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Modeling of local heat transfer on supercritical pressure CO_2 in horizontal semicircular tube

Joo Hyun Park[a,b,*], Moo Hwan Kim[b,c]

[a] Korea Atomic Energy Research Institute, Daejeon 34057, Republic of Korea
[b] Division of Advanced Nuclear Engineering, POSTECH, Pohang 790-784, Republic of Korea
[c] Department of Mechanical Engineering, POSTECH, Pohang 790-784, Republic of Korea

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ABSTRACT

The cross-section of the channel in a printed circuit heat exchanger (PCHE) has a semicircle shape. However, a heat transfer model for a semicircular channel (tube) containing supercritical pressure fluid has not yet been developed. Therefore, a semicircular tube (SCT) with supercritical CO_2 was experimentally investigated to develop a heat transfer model for a realistic shape of PCHE. The results show significant differences in heat transfer depending on the location in the tube. These results are attributed to the buoyancy and flow acceleration induced by the drastic variation in thermophysical properties near the critical point. In this study, a new heat transfer model for the SCT is proposed as a form of mixed convection, which is the superposition of forced convection for flow acceleration and natural convection for buoyancy. To reflect the deformation of the natural convection non-dimensional boundary layer thickness (δ_{nc}^{+}), a shape factor, $(\frac{l_{depth}}{D_h})^E$, is proposed. The top and bottom regions of the heat transfer model of the SCT had MADs of 10.48% and 17.84%, respectively. The proposed model of the SCT reliably predicted the heat transfer phenomena in the horizontal flow of supercritical CO_2.

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1. Introduction

Carbon dioxide (CO_2) has a moderate critical point (30.98 °C, 7.38 MPa), which is a relatively low temperature similar to atmospheric temperature [1]. At this point, the properties of CO_2 change drastically and vary widely. In particular, CO_2 has a high density and low compressibility near the critical point. This means that if CO_2 is compressed near the critical point in the Brayton cycle, the workload of the compressor would be reduced and high thermal efficiency can be attained. Therefore, the supercritical CO_2 (sCO_2) Brayton cycle has been receiving considerable attention as a promising power-conversion system [2].

One of the advantages of the sCO_2 Brayton cycle is the small size of the turbomachinery. Therefore, when constructing a compact sCO_2 Brayton cycle system, the heat exchanger (HX), which is the largest component in the system, should be compact. Moreover, the sCO_2 Brayton cycle requires intensive heat transfer and durability to withstand the harsh conditions of high temperature and pressure. Among compact HXs, the printed-circuit heat exchanger (PCHE) is suitable for sCO_2 Brayton cycle systems to its advantages of small size and structural rigidity. The PCHE typically exploits the diffusion bonding of plates, which has an etched channel [3]. The densely stacked structure allows high compactness, and the diffusion-bonded junctions enable high rigidity. Because of the photochemical etching characteristics, the PCHE channel has a semicircular shape, which is neither perfectly rectangular nor circular.

Previous investigations on the heat transfer performance of supercritical-pressure fluid near the critical point have mainly been conducted using circular tubes [4–29]; these studies will be reviewed in detail in Section 2.2. Because these studies were performed using circular tubes, the realistic shapes of PCHE channels were not considered. Recently, the heat transfer characteristics of horizontal flow in a semicircular tube (SCT) has received considerable attention for their realistic shapes of PCHE channels. Numerical investigations have been performed to estimate the local heat transfer of SCTs with supercritical CO_2. Zhang et al. [30] conducted numerical investigations on the coupled heat transfer characteristics of supercritical pressure CO_2 in horizontal semicircular channels. They suggested that the Se/*Re* criterion yields a better prediction of the buoyancy effect. Zhang et al. [31] studied the local heat transfer characteristics of sCO_2 through numerical analysis. They suggested that the buoyancy effect plays more important role than thermal acceleration effects in the deteriorated heat transfer. However, there exists no experimental data on horizontal SCT to verify their numerical analysis. Experimental data on horizontal SCT

* Corresponding author.
E-mail address: joohp@kaeri.re.kr (J.H. Park).

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