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ANSYS CFX, CFD ANALYSIS: HELICAL COILED CAPILLARY TUBE.

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Abstract This research paper analysis of R152a, eco-friendly refrigerants with zero ozone depletion potential (ODP) and low global warming potential (GWP), to replace R12 and R22 in domestic refrigerator. The model is made for to develop mathematical model to determine the flow characteristics of refrigerant inside a straightcapillary tube for adiabatic flow conditions. The proposed model can predict the length and diameter of the adiabatic straight capillary tube for a given mass flow rate. A capillary tube designed and developed to work with R22 was tested in literature Y Rajaet. al. [39], and its performance using R152a is evaluated and compared with its performance when R22 was used. Finally, the results of mathematical model are valuated with ANSYS CFX and the results are found to be in fair agreement.

Keyword NSYS CFX, CFD, Analysis

Introduction

A capillary tube is a long, narrow tube of constant diameter. The word “capillary” is a misnomer since surface tension is not important in refrigeration application of capillary tubes. Typical tube diameters of refrigerant capillary tubes range from 0.5 mm to 3 mm and range of length is 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 leadsto 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 $\dot{m} = \rho VA$. The increase in velocity or acceleration of the refrigerant also requires pressure drop.

Several combinations of length and bore are available for mass flow rate and pressure drop. However, once a capillary tube of some diameter and length has been installed in a refrigeration system, in this refrigeration rate of mass flow through it will vary in such a manner that the total pressure drop through it matches with the difference ofpressure between condenser and evaporator. Its mass flow rate is totally dependent upon the pressure difference across it; it cannot adjust itself to variation of load effectively.

Literature Review

Hirendra Kumar Paliwal and Keshav Kant (2006) developed a flow model for designing and studying the performance of helical coiled capillary tubes and tomathematically simulate a situation closer to one existing in real practice. Homogeneous flow of two phase fluid was assumed through the adiabatic capillary tube. The model included the second law restrictions. The effect of the variation of different parameters like condenser and evaporator pressures, refrigerant flow rate, degree of sub cooling, tube diameter, internal roughness of the tube, pitch and the diameter of the helix and the lengthof the capillary tube were included in the model. Theoretically predicted lengths of helicalcoiled capillary tube for R-134a are compared with the length of the capillary tube actuallyrequired under similar experimental conditions and majority of predictions were found to be within around 10% of the experimental value. [28]

M.Y.Taib et al. (2010) studied the performance of a domestic refrigerator and developed a test rig from refrigerator model NRB33TA. The main objective of theperformance analysis was to obtain the performance of the system in terms of refrigeration capacity, coefficient of performance (cop), and compressor work by determining three important parameters which are temperature, pressure and refrigerant flow rate. The analysis of the collected data gave the cop of the system as 2.75 while the refrigeration capacity was ranging from 150 watt to 205 watt. [29]

Sanggoon Park et al. (2008) simulated the effects of a non adiabatic capillary tubeon refrigeration cycle. The simulation focused on the effect of capillary tube- suction line heat exchangers (CT-SLHX). The simulation of steady state were based on the fundamentalconservation equations of mass and energy and these equations were solved simultaneouslythrough iterative process. The non – adiabatic capillary tube model was based on homogenous two phase model. The length and location of soldering region betweencapillary tube and suction line tube were changed and performance of the refrigeration cycle was compared in terms of condenser pressure, evaporator pressure, refrigerationeffect, compressor work and cop. The simulation results showed that both the location andlength of the heat exchange section influence the cop of the system. [30]

J.K.Dabas et al. (2011) studied the behavior of performance parameters of a simplevapour compression refrigeration system while its working under transient conditions occurred during cooling of a fixed mass of brine from initial room temperature to sub-zero refrigeration temperature. The effects of different lengths of capillary tube over these characteristics were also investigated. The investigation showed that with constantlyfalling temperature over evaporator, refilling of it with more and more liquid refrigerant causes increase in heat transfer coefficient which maintains the refrigeration rate at falling temperature. The study revealed that larger capillary tubes decreases the tendency of refilling but offers less evaporator temperature while shorter capillary tubes ensure highercop initially but it deteriorates at a faster rate in lower temperature range. [31]

M.M.Tayde et al. (2013) compared the performance of a miniature vapour compression refrigeration system with four different refrigerants namely NH3, R12, R22 and R134a. The study revealed that NH3 gives maximum value of cop for the system. Next highest cop for the system came out for R12 and then for R134a. Refrigerant R22 gave theleast cop for the miniature system. [32]

Nishant P. Tekade et al. (2012) reviewed the investigation about the coiling effectof spiral capillary tubes on the refrigerant mass flow rate for the same cooling load. The work also reviewed the effects of changes in the parameters such as capillary tube dimension i.e. capillary tube diameter, capillary tube length, coil pitch and inlet conditionsof the refrigerant to the capillary tube i.e. degree of subcooling and inlet pressure of the refrigerant charge. [33]Ankush Sharma and Jagdev Singh (2013) experimentally investigated about the effects simple and twisted spirally coiled adiabatic capillary tubes on the refrigerant flow rate. Several capillary tubes with different bore diameters, lengths and pitches were taken as test sections. LPG was used as an alternative for R134a. mass flow rates for different capillary tubes were measured for different degrees of subcooling with constant inlet pressure of the capillary tube. Experiments were conducted on straight capillary tubes as

well so as to facilitate proper comparison. The test results showed that mass flow rate is greater in straight capillary tube and least in twisted spirally coiled capillary tube. [34]

Sudharash Bhargava and Jagdev Singh (2013) experimentally investigated the of pitch and length of the serpentine coiled adiabatic capillary tube on the flow of a ecofriendly gas. The azeotropic blend (30% propane, 55% n-butane, 15% iso-butane) is used as refrigerant in the experiment. Various capillary tubes with distinct lengths, pith and bore diameter were used as the test sections in the experiment. Inlet pressure of the capillarytubes was kept constant and then mass flow rates for different capillary tubes with differentlengths and pitches were measured. Straight capillary tubes were also investigated. The data from the experiments showed that mass flow rate of the refrigerant in the system wasless for serpentine coiled capillary tubes and was grater for straight capillary tubes. [35]

Thamir K. Salim (2012) experimentally investigated the performance of the capillary tube expansion device using R134a as the refrigerant in the system. All the properties of the refrigeration system was measured for the mass flow rate ranging from 13kg/hour to 23 kg/hour and capillary tube coil number (0-4) with fixed length (150 cm) andcapillary tube bore diameter (2.5 mm). the test results showed that the theoretical compression power increases by 65.8% as the condenser temperature increases by 2.71% and the theoretical compression power decreases by 10.3% as the capillary tube coil number increases. The test results also showed that cooling capacity increases by 65.3% asevaporator temperature increases by 8.4% and the cooling capacity increases by 1.6% as the capillary tube coil number increases in the range (0-4). The cop decreases by 43.4% asthe mass flow rate increases by 76.9% and the cop of the system increases by 13.51% as the capillary tube coil number increases in the range (0-4). The study showed that coil number 4 was the best for the lowest mass flow rate (13 kg/hour) and the highest mass flowrate (23 kg/hour). [36]

Methodology

Computational Fluid Dynamics (CFD/CFX) Analysis

Computational fluid dynamics (CFD/CFX) simulation software allows you to predict, withconfidence, the impact of fluid flows on your product throughout design and manufacturing as well as during end use. The software's unparalleled fluid flow analysis capabilities can be used to design and optimize new equipment and to troubleshoot already existing installations. Whatever phenomena you are studying single or multi-phase, isothermal or reacting, compressible or not ANSYS fluid dynamics solutions give you valuable insight into your product's performance.

Modeling

The body about which flow is to be analyzed requires modeling. This generally involves modeling the geometry with a CAD software package. Approximations of the geometry and simplifications may be required to allow an analysis with reasonable effort. Concurrently, decisions are made as to the extent of the finite flow domain in which the flow is to be simulated. Portions of the boundary of the flow domain coincide with the surfaces of the body geometry. Other surfaces are free boundaries over which flow entersor leaves. The geometry and flow domain are modeled in such a manner as to provide inputfor the grid generation. Thus, the modeling often takes into account the structure and topology of the grid generation.

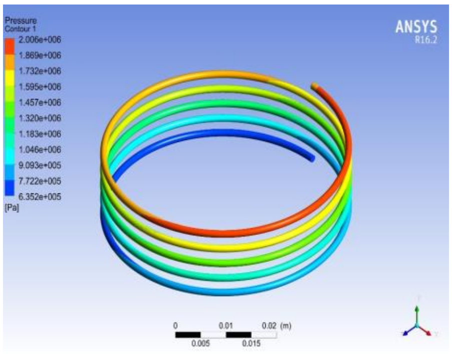
In this project, the various capillary geometries have been taken [39] for ANSYS CFX analysis. The Y Raja Kumar [39] has been done the investigation and validated the experimental result. This investigation taken R22 refrigerant and extract the results like pressure drop, mass fraction in liquid and vapour. In present investigation R152a refrigerant is used as reference fluid and extract the all results and validated from literature. The various geometries are following and properties of capillary tube K Raja Kumar et.al. [39] as shown in table 5.1 and 5.2 and properties of R152a refrigerant in table5.3 [40].

Table 1 Helical coiled capillary tubes model's K Raja Kumar et.al. [39]

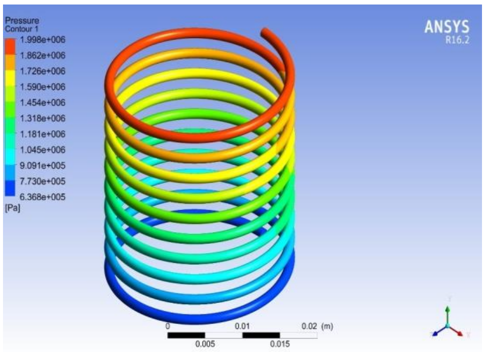
Models	**No. of turns (N)**	**Pitch of the coil (p) (mm)**	**Diameter of the Helix (D) (mm)**	**Length of the coil (L) (mm)**
1	5	3	48.5	761.98
2	10	3	24.2364	761.99
3	30	3	8.0248	762
4	40	3	5.988	761.98

Table 2 Properties of Experimental and Computational for the straight capillary K RajaKumar et.al. [39]

Properties	**Experimental**	**Computational**
Inlet temperature (Tin)	52 °C	51.3 °C
Outlet temperature($Tout$)	8 °C	9.1 °C
Inlet pressure (Pin)	20.328 bar	20.07 bar
Outlet pressure ($Pout$)	6.406 bar	6.629 bar
Inlet mass fraction liquid	1	1
Outlet mass fraction of liquid	0.7205	0.719
Inlet mass fraction of vapour	0	0
Outlet mass fraction of vapour	0.2795	0.2806



a



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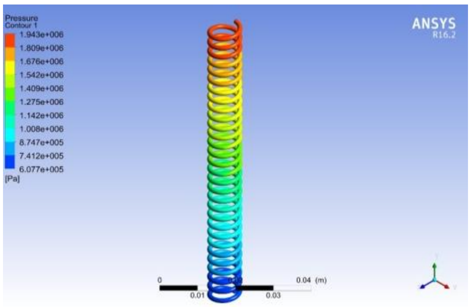

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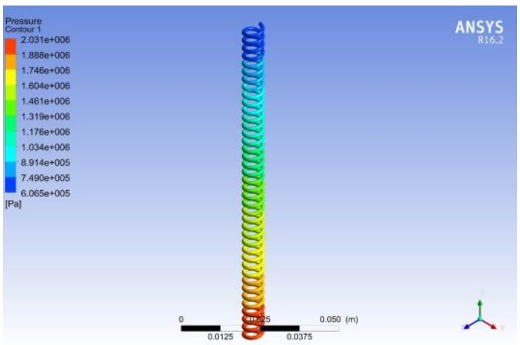


d

Figure 1 Pressure contours of helical coiled capillary tube.

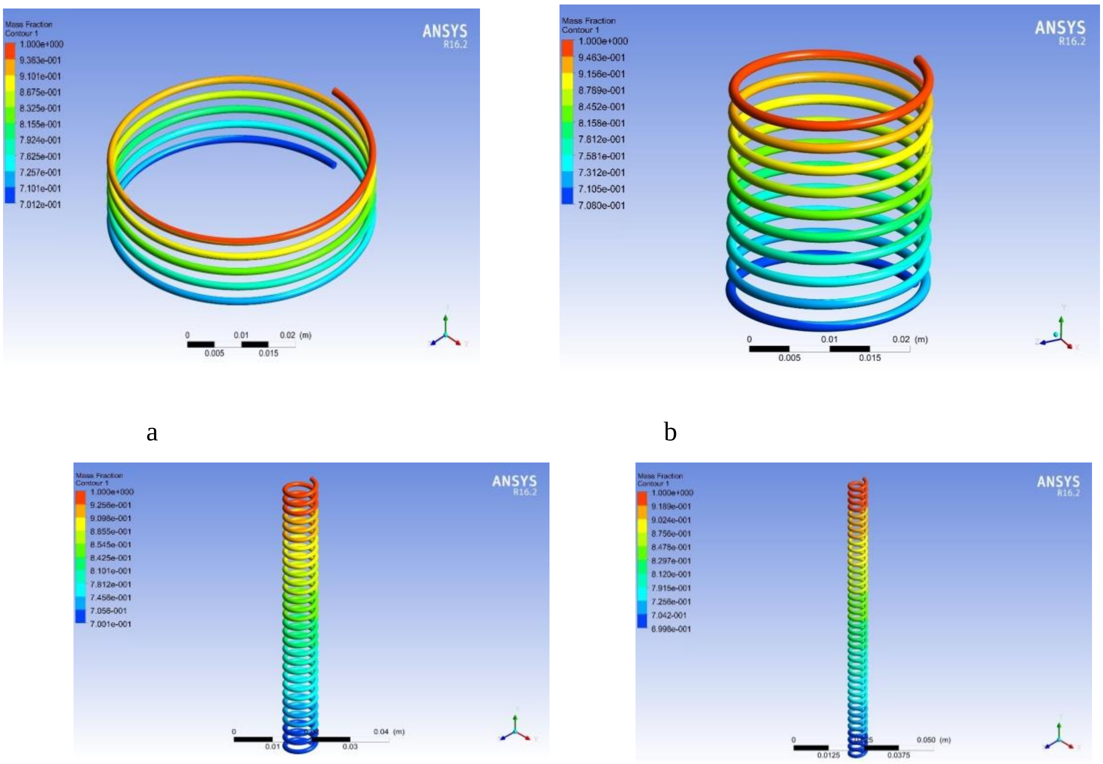
(a) When n=5, (b) When n=10, (c) When n=30, (d) When n=40

As show in the figure 6.1 a-d, the helical capillary tube by replacing straight capillary tube.The pressure contours are observed form the above figure 2 a-d. The basic function of capillary tube to decrease pressure of the capillary tube so the pressure has been decreased.

In literature, the pressure drop from capillary tube is 11.194, 10.96, 12.819 and 14.0681 bar, when number of turns in 5, 10, 30 and 40 respectively, and the Experimental calculations are from 20.328 bar to be decreased to 6.406 bar. But in present investigationwhich concluded that the pressure drop from capillary tube is 13.75, 13.679, 13.379 and 13.969 bar when number of turns in 5, 10, 30 and 40 respectively.

The pressure drop difference between literature and present work is 2.556, 2.719,

0.56 and 0.0991. In the above results, the number of turn 40 is suitable for helical capillarytube.



a b

C d

Figure 2 Mass fraction contour of liquid for helical coiled capillary tube.

(a) When n=5, (b) When n=10, (c) When n=30, (d) When n=40The liquid Mass fraction is calculated from ANSYS CFX as shown figure 3 a-d. The main function of capillary tube is to decrease the mass fraction of the capillary tube so the difference between literature Y Raja et. al. [39] and present work of mass fraction of liquidhas been obtained as 0.0123, 0.0052, 0.0013 and 0.0268. Hence also number of turn 40 (n=40) is suitable for helical capillary tube geometry. The vapour mass fraction contours are observed form the above table 6.2 the basicfunction of the capillary device to increase mass fraction of vapour of the capillary tube sothe difference between literature Y Raja et. al. [39] [39] and present work of mass fractionof vapour has been calculated as 0.005, 0.01, 0.009 and 0.017. Hence also number of turn40 (n=40) is suitable for helical capillary tube geometry.

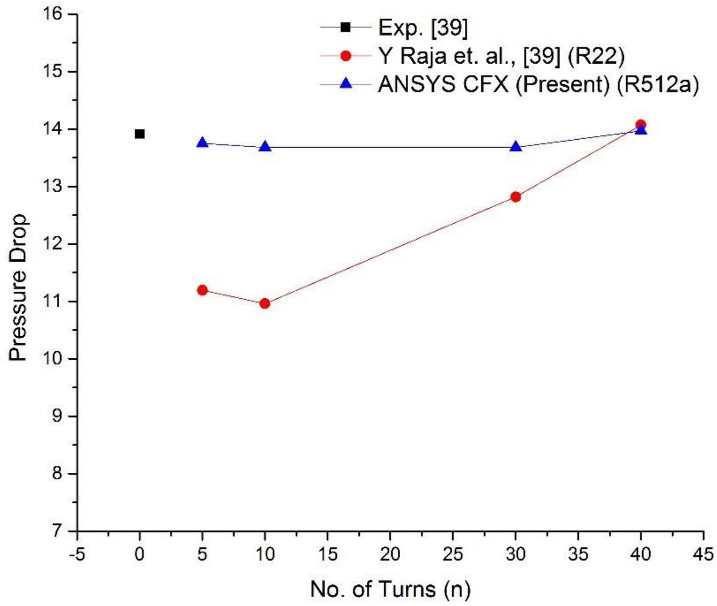


Figure 3 Graph plotted b/w pressure drop in tube and no. of turns

The above figure 4 has been shows that the pressure drops in capillary tube in literature and present work. In this graph concluded that the replacing of R22 refrigerant to R152a isbest for capillary device. It is also concluded that when number of coil turn is 40 the capillary tube performance is increases. In present investigation, the pressure drop is 0.7044% more efficient as compare to literature work Y Raja et. al., [39].

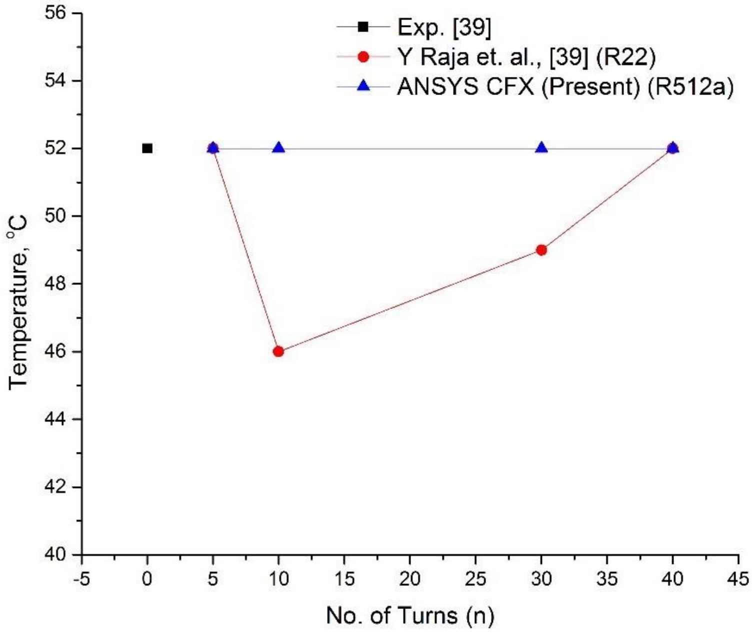


Figure 4 Graph plotted b/w Inlet temperature in tube and no. of turns

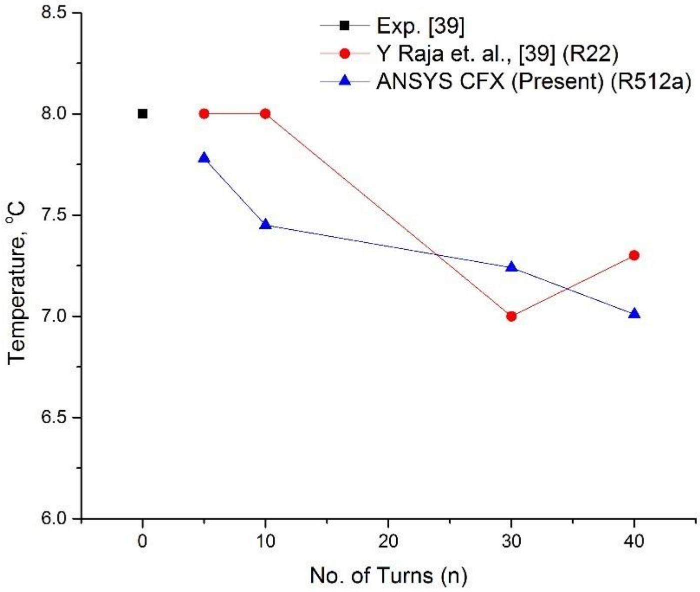


Figure 5 Graph plotted b/w Outlet temperature in tube and no. of turns

The above figure 4 has been shows that the outlet temperature in capillary tube in literature Y Raja Kumar et. al., [39] and present work. In this graph concluded that the replacing of R22 refrigerant to R152a is best for capillary device. It is also concluded that when number of coil turn is 40 the capillary tube performance is increases. In present investigation the temperature is fall 1.15% more as compare to literature work Y RajaKumar et. al., [39].

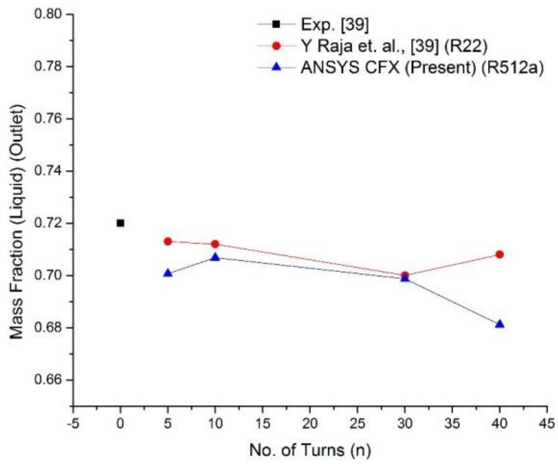


Figure 6 Graph potted between Mass fraction of liquid and number of coil turns

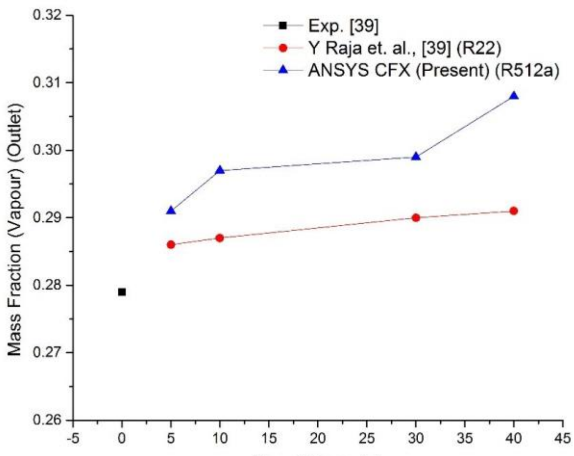


Figure 7 Graph potted between Mass fraction of Vapour and number of coil turns

The above figure 6 and 7 has been shows that the mass fraction of liquid and vapourformed in capillary tube in literature Y Raja Kumar et. al., [39] and present work ANSY CFX. In these investigation, we have to concluded the liquid mass fraction is decrease 2.74% as compare to literature work Y Raja Kumar et. al., [39] and vapour mass fraction in present work is 3.78% more as compare to literature work Y Raja Kumar et. al., [39].

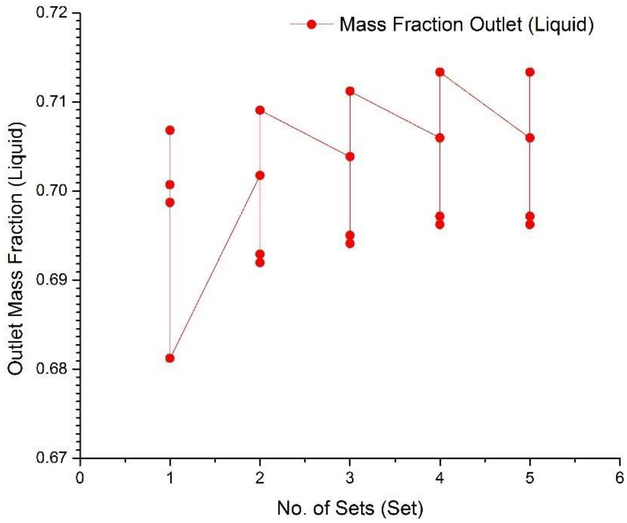


Figure 8 Comparison of predicted sets results according to outlet mass fraction (liquid)

The figure 8 indicates that the comparison the results between number of sets has been predicted according to the outlet mass fraction (liquid) in ANN tool. In the prediction has been concluded that the when in prediction sets the diameter is reduced at different tube turn, the outlet mass fraction of liquid is decreases and this is good for tube and refrigerant. The above results or comparison is shows that the prediction set 1 is preferable. In this setthe 40 turns and diameter of tube is 1.25mm is preferable.

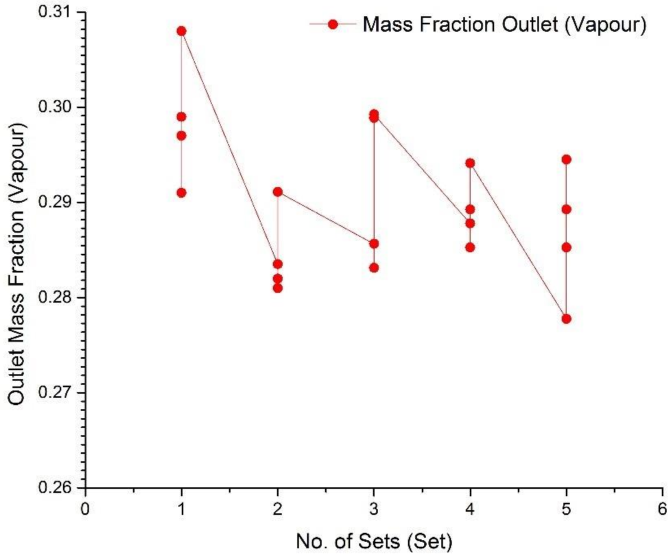


Figure 9 Comparison of predicted sets results according to outlet mass fraction (vapour)

Above figure 9 represents diameter set comparison between Neural Network generated values to obtain the optimized value of diameter in ANSYS CFX validated results like based on output mass of fractions etc. The figure 6.9 indicates that the comparison the results between number of sets hasbeen predicted according to the outlet mass fraction (vapor) in ANN tool. In the predictionhas been concluded that the when in prediction sets the diameter is reduced at different tube turn, the outlet mass fraction of vapour is increases. The above results or comparisonis shows that the prediction set 1 is preferable. Also in this set the 40 turns and diameter oftube is 1.25mm is preferable.

CONCLUSION

The following conclusion and future scope can be drawn.

- Due to eco-friendly refrigerants with zero ozone depletion potential (ODP) and low global warming potential (GWP), to replace R22 to R152a.
- The literature was investigating when taken diameter of tube as 1.27mm, but in present investigation has been take tube diameter as 1.25mm, because the R152a is easily flowwhen pipe diameter is small or less as compare to R22. Hence present investigation also reduces the size assembly and cost.
- The pressure drop difference between literature and present work is 2.556, 2.719, 0.56and 0.0991. In the above results, the number of turn 40 is suitable for helical capillarytube. Hence the n=40 is suggested.
- Difference between literature Y Raja Kumar et. al., [39] and present work of mass fraction of liquid has been obtained as 0.0123, 0.0052, 0.0013 and 0.0268. Hence alsonumber of turn 40 (n=40) is suitable for helical capillary tube geometry.
- Difference between literature Y Raja Kumar et. al., [39] and present work of mass fraction of vapour has been calculated as 0.005, 0.01, 0.009 and 0.017. Hence also number of turn 40 (n=40) is suitable for helical capillary tube geometry.

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