"CFD analysis of Fluid Flow in a capillary tube using R-22 and R-12 Refrigerant"

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Abstract: **In the past several years a number of new alternative refrigerant have been discovered to replace the existing refrigerants used in refrigerating equipment for improvement of performance. In order to study these refrigerants extensively an in-depth knowledge of their single-phase heat transfer characteristics, thermodynamic properties as well as simulation analysis is needed. This paper provides an analysis which has been conducted on single phase flow for alternative refrigerants, addresses a number of relations for determining the thermo dynamic properties of these alternative refrigerants with computational fluid analysis using software likewise ANSYS CFX ; and discusses their sensitivity to uncertainty. Finally, an overview of some of the current research that has been conducted on various enhancements and refrigerants are provided as well. Present paper gives a brief study about Validation and comparison of the performance of refrigerant coil using R22 and R12 was done using experimental and CFD through ANSYS CFX. For this geometry is modelled in 3D in Autodesk inventor.**

Keywords- **Capillary tube analysis, Refrigerants R22 and R12, CFD analysis through ANSYS CFX, Geometry modelling Autodesk inventor**

INTRODUCTION

The cooling effects of a vapour-compression refrigeration (VCRS) cycle are accomplished by evaporating and condensing the refrigerant at low and high pressure states, respectively. An ideal system operates entirely in the two-phase region, but actually , this is not practical for the actual system. The dry compression is carried out entirely in the single-phase vapour region, to avoid erosion damage within the compressor. In addition, the outlet phase of the condenser is slightly sub-cooled, residing in the liquid phase. The single phase heat transfer for the superheated vapor and sub-cooled liquid regions of the evaporators and condensers are important aspects of an efficient vapour-compression refrigeration cycle. Accurate thermodynamic properties of refrigerants are essential for determining the energy efficiency and capacity of a vapour compression cycle. In addition, their transport properties are needed for the design of the equipment and its economic feasibility. With the advent of alternative refrigerants, accurate correlations and a knowledge of their sensitivity to uncertain properties, mass flow rates, and other parameters are needed for a thorough analysis of a system's design and performance. Furthermore, the determination of the heat transfer in enhanced tubes becomes more difficult when the thermodynamic properties of alternative refrigerants are uncertain.

Capillary Tube

A capillary tube is a long, narrow tube of constant diameter. The "capillary" is a misnomer since surface tension is not important in refrigeration application of capillary tubes. Typical tube diameters of refrigerant capillary tube range from 0.5 mm to 3 mm and the length ranges from 1.0 m to 6 m.

The pressure reduction in a capillary tube occurs due to the following two factors:

1. The refrigerant has to overcome the frictional resistance offered by tube walls. This leads to some pressure drop.

2. The liquid refrigerant flashes (evaporates) into mixture of liquid and vapour as its pressure reduces. The density of vapour is less than that of the liquid. Hence, the average density of refrigerant decreases as it flows in the tube. The mass flow rate and tube diameter (hence area) being constant, the velocity of refrigerant increases since $m = \rho VA$. The increase in velocity or acceleration of the refrigerant also requires pressure drop.

Several combinations of length and bore are available for the same mass flow rate and pressure drop. However, once a capillary tube of some diameter and length has been installed in a refrigeration system, the mass flow rate through it will vary in such a manner that the total pressure drop through it matches with the pressure difference between condenser and the evaporator. Its mass flow rate is totally dependent upon the pressure difference across it; it cannot adjust itself to variation of load effectively. On the basis of Geometrical shape the capillary tubes can be classified as under: [9]

1. Straight capillary tube

2. Coiled capillary tube

- ***Straight Capillary Tube:*** 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. As the liquid refrigerant flows through the capillary, the pressure drops linearly due to friction while the temperature remains constant. As the pressure of refrigerant falls below the saturation pressure a fraction of liquid refrigerant flashes into vapor. The fluid velocity increases because of the fall in density of the refrigerant due to vaporization. Thus, the entire capillary tube length seems to be divided into two distinct regions. The region near the entry is occupied by the liquid phase and the other as the two-phase liquid vapour region.[2]

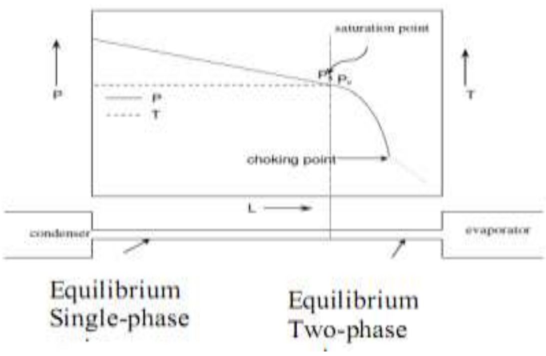

Figure 1 Temperature and pressure variation along the adiabatic capillary tube

1.2 Coiled Capillary Tubes

The helical capillary tubes in a domestic refrigerator or in a window air conditioner are no more a new thing. The difference between the consecutive turns of the coiled capillary tube is termed as coil pitch, denoted by 'p'. In helical capillary tubes there are two coiling parameters one is coil pitch and another is coil diameter. Fig 2 shows the helical and spiral tubes depicting the geometric parameters, viz. coil pitch, coil diameter and tube diameter. [3]

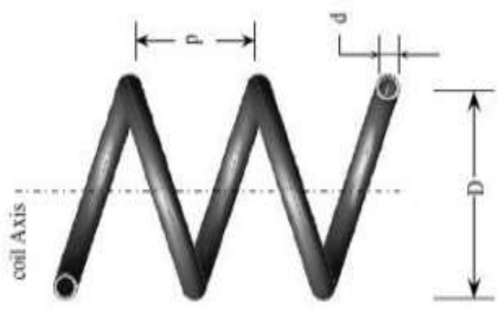

Fig 2 helically coiled capillary tubes

LITERATURE REVIEW

Shivkumar et.al.(2013) developed mathematical model to determine the flow characteristics of refrigerant inside a straight capillary tube for adiabatic flow conditions.. In that study R-12 has been used as a working fluid inside the straight capillary tube of diameter 1.17 mm and 1.41 mm and used the same model to study the flow characteristics of refrigerant in ANSYS CFX software. Finally the results of mathematical model are valuated with ANSYS CFX and the results are found to be in fair agreement.

Y Raja Kumar et.al.(2013) In that investigation, an attempt is made to analyze the flow Analysis of the refrigerant inside a straight capillary tube and coiled capillary tube for adiabatic flow conditions. The proposed model can predict flow characteristics in adiabatic capillary tubes for a given mass flow rate. In the present studyR-22 has been used as a working fluid inside the straight capillary tube and coiled capillary tube of diameter 1.27 mm and used the same model to study the flow characteristics of refrigerant in ANSYS CFXsoftware. It was observed from the results dryness fraction by using the helical capillary tube is better than straight capillary tube. The best suitable helical coiled design is suggested.

METHODOLOGY

Experiment has been performed on the straight capillary. The two case of the working fluid was considered. The working fluid taken in consideration was R12 and R22. The experiment set up is working on R22. This experimental result was validated using CFD.

The experimental result is given below:-
The capillary tube inlet temperature is Tin = 52 °C
And the capillary tube outlet temperature is $Tout$ = 8 °C
Corresponding pressures are Pin = 20.328 bar and
$Pout$ = 6.406 bar

As per the experimental data the actual dryness fraction of the refrigerant was found to be 0.72.

From the p-h diagram

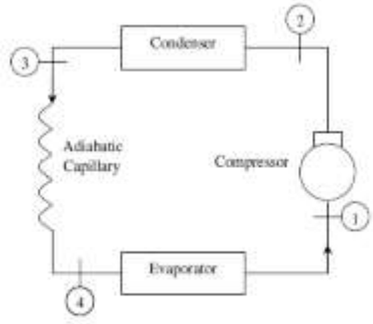

Fig 3 Schematic diagram VCRS system

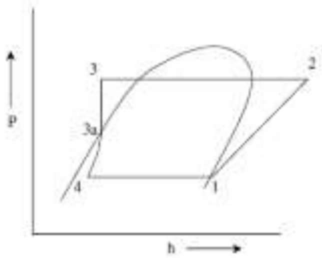

Fig4 P-h diagram VCRS system

$$h_3 = h_{4f} + xh_{4fg}$$

h_3= Enthalpy at the inlet of capillary tube

h_4= Enthalpy at the outlet of capillary tube

x = dryness fraction

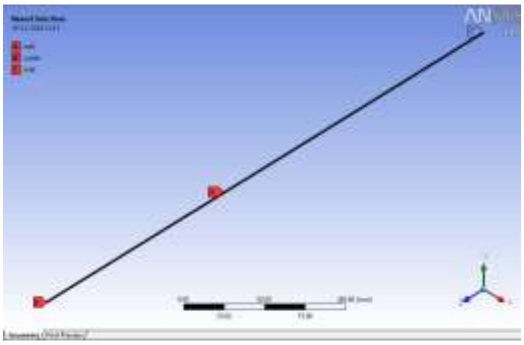

Fig 5 Straight capillary with boundary conditions

Dimension of straight capillary

Diameter of tube = 1.27mm

Length = 762 mm

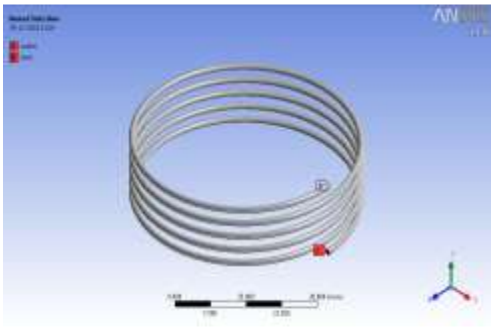

Fig 6 Helical coil capillary with boundary conditions

Dimension of helical coil capillary

Diameter of tube = 1.27 mm

Diameter of coil = 48.5 mm

Length = 762 mm

Pitch of coil = 3 mm

No of turns = 5

Computational fluid dynamics analysis

Computational Fluid Dynamics, abbreviated as CFD, uses different numerical methods and a number of computerized algorithms in order to solve and analyze problems that involve the flow of fluids. The calculations required simulating the interaction of fluids with surfaces defined by boundary conditions, and initial conditions are done by the ANSYS CFX v13.0. The Navier-Stokes equations form the basis of all CFD problems. The equations of fluid mechanics which have been known for over a century are solvable only for a limited no. of flows. The known solutions are extremely useful in understanding fluid flow but rarely used directly in engineering analysis or design. CFD makes it possible to evaluate velocity, pressure, temperature, and species concentration of fluid flow throughout a solution domain, allowing the design to be optimized prior to the prototype phase. Availability of fast and digital computer makes techniques popular among engineering community. Solutions of the equations of fluid mechanics on computer has become so important that it now occupies the attention of a perhaps a third of all researchers in fluid mechanics and the proportion is still is increasing. This field is known as computational fluid dynamics. At the core of the CFD modeling is a three-dimensional flow solver that is powerful, efficient, and easily extended to custom engineering applications.

. Two equation models are used for the simulations, and different models are discussed below.

$$\frac{\partial \rho}{\partial t}+\frac{\partial \rho U_1}{\partial x_1}+\frac{\partial \rho U_2}{\partial x_2}+\frac{\partial \rho U_3}{\partial x_3}=0$$

Momentum Conservation Equations

Conservation of momentum in an inertial (non-accelerating) reference frame is described

$$\frac{\partial}{\partial t}(\rho\vec{v})+\nabla.(\rho\vec{v}\vec{v})=-\nabla p+\nabla.(\bar{\bar{\tau}})+\rho\vec{g}+\vec{F}$$

TWO PHASE MODELING EQUATIONS

A large number of flows encountered in nature and technology are a mixture of phases.

Physical phases of matter are gas, liquid, and solid, but the concept of phase in a multiphase flow system is applied in a broader sense. In multiphase flow, a phase can be defined as an identifiable class of material that has a particular inertial response to and interaction with the flow and the potential field in which it is immersed. Currently there are two approaches for the numerical calculation of multiphase flows: the Euler-Lagrange approach and the Euler-Euler approach.

RESULT

The results obtained below was from the Experimental model validated with the commercial ANSYS CFX module and the effect of flow properties on the refrigerant inside the straight tube adiabatic capillary tube has been observed.

EXPERIMENTAL RESULTS

An experiment was conducted in VCRS test rig using a straight capillary tube using R22 as working refrigerant. The inlet pressure is 20.23 bar and outlet pressure is 6.19 bar. At the inlet mass fraction of liquid is 1. As we know that after the condenser the refrigerant is undergoes in liquid phase. So there will be no vapour present in inlet. At the outlet there will be vapour phase present in the capillary.

Validation and comparison of the experimental and CFD data obtained below tabulated

Table 1 gives the approximation value of the different parameters

Straight tube			
R22			
Properties	Experimental	Computational	Theoretical
Pressure (inlet)	20.23 bar	17.06 bar	20.23 bar
Pressure (outlet)	6.19 bar	6 bar	6.19 bar
Mass fraction liquid (inlet)	1	1	1
Mass fraction liquid (Outlet)	0.72	0.723	0.96
Mass fraction vapour (inlet)	0	0	0
Mass fraction vapour (inlet)	0.28	0.277	0.04

The above table give the approximation value using CFX. The different parameter are compared and validate.

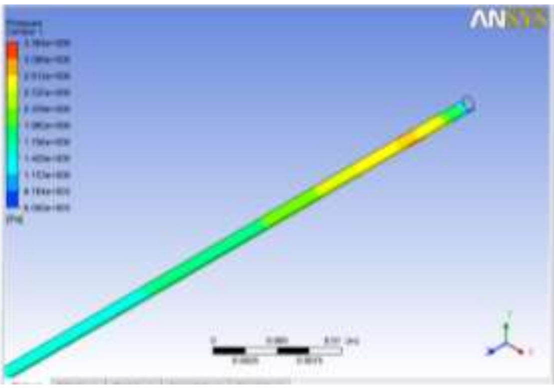

Fig 7 Pressure contour in front inlet section

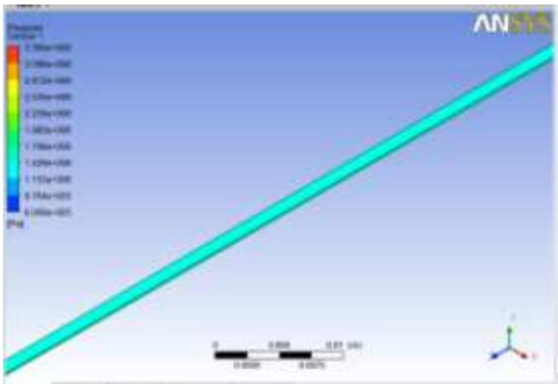

Fig 8 Pressure contour in middle section

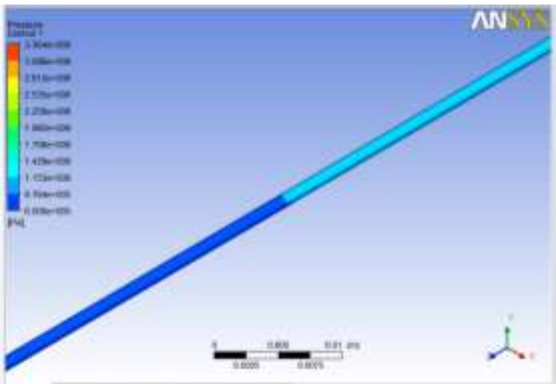

Fig 9 Pressure contour in middle section

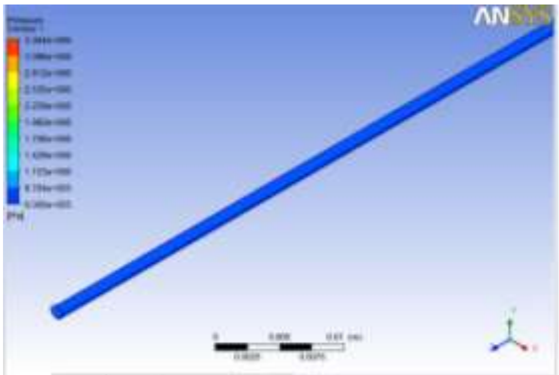

Fig 10 Pressure contour in outlet section

Fig 7-10 shows the variation of pressure in the straight capillary tube using R22. As it is clear from the figures that when the refrigerant enters into the capillary the pressure is 17.06 bar and gradually it decreases up to 6 bar. Maximum pressure of the domain calculated by CFX is 33 bar. This pressure is below critical pressure of R22.

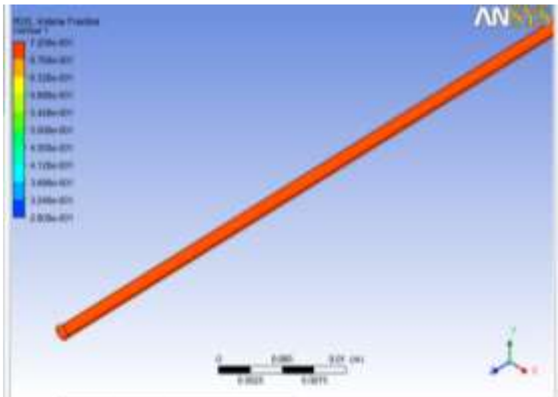

Fig 10 R22 liquid Mass contour

Figure 10 shows the liquid mass fraction contours. The main function of the capillary tube is to decrease the pressure from condenser pressure to evaporator pressure. During this process enthalpy remain constant due to throttling process. From the ph chart it has been observed that enthalpy remain constant. But on the other hand there will be some traces of vapour also seen. In the figure the maximum mass fraction is 0.72 for liquid.

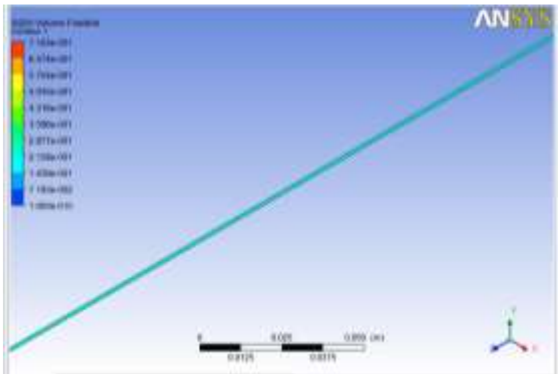

Fig 11 R- 22 vapour contour

Figure 11 shows the vapour mass fraction contours. As it was discussed earlier that the main role of capillary is to decrease the pressure up to evaporator pressure. From experiment it was seen that mass fraction of vapour is increasing in the some section of straight capillary. At the inlet the mass fraction is 0. But when the refrigerant moves toward outlet the composition changes from 0 to 0.277.

Helical coil

For the analysis of flow properties inside the coiled capillary tube R-22 and R-12 is used as a working fluid. In this project the straight capillary tube length as 762 mm and it is replaced, with this same length of helical coiled tube by varying with pitch and number of turns.

Below the tabulated values shows the computational analysis:

Helical Coil		
	R-12	R-22
Properties	Computational	Computational
Pressure(Inlet)	19.1 bar	19.41 bar
Pressure (Outlet)	5.97 bar	5.97 bar
Mass fraction liquid(inlet)	1	1
Mass fraction liquid(Outlet)	0.84	0.87
Mass fraction Vapour(inlet)	0	0
Mass fraction Vapour (Outlet)	0.16	0.13

The above table shows the parametric anslysis of helical coil using R12 and R22 as refrigerant. It was observed that in case of helical coil the vapour composition will decrease. At the inlet in case of R12 19.1 bar pressure and R22 19.41 bar is observed. The mass fraction of liquid at inlet is 1. As refigerant moves toward outlet the mass fraction changes from 1 to 0.84.

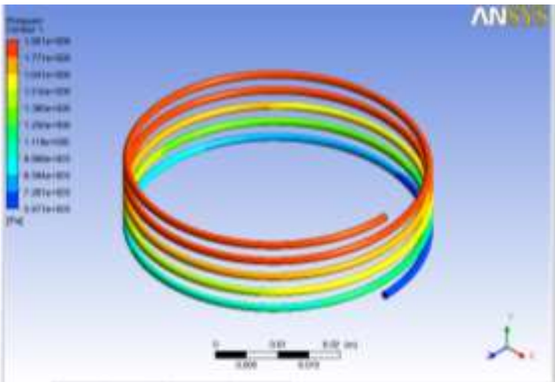

Fig 12a: - pressure contour R12 helical coil

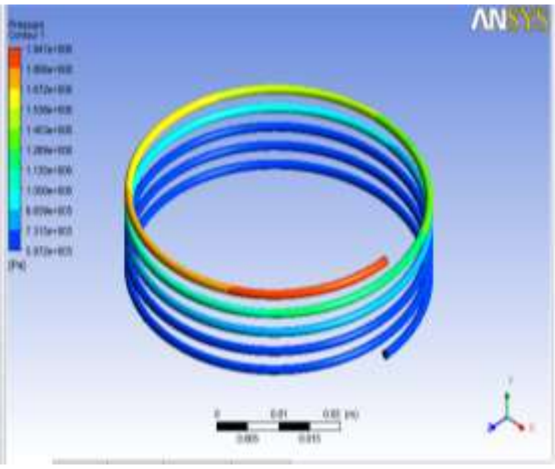

Fig 12b: - Pressure contour R22 helical coil

As show in the figure 12a and 12b pressure contour of R12 and R22 respectively. From the above figure it is seen that the pressure will decrease upto evaporator pressure. In case of R12 the pressure reches at the last two turns. In case of R22 the pressure retain at the single turn. R22 has achieved the evaporator pressure in the last two turns.

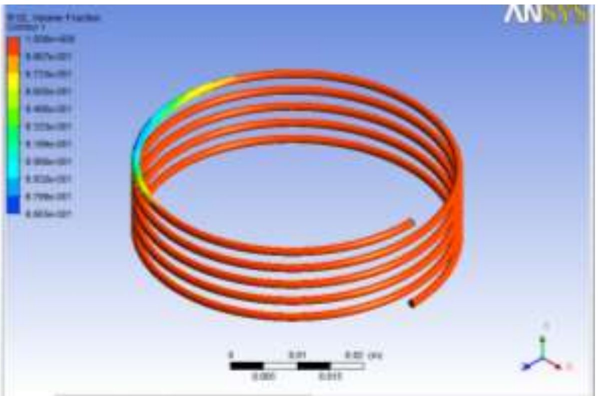

Fig 13a liquid contour R12 helical coil

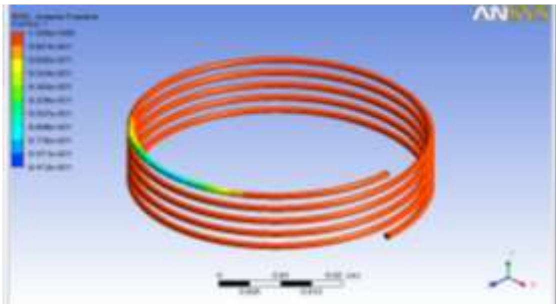

Fig 13b Liquid contour R22 helical coil

The liquid mass fraction contours are observed in above Fig 13a and 13b. In case of R12 the mass fraction of liquid decreases from 1 to 0.86. in case of R22 the mass composition of liquid decrease from 1 to 0.84.

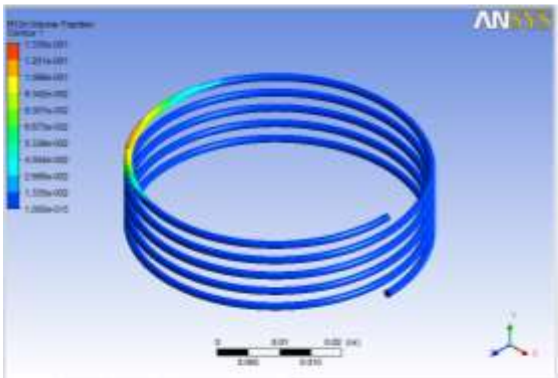

Fig14a Vapour contour R12 helical coil

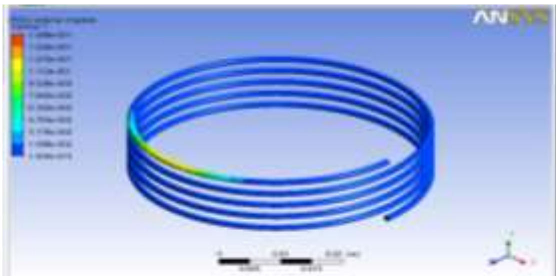

Fig 14b Vapour contour R22 helical coil

The liquid mass fraction contours are observed in above Fig 9a and 9b. In case of R12 the mass fraction of vapour decreases from 1 to 0.13. in case of R22 the mass composition of vapour decrease from 1 to 0.15.

CONCLUSIONS

The following conclusions are drawn from above results:-

- The computational model of straight capillary tube has been validated with the experimental results using R22.
- Theoretical value has been compared with the experimental and CFD results. It was observed that losses were found in the experimental result.

- A helical coil is design to replace straight coil. The mass fraction of liquid is increasing in case of helical coil. As we know that liquid should be enter into the evaporator so as to vaporization. So by taking R12 and R22 as refrigerant both the cases shows the better performance in helical coil.

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