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An experimental study on heat transfer of CO_2 solid–gas two phase flow with dry ice sublimation

Xin-Rong Zhang [a,*], Hiroshi Yamaguchi [b]

[a] Department of Energy and Resources Engineering, College of Engineering, Peking University, Beijing 100871, China
[b] Department of Mechanical Engineering, Doshisha University, Kyo-Tanabeshi, Kyoto 610-0321, Japan

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ABSTRACT

Knowledge on heat transfer characteristics of CO_2 solid–gas two phase flow is important to design of some new refrigeration systems. Continuously obtaining CO_2 solid–gas fluid flow in a closed loop is necessary to measure its heat transfer. In this paper, an experiment set-up is designed, constructed and tested in order to measure the temperatures, pressures of the CO_2 solid–gas two phase flow, and also further its heat transfer characteristics. As the first step of the investigation, the measurement work is conducted in a horizontal circular tube. Based on the obtained results, it is verified the present experiment set-up can continuously obtain CO_2 solid–gas fluid flow in the closed loop and also heat transfer measurement is possible. The results show an average value 310 W/(m^2 K) of heat convective coefficient is experimentally obtained in the present range, which is higher than that of gas flow. The Nusselt number is found to increase along the tube length in the sublimation area. In addition, some knowledge on the heat transfer characteristic of the CO_2 solid–gas flow is learned from the present study.

1. Introduction

From the viewpoint of protecting the ozone layer and preventing global warming, there is now strong demand for science and technology based on ecologically safe ‘natural’ working fluids – carbon dioxide. The thermodynamic and transport properties of CO_2 seem to be also favorable in terms of heat transfer and pressure drop, compared to other typical fluids [1,2]. Based on the advantages, more and more energy technologies tend to use CO_2 as working fluid [3–6]. Among these energy technologies using CO_2 as working fluid, CO_2 compression refrigeration and heat pump systems seem to be most promising one. For recent several years, many researchers carried out a lot of scientific investigation on the field of CO_2 compression refrigeration [7–11]. For the refrigeration processes and equipments using CO_2 as working fluid, the refrigeration temperature range is usually about from −30.0 to 0.0 °C achieved by CO_2 evaporation process. However, the refrigeration technology below −30.0 °C is needed for some important industrial applications, for example, fishing industry, biomedical engineering etc. Several years ago, a refrigeration method using CO_2 as working fluid was proposed and this can achieve a cryogenic temperature below CO_2 triple point temperature — −56.6 °C [6,12]. Fig. 1 shows a schematic diagram of the CO_2 refrigeration principle, in which the refrigeration is achieved by liquid CO_2 expanding into solid–gas two phase fluid. The process of a–b represents the liquid CO_2 expansion into the two phase flow, the dry ice region, shown in Fig. 1(a), which goes down through the CO_2 triple point in CO_2 *P–h* diagram. By the CO_2 expansion process, the CO_2 solid–gas two phase fluid is obtained, which is below −56.6 °C. Fig. 1(b) shows the refrigeration method, that is, CO_2 solid particles obtained from the expansion process sublimate and absorb heat quantity when flowing through a pipe, which is also shown in the b–c process in CO_2 *P–h* diagram in Fig. 1(a). The process shown in Fig. 1 presents a refrigeration possibility using CO_2 as working fluid, which can achieve a temperature environment below −56.6 °C. This refrigeration method proved to be feasible by experiments [6] and theoretical analysis [12]. Based on the refrigeration method, a new CO_2 heat pump technology has been proposed [13], which has a potential of providing the user a cryogenic environment below −56.6 °C and at the same time thermal energy supply above 80 °C. In addition, important knowledge is provided by the previous studies [14–16], which are related to CO_2 solid–gas flow. Especially, a Lagrangian particle-trajectory model and a Nusselt-type model [14] are presented for the deposition and melting process during throttling high pressure CO_2 into atmosphere, in order to get the suitable parameters to get a longer duration of the deposition and a shorter duration of melting. An experimental work [16] of simulating the CO_2 flow through the safety valve and its downstream line is carried out in order to know the influence of the upstream vapor

* Corresponding author.
E-mail address: scho@mail.doshisha.ac.jp (X.-R. Zhang).

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