Chapter 5
Effect of Flow Acceleration and Buoyancy on Thermalhydraulics of sCO_2 in Mini/Micro-Channel

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ABSTRACT

Supercritical fluids have found enhanced applications in several sectors. High efficiency and high compactness associated with supercritical carbon dioxide power cycle are of major interest to the thermal engineers. Additionally, due to environment friendly properties, such as zero ODP, considerably lower GWP, non-toxic and nonflammable supercritical carbon dioxide has emerged as a potential substitute of conventional refrigerants. The peculiar properties of supercritical fluids ensured distinct flow and thermal characteristics of supercritical systems. Therefore, the chapter is aimed to discuss the thermalhydraulic characteristics of supercritical carbon dioxide in minichannel and microchannel. Both experimental and numerical studies on flow and thermal behavior of supercritical carbon dioxide will be discussed. The focus of this chapter is to examine the effect of buoyancy and flow acceleration on heat transfer performance. Considering the widespread applicability, the comprehensive discussion introduced in the chapter will affirmatively help the researchers.

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INTRODUCTION

With the growing need for higher power density and enhanced efficiency due to decreasing fossils, reserve fuel and also environmental hazards related to fossil fuels has led researchers to seek for alternate working fluids as well as higher efficiency for the existing cycles. Two-phase fluids have been extensively employed as the working fluids which are capable of large energy transport and significant volumetric expansion but suffer from flow instabilities, critical heat flux (CHF) restriction, and wall dry out. Supercritical fluids are of prime interest to researchers due to its superior heat transfer characteristics near the pseudocritical point. Owing to high volumetric heat capacity and thermal conductivity ensured high heat flux thermal management and lower pumping requirement as compared to single-phase and two-phase fluids. Supercritical CO_2 is also more preferable because its critical pressure (7.38 MPa) and temperature (304.13 K) is much lower as compared to that of water (22.06 MPa & 647 K). Also, due to its zero ozone depletion potential and substantially smaller global warming potential has made more inclination towards the use of supercritical carbon dioxide as a substitute for conventional refrigerants. In recent years, heat transfer and fluid flow in mini/micro-channel have attracted researchers, such as for the biological understanding of human life, chemical engineering, medicine, energy, and resources engineering (Ameel et al., 1997). The analysis and design of these engineering systems require consideration of mini/micro-channel effects for supercritical fluid flow and thermal characteristics. Therefore, by combining the advantages of both supercritical fluid and mini/micro-channel enhanced thermal performance can be achieved. Supercritical fluid properties are relatively complex as compared to single fluid properties due to non-linear thermophysical properties variation of supercritical fluids. Consequently, mini/micro-channel based heat exchangers using sCO_2 as working fluid has got various potential applications such as receivers for concentrated solar power tower systems(Ho & Iverson, 2014; Hyder & Fronk, 2018; Zada et al., 2016), printed circuit board heat exchangers for the recuperators in the supercritical Brayton cycles (Carlson et al., 2014) and thermal management of high heat-generating electronics(Rosa et al., 2019; Fronk & Rattner, 2016).

The flow and heat transfer behavior of the supercritical fluid inside mini/micro-channel is determined by the thermophysical properties variation, especially near the pseudocritical point (pc). In particular, supercritical fluid flow inside microchannel requires special attention while handling fluid flow and heat transfer problems (Rosa et al., 2009), such as non-linear fluid properties, fluid compressibility, boundary slip effect, wall roughness effect, and wettability. Due to non-linear property variation density gradients in axial and radial direction causes buoyancy effects, and it also affects turbulent transport properties which can either enhance or deteriorate heat transfer due to higher Prandtl number. Moreover, Axial and the radial variation in fluid density determines flow acceleration which, combined with buoyancy force can either complement or subdue the heat transfer.

In this chapter, the previous work of the experimental and numerical development on flow and heat transfer characteristics of the supercritical CO_2 in mini/micro-channel will be reviewed. The effect of buoyancy and flow acceleration on heat transfer characteristics will be discussed in detail. The enabling concept that is essential in understanding the buoyancy and flow acceleration aspect will be addressed. This is followed by the discussion on controversies and problems associated with the mini/micro scale systems behavior in respect to heat transfer phenomena. Considering the widespread applicability, the comprehensive discussion introduced in the present chapter will affirmatively help the researchers.

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