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Experimental study of in-tube cooling heat transfer and pressure drop characteristics of R134a at supercritical pressures

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ABSTRACT

The in-tube cooling flow and heat transfer characteristics of R134a at supercritical pressures are measured experimentally for various pressures and mass fluxes in a horizontal tube. The tube is made of stainless steel with an inner diameter of 4.01 mm. Experiments are conducted for mass fluxes from 70 kg/m^2 s to 405 kg/m^2 s and pressures from 4.5 MPa to 5.5 MPa. The inlet refrigerant temperature is from 80 °C to 140 °C. The results show that the refrigerant temperature, the mass flux and the pressure all significantly affect the flow and heat transfer characteristics of R134a at supercritical pressures. The experimentally measured frictional pressure drop and heat transfer coefficient are compared with predicted results from several existing correlations. The comparisons show that the predicted frictional pressure drop using Petrov and Popov's correlation accounting for the density and viscosity variations agree well with the measured data. Gnielinski's correlation for the heat transfer coefficient agrees best with the measured data with deviations not exceeding 25%, while correlations based on supercritical CO_2 heat transfer data overcorrect for the influence of the thermophysical property variations resulting in larger deviations. A new empirical correlation is developed based on the measured results by modifying Gnielinski's equation with thermophysical property terms including both the property variations from the inlet to the outlet of the entire test section and from the bulk to the wall. Most of the experimental data is predicted by the new correlation within a range of 15%.

1. Introduction

In the gas cooler of a trans-critical heat pump cycle, heat is rejected as sensible heat with no phase change occurs, so both the working fluid and the cooling fluid temperatures vary continuously. Thus, it is suitable for counter-current heat exchange process and for high-temperature heat generation. A wide temperature range is possible with moderate compressor pressure ratios with trans-critical cycles when the pressure and temperature are independent of each other and not restricted as in sub-critical cycles where the saturation pressure and temperature are not independent [1]. In addition, the trans-critical heat pump cycles work at higher pressures, which reduce the friction losses to give better performance. The size and complexity of the equipment are also reduced compared with the conventional sub-critical cycle.

Several conventional refrigerants including SF_6, C_3F_8, C_2HF_5, c-C_4F_8 have been proposed as working fluids for the trans-critical heat pump cycle with various performance characteristics [1]. The trans-critical heat pump cycle with R116 (C_2F_6) and R23 (CHF_3) as the working fluid have been analyzed theoretically [2,3]. R134a ($C_2H_2F_4$) is non-flammable, its ODP (ozone depleting potential) is zero and its GWP (global warming potential) is much lower than for R23 and R116, thus, R134a has been widely used as a refrigerant for domestic refrigerators and automobile air conditioners. R134a is more suitable as the working fluid in trans-critical cycles for high-temperature heat generation because of its higher critical temperature (compared with R23 and R116) and lower operating pressure (compared with trans-critical heat pumps with CO_2 as the working fluid), as well as its fairly good thermophysical properties and good thermal stability. Supercritical cycles with R134a as the working fluid for geothermal power generation system has been proposed and studied [4].

When the R134a is above the critical pressure (p_{cr} = 4.06 MPa for R134a), as shown in Fig. 1, the specific heat variation with temperature shows a sharp peak at a specific temperature which is defined as the pseudo critical temperature, T_{pc}. This temperature increases with increasing pressure. Other properties including the density, thermal conductivity and viscosity vary also significantly within a small range of temperature in the vicinity of T_{pc}. With these thermophysical characteristics, the flow and heat transfer of supercritical R134a will be strongly influenced and quite different from those of fluids with constant thermophysical properties, such as working fluids in conventional cycles at sub-critical pressures.

There have been many papers published on internal forced and mixed flow and heat transfer of supercritical fluids in-tubes. Most

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