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Effect of micro-grooves on the two-phase pressure drop of CO_2 in a mini-channel tube

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ABSTRACT

The pressure drop characteristics of CO_2 have been experimentally investigated for a mini-channel tube with and without micro rectangular grooves. The multiple mini-channels have an inner diameter of 0.8 mm and the grooves have a rectangular cross section (0.1×0.2 mm). The pressure drop was measured for a saturated liquid phase and two-phase. Using the hydraulic diameter, the pressure drop in the grooved mini-channel can be successfully estimated with the correlations used for smooth channels. Because of a smaller hydraulic diameter, the pressure drop of the grooved channel was found to be about 1.3 times and 1.1–1.45 times greater than that of the smooth channel, for liquid and two-phase, respectively. The experimental results were compared with widely used two-phase pressure drop models. Most of the models showed the mean absolute error of 17–35% for the smooth channel and 13–32% for the grooved channel.

Effet des micro-rainures sur la chute de pression diphasique du CO_2 à l'intérieur d'un mini-canal

Mots clés : diphasique ; chute de pression ; micro-rainures ; mini-canal ; dioxyde de carbone

1. Introduction

Since the regulations on HCFCs and HFCs are getting stricter than ever, natural refrigerants are drawing a renewed attention as alternative refrigerants. Among the natural refrigerants, CO_2 has been spotlighted and widely investigated since it has good characteristics as a refrigerant for vapor compression refrigeration systems. Sarkar (2012) reported a positive outlook on a transcritical CO_2 system though it has a lower COP compared with conventional systems. However, the working pressure of CO_2 is much higher than that of conventional refrigerants. Therefore, extruded aluminum tubes which have multiple mini-channels with a diameter of 0.5–1.0 mm are considered to be suitable for CO_2 evaporators. Applying a smaller diameter, mini-channel tubes can have a higher mechanical strength and much bigger heat transfer area per unit volume than conventional ones.

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Nomenclature

A	heat transfer area [m^2]
A_{cr}	cross sectional area for the refrigerant flow [m^2]
D	diameter [m]
D_h	hydraulic diameter [m]
f	friction factor
G	mass flux [kg/m^2 s]
h	enthalpy [kJ kg^{-1}]
ℓ	tube length [m]
ℓ_{wp}	wetted perimeter [m]
$\dot{m}$	mass flow rate [kg s^{-1}]
MAE	mean absolute error [%]
P	pressure [kPa]
P_r	reduced pressure
q''	heat flux [kW m^{-2}]
$\dot{Q}$	heat transfer rate [kW]
R	resistance [Ω]
V	voltage [V]
x	quality
z	length from the inlet [m]

Subscripts

a	acceleration
ad	adiabatic
chf	constant heat flux
ex	exit
fg	difference in property for saturation vapor and liquid
in	inlet
l	liquid
lo	liquid only
ph	pre-heater
ref	refrigerant
ts	test section
TP	two-phase
v	vapor
vo	vapor only

Greek symbols

α	void fraction
μ	viscosity [Pa s]
ρ	density [kg m^{-3}]
ξ_{20}	fraction of the data within the error of ±20% [%]

To increase the heat transfer area, various shapes of grooves have been applied at inner surface of the channels. For macro-channels, the grooves have been widely applied and their effects on the pressure drop and heat transfer have been extensively studied. Seo and Kim (2000) as well as Kim et al. (2002) studied the evaporation heat transfer and pressure drop of R-22 and R-410A in micro fin tubes. In their studies, both heat transfer and pressure were increased by the grooves. Inoue and Ichinose (2012) performed experiments with various helical grooved tube and investigated the effect of various design variables. Schael and Kind (2005) observed a flow pattern and heat transfer of two-phase CO_2 in a micro fin tube. Also, considerable enhancement of heat transfer and pressure drop was observed in their study.

However, the effect of the grooves in mini-channels has been scarcely investigated because the fabrication of the grooves inside a mini-channel is not easy and their effect is not clear. Kim et al. (2007) investigated the micro-fin flat tube with a hydraulic diameter of 1.56 mm. The height of the micro-fin was 0.4 mm. In their result, the laminar heat transfer coefficient in the micro-fin tube turned out to be lower than the smooth tube.

In our previous study (2009), the authors fabricated a mini-channel tube with micro-grooves and measured the heat transfer coefficient of CO_2. The micro-grooves showed an increase of evaporative heat transfer, especially in low quality region. However, the study was focused on the heat transfer, and detailed pressure drop characteristics were not investigated.

To utilize the micro-grooved channels for CO_2 refrigeration systems, the information on the pressure drop is essential as well as heat transfer characteristics. In this study, therefore, the two-phase pressure drop of CO_2 has been experimentally investigated for the mini-channels (ID: 0.8 mm) with and without micro rectangular grooves (0.1 × 0.2 mm). The experimental results were compared with several two-phase pressure drop models.

2. Experimental apparatus

Fig. 1 shows the schematics and the photo of the cross section of the smooth and micro-grooved tubes which are made of extruded aluminum. The smooth tube without grooves (reference tube) has 6 mini-channels of which the diameter is 0.8 mm. The micro-grooved tube has 8 mini-channels whose inner diameter is 0.8 mm. Each channel has 8 grooves of which the cross section is rectangular (0.1 × 0.2 mm). The

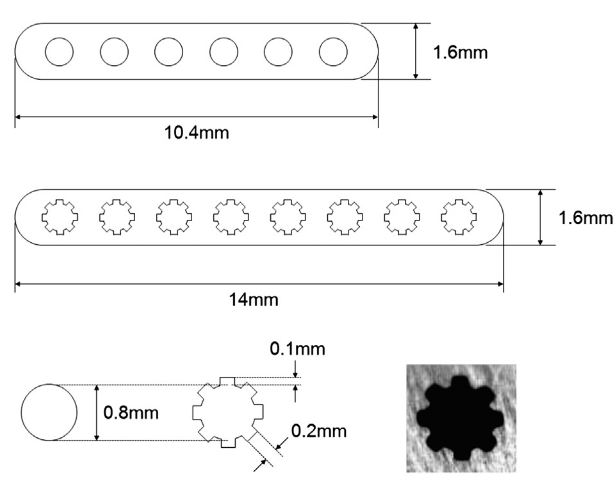

Fig. 1 – Cross section of the tested mini tubes (unit: mm).