International Communications in Heat and Mass Transfer 38 (2011) 1156–1161

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Visual study of flow patterns during condensation inside a microfin tube with different tube inclinations☆

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ARTICLE INFO

Available online 14 May 2011

Keywords:
Flow pattern
Condensation
Microfin tube
R-134a
Inclination

ABSTRACT

In this paper, flow patterns and their transitions for refrigerant R-134a condensing in a microfin tube are visually observed and analyzed. The microfin tube has been provided with different tube inclination angles of the direction of fluid flow from horizontal, α. The experiments were performed for seven different tube inclinations, α, in a range of −90° to +90° and refrigerant mass velocities in a range of 53 to 212 kg/m^2s for each tube inclination angle during condensation of R-134a vapor. From analysis of acquired data, it was found that the tube inclination strongly influenced the vapor and condensate liquid distribution. Annular flow was the dominant flow pattern for vertical downward flow, α = −90°. Annular flow, semi annular flow and stratified flow were observed for α = −60°and −30°. Annular flow, wavy-annular flow and stratified-wavy flow exist in sequence for horizontal tube. Annular flow and wavy-annular flow were observed for α = +30°and +60°. Annular flow, annular-wavy flow, churn flow and slug flow occurred for α = +90°.

1. Introduction

In-tube condensation of refrigerants is extensively used in the air-conditioning, refrigeration and process industries. The use of heat transfer enhancement devices for condensers is common, and the use of helical micro-fin tubes is the most prevalent passive enhancement device in use today. These tubes promote significant increments in heat transfer though not affecting in the same proportion the pressure drop. These characteristics have promoted their widespread application in the refrigeration industry. On the other hand, it is obvious that the mechanism of heat transfer augmentation in microfin tubes is dependent on the flow regime of two-phase flow. The heat transfer coefficient generally keeps changing as the flow pattern changes along a condenser tube [1], therefore many investigations of the flow patterns for in-tube condensation have been reported in literatures.

A review of the existing literature reveals that, although vast studies have been done on flow regimes in these tubes, yet the focus of almost all of the studies is on two phase refrigerant flow in horizontal tubes [2–4]. However, gravitational force, vapor–liquid interfacial shear stress and surface tension are known as dominant factors controlling the vapor and liquid distribution inside the tube. Thus, there is a great necessity to obtain information about how the gravitational force affects the two-phase flow pattern for condensation in a micro fin tube. Therefore, a visual study has been carried out to determine the flow patterns for condensation of R-134a inside a microfin tube with different inclinations of the tube.

In our previous paper [5], condensation heat transfer of R-134a inside inclined microfin tubes has been studied. The experimental results indicated that the tube inclination affected the condensation heat transfer in a significant manner.

2. Test apparatus and procedure

The schematic diagram of the test apparatus has been shown in Fig. 1. In fact, the experimental set-up was a well instrumented vapor compression refrigeration system. It is consisted of a compressor, an evaporator, an expansion valve, a pre-condenser, a test-condenser or test-section, an after-condenser, and necessary instruments for measurements and controls.

The test-condenser is a 1.04 m long double pipe counter-flow heat exchanger using water as a coolant. The refrigerant vapor condenses inside the inner microfin tube while cooling water flows in the annulus between the inner tube and the outer tube. The microfin tube is a copper tube having internal microfins with triangular fin cross-section. The geometrical parameters of microfin tube are shown in Fig. 2. In order to change the inclination angle of the test-condenser the connections to this condenser were made by flexible pressure hoses. The complete condensation of dry vapor inside the test condenser is difficult to attain. Therefore, a pre-condenser was provided to control the test-condenser-inlet vapor quality, thus, the whole domain of vapor quality was covered. The pre-condenser was also a double pipe heat exchanger in which the coolant was circulated in the annulus and the refrigerant flowed

☆ Communicated by W.J. Minkowycz.
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doi:10.1016/j.icheatmasstransfer.2011.04.032