

CFD Parametric Investigation for Two Phase Flow of Refrigerant R134a in Helical Coiled Adiabatic Capillary Tubes

Mohd Salman Saifi¹, Dr. O. P. Jakhar²M.Tech Scholar, Dept. of Mechanical Engineering, Govt. Engineering College Bikaner, Rajasthan, India ¹Associate Professor, Dept. of Mechanical Engineering, Govt. Engineering College Bikaner, Rajasthan, India ²

ABSTRACT: Capillary tubes are widely used as refrigerant flow control device in 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, Volume of fluid Method, 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.

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

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

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 COMPUTATIONAL METHOD

A typical geometry and flow domain of a capillary tube has been shown in Fig.1. The diameter of the straight & helical 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.

TABLE 1
PARAMETERS OF HELICAL CAPILLARY TUBES

S.No.	No. of Turns	Length of the Tube	Diameter of coil	Pitch	Length of the Coil
1	5	1.2	0.07618411	0.01	0.05
2	10	1.2	0.037987013	0.01	0.1
3	20	1.2	0.018888464	0.01	0.2

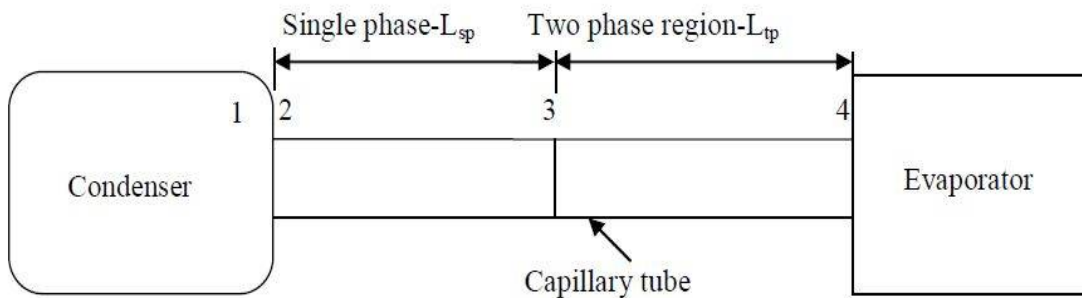


Fig. 1 Computational domain of straight adiabatic capillary tube

A pressure outlet boundary condition has been applied at the outlet of the capillary tube as prescribed in Table 2. Noslip 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. 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. The flow conditions are given in Table 2 as follows.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

TABLE 2
EXPERIMENTAL DATA PRESENTED BY Liang et al. (2001).

Parameters	Data
P_{in} (bar)	9.67
T_{in} ($^{\circ}$ C)	31.4
D (mm)	0.66
ϵ/D	3.0303×10^{-3}
m^0 (kg/s)	1.131×10^{-3}

III. RESULTS AND DISCUSSION

Computational fluid dynamics modeling is developed for three different helically coiled adiabatic capillary tubes i.e. 5 circulations, 10 circulations, and 20 circulations helical capillary tubes. They have different coil diameters and same pitch. The parametric investigations of refrigerant R134a in different helical coiled capillary tubes have been carried out.

3.1 Grid Independence Study

To trust a result, it must be grid-independent. In other words, if the mesh is refined further, the solution does not change. The grid independence study was done with different number of mesh element i.e. 158170, 278644 and 678351 elements in grid 1, grid 2, and grid 3 respectively.

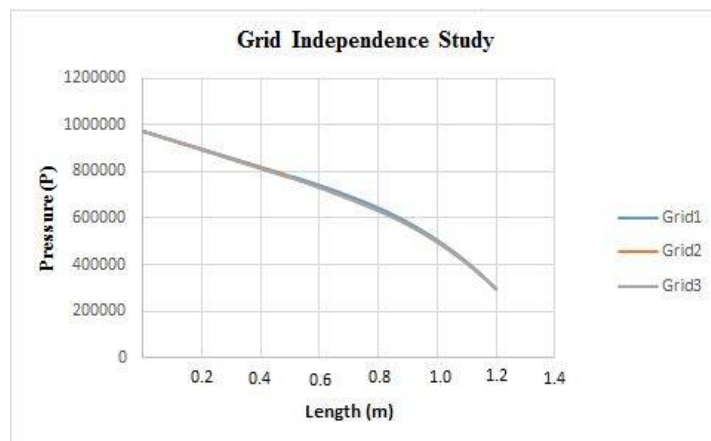


Fig. 3 Grid Independence Study with three Different Grids

3.2 Validation of CFD Model to Experimental Data

The CFD based adiabatic straight capillary tube modeling is validated by taking experimental data from the research paper of S.M. Liang and T.N. Wong. The good agreement between those results indicates that the present CFD model is suitable for the prediction of refrigerant R134a two-phase flows in capillary tubes.

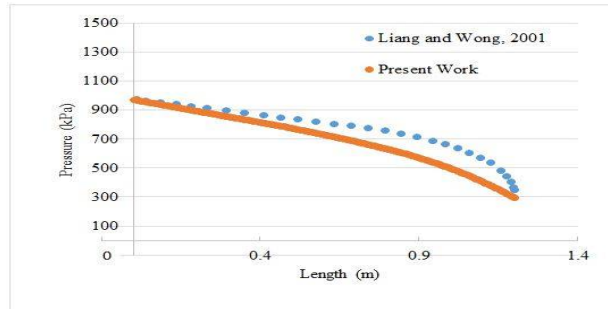


Fig. 4 Comparison between Present CFD model and experimental results of Liang et al (2001)

3.3 Pressure Drop Results along the Lengths of Capillary tubes

The pressure variation along the helical coiled capillary tubes of 5 circulations 10 circulations and 20 circulations considering homogeneous and separated flow model, respectively. The results reveal that both the two phase flow models yield reasonably good results. At inlet of helical coiled capillary tubes pressure are 974232 Pascal and exit of capillary tubes pressure is 295918, 295835 and 295595 Pascal for 5 circulations, 10 circulations and 20 circulations respectively. The average pressure drop in helical coiled capillary tube is 679193 Pascal. This is shown in fig. 5.

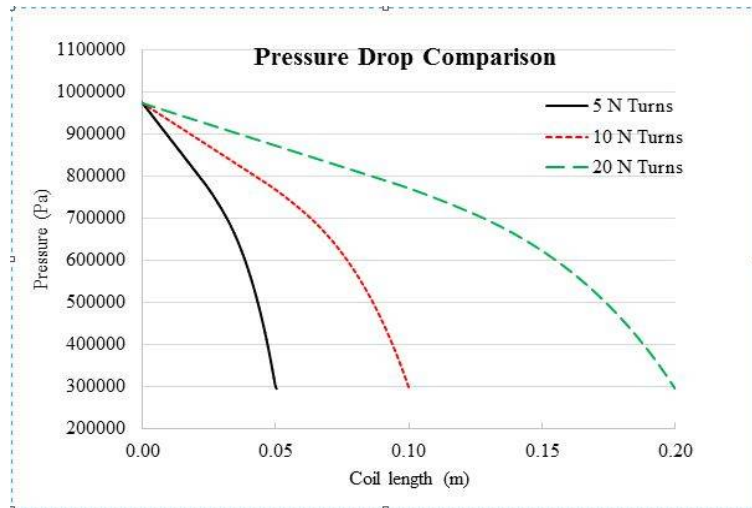


Fig. 5 Pressure drop comparison graph

3.4 Temperature Drop Results along the Lengths of Capillary tubes

At inlet of helical coiled capillary tubes temperature are 304.4 K and exit of capillary tubes temperatures is 289.70 K, 289.52 K and 289.54 K for 5 circulations, 10 circulations and 20 circulations respectively. The average temperature drop in helical coiled capillary tube is 14.88 K. This is quiet good as results of temperature drop in experimental data of Li et al. (2001). This is shown in fig. 6.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

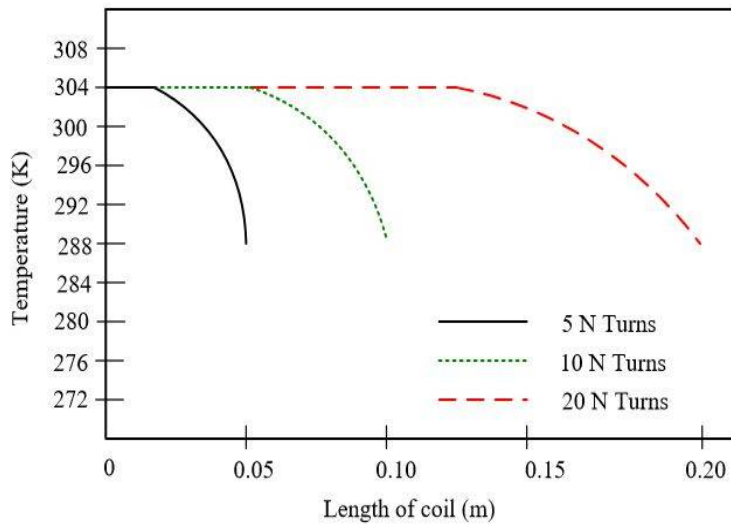


Fig. 6 Temperature drop comparison graph

3.5 Velocity Distribution Results along the Lengths of Capillary tubes

At inlet of helical coiled capillary tubes velocities are 3.0689, 3.0060 and 2.8281 m/s and exit of capillary tubes velocities is 19.7900, 19.3950 and 18.9047 m/s for 5 circulations, 10 circulations and 20 circulations respectively. The average velocity increase in helical coiled capillary tube is 16.7211 m/s. This is quiet good as results of temperature drop in experimental data of Liang et al. (2001). It can be observed that in two phase region, R134a vapour velocity increases rapidly and hence liquid and vapour velocity difference is significantly large for R134a. Homogeneous two phase velocity of refrigerant is much smaller than that of the vapour velocity for R134a. This is shown in fig. 7.

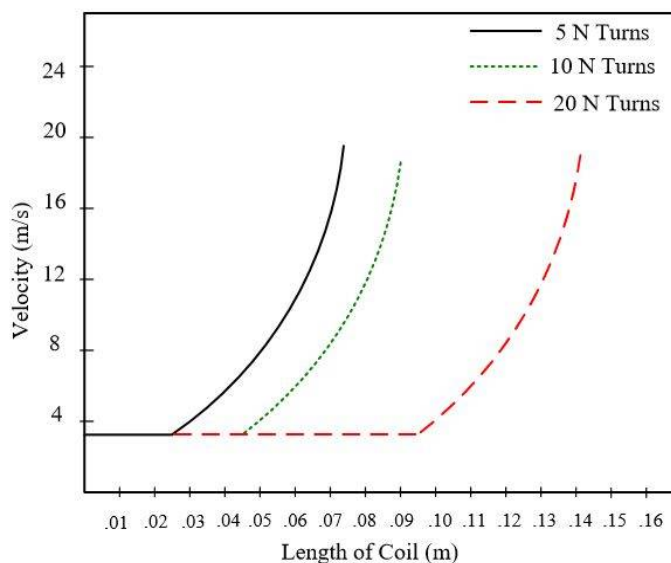


Fig. 7 Velocity distribution comparison graph

3.6 Phase Change Comparison of Helical Coiled Capillary tubes

The phase change or flashing points are 0.023092 m, 0.046062 m and 0.093931 m for 5 circulations, 10 circulations and 20 circulations helical coiled capillary tubes respectively. This is shown in fig. 8.

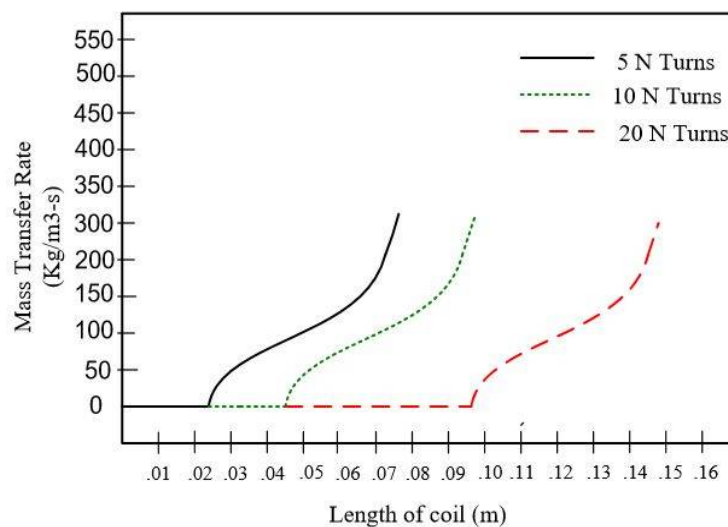


Fig. 8 Flashing Point comparison graph

IV. CONCLUSION

The flow parametric characteristics of refrigerant R-134a in experimental data of Liang et al. (2001) and present work of CFD model are close to each other at same condenser pressure and temperature. The pressure drop, temperature distribution, velocity distribution, flashing point (phase change) contours and graph of different helical coiled capillary tubes have been found for refrigerant 134a at same condenser pressure and temperature. Parametric comparison of straight, 5 circulations, 10 circulations and 20 circulations helical coiled capillary have been carried out. It is investigated that we can choose any above straight or helical capillary tube for same performance according to the space of the system.

REFERENCES

- [1] Liang, S. M., Wong, T. N., "Numerical modeling of two phase refrigerant flow through adiabatic capillary tubes", Applied Thermal Engineering, Vol.-21, pp.1035-1048, 2001.
- [2] Prajapati, Y. K., MARCH 2015, "Computational Fluid Dynamics Modeling of Two-Phase Flow in an Adiabatic Capillary Tube" Journal of Thermal Science and Engineering Applications, Vol. 7, pp 0110061-67.
- [3] Marcy, G. P., 1949, "Pressure Drop With Change of Phase in a Capillary Tube," Refrig. Eng., 57(1), pp. 53-57.
- [4] Bansal, P. K. and Rupasinghe, A. S., 1998, "A Homogeneous Model for Adiabatic Capillary Tubes," Appl. Therm. Eng., 18(3-4), pp. 207-219.
- [5] Khan, M. K., Kumar, R. and Sahoo, P. K., 2009, "Flow Characteristics of Refrigerants Flowing Through Capillary Tube," Appl. Therm. Eng., 29(8-9), pp. 1426-1439.
- [6] Hirt, C. W. and Nichols, B., 1981, "Volume of Fluid (VOF) Method for Dynamics of Free Boundaries," J. Comput. Phys., 39(1), pp. 201-225.
- [7] Tryggvason, G., Bunner, B., Esmaeeli, A., Juric, D., Al-Rawahi, N., Tauber, W., Han, J., Nas, S., and Jan, Y. J., 2001, "A Front-Tracking Method for the Computations of Multiphase Flow," J. Comput. Phys., 169(2), pp. 708-759.
- [8] Chen, W. X., Chong, D. T., Yan, J. J., Dong, S. C., and Liu, J. P., 2014, "Numerical Investigation of Two-Phase Flow in Natural Gas Ejector," Heat Transfer Eng., 35(6-8), pp. 738-745.
- [9] Liu, Z., Sunden, B., and Yuan, J., 2012, "VOF Modeling and Analysis of Filmwise Condensation Between Vertical Parallel Plates," Heat Transfer Res., 42(1), pp. 47-48.
- [10] Welch, S. W. J., and Wilson, J., 2000, "A Volume of Fluid Based Method for Fluid Flows With Phase Change," J. Comput. Phys., 160(2), pp. 662-682.
- [11] Lee, W. H., 1980, "A Pressure Iteration Scheme for Two Phase Flow Modeling," Multiphase Transport Fundamentals, Reactor Safety, Applications, Vol. 1, T. N. Veziroglu, ed., Hemisphere Publishing, Washington, DC.
- [12] Yang, Z., Peng, X. F., and Ye, P., 2008, "Numerical and Experimental Investigation of Two Phase Flow During Boiling in a Coiled Tube," Int. J. Heat Mass Transfer, 51(5-6), pp. 1003-1016