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Flow characteristics of helical capillary tube for transcritical CO_2 refrigerant flow

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Abstract

Helically coiled capillary tubes flow is characterized for transcritical CO_2 refrigerant numerically, developing theoretical model established on fundamental equations of mass, energy and momentum considering homogeneous two phase flow. Various friction factors models are compared, present in the open literature. The results obtained from the present model are fairly matches with the simulation results Mori & Nakayama and Schmidt friction factors agree reasonable well with mean average error of 2.2% and 5.7% for R744, respectively. The present model may be used to design helical capillary tubes working with CO_2 refrigerant.

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Keywords: Transcritical, Helical, Capillary tube, Adiabatic, friction factor

1. Introduction

In the research of the alternative refrigerants, it is narrowed down to natural refrigerants being the ecological safe. CO_2 is the strong contender of natural refrigerants which have a perceived a revival [1]. Serving with advantages such as low cost, low starting torque and simple, capillary tubes are considered to most suitable for small-capacity refrigerating and air-conditioning units typically lower than 10 kW as expansion devices. Flow in a capillary tube is a complex phenomenon where internal surface friction and flow momentum both contribute to expansion of refrigerant. However, in the two-phase region existence vapour dominates momentum pressure drop over friction pressure drop. As a result enthalpy reduces in the two phase region of the capillary tube as part of the total energy is transformed to kinetic energy.

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Nomenclature

A	Cross-sectional area of capillary tube (m^2)
Cp	Specific heat (kJ kg^{-1} K^{-1})
d	Helical Capillary tube diameter (mm)
f	Friction factor
G	Mass flux (kgm^{-2} s^{-1})
L	Capillary tube length (m)
m	Mass flow rate (kgs^{-1})
P	Pressure (bar)
P	Pitch (mm)
Re	Reynolds number
T	Temperature (K)
V	Velocity (ms^{-1})
h	Specific enthalpy (kJ kg^{-1})
x	Dryness fraction
De	Dean Number
Dc	Coil diameter (mm)
f_c	Friction factor coiled capillary tube
f_s	Friction factor straight capillary tube
He	Helical number
ΔT_{sub}	Degree of subcooling (K)

Subscripts

1–4	Capillary tube state points
c	Capillary
ev	Evaporator
gc	Gas cooler
g	Saturated Vapour
l	Saturated liquid
sp	Single phase
12	Super-critical
23	Transcritical
34	Subcooling liquid
i	Element
h	Helical capillary tube
s	Straight capillary tube

Greek Symbol

ρ	Density (kgm^{-3})
ε	Internal surface roughness(mm)
μ	Dynamic viscosity (Pa s)
σ	Surface tension (Nm^{-1})
ϕ	Frictional multiplier

Combination of inner diameter and length of a capillary tube is pivot which decides the flow characteristics and has a large impact on the conduct of the overall system. Capillary tube specification (diameter and length) at a given operating situation and tube surface roughness are the main things in the design of a capillary tube.Coiled capillary tubes have large functional uses to save area in small capacity systems. It has been presented much in the open literature. A moderate amount of work has been carried out on the coiled capillary tube with the subcritical refrigerants like R-22, R-407C, R134A and R-410A [2-6]. These works largely includes hydro fluorocarbons (HFCs), hydrocarbon refrigerants and their mixtures.

Being the different scenario, flow characterization of capillary tube with transcritical CO_2 as a refrigerant flow is addressed less in open literature. Madsen et al. [7] addressed a theoretical wok on an adiabatic straight capillary tube with CO_2 as refrigerant. It was recommended that coefficient of performance (COP) is improved with a properly designed capillary tube than that of fixed gas cooler pressure. Agrawal and Bhattacharyya [8] conducted experiment for a straight adiabatic capillary tube with CO_2 as refrigerant. It was reported that performance drop was more serious at undercharged situation than at overcharged situation. Wang [9] carried out theoretical study considering separated and metastable flow model for adiabatic helically coiled capillary tube with CO_2 as refrigerant. Almost large variation was observed between the homogeneous and separated flow model when the length of the two-phase flow region employs more fraction of the total capillary length. In the metastable two-phase flow region, the quality and void fraction enhance largely due to the presence of metastable superheated liquid. Agrawal and Bhattacharyya [10] performed theoretical work on helical capillary tube. They reported that the mass flow rate of refrigerant increases as the coil diameter increases, but variation is small ahead of 180 mm coil diameter.

Although some information is presently accessible on the flow characteristics of refrigerants in helically coiled capillary tubes using hydrocarbon and hydro fluorocarbons (HFCs), expansion of transcritical CO_2 through a helically coiled adiabatic capillary tube is relatively less addressed in open literature. It provides room for research to predict flow characteristics of CO_2 refrigerant with adiabatic helical capillary tube using suitable friction factor. In the present work a numerical model, considering homogenous two phase flow is developed to characterize the flow of a CO_2 refrigerant flowing through a helical coiled capillary tube. Various related friction factor correlations available in open literature are compared and suitable friction factors are suggested based on the agreements with the published test results.