CFD Parametric Investigation for Two Phase Flow of Refrigerant 134a In an Adiabatic Capillary tube

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***Abstract*—** *Capillary tubes are widely used as refrigerant flow control device in a small refrigeration systems. Since the flow behavior inside a capillary tube is complex, several physical models are necessary to predict the characteristics of refrigerant flow in the capillary tube. A refrigerant leaves the compressor at high pressure & temperature and enters the condenser. After leaving the condenser the refrigerant is at medium temperature & high pressure and then it enters the Capillary tube. In a Capillary tubes the pressure and the temperature of a refrigerant is reduced drastically and suddenly. Thus us it is a throttling valve where the temperature of the refrigerant is reduced and it is then able to produce the cooling effect in evaporator of the refrigerator or cooling coil of the air conditioner.*

In the present investigation, an attempt is made to analyze the two phase flow of the refrigerant 134a inside a helical capillary tube for adiabatic flow conditions. First of all a validation of Liang and Wong 2001 is made to analyze. The proposed model investigate flow characteristics in adiabatic capillary tubes for a given mass flow rate. In the present study 134a has been used as a working fluid inside the helical capillary tube of diameter 0.66 mm and used the same model to study the flow characteristics of refrigerant in ANSYS FLUENT software.

Keywords*— *Computational Fluid Dynamics, Finite Volume Method, Implicit Method, Refrigerant, Two Phase Flow.

I. INTRODUCTION

The Capillary tubes have been investigated in detail for many decades. The capillary tube is common expansion device used in small sized refrigeration and the air-conditioning systems. The capillary tube is constant area expansion device used in the vapour-compression refrigeration system located between condenser and the evaporator and whose function is to reduce high pressure in the condenser to low pressure in evaporator. The capillary tube is an expansion device which is widely used in the refrigeration equipment, especially in small units such as a household refrigerators, freezers & small air conditioners. Its simplicity is a most important reason to continue using it instead of other expansion devices. The Capillaries substitute for more expensive and a complex thermostatic valves. For instance, The capillary tubes are used in the some complex cooling Systems for a particle detectors installed. Nevertheless, one can find other reasons for their Use in the highly specialized cooling circuits [2-5]. Geometrical shape the capillary tubes can be classified as under.

1.1 Adiabatic Capillary Tube

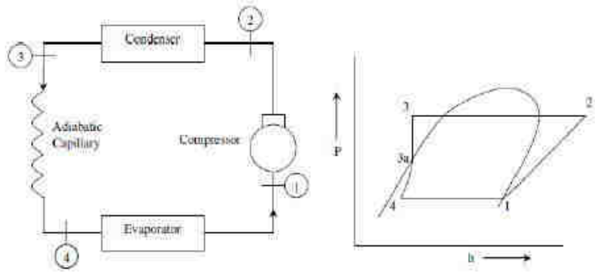

Fig. 1: Adiabatic capillary tube (a) block diagram (b) P-h diagram

Figure 1.1a shows the vapour compression system employing the adiabatic capillary tube as an expansion device. As the flow through the capillary tube is adiabatic, the enthalpy of in adiabatic capillary tube, the refrigerant expands from high pressure side to low pressure side with no heat exchange with the surroundings. The refrigerant often enters the capillary in a sub cooled liquid state [1]. As the pressure of refrigerant falls below the saturation pressure a fraction of liquid refrigerant flashes into vapor.

1.2 Diabatic Straight Capillary Tube

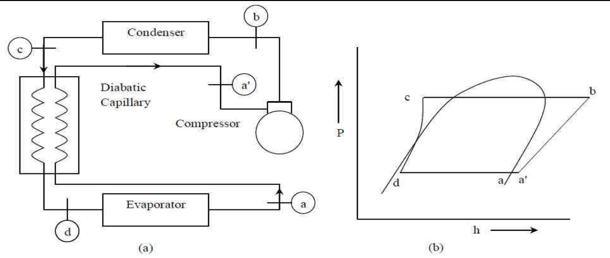

Fig. 2: Diabatic capillary tube (a) block diagram (b) P-h diagram

Diabatic capillary tube act as heat-exchanger. In a diabatic flow arrangement, the capillary tube is bonded with the cold compressor suction line in a counter flow arrangement as shown in Fig. 2a. In this tube refrigerant expands from condenser pressure to evaporator pressure. As refrigerant expands through capillary tube from high to low pressure (c to d) it transfer its heat to refrigerant passing through the suction line of compressor (a to a') as shown in Fig. 2b. So here liquid region length increases as compare to adiabatic capillary tube. As result of this refrigerating capacity increases, also cause improvement in efficiency of cycle [3-4].

The flow inside the capillary tube of a refrigeration system can be divided into a sub cooled liquid region from the entrance to the point in which the fluid reaches saturated conditions, and a two phase flow region after that point until the end of the capillary tube In Figure 2, the variation of refrigerant temperature and pressure has been plotted against the capillary tube length. The pressure falls linearly in the liquid region of the capillary tube while the temperature remains constant as the flow through capillary tube is considered adiabatic[2-5].

1.3 Computational Fluid Dynamics

During last few decades, significant progress has been made on the development of various types of CFD techniques [7-8] for investigating multiphase or interfacial flows. Among different multiphase models, few prominent models such as volume of fluid, level set, Lattice–Boltzmann, and smoothed particle hydrodynamics have been mostly reported in the literature. At initial stage, these multiphase models were widely used to investigate the isothermal two-phase flows such as motion and deformation of droplets and thin film flows and later on, they were extended to study the phase change problems of boiling and condensation process. In the recent years, several studies have reported the use of volume of fluid method (VOF) model using commercial software for the phase change problems [6]. Liu et al.[4] have successfully implemented the source term in VOF model to analyze the condensation between parallel plates. The phase transformation of flowing fluid usually takes place in a highly unsteady state, where tracking the interface of liquid and vapor phase becomes very complicated [1]. To track the complicated interface, precise solutions of governing equations and accurate imposition of boundary conditions at the unsteady interface are required in numerical simulation of phase change problems. Due to all these complexities, direct CFD simulation of phase change phenomena in refrigeration and air-conditioning problems have not gained much momentum [11-12].

II. MATHEMATICAL FORMULATION AND NUMERICAL METHOD

A typical geometry and flow domain of a capillary tube has been shown in Fig. 1. The diameter of the straight tube has been considered as 0.66mm and its length is 1.2m. The tube is made of aluminum and the average value of internal roughness of the tube wall has been considered as 3.0303×10^{-3} m. Simulation has been carried out for R134a flow. The input operating parameters have been shown in Table 1.

Present computations have been made using these assumptions: (1) 3D adiabatic flows (i.e., no heat transfer across the tube wall) have been considered; (2) refrigerant R134a is Newtonian fluid, viscous and the flows exhibit incompressible nature in liquid region; (3) refrigerant properties i.e., density, viscosity, and surface tension have been considered to be temperature dependent; (4) in two-phase flow region, the velocities of liquid and vapor phases have been assumed to be same. However, this assumption is more appropriate in the interface region. (5) based on the inlet mass flow rate and corresponding velocity of the flow, the refrigerant flow has been considered as turbulent.

TABLE.1 INPUT PARAMETERS FOR R134a

Parameters	**Values**
Inlet pressure (P_{in})	9.74 bar
Outlet pressure (P_{out})	2.95 bar
Inlet temperature (T_{in})	304.4 K
Mass flow rate (m)	2.32 Kg/h
Inlet subcooling (ΔT_{sub})	15.65 K
Roughness (e)	3.0303×10^{-3} m

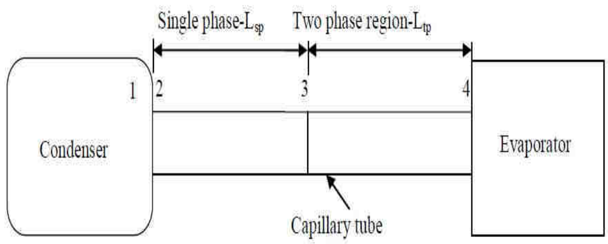

Fig. 3: Adiabatic capillary tube

2.1 Boundary Conditions.

At the inlet to the capillary tube a pressure inlet condition has been used where the subcooled pressure condition of the refrigerant has been used as mentioned in Table 1. The corresponding subcooled temperature has also been prescribed at the inlet to the capillary tube. The value of volume fraction at the inlet of the capillary tube has been set as zero representing the liquid refrigerant only. A pressure outlet boundary condition has been applied at the outlet of the capillary tube as prescribed in Table 1. No-slip and adiabatic conditions have been applied at the wall of the tube and the average roughness of the wall has been considered as 3.0303×10-3 m. Wall roughness is entered through the user interface of the ANSYS FLUENT software. A moderate turbulence level (intensity 5%) has been assumed at the inlet of the capillary tube.

2.2 Numerical Methodology.

Computations have been performed using finite volume based CFD code ANSYS FLUENT 14.5. The steady segregated solver has been employed to solve the governing equations in a sequential manner. The momentum and energy equations have been discretized with 2nd order upwind scheme and higher order QUICK scheme has been used to discretize the volume fraction equation. The coupling of pressure with velocity has been made using the PISO (pressure implicit with splitting of operators) algorithm. The VOF along with the CSF techniques have been used to calculate the void fraction of the vapor phase and also to track the fluid interface between the two phases. To avoid the diffusion at the interface, a geometry reconstruction scheme has been used in the simulation. The unsteady term has been treated with first-order implicit time stepping. For numerical stability very small time steps (10^{-6} s) have been used in the simulations. The solution has been assumed to be converged and therefore iterations have been terminated when the sum of residual mass was less than 10^{-4} and the variation of other variables in successive iteration was less than 10^{-4}. A system of non-uniform grid has been used, where grids have been clustered near the walls. Computations have been made using 455,000 numbers of control volumes after a grid independent study. Hexahedral elements have been used and grids have been clustered near the wall. A layout of grids across the half tube cross section has been shown in Fig. 2. The simulations were made on a P4machine with 4 GB random access memory) and it takes 240–250 central processor unit hour for full simulation.

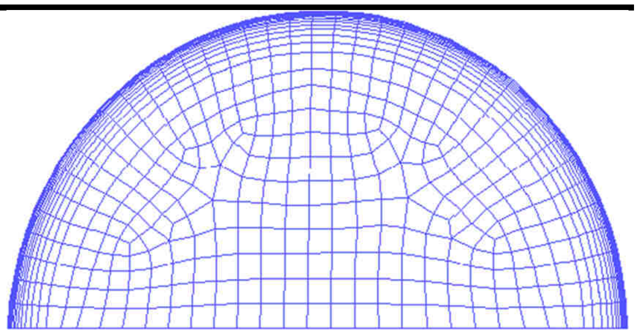

Fig. 4: Grid of hexahedral elements

Another user-defined function has been incorporated in the code to express the saturation temperature as a function of pressure and other properties of liquid and vapor phase. Refrigerant property database REFPROP 9.0 has been used to derive the functional dependence of these properties on temperature.

2.3 Grid Independence Test.

The grid independence study was done with different number of mesh element i.e. 1,58170 , 2,78644 and 6,78351 elements in grid 1, grid 2, and grid 3 respectively.

TABLE 2 GRID INDEPENDENCE STUDY WITH DIFFERENT NUMBER OF MESH ELEMENT

S.no.	Number of element	Outlet Pressure of Capillary Tube (bar)
1	1,58170	2.96367
2	2,78644	2.96272
3	6,78351	2.96086

2.4 Validation of the Code.

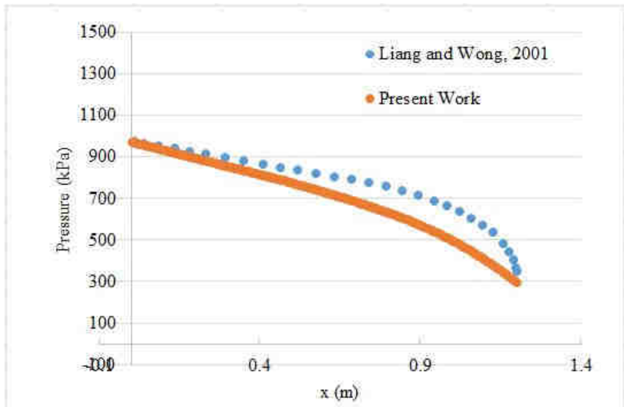

Fig. 5: Validation of present model with Li et al. [37] experimental data

The present code has been validated with the experimental data of Li et al. for the flow of refrigerant R134a in an adiabatic capillary tube. The present code methodologies have been applied to investigate the problem with same inflow and operating conditions. The comparison of pressure predictions by present simulation with the experimental results has been shown in Fig. 5. It can be observed that the results of present code are in reasonably good agreement with the experimental data. The following observations can be made from Fig. 5.

III. RESULTS AND DISCUSSION

It has already been mentioned that adiabatic flow analysis and the variations of refrigerant flow properties across the cross section of the capillary tube have not been reported in the literature. Both these issues have been addressed in the present investigation. The properties of refrigerant 134a at inlet and outlet of capillary tube are describe in table 3.

TABLE 3 RESULTING PARAMETERS

S. No.	Properties	Inlet	Outlet
1	Pressure(bar)	9.74bar	2.95 bar
2	Temperature(K)	304.4 K	288.75 K
3	Velocity(m/s)	3.046 m/s	20.654 m/s

3.1 Pressure variation in the adiabatic capillary tube.

The main function of the capillary tube is to decrease the pressure of the refrigerant so the pressure of refrigerant 134a has been decreased from 9.74 bar to 2.95 bar. Total pressure drop is 6.79 bar is shown in fig. 5&6 which is fair to be in agreement.

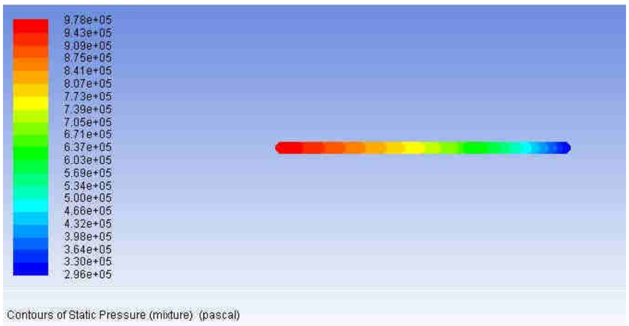

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Fig. 6: Pressure contour of adiabatic capillary tube

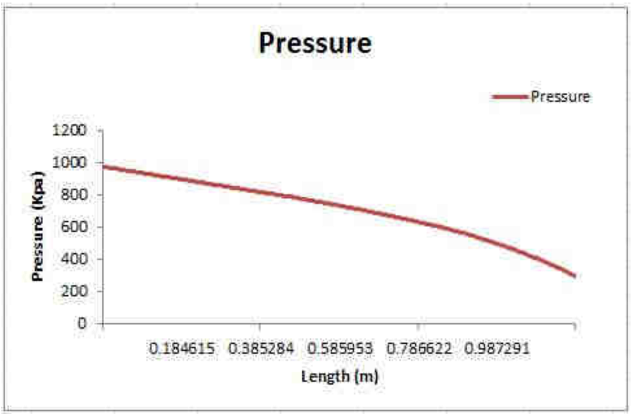

Fig. 7: Pressure Drop in adiabatic capillary tube

3.2 Temperature variation in the adiabatic capillary tube.

The another main function of the capillary tube is to decrease the temperature of the refrigerant so the temperature of refrigerant 134a has been decreased from 304.4 K to 288.75 K. Total temperature drop is 15.65 K is shown in fig. 7&8 which is fair to be in agreement**.**

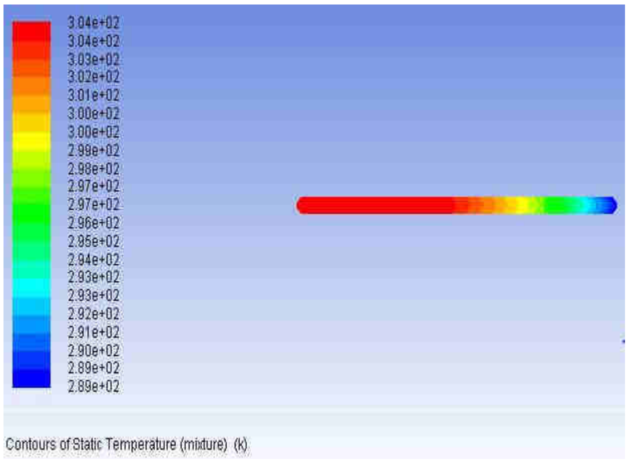

Fig. 8: Temperature contour of adiabatic capillary tube.

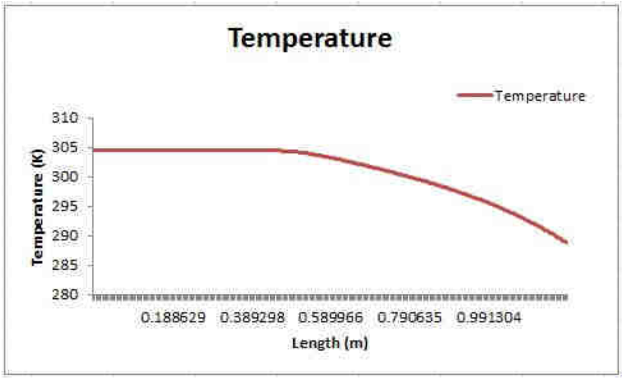

Fig. 9: Temperature drop in adiabatic capillary tube.

3.3 Phase change in the adiabatic capillary tube.

It is investigate from the study that length 0m to 0.481605m single phase flow of refrigerant 134a in the given adiabatic capillary tube and length from 0.481605m to 1.2m two phase flow in adiabatic capillary tube. So that 0.481605m is the flashing point of the given adiabatic capillary tube is showing in fig. 9&10.

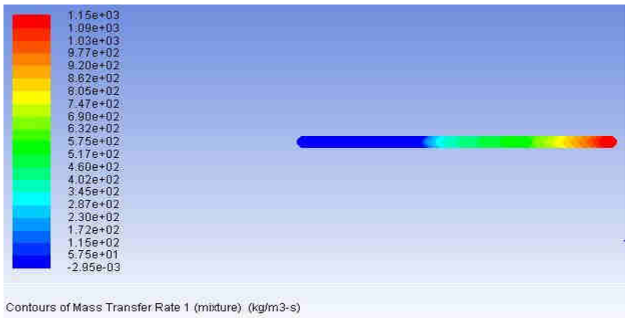

Fig. 10: Phase change contour

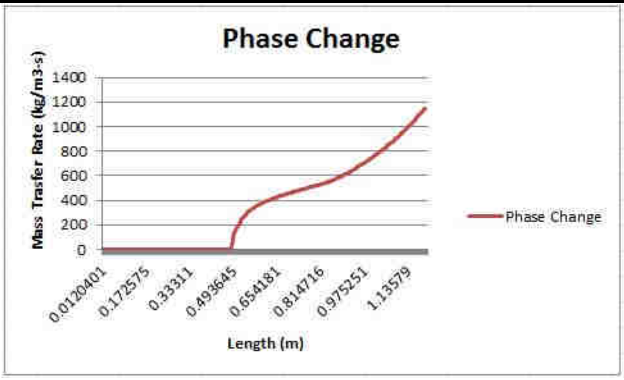

Fig. 11: Flashing point of adiabatic capillary tube.

3.4 Velocity variation in the adiabatic capillary tube.

The velocity profiles of refrigerant R134a of the tube at different locations of the tube have been shown in Fig. 4. The velocity at the outlet section of the tube is quite high due to inception of vaporization after flashing occurs in the capillary tube. At inlet velocity is 3.046 m/s and outlet 20.654 m/s is shown in fig. 11&12.

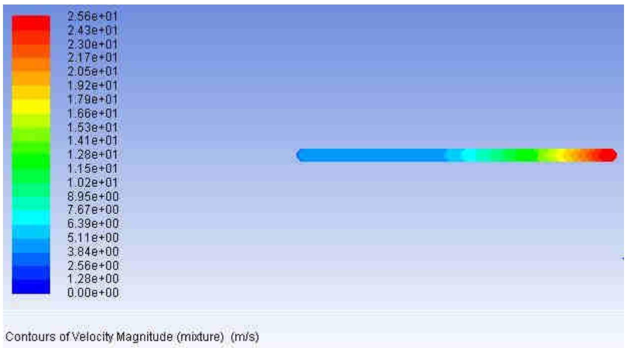

Fig. 12: Velocity contour of adiabatic capillary tube.

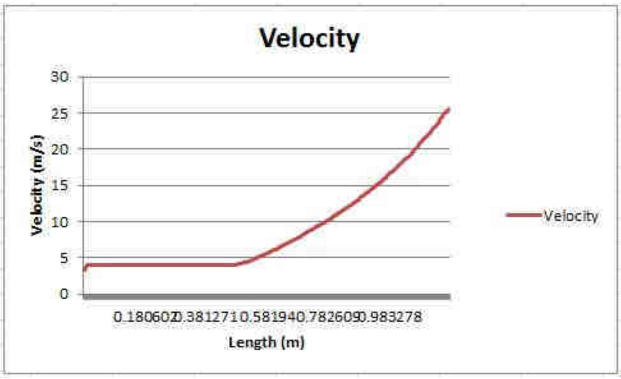

Fig. 13: Velocity profile of adiabatic capillary tube.

IV. CONCLUSION

A CFD technique has been developed to simulate the detailed flow characteristics of refrigerant flow through adiabatic capillary tube. The steady state flow behavior as well as flow variations across the tube for different locations have been presented for refrigerant R134a. The refrigerant flow properties change drastically as the phase transformation from liquid to liquid–vapor mixture takes place. The change in velocity profile, pressure and temperature has been observed. The exact location of vapor formation inside the tube has been indicated. The vaporization initiate at the wall contradicting the available observations on aluminum capillary tube.

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