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Experimental investigation of two phases evaporative heat transfer coefficient of carbon dioxide as a pure refrigerant and oil contaminated under forced flow conditions in small and large tube

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ABSTRACT

The evaporative two-phase heat transfer coefficient of CO_2/oil contaminated as a refrigerant under forced flow conditions through a smooth horizontal tube was experimentally investigated. The experiments were carried out for two test sections of evaporators. The test sections were made of seamless precision steel tubes with a length of 1.12 m and two inner diameters of 4 and 10 mm to fulfill the influence of the evaporator geometry. Experimental parameters include mass fluxes varied from 90 to 750 (kg m^{-2} s), heat flux ranged from 5 to 40 (kW m^{-2}), evaporation temperatures changed from −10 to −35 °C, and the oil concentration is varied from 0.2 to 7 %. The results from the experiment are compared with those calculated from correlations reported in the literature. The results of this study are of technological importance for the efficient design of evaporators when systems are assigned to utilize CO_2 as a refrigerant.

Etude expérimentale du coefficient de transfert de chaleur évaporatif diphasique du dioxyde de carbone comme frigorigène pur et d'huile contaminée en conditions d'écoulement forcé dans un petit et un large tube

Mots clés : Diphasique ; Transfert de chaleur ; CO2 ; Contamination d'huile ; Tube horizontal

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Nomenclature

D	Tube diameter (m)
G	Mass flux (kg s^{-1} m^2)
h	Heat transfer coefficient (W m^{-2} K)
k_w	Wall thermal conductivity (W m^{-1} K)
L	Length of the pipe
Pc	Condenser pressure (bar)
Pe	Evaporator pressure (bar)
q	Heat flux (W m^{-2})
Q	Heat transfer rate (W)
$T_{ev,o}$	Outlet evaporator temperature (°C)
T_r	Refrigerant temperature (°C)
T_w	Wall temperature (°C)
ξ_O	Oil mass concentration (%)
X_{ave}	Average quality (–)

Abbreviations

ACV	Automatic control valve
CSG	Calibrated stand glass
GWP	Global warming potential
ODP	Ozone depletion potential
OHE	Oil heat exchanger
OPV	Oil provider vessel
ORV	Oil receiver vessel
OS	Oil separator
P.H	Pre-heater
S.H	Super-heater
T.E	Test evaporator

1. Introduction

Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are the substances responsible for the ozone depletion substances (ODS). From the environmental viewpoint, alternative refrigerants to Chlorofluorocarbon (CFCs) and Hydrofluorocarbon (HFCs) are necessary. Natural refrigerants, which include air, water, noble gases, hydrocarbons, ammonia, and carbon dioxide, have attracted the attentions of researchers and have been gradually considered as long-term substitutes. Among these natural refrigerants, CO_2 has been extensively used in conventional compression-type refrigerating machines in the initial forty years of the past century, due to its unique properties such as inflammable, nontoxic, the ozone depletion potential ODP = 0 and the global warming potential GWP = 1. CO_2 has a much higher heat conductivity than the CFCs, HCFCs and HFCs so it is expected that oil could have a more pronounced influence on heat transfer with CO_2 as refrigerant than when using the CFCs, HCFCs and HFCs (Yun et al., 2001).

From literature survey The flow boiling heat transfer characteristics of CO_2 for smooth and micro-fin tubes, the influence of lubricating oil (PAG, kinetic viscosity 100 mm^2 s^{-1} at 40 °C), and the enhancement effects of micro-fin tube on flow boiling heat transfer and dryout was clarified through (Lei and Tomohiro, 2006). The heat transfer coefficient in both the pre- and post-dryout regions and the dryout quality were measured (Danga et al., 2013). The study presents only experimental results because it was difficult to correlate them over a wide range of experimental conditions. Many researchers experimentally investigated two phase evaporative heat transfer coefficient of carbon dioxide as a pure refrigerant (Thome and Ribatski, 2005) and (Zhao et al., 2007). Especially at low evaporation temperatures under, several experiments had been conducted by (Knudsen and Jensen, 1997; Park and Hrnjak, 2005, 2007; Zhao et al., 2009; Kim et al., 2010). Comparing to pure CO_2, however, experimental studies on oil/CO_2 mixtures are somewhat limited. In typical refrigeration or air-conditioning systems, a small amount of the lubricating oil migrates from the compressor and through the system, which considerably affect the heat transfer performance of the components. In order to understand the effect of oil on the heat transfer characteristics, it is necessary to measure the flow boiling heat transfer coefficient of both pure CO_2 and oil/CO_2 mixtures.

By collecting the measurement data, several correlations predicting evaporative heat transfer coefficients have been proposed, unfortunately, it is not so easy to find the measured data of evaporative heat transfer coefficients and the correlations to predict the heat transfer coefficients CO_2. Currently, correlations by (Kandlikar, 1990; Shah, 1982; Gungor and Winterton, 1986), which adopted the superposition or enhancement model, have been used to predict evaporative heat transfer coefficients. This paper will present some experimental results obtained with boiling of carbon dioxide in a pipe.

The aim of this work is to investigate experimentally the two phase evaporative heat transfer coefficient of carbon dioxide as a pure refrigerant and oil contaminated under forced flow conditions in small and large tubes, in addition to a comparison of the heat transfer coefficients with different correlations.

2. Experimental test rig and procedures

2.1. Test rig description

A schematic diagram of the experimental apparatus is shown in Fig. 1. It consists of two well-instrumented vapor-compression refrigeration systems, the primary cycle and the secondary cycle. The primary cycle is a conventional R22 refrigeration plant providing the necessary cooling to condense carbon dioxide, and this leads the secondary cycle to work at sub-critical conditions. The primary cycle is indicated in Fig. 1 by dashed lines. It provides cooling effect to the sub-cooler for carbon dioxide and cooling effect for oil cooler. The design and the selection of the conventional R22 refrigeration cycle components give the possibility to control the state of the carbon dioxide at the outlet of the evaporator as well as the condenser. The main components of the secondary cycle are; evaporator test section, a refrigeration loop, a special system