Two Phase Frictional Pressure Drop of Carbon Dioxide in Horizontal Micro Tubes

M. Tarawneh

Abstract—Two-phase frictional pressure drop data were obtained for condensation of carbon dioxide in single horizontal micro tube of inner diameter ranged from 0.6 mm up to 1.6 mm over mass flow rates from $2.5 \times 10^{-3}$ to $17 \times 10^{-2}$ kg/s and vapor qualities from 0.0 to 1.0. The inlet condensing pressure is changed from 33.5 to 45 bars. The saturation temperature ranged from -1.5 °C up to 10 °C. These data have then been compared against three (two-phase) frictional pressure drop prediction methods. The first method is by Muller-Steinhagen and Heck (Muller-Steinhagen H., Heck K). A simple friction pressure drop correlation for two-phase flow in pipes. Chem. Eng. Process 1986:20:297–308) and that by Gronnendal R. Investigation of liquid hold-up, flow-resistance and heat transfer in circulation type evaporators, part IV: two-phase flow resistance in boiling refrigerants, Annex 1972. Then the method used by Friedel L. Improved friction pressures drop in horizontal and vertical two-phase pipe flow. European Two-Phase Flow Group Meeting, Paderborn, 1979 June, (Spain, Italy). The methods are used by M.B. Ould Didi et al [3] “Prediction of two-phase pressure gradients of refrigerants in horizontal tubes” Int. J. Refrigeration 25(2002) 935–947. The best available method for annular flow was that of Muller-Steinhagen and Heck. It was observed that the peak in the two-phase frictional pressure gradient is at high vapor qualities.

Keywords—Two-phase flow, frictional pressure drop, horizontal micro tube, carbon dioxide, condensers.

I. INTRODUCTION

Prediction of two-phase frictional pressure drops during the condensation of two-phase flow refrigerants is important for accurate design and optimization of refrigeration, air-conditioning and heat pump systems. Associated with the compactness resulted from the use of CO$_2$ as working fluid, the use of the micro tube technology (tubes having diameter of less than 3 mm) in the heat exchangers design yields a very compact and lightweight equipments. The high heat transfer coefficients and significant potential in decreasing the heat exchanger surface area are the major advantages of using this kind of geometry. For these reasons micro tube heat exchangers have been used in bioengineering and microelectronics as well as in evaporators and condensers of refrigeration systems. The optimal use of the two-phase pressure drop during the condensation of refrigerants to obtain the maximum heat transfer performance is one of the primary design goals. Also, the accurate prediction of two-phase pressure drops is a particularly important aspect of the first and second law optimizations of these systems. Yun and Kim [1] investigated two-phase pressure drops of CO$_2$ in mini tubes with inner diameters of 2.0 and 0.98 mm and in micro channels with hydraulic diameters from 1.98 to 1.54 mm. The pressure drop of CO$_2$ in the mini tubes shows very similar trends with those in large diameter tubes. Huai et al. [2] presented experimentally a study of boiling heat transfer and pressure drop of CO$_2$ flowing in a multi-port extruded aluminum test section, which had 10 circular channels, each with an inner diameter of 1.31 mm. The results indicated that pressure drop along the test section is very small. Ould Didi et al. [3] studied the prediction of two-phase pressure gradients of refrigerants during evaporation in horizontal tubes of more than 10 mm diameter for different mass velocities and different vapor qualities. The resulted experimental data have been compared against seven two-phase frictional pressure drop prediction methods. Kattan et al. [4] studied the flow boiling in horizontal tubes through the development of an adiabatic two phase flow pattern map. Moreno Quibien, J., Thome, J. R. [5] presented a flow pattern based two-phase frictional pressure drop model for horizontal tubes through an adiabatic experimental study. In the present study, experimental test data resulted from the condensation of CO$_2$ in horizontal copper micro tubes under the effect of free convection inside a chest freezer have been compared to the following three widely quoted prediction methods for the frictional pressure drop in two-phase flows: Friedel [6], Gronnendal [7], and Muller-Steinhagen and Heck [8]. The two-phase pressure drop tests cover three different tube diameters (0.6, 1.0, and 1.6 mm) with total length of 29.72 m over mass flow rates from $2.5 \times 10^{-5}$ to $17 \times 10^{-2}$ kg/s for saturation pressures ranging from 33.5 to 45 bars and saturation temperature ranged from -1.5 °C up to 10 °C. The comparisons were based mainly on the variation of the vapor quality with the frictional pressure drop for different inlet pressures, different mass flow rates, different saturation temperatures and different tube diameters.

A. Nomenclature

\begin{align*}
\text{a} & \quad \text{parameter in Eq. (36) (Pa m}^{-1}) \\
\text{b} & \quad \text{parameter in Eq. (36) (Pa m}^{-1}) \\
\text{B} & \quad \text{parameter of Chisholm} \\
\text{C} & \quad \text{constant of Lockhart and Martinelli (m)} \\
\text{d}_i & \quad \text{tube internal diameter} \\
\text{E} & \quad \text{parameter of Friedel} \\
\text{F} & \quad \text{parameter of Friedel} \\
\text{f} & \quad \text{friction factor} \\
\text{ffr} & \quad \text{Froude friction factor} \\
\text{g} & \quad \text{acceleration due to gravity (m s}^{-2}) \\
\end{align*}