mass transfer and multiphase (water, gas, hydrate) flow. Therefore, exploring the multiphase seepage characteristics of natural gas hydrate reservoirs under in-situ conditions is the key to evaluating the gas production efficiency during the production process. Japan is an early country to develop in situ conditional hydrate reservoir flow characteristics. Konno et al. [3] experimentally tested the water phase effective permeability of gas hydrate cores under in situ conditions of 47 mD (SH =70%), and the absolute permeability was 840 mD (SH=0). However, it is very difficult to test the relative permeability of gas hydrate reservoirs because it is difficult to prevent the influence of new hydrate formation on pore results in gas-liquid two-phase flooding experiments. Therefore, it is necessary to explore the gas-liquid relative permeability and its influencing factors of natural gas hydrate reservoirs under in-situ conditions by numerical simulation.

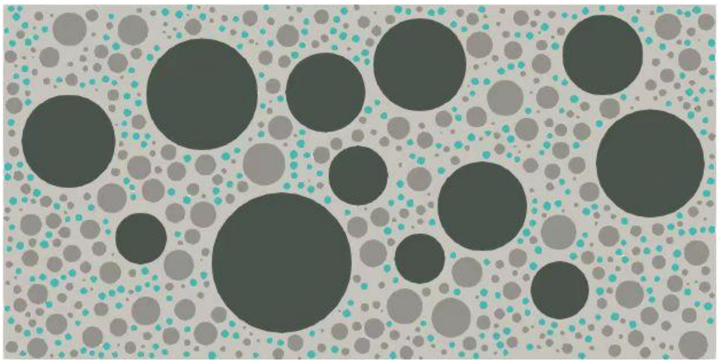

Fig. 1. Schematic of the generated 2-D simulation domain for the silty sand HBS with S_H=10% in simulation (dark blue refers to sand particle; light blue refers to hydrate particle; gray refers to silty sand)

One of the major variables impacting gas production is the behavior of gas and water transport, which is governed by pore features and capillarity in hydrate-bearing sediments (HBS). Based on CT images, the geometric models of HBS with various hydrate saturation were constructed on the premise that particle size accorded following normal random distribution in this study (Fig. 1.). The fluid volume method (VOF) is used to simulate the flow field evolution and dynamic process of gas-liquid two-phase flow in porous media containing hydrate sediments in OpenFOAM programming library, as shown in FIG. 2.

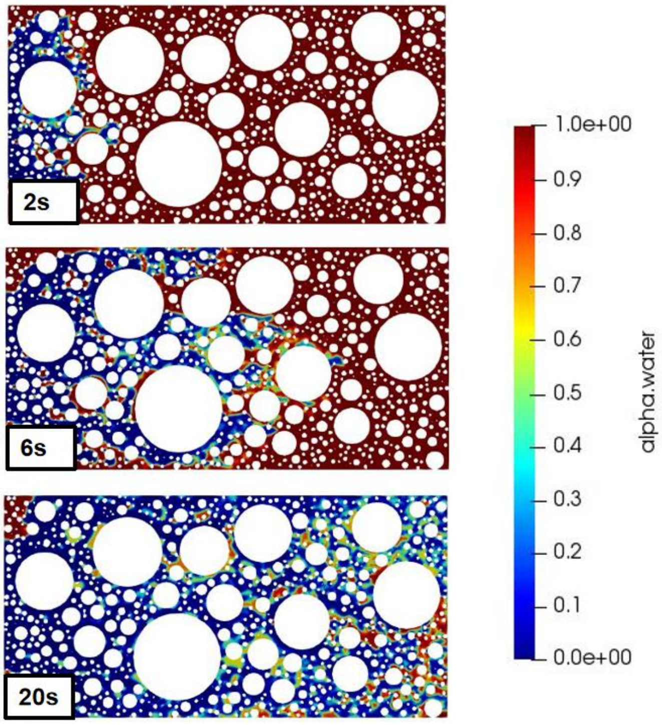

Fig. 2. Gas injection for the drainage of water in HBS solved at the pore-scale using the VOF method in OpenFOAM.

In this study, the effects of hydrate saturation and hydrate morphology on permeability and relative permeability of hydrate-bearing porous media were analyzed, and the influencing factors such as quartz sand size, surface characteristics, and hydrate formation method were evaluated. The results show that the increasing density of solid skeleton significantly increases the residual water saturation and leads to the decrease of gas-phase permeability. Hydrate sediment sand and hydrate wettability are important parameters affecting the relative permeability.

To investigate the effect of wettability on the relative permeability of two-phase flow in porous media, a component of the contact angle was added to the OpenFOAM simulation. As a result, referring to the existing study [4], the contact angles for water on the surfaces of sand grains and hydrates were set at 15° and 60°, respectively. As the hydrate saturation increases, the HBS porosity further decreases, and at the same pressure difference, the gas saturation decreases. This is because hydrates in the pore-filling condition create narrower pore spaces, resulting in narrower flow paths and higher flow resistance. The simulation results and theoretical analysis show that the relative permeability of two-phase flow in porous media is closely related to fluid saturation, specific interface length of fluid, surface tension effect of two-phase flow interface and contact Angle at the wetting wall.

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