Numerical Analysis on the Thermal Responses of Near-Critical Fluid to Transient Cooling Process

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Abstract: The heat transfer of near-critical fluids has become a key topic as the transcritical/supercritical energy systems are more and more proposed in recent years. When fluids go across the critical point or the equilibrium curve in the phase boundaries in the critical region, dramatic changes happen in fluid properties. For example, the thermal diffusivity goes to zero and the compressibility diverges. Such effects introduce additional complexibility in thermal systems with supercritical fluids (heat exchanger, turbines, reactors, etc.). For the efficiency analysis in heat transfer and stability in small-scale, the current numerical study is proposed. In this study, non-equilibrium cooling process is discussed with the highly compressible near-critical fluid inside a two-dimensional chamber model. The typical size of the critical chamber is around 5 mm, in which the fluid is initially rested under 1g or 0g conditions. The system is described by a continuous Navier-Stokes equations and solved by coupling the equation of state that written in scaling form for the near-critical properties, which is defined by the distance parameter $\varepsilon = (T-T_c)/T_c$. The equations are solved by a Finite Volumn Method. It is found that the basic wave propation process happen in ~10^{-4} second time-scale, which is generated from the cooling boundary. Under such conditions, the collapse of the boundary layer happens when the near-wall fluid firstly become near-critical and it condensed toward the cooling wall. After that, the acoustic waves go forth and back through the chamber and the critical boundary line moves forward toward the adiabatic side. For 1g cases, it is found that the near-critical fluid would fall strong convection near the wall region and form interesting structures in the lower region of the cell. This study reports the first results on near-critical cooling process. Detailed parameter evolutions and indications for critical cooling process are discussed into detail in this study.

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