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Research Article

CFD Analysis of Dual Phase Refrigerant Flow Inside an Evaporator Tube of Refrigerator

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Abstract

In-tube two phase flow finds its applications in steam power plants, refrigeration and air conditioning, distillation and desalination units and transport of oil and slurry etc. The two phase flow is described by the parameters like mass flux, vapor quality and void fraction etc while the performance parameters of two phase flow are given by heat transfer coefficient and pressure drop. The salient feature of in-tube two phase flow is the formation of flow regimes, viz., stratified, slug, annular etc due to counter acting forces of gravity and vapor shear. The present paper focuses primarily on the development of test facility to evaluate the two phase heat transfer coefficient and pressure drop of refrigerants, R22, R134a and R407C at high pressures with a maximum pressure limit of 20 bar. Using the three refrigerants, performance parameters of two phase flow are studied in the pressure range of 10 - 16 bar. The CFD analysis is performed using commercial CFD software, FLUENT. The numerical model is developed by considering physical model of annular flow regime as 60-70% of heat exchanger length is occupied by annular flow. The pressure gradient and wall shear stress from CFD analysis is taken as input in the numerical model. It aims to develop a predictive procedure using CFD analysis for the prediction of flow regimes and pressure drop and subsequently develop numerical model for the prediction of heat transfer coefficient.

Keywords: *Evaporator, Two Phase, Computational Fluid Dynamics (CFD, Pressure, Performance*

Introduction

The simultaneous flow of two different species inside a channel such as solid-liquid, liquid-liquid, gas-liquid under adiabatic/diabatic conditions with applications in the transport of oil, slurry, sedimentation etc or that of the same species such as vapor-liquid under diabatic conditions in viz., boilers, condensers, distillation columns, desalination plants, refrigeration and air conditioning processes are common.

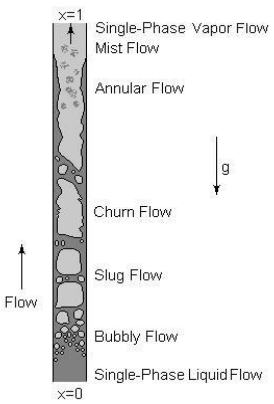

Fig.1 Two Phase Boiling in a Vertical Tube

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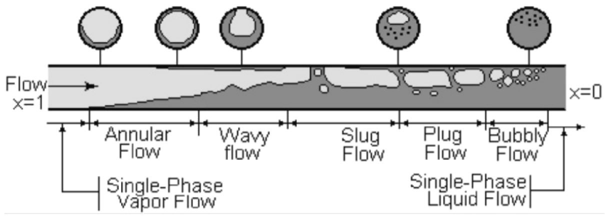

Fig. 2 Two Phase Condensation in a Horizontal Tube

Parameters such as transport properties, vapor quality and void fraction etc. are used to describe the condition of two phase flow while pressure drop and heat transfer coefficients are the performance parameters. The two phase flow regimes in a vertical and horizontal tube undergoing evaporation and condensation process are shown in Fig 1.1 and 1.2 respectively.

Refrigerants in the Present Work

The present work focuses on the study of two phase flow at high pressures. Accordingly, refrigerants, R22, R134a and R407C are considered as working fluids and two phase flow during condensation is studied. R22 is used to validate the experimental set up as the condensation heat transfer data of R22 is well reported in the literature.

The selection of refrigerants is based on the local availability and the maximum pressure the test facility can withstand. Accordingly, the condensing temperature of 40^{0}C is selected that is generally used for water cooled condensers which results into a saturation pressure range of 10-16 bar for the three refrigerants.

R134a is a low pressure refrigerant and R22 and R407C are high pressure refrigerants. R407C is a blend of different HFCs such as R32, R125 and R134a. The change in composition during phase change causes the saturation temperature of fluid to change and thus producing temperature glide. R407C is considered in the present work to study the effect of mixture refrigerant on the performance parameters of two phase flow. The properties of refrigerants are obtained using refrigerant property data base, REFPROP version 6.01. The chapter summarizes the internal two phase flow phenomena, the classification of flow regimes based on flow velocities and void fraction and the flow regime maps developed to predict the flow regimes.

Literature Review

Later Dongsoo Jung *et al*. [2004] also conducted experiments with R22, R134a, R407C and R410A and observed that the heat transfer coefficients of R134a and R410A were similar to those of R22 while heat transfer coefficient of R407C were 11-15% lower than those of R22, due to strong mass transfer resistance. They explained the comparative performance of condensing refrigerants using liquid property combination, given by Jung *et al*. [1989] for evaporating flows. Aprea *et al*. [2003] obtained quasi local heat transfer coefficients of R22 and R407C for gravity driven flow regime inside a tube of diameter, 20mm and length, 6.6 m divided into 12 subsections for mass flux ranging from 45 120 kg/m2s. They reported that the heat transfer coefficient of R22 is always greater than R407C with percentage difference decreasing with increasing mass flux. They compared their experimental data with correlations of gravity driven condensation, using Silver-Bell-Ghaly correction factor for mixtures and reported that Dobson *et al*. correlation is best fitting for their experimental data. Infante Farreira *et al*. [2003] obtained condensation heat transfer coefficients of R404A inside a horizontal tube of 3/8 diameter and 1m length for a mass flux ranging 200 600 kg/m2s. They compared their experimental data with Dobson *et al*. [1998] and Shah [1979] correlations and observed that Dobson correlation under predicted the wavy flow region by about 20%. Shah correlation predicted the experimental data well with an average error of 3%. They compared their findings with that of Boissieux *et al*. [2000] for R404A.

Scope of the Project

The experimental pressure drop obtained from the present study is compared with the correlations available in the literature in the previous chapter and the salient points of the results that form the motivation for the present chapter are presented as follows. At low mass flux of 200 kg/m2s, all the correlations of pressure drop used in the comparison exhibited larger deviations of more than 30-40% from the experimental data. It is observed that Lockhart and Martinelli correlation which is widely used in the analytical modeling of condensing flows exhibits more than 100% deviation depending on the mass flux. In addition, comparatively larger deviations, in the range of 20-45% are observed for low pressure refrigerant, R134a. These results give scope for the modeling of two phase flow using CFD analysis.

The objective of this work is to perform CFD analysis for simulating flow regimes and to obtain pressure drop of two phase flow of refrigerants at high pressures. The scope of the present chapter is to simulate the flow regimes predicted by Thome *et al*. [2003a] flow regime map for refrigerants, R22, R134a and R407C using existing VOF model in the commercial CFD software, FLUENT under adiabatic conditions. Secondly, to obtain the pressure drop from the VOF model and compare with the experimental data and correlations.

The Volume of Fluids (VOF) Model

In the volume of fluid (VOF) model [2005], a single set of conservation equations is shared by the phases and the volume fraction of each of the phases is tracked in each computational cell throughout the domain.

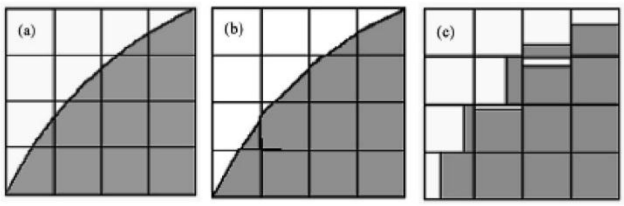

Fig.3 VOF interface reconstruction methods (a) Actual interface method (b) Piecewise Linear Interface Calculation (PLIC) method (c) Simple Line Interface Calculation (SLIC)

Methodology

Comparison of CFD Model with Experiment

The pressure gradient obtained from CFD simulations is compared with that of experimental data and is presented in Figs 4 and 5 for refrigerants, R22, R134a and R407C.

In general, CFD data over predicts the experimental data as shown in Fig 3.21a). For R134a and R407C at medium and high qualities for a high mass flux of 600 kg/m^{2}s, the model under predicts the experimental data as shown in Figs 4 and 5 that most of the data falls within the deviation of ±20%, except the points representing low mass flux that fall outside the ±20% deviation lines.

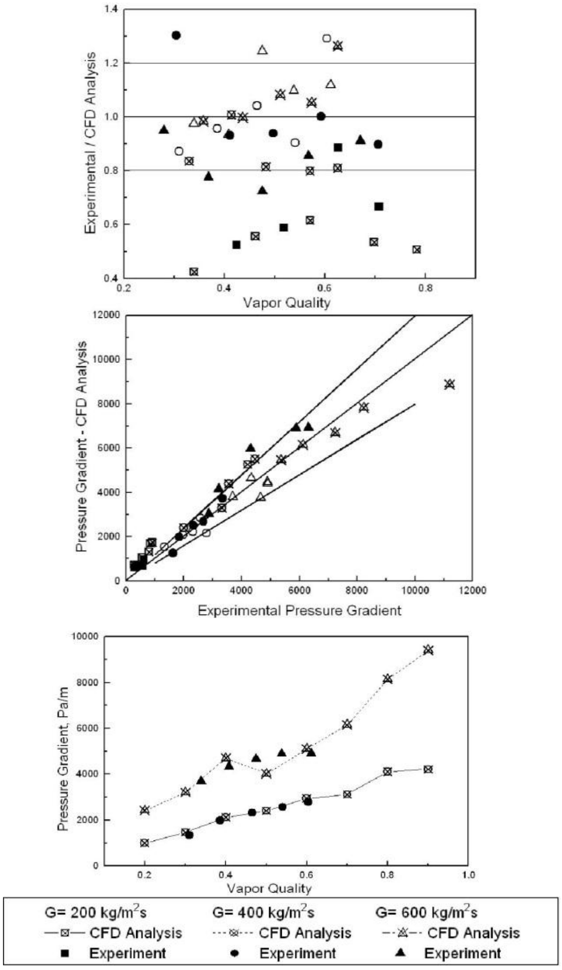

Fig.4 Comparison of CFD Data of Pressure Gradient with that of Experiment for a) R22 b) R134a and c) R407C

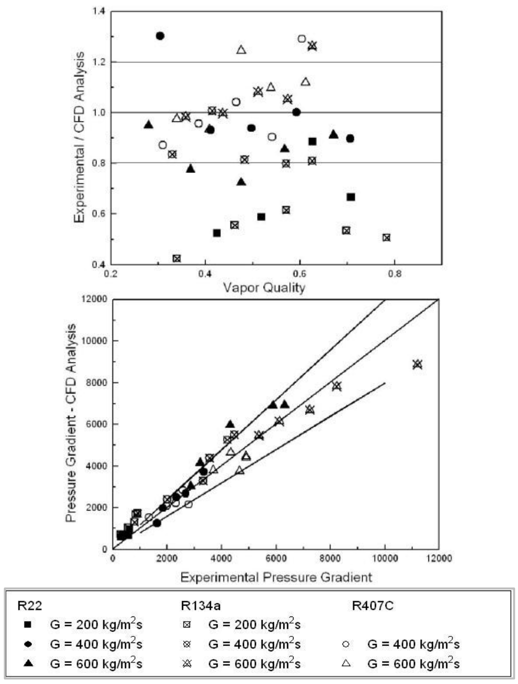

Fig.5 Comparison of CFD Data of Pressure Gradient with that of Experiment for a) Deviation Graph b) Parity Graph

Comparison of CFD Data with Correlations

(a) Comparisons for R22

CFD simulations using VOF model and from the correlations in predicting the experimental data of R22 obtained in the present study.

At low mass flux, only CFD model and Müller - Steinhagen and Heck correlation predicted the experimental data within 20- 40% deviation as shown in Figs 6 a) and d). All other correlations exhibited further larger deviations

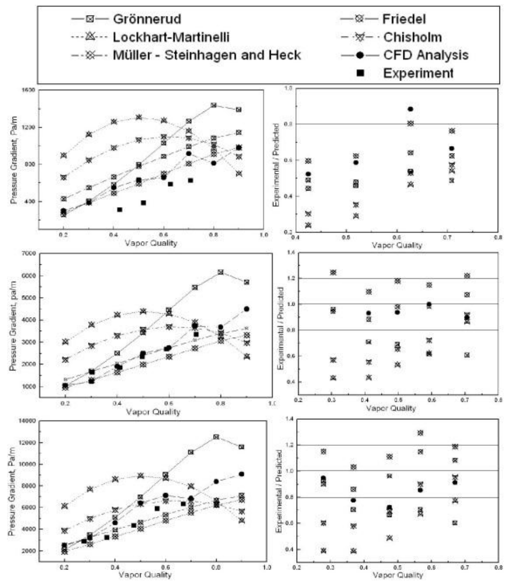

Fig.6 Comparison of CFD Data of Pressure Gradient with that of Experiment and Correlations for R22 at a) G= 200 b) 400 and c) 600 kg/m^{2}s d) Deviation Graph e) Parity Graph

(b) Comparisons for R134a

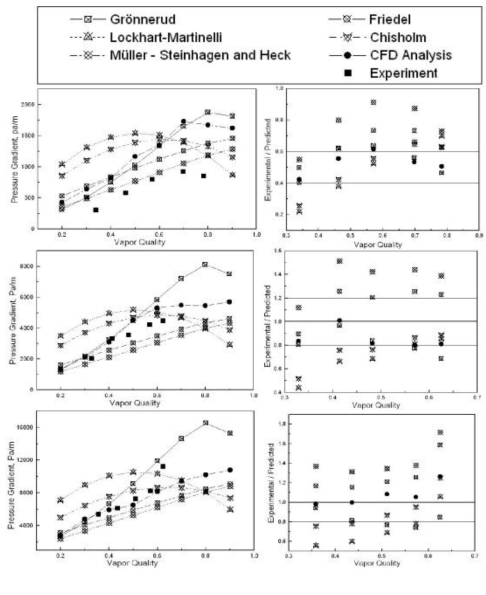

Fig.7 Comparison of CFD Data of Pressure Gradient for R134a a) G= 200 b) 400 and c) 600 kg/m^{2}s d) Deviation Graph e) Parity Graph

(c) Comparisons for R407C

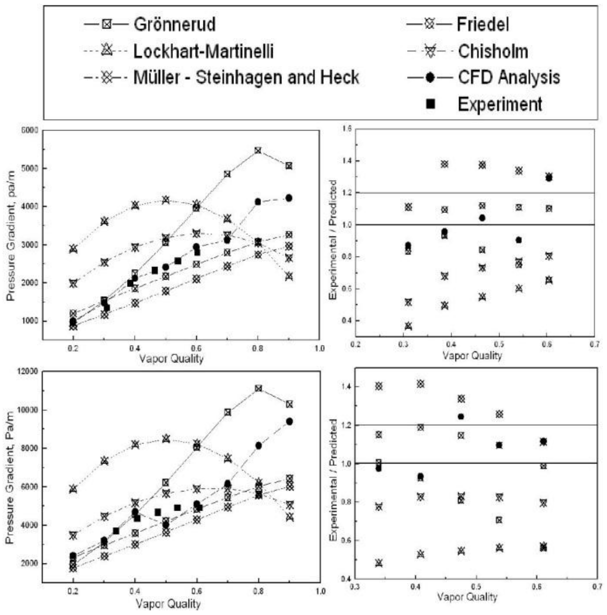

Fig.8 CFD Data of Pressure Gradient for R407C at a) G= 400 b) 600 kg/m2s d) Deviation Graph e) Parity Graph

Conclusions

Based on the computational investigation to analyze the performance the following conclusions were made:

Liquid vapor flow of low and high pressure refrigerants, viz.R134a, R22 and R407C is modeled using VOF model from existing CFD software, FLUENT.

Transient simulations are performed to track the geometry of the interface and hence obtain flow regimes at different operating conditions for low, medium and high mass fluxes.

The flow regimes obtained by plotting the contours of mixture density, showed that the VOF model reproduced all the flow regimes including the flow regime transitions given by Thome *et al*. [2003a] map accurately.

For a low mass flux, CFD model exhibits higher deviations in the range of 30-45% from the experimental data obtained. However, its predictions are better than most of the pressure drop correlations.

The CFD results of pressure drop are observed to represent higher deviations for low pressure refrigerant, R134a at very low qualities in case of a low mass flux of 200 kg/m^{2}s considered in the simulations and at medium qualities for a mass flux of 400kg/m^{2}s, where the flow regime is bubbly and plug/slug (Intermittent) respectively. These regimes represent mixing type flow without a clear interface between vapor and liquid. Since the VOF model used in the CFD analysis is based on interface flows, larger deviations are observed at these flow conditions.

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