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Study of Forced Convection Heat Transfer of Supercritical CO_2 in a Horizontal Channel by Lattice Boltzmann Method

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Abstract. The problem of forced convection heat transfer of supercritical CO_2 in a horizontal channel is investigated numerically by a lattice Boltzmann method. This study is stimulated by our recent experimental findings on solar collectors using supercritical CO_2 as a working fluid, which can achieve the collector efficiency high up to 70%. To deeply understand the heat transfer characteristics of supercritical CO_2 and provide a theoretical guidance for improving our current experimental system, in present study several typical experimental flow conditions are simulated. In particular, the work focuses on the convective heat transfer characteristics of supercritical CO_2 flowing in a horizontal channel with mediate Reynolds numbers ranging from 210 to 840 and constant heat fluxes from 400.0 to 800.0 W/m^2. The simulations show that the heat transfer increases with heat flux and decreases with Reynolds number. Furthermore, the mechanisms of heat transfer enhancement of supercritical CO_2 fluid are identified.

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Key words: Forced convection, supercritical CO_2, lattice Boltzmann method.

1 Introduction

Solar energy powered thermodynamic systems using supercritical CO_2 as a working

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fluid have been proposed for combined generation of electrical power and thermal energy/refrigeration supplies [1,2]. Experimental studies [3,4] have been carried out to investigate supercritical CO_2-based cycle performance. Power generation efficiency is found to be 8.0%, comparable with that of solar cells and in addition, the cycle can also supply thermal energy/refrigeration to user. One of the major factors contributing to the high system efficiency is that the collector efficiency is surprisingly high, as found to be above 70.0%. The collector efficiency of 70.0% is much higher than that using water as the working fluid, in which case the maximum efficiency is only 50.0% [3–5]. In the experimental tests, all-glass evacuated solar collectors with a U-tube heat removal system are used and details of the collectors can be seen in references [2,3].

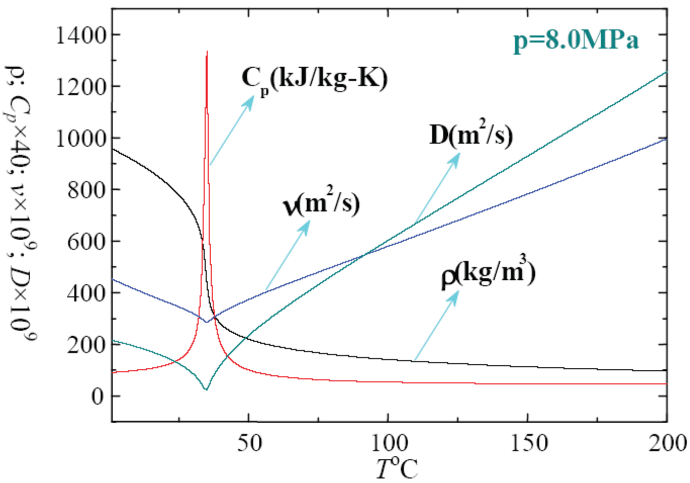

Figure 1: Thermophysical coefficients of CO_2 as functions of temperature.

However, the details and fundamental reasons for the enhanced convective heat transfer in a collector tube in the case of using supercritical CO_2 as the working fluid are still not very clear. This is because the behaviors of the thermophysical coefficients of CO_2, such as density, specific heat, viscosity and thermal diffusion are very complicated in the supercritical state. Fig. 1 shows variations of the CO_2 thermophysical coefficients of density ρ, specific heat C_p, kinematic viscosity v and thermal diffusion D as a function of temperature at the pressure of 8.0MPa. It is seen that the coefficients are very sensitive to the change of temperature. C_p achieves a sharp peak around 35°C and this is the pseudo-critical temperature for 8.0MPa; meanwhile, the two transport coefficients are minimal. The thermophysical properties are also influenced by the pressure. The striking dependence of thermophysical properties on both temperature and pressure would influence the flow and heat transfer characteristics.

As the first step towards a fundamental understanding and estimation of the heat transfer characteristics of supercritical CO_2 under forced convection conditions, in this paper, a lattice Boltzmann investigation of the supercritical CO_2 thermal flow in a simple geometrical configuration–a two-dimensional horizontal channel is carried out.