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Flow and heat transfer characteristics of supercritical nitrogen in a vertical mini-tube

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ABSTRACT

Supercritical fluids show many tremendously strange characteristics, such as singularities in compressibility and viscosity, diminishing difference in vapor and liquid phases and so on, which have attracted a lot of experimental and theoretical investigations for the fundamental research. In the present study, experimental investigations of the fluid flow and heat transfer characteristics of supercritical nitrogen in a mini-tube of about 2.0 mm in diameter and 220.0 mm in length are carried out, the effects of many influential factors on the fluid flow and heat transfer are studied. Meanwhile, the numerical analysis of the fluid flow and heat transfer characteristics of supercritical nitrogen is also conducted by using FLUENT. It is found that the agreement between the experimental and numerical results is quite good and the further interpretation and discussion are carried out.

1. Introduction

The fluid becomes the supercritical fluid as its pressure and temperature exceed the critical values, when the thermal properties, such as viscosity, density, specific heat capacity and others vary significantly. The difference between the vapor and liquid phases is also not evident, which inspires many useful industrial applications in the energy-related fields. For example, in the cooling of the superconducting magnet in the next-generation nuclear fusion reaction power station, low temperature supercritical fluids (e.g., supercritical helium) are employed, which are mostly due to the single-phase fluid behavior of the supercritical fluids and their low viscosities. With the developing of the high temperature superconducting science and technology, the superconducting transition temperature has been elevated to liquid nitrogen temperature range (77 K), which enables supercritical nitrogen to be used as the coolant as in the case that supercritical helium has been used for the cooling of the low temperature superconducting magnet in the current applications. Supercritical nitrogen is also frequently used in chemical engineering, e.g., polymer processing, due to its inert characteristics, in which the fluid flow and heat transfer features are apparently important. Furthermore, liquefied natural gas (LNG) is one of the clean energy resources, which can be dispatched by the cargo to all over the world in liquid state. However, prior to the pipe-dispatching to the individual user terminal, LNG must be vaporized at the port by using sea water as the heat exchange medium because the latent heat associated with the liquid-vapor phase change is so large even that people are considering the effectual heat exchangers or thermodynamic cycles to recover the cold energy involved in this process. One of the practical problems is that the state of vaporized natural gas is within the critical regime during vaporization, which poses a problem that the heat transfer and fluid flow characteristics should be well understood in order to have the proper design of the heat exchanger, vaporizer and even system. For the practical experimental investigation, liquid nitrogen can be used to simulate LNG because the latter is more or less dangerous for the lab management. Thus, it is very instructive to carry out the investigation of the flow and heat transfer characteristics of the supercritical nitrogen which has the critical temperature of about 126.2 K and critical pressure of about 3.4 MPa. Shown in Fig. 1 is the variation of the specific heat capacity and viscosity for nitrogen near the critical or pseudo-critical points at different pressures. It is seen that the thermal properties, such as specific heat capacity and viscosity, vary drastically around critical or pseudo-critical temperatures, which apparently affects the flow and heat transfer characteristics of supercritical fluids.

In the year of 1970, R. L. Von Berg et al. [1] investigated experimentally the forced convection heat transfer of supercritical nitrogen in the vertical tube, which indicated that the heat transfer coefficient increased slowly first and then decreased drastically with the bulk fluid temperature increasing from subcritical to supercritical at the supercritical pressure. And the heat transfer

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