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Experimental investigation of buoyancy effects on local heat transfer of supercritical pressure CO_2 in horizontal semicircular tube

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ABSTRACT

To estimate the characteristics of local heat transfer in the channel of a printed circuit heat exchanger (PCHE), a semicircular channel (tube) was manufactured to replicate the channel shape of the PCHE. The heat transfer in a horizontal semicircular tube has different behaviors at the top and bottom walls. Buoyancy and flow acceleration have substantial influence on the convective heat transfer of a semicircular tube with supercritical pressure fluids. They are induced by a drastic variation in the thermophysical properties near the critical point, especially density. Thus, in this study, to investigate the effect of buoyancy and flow acceleration on the heat transfer of supercritical CO_2, an experiment was conducted in a horizontal semicircular tube. The tube test section had a hydraulic diameter of 4.73 mm, width of 7.75 mm, depth of 3.88 mm, and a heated length of 1.0 m. The experimental variables were mass flux (70–200 kg/(m^2·s)) and heat flux (14.6–50.7 kW/m^2) with constant inlet temperature (30 °C) and pressure (7.7–7.8 MPa). The temperature of the outer wall was measured at four positions (top center (TC), top side (TS), bottom side (BS), and bottom center (BC)) in the cross section of the tube. The stratification of the temperature along the wall in the cross section of the semicircular tube was verified by the experimental results. The heat transfer deterioration at the top region (TC and TS) was greater than that at the bottom region (BS and BC). This difference in heat transfer deterioration was caused by the upward push of the buoyancy of the low-density fluid along the inner wall in the cross section of the tube.

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1. Introduction

The supercritical carbon dioxide Brayton cycle (sCO_2 BCE) possesses advantages of high thermal efficiency, simple cycle layout, compactness of components, and wide operation range [1]. The aforementioned advantages are attributed to the high density and low compressibility of sCO_2 near the critical point of CO_2 (30.98 °C, 7.38 MPa) owing to the wide and rapid variation in the thermodynamic properties of sCO_2 near this point [1,2]. Because of its low compressibility, the size of the turbomachinery for the sCO_2 BCE system can be made compact and the degree of compactness is dependent on the size of the heat exchanger (HX). Therefore, the use of printed circuit heat exchanger (PCHE) for achieving a compact sCO_2 power conversion system has attracted research attention [3,4].

The PCHE typically comprises a diffusion-bonded array of plates on which semicircular channels are engraved via etching [5]. The densely stacked structure allows for high compactness, and the diffusion-bonded junctions allow for high rigidity, which is required for intensive heat transfer and durability even under harsh conditions of high temperature and pressure. PCHEs possess the advantages of small size and structural rigidity compared with those of conventional HXs such as shell and tube HX. Therefore, they are widely applied as heat sources and sinks for compact sCO_2 power conversion systems. Previous researcher [6] compared the cooling and heating mode and concluded that two mode shows an almost same at q = 30 kW/m^2, q/G = 0.039, that conditions correspond with sCO_2 PCHE operation conditions. During the cooling or heating process, the CO_2 in PCHEs experiences significant changes in its thermophysical properties near the critical point. Because of these changes in properties, the heat transfer phenomena are more complex. Therefore, the flow and heat transfer mechanisms of CO_2 near the critical point have been investigated extensively for understanding such phenomena.

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