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Coupled mass and heat transfer model in porous media under high Knudsen number

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In the field of oil recovery and other industrial applications, the significance of an accurate and efficient model for porous media cannot be overstated. At present, most of the macroscopic models for the gas flow in porous media at a high Knudsen number are only investigated under pressure gradient. What's more, the thermal effect becomes prominent in a single tube as the rarefication degree increases whereby mass flow could occur in the direction of inverse temperature gradient, which is named as Transpiration flow. This phenomenon will surely make a difference in the mass transport and heat transfer process in porous media, leading us to determine the mass and heat transport coefficient in porous media under pressure gradient and temperature gradient, as the existing coefficients for mass transport are physically ambiguous and coefficients for heat transfer in porous media are not specified. Therefore, to fully reveal the transport mechanism in porous media under moderately high Knudsen numbers at a macroscopic scale, a novel approach is developed.

Specifically, the analytical solutions of velocity and heat flux to the Poiseuille flow and Transpiration flow in a cylindrical tube by the R13 moment method of rarefied gas theory are first obtained. Subsequently, they are separately incorporated into a three-dimensional pore network model that comprises thirty pores in each direction via newly derived mass flow conductivity and heat transfer conductivity in the form of Knudsen number. As a result, these pore network modellings derive the apparent permeability and the apparent Knudsen diffusion coefficient for mass flow and heat transfer under pressure gradient and temperature gradient respectively. It is found that the above four numerically computed properties fitted with the effective Knudsen number are consistent with their explicitly analytical form in a cylindrical tube. Hence, the analytical form of macro properties is then applied to the macro model for porous media simultaneously subjected to pressure gradient and temperature gradient. Also, a validation of the macro model is made by developing a heat and mass-coupled pore network model under the same boundary condition when the Knudsen number is under unity. To summarize, in this work, a computationally efficient and precise macro model for rarefied gas flow in porous media with the Knudsen number ranging from 0.001-1.0 is established.

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