

Chapter 3

Thermal–Mechanical Effects and Near–Critical Fluid Dynamic Behaviors in Micro–Scale

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ABSTRACT

Supercritical CO₂ fluid has been widely used in chemical extraction, chemical synthesis, micro-manufacturing, and heat transfer apparatus, and so forth. The current chapter deals with near-critical CO₂ micro-scale thermal convective flow and the effects of thermal-mechanical process. When the scale becomes smaller, new, and detailed figures of near-critical thermal effects emerges. To explore this new area, theoretical developments and numerical investigations are discussed and explained in this chapter. From a theoretical point of view, the thermal-mechanical nature of near-critical fluid would play a leading role in small time and spatial scales. This effect is found dominant to the thermal dynamic responses and convective structures of micro-scale fluid behaviors. The scaling effects, boundary thermal-mechanical process, instability evolutions, mixing flows and characteristics, possible extensions, and applications are also discussed in this chapter.

DOI: 10.4018/978-1-7998-5796-9.ch003

BASICS OF CRITICAL FLUID FLOW AND HEAT TRANSFER: FROM SUPERCRITICAL TO NEAR-CRITICAL

Supercritical Flow and Heat Transfer in Microchannels

Near-Critical Background and General Applications

In recent years, supercritical fluid and near-critical fluid have been utilized in micro-/nano-chemical synthesis, microscale fluid flow and heat transfer devices, chemical extraction and separation, biological synthesis and many other fields. The applications of critical fluids have been welcomed in many advanced strategic technologies of 21st century, such as novel chemicals, energy technology, biology and other fields (Kuang et al., 2004; Kumar et al., 2011; Zhao et al., 2011). For example, the utilization of supercritical H₂O and CO₂, by using their special density and diffusivity characteristics, has been found very effective for chemical extraction and preparation processes, which have become matured 'green' technology nowadays (Wang et al., 2011). Also, based on the preferable thermal and transport properties of supercritical/near-critical fluids, new heat transportation designs have been proposed and tested, which have shown potential in new generation of renewable energy technologies and energy conversion systems (Zhang et al., 2007; Zhang and Yamaguchi, 2008; Chen and Zhang, 2011). For example, for new generation of nuclear power plant, supercritical fluids based system has become one of the promising choices in recent framework for the global development (Dimmic et al., 2002). The application fields of critical fluids also include solar conversion, heat pump design, cooling and drying, micro-scale cooling, micro-devices and heat transfer designs. Such system design and performance analysis have drawn the attention of both engineers and scientists around the world and have become one major direction of future development in fluid and energy technology fields.

At the same time, the fluid flow and heat transfer engineering field has been more focused on micro-scales in recent years, such as for molecular level understanding of human life, chemical engineering, medicine, energy and resources engineering (Ameel et al., 1997). Several representative projects of the supercritical/near-critical fluids in microscale engineering can be found in Figure 1, where the micro-/nano-scale chemical synthesis, chemical mixing and reaction, novel energy conversion and heat transfer heating/cooling applications are shown. The scientific analysis and design of those processes have to consider the microscale effects for critical fluid flow and heat transfer under designed conditions. There are a lot of question to be asked before one can try to see into the new world of supercritical/near-critical world! For instance, if the nanoparticle is to be synthesized in a microscale chamber, which is one typical situation of nanoparticle synthesis, the dynamics of fluid confinement and local heat transfer (equilibrium or irreversible procedures) of critical fluids should also be considered, besides the generally known microscale temperature and pressure control (Kuang et al., 2004; Wang et al., 2011; Zhao et al., 2011).

For supercritical/near-critical fluid, the challenges for system control and stability formation are much different from traditional kinds of operation systems. This is due to the microscale effect. The near-critical synthesis of nanoparticles in micro-chamber can provide not only much better products for customers but it also yields much critical conditions of formation (Beckman, 2004; Sierra-Pallares, et al., 2011). The near-critical fluids have very large changes of properties when they go across (or near) the critical point. The specific heat tends to infinity while the thermal dif-

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