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An experimental study of flow pattern and pressure drop for flow boiling inside microfinned helically coiled tube

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Abstract

In this paper, flow patterns and their transitions for refrigerant R134a boiling in a microfinned helically coiled tube are experimentally observed and analyzed. All the flow patterns occurred in the test can be divided into three dominant regimes, i.e., stratified-wavy flow, intermittent flow and annular flow. Experimental data are plotted in two kinds of flow maps, i.e., Taitel and Dukler flow map and mass flux versus vapor quality flow map. The transitions between various flow regimes and the differences from that in smooth straight tube have also been discussed. Martinelli parameter can be used to indicate the transition from intermittent flow to annular flow. The transition from stratified-wavy flow to annular or intermittent flow is identified in the vapor quality versus mass flux flow map. The flow regime is always in stratified-wavy flow for a mass flux less than 100 kg/m^2 s.

The two-phase frictional pressure drop characteristics in the test tube are also experimentally studied. The two-phase frictional multiplier data can be well correlated by Lockhart–Martinelli parameter. Considering the corresponding flow regimes, i.e., stratified and annular flow, two frictional pressure drop correlations are proposed, and show a good agreement with the respective experimental data.

Keywords: Flow boiling; Flow pattern; Pressure drop; Helically coiled tube; Microfin tube

1. Introduction

On the cases of intube convective boiling or condensation, accurate modeling and trustworthy evaluation of heat transfer and pressure drop characteristics require precise predictions of the local two-phase flow patterns, since distinct flow regimes can be characterized by quite different flow and heat transfer mechanisms. Therefore, studies of two-phase flow patterns and their transitions during intube flow boiling and condensation have gained increasing interest for several decades. Kattan et al. [1] proposed a diabatic flow pattern map for evaporation (boiling) in horizontal straight smooth tube. They stated that their flow pattern map was developed based on flow pattern data for five different refrigerants, including R134a. Muzzio et al. [2] investigated the flow patterns in flow boiling and convective condensation of refrigerant R22 in a microfin tube. The present authors' research group have developed a new kind of cross-grooved microfin tube, called three-dimensional (3-D) microfinned tube, and have done a lot of investigations on flow boiling and convective condensation flow patterns in such kind of straight tubes, such as Zhou and Xin [3] and Chen et al. [4].

Because of the high efficiency in heat transfer and compactness in volume, helically coiled tubes are used extensively in heat exchangers, nuclear reactors, solar collectors, and the food, drug and refrigeration industries. Comparing with the extensive studies in straight tubes, the investigation of two-phase flow patterns, especially diabatic two-phase flow patterns, in helically coiled tubes is insufficient. In a recently published review paper [5], more than one hundred papers have been reviewed in details. However, there is none of reviewed papers deals with flow

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Nomenclature

d_i	inner diameter of tube, m
f	friction factor
F_{td}	modified Froude number, defined as Eq. (2)
g	gravity acceleration, m s^{-2}
G	total mass flux, kg/m^2 s
u	velocity, m s^{-1}
x	vapor quality
X_{tt}	Lockhart–Martinelli parameter
Greek symbols	
ρ	density, kg m^{-3}
μ	kinetic viscosity, Pa s
γ	helix angle of the coiled tube, degree
ε	void fraction
Φ_{lo}	two-phase frictional multiplier
ΔP	pressure drop gradient, Pa/m
Subscripts	
l	liquid
in	inlet
out	outlet
tp	two-phase condition
v	vapor

boiling or condensation flow patterns in helically coiled or even curved tube. In fact, for design purpose, it is important to know the flow pattern and pressure drop information in helically coiled tube.

In the open literature, most researches on two-phase flow in curved ducts are adiabatic gas and liquid flow, such as the studies of Whalley [6] and Xin et al. [7,8], they all used air and water as the experimental fluids. Some researchers, such as Jensen and Bergles [9], Guo et al. [10], and Zhao et al. [11], have studied the heat transfer and pressure drop characteristics of steam-water flow in helical tubing. In the authors' knowledge, however, investigations on diabatic two-phase flow of refrigerant in helically coiled tube have rarely been conducted. In this paper, therefore, the studies focus on the flow patterns and pressure drop for flow boiling of oil free refrigerant R134a, an environment-friendly refrigerant that has replaced R12 and in part R22, in a 3-D microfinned helically coiled tube.

2. Experimental setup

Fig. 1 shows the schematic diagram of the experimental apparatus used in this study. A complete description of the experimental test facility was also described in Li et al. [12] and Cui et al. [13].

The test data are obtained for evaporating conditions inside a 11.2 mm inner diameter microfinned helically coiled, copper tube test section that were heated by electrical resistance wire wound around the tube. The tested helically coiled tube is vertically positioned, i.e., refrigerant enters the test section from the lower inlet and exits from the upper outlet. The geometries of the test tube are listed in Table 1, where the two different values of fin height and

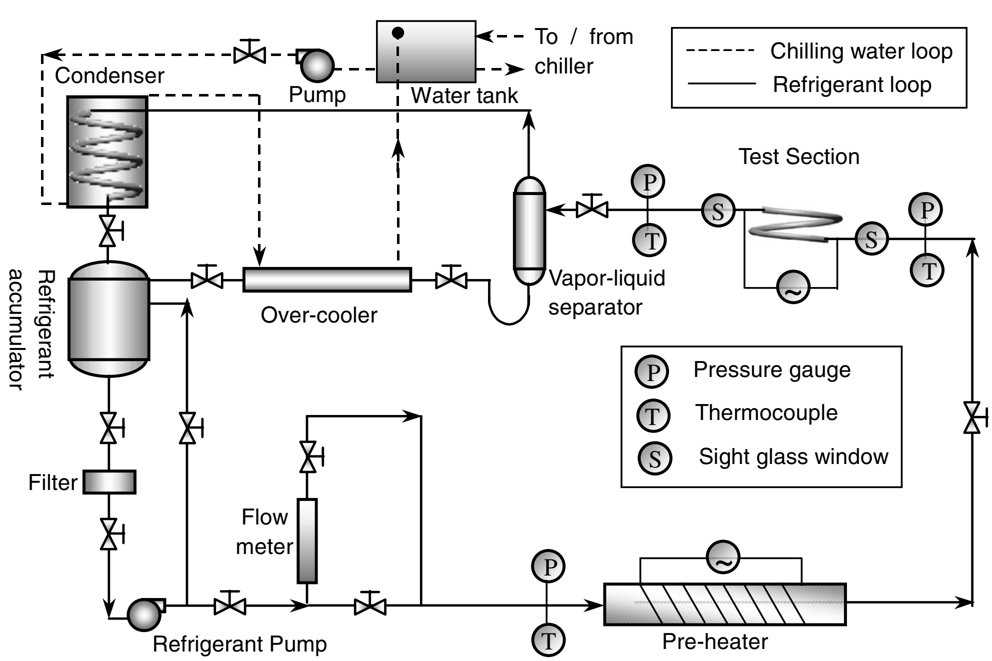

Fig. 1. Schematic diagram of the test loop.