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Numerical simulation for apparent viscosity change under oscillating boundary condition using lattice Boltzmann method

UEDA, Ryuta[1*] ; MIKADA, Hitoshi[1] ; GOTO, Tada-nori[1] ; TAKEKAWA, Junichi[1]

[1]Kyoto University

Unsteady fluid dynamics in Newtonian and non-Newtonian fluid is the main concern of aeronautical engineering, mechanical engineering, chemical engineering, resource engineering and civil engineering. It is also true to the oil industry because the amount of oil production in the world is decreasing recently, it is of importance to seek the technological development for enhanced oil recovery (EOR) in place in the subsurface. Recently, many laboratory experiments and field tests have been performed such as water, gas, chemical, or thermal injections to attempt the enhancement of oil production. Seismic stimulation is known as one of the EOR methods and unsteady flow problem. Numerous observations show that seismic stimulation of oil reservoir may improve oil production. However, for effective usage of seismic EOR, we need to understand the characteristics of changing apparent viscosity under oscillating solid-phase. In this study, we attempt to demonstrate the apparent viscous change in laminar flow under oscillating boundary condition with the models of single pore throats and porous media.

We use Lattice Boltzmann method (LBM) describing Boltzmann equation. We use 2-dimensional 9-velocity (2d9v) model to simulate 2-dimensional incompressible viscous flow. We assume that the background pressure difference between inlet and outlet is constant. The flow is generated by a constant pressure difference.

We discuss the apparent viscosity of a single pore throat and porous media.

First, we discuss four characteristics of an incident elastic wave: amplitude, frequency, angle, and pressure disturbance (P wave). The characteristics of amplitude, frequency and angle are largely related with the amount of changing apparent viscosity. The flux increases under cases with large amplitude, high frequency, and large angle (S wave) of incident to the wall. On the other hand, the pressure disturbance (P wave) is not effective for changing apparent viscosity. We then discuss the possibility of changing apparent viscosity in terms of fluid properties. Wall oscillation can cause improving relative permeability. So, if the rock has water wettability, the oil flux largely increase with wall oscillation. After that, we examine the possibility of changing apparent viscosity in terms of pore scales or shapes under the oscillating boundary condition with LBM. The models of single pore throat consists of two half pore and one pore throat. The models of porous media consist of several pore spaces connected by pore throats from one pore to the others. The shapes of single pore throats are also largely related with changing apparent viscosity. The apparent viscosity decreases with increasing length of the pore throats and radius of the pore throats, and with decreasing width of the pore throats and large pore radius. Comparing single pore throat model and porous media model, we find the apparent viscosity change in porous media models cannot be replaced by linear combination of the apparent viscosity changing in single pore throat models.

Our numerical results imply: i) the flow resistance under oscillating condition increases because the velocity difference between the wall and the center of flow is larger than that in steady flow, ii) the effect of the advection term in oscillating boundary condition is larger than that in steady flow, iii) fluid extrusion is generated by partial pressure gradient near the wall and pore throat, and iv) the oscillating boundary may cause improving pressure loss.

Keywords: Lattice Boltzmann method, Unsteady flow, Seismic EOR, Apparent viscosity, Pore throat scale