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Instability of uniform gas flow within liquid-saturated porous medium

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Problem of flow instability in porous media are important for applied fields like mining, water supply, etc. There is a fundamental interest to mechanisms are influence on flow too. E.g., a viscous fingering is typical phenomenon of displacement processes in porous medium [1,2]. The instability of gas flow in liquid-saturated domain have no wide studies but it can make significant influence on heat and mass transport. If the one phase have a high saturation, the other phase will form the droplets are break and captured within pores due to the capillary forces [2–4]. It is possible to neglect the capillarity if the saturation of both fluids exceed a percolation thresholds [5,6].

We consider an infinite flat layer of uniform porous medium is saturated with gas and liquid have close saturation. Its upper boundary is impermeable for liquid phase and gas can pass freely through the border, and the down boundary is permeable for both phases. The temperature and pressure are fixed at the top while their gradients are fixed at the bottom side. Neglecting the capillarity, gas solubility, liquid evaporation and any phase transitions, we obtain a steady solution and study its' stability. The governing parameter of the flow is

$$\alpha = \alpha_g A \mathrm{Pe}, \quad \alpha_g = (\rho_w C_g)/(\rho_s C_s), \quad A = \rho_{stat} v_{stat} \tag{1}$$

where Pe is the thermal Peclet number determines a ratio between convective and conductive heat transfer, α_g is ratio of thermal capacities of fluid and matrix, and A is determined by gas density and velocity in the steady state.

Analyzing the perturbations, we found that a long-wave instability realizes in the system. The critical value of parameter is:

$$\alpha_c = a_1 + k^2 a_2 + O(\rho_g/\rho_w), \tag{2}$$

where a_1, a_2 are positive coefficients are calculated using thermal perturbations combinations and k is wave number along horizontal direction. The minimal α_c equals 2.47, and it correspond the critical Peclet number near 200 in the methane–water system. An error of the dependence is of order of gas to water density ratio at small k.

The critical value of α is independent on system parameters in the first approximation. Therefore, the main mechanism of instability development is only an interaction of conductive and convective heat transfer in fluid flows unlike systems are described in [7,8]. The α is independent on average values of temperature and pressure. The fundamental mechanism of long-wave instability of gas flow is not connected with capillarity effects, phase transitions, etc. Thermal expansion of the liquid does not change the flow stability threshold rapidly.

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