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Capillary Helix Tube Diameter Optimization Using Neural Network Tool

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Abstract: *This investigation the model is made for to develop mathematical model to determine the flow characteristics of refrigerant inside a straight/helix capillary tube for adiabatic flow conditions. A capillary tube designed and developed to work with R22 was tested in literature Y Raja et. al. [4], 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 suitable result is optimized using neural Network tool, which this results are found to be in fair agreement. It is observed from the results dryness fraction by using the helical capillary tube (R152a refrigerant flow) is better than straight and existing helical capillary tube (R22 refrigerant flow). The best suitable helical coiled design is suggested.*

Keywords: *Capillary tube, ANSYS CFX, ANN Tool.*

I. 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 leads to some pressure drop, and
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.

Fig 1: Air Preheater [1]

II. MATHEMATICAL MODELING

2.1 GOVERNING EQUATIONS

The main equations governing capillary tube flow in the mass, momentum and energy conservation equations. In a 1D mesh, these equations can be integrated and solved simultaneously by an iterative process for each control volume of length Δz like the shown in figure 2.

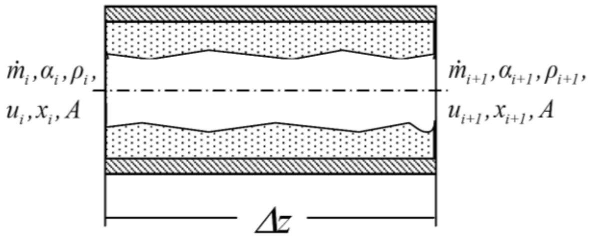


Fig 2: Control volume

2.1.1 Conservation equations

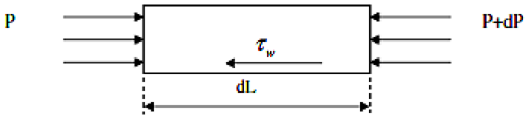


Fig 3: Forces acting on the fluid element

Mass Balance: Application of continuity equation results into the following:

$m = \rho AV \text{ or } G = \frac{m}{A} = \rho V$ -----------------(1)

Momentum Balance: On applying the principle of momentum conservation or the Second law of Thermodynamics, the following equation will result:

$$P.A - (P + dP).A - \tau_w (\pi d)dL = mdV$$

$$-dP = \frac{f}{2d}\rho V^2 dL + \rho V dV$$

Taking log both sides of above equation and then differentiating and simplifying

$$-\frac{dV}{V} = \frac{d\rho}{\rho}$$

Hence, $dL = \frac{2d}{f}\left(\frac{\rho dP}{G^2} - \frac{d\rho}{\rho}\right)$-----------------(2)

Energy Balance: On applying the steady flow energy equation on the element to get,

$\delta q - \delta w = dh + VdV + gdZ$ -----------------(3)

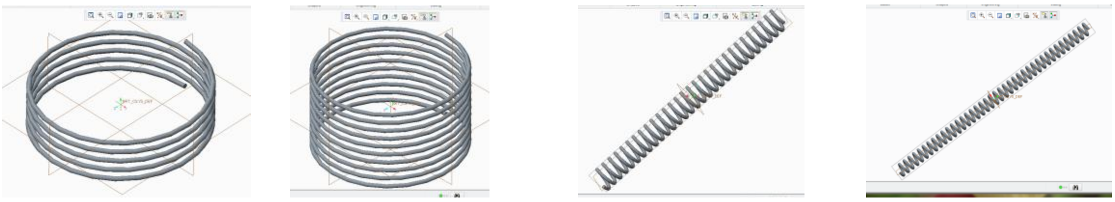
III. METHODOLOGY

3.1 COMPUTATIONAL FLUID DYNAMICS (CFD/CFX) ANALYSIS

Computational fluid dynamics (CFD/CFX) simulation software allows you to predict, with confidence, the impact of fluid flows on your product throughout design and manufacturing as well as during end use.

3.1.1 Modelling

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.

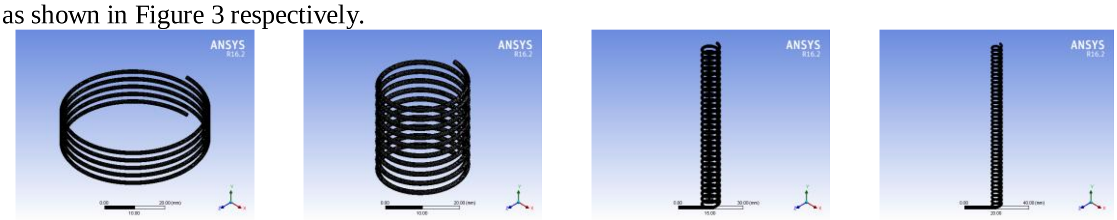


(a) (b) (c) (d)

Fig 2a-d: 3D Modeling of different trials helix/coiled capillary tube

3.2 Meshing of Model

After importing the product in ANSYS CFX and generate mesh in model. In this process can uses unstructured meshing method as shown in Figure 3 respectively.

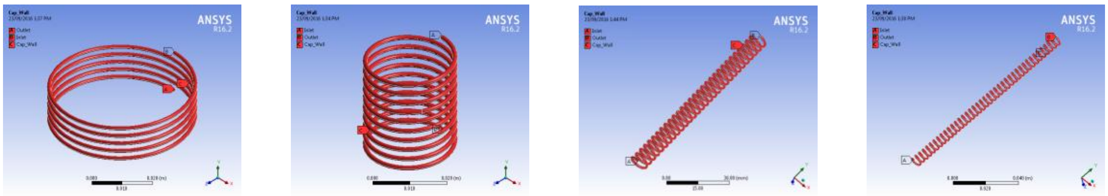


(a) (b) (c) (d)

Fig 3a-d: Meshing view of different trials helix/coiled capillary tube

3.3 Boundary Conditions

Since a finite flow domain is specified, physical conditions are required on the boundaries of the flow domain. The simulation generally starts from an initial solution and uses an iterative method to reach a final flow field solution. The boundary conditions are defined in this investigation are as shown in fig 4a-d. The boundary name is defined like; Inlet, Outlet and Capillary wall (Cap_Wall).



(a) (b) (c) (d)

Fig 4a-d: Boundary Conditions of different trials helix/coiled capillary tube

Table 1: Boundary conditions obtained from Y Raja et. al., [4]

Properties	No. of Tubes				
	Exp. (Plain)	**5**	**10**	**30**	**40**
Inlet temp. (Tin), °C	52	52	46	49	52
Outlet temp. ($Tout$) °C	8	8	8	7	7. 3
Inlet pre. (Pin), bar	20.32	17.6	17.53	19.0	20.28
Outlet pre. ($Pout$), bar	6.406	6.406	6.37	6.181	6.2112
Inlet mass fraction of liquid	1	1	1	1	1
Outlet mass fraction of liquid	0.72	0.713	0.712	0.70	0.708
Inlet mass fraction of vapour	0	0	0	0	0
Outlet mass fraction of vapour	0.279	0.286	0.287	0.29	0.291

IV. RESULTS AND DISCUSSIONS

The various results obtained from analysis and optimization using ANSYS CFX and ANN Tool.

Table 2: Results obtained from ANSYS CFX and Artificial Neural Network (ANN) Tool

No. of Prediction Sets	No. of Tubes	Tube Diameter	Mass Fraction Inlet (Liquid)	Mass Fraction Outlet (Liquid)	Mass Fraction Inlet (Vapour)	Mass Fraction Outlet (Vapour)
			Pred. Output	**Pred. Output**	**Pred. Output**	**Pred. Output**
Set 1 (ANSYS CFX)	**5**	**1.25**	**1**	**0.7007**	**0**	**0.2910**
	10	**1.25**	**1**	**0.7068**	**0**	**0.2970**
	30	**1.25**	**1**	**0.6987**	**0**	**0.2990**
	40	**1.25**	**1**	**0.6812**	**0**	**0.3080**
Set 2	5	1.2	1	0.70173	0	0.2835
	10	1.2	1	0.69291	0	0.2810
	30	1.2	1	0.69197	0	0.2820
	40	1.2	1	0.70907	0	0.2911
Set 3	5	1.15	1	0.70384	0	0.2856
	10	1.15	1	0.69502	0	0.2831
	30	1.15	1	0.69409	0	0.2989
	40	1.15	1	0.7112	0	0.2993
Set 4	5	1.1	1	0.70595	0	0.2878
	10	1.1	1	0.69714	0	0.2853
	30	1.1	1	0.69621	0	0.2892
	40	1.1	1	0.71332	0	0.2941
Set 5	5	1.1	1	0.70595	0	0.2778
	10	1.1	1	0.69714	0	0.2853
	30	1.1	1	0.69621	0	0.2892
	40	1.1	1	0.71332	0	0.2945

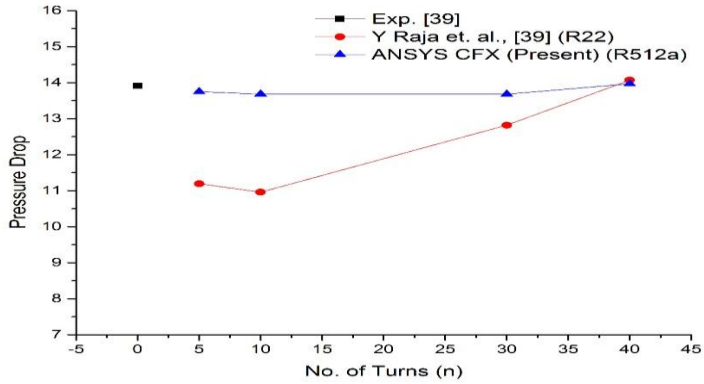


Fig 5: Graph plotted b/w pressure drop in tube and no. of turns

The above figure 5 has been shows that the pressure drops in capillary tube in literature and present work.

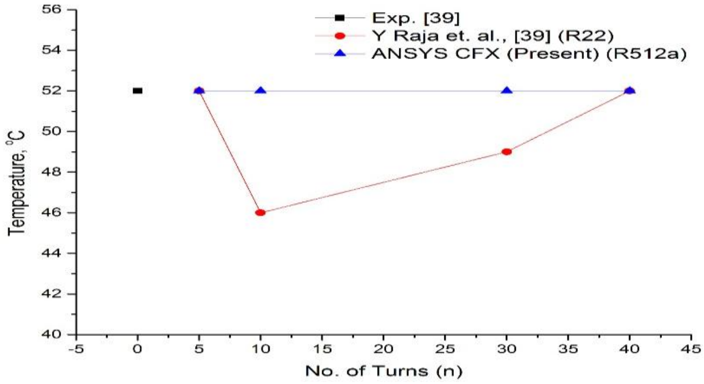


Fig 6: Graph plotted b/w Inlet temperature in tube and no. of turns

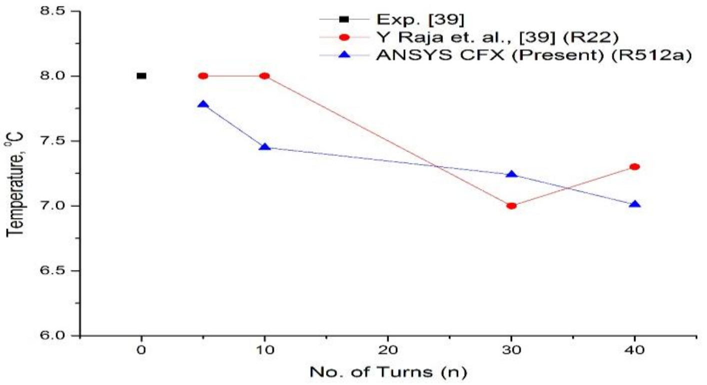


Fig 7: Graph plotted b/w Outlet temperature in tube and no. of turns

The above figure 6 and 7 has been shows that the inlet and outlet temperature in capillary tube in literature Y Raja Kumar et. al., [4] and present work. In this graph concluded that the replacing of R22 refrigerant to R512a is best for capillary device

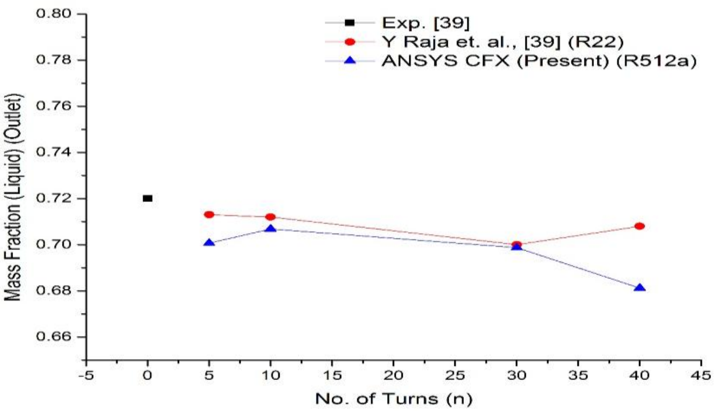


Fig 8: Graph potted between Mass fraction of liquid and number of coil turns

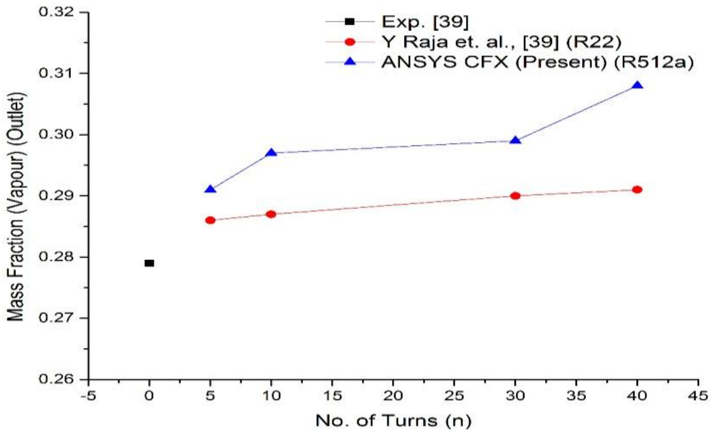


Fig 9: Graph potted between Mass fraction of Vapour and number of coil turns

The above figure 8 and 9 has been shows that the mass fraction of liquid and vapour formed in capillary tube in literature Y Raja Kumar et. al., [4] and present work ANSYS CFX.

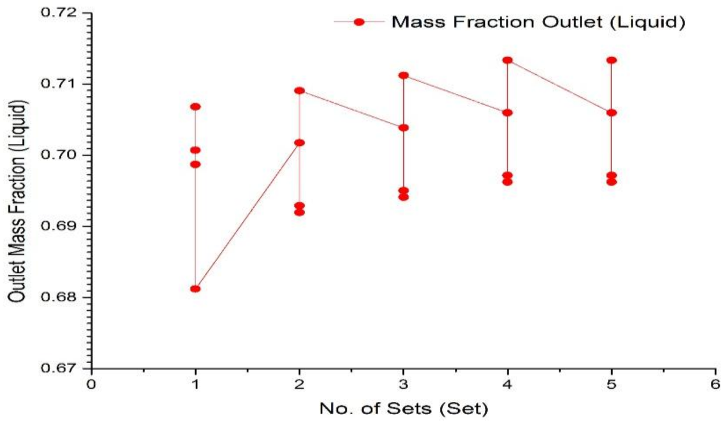


Fig 10: Comparison of predicted sets results according to outlet mass fraction (liquid)

The figure 10 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.

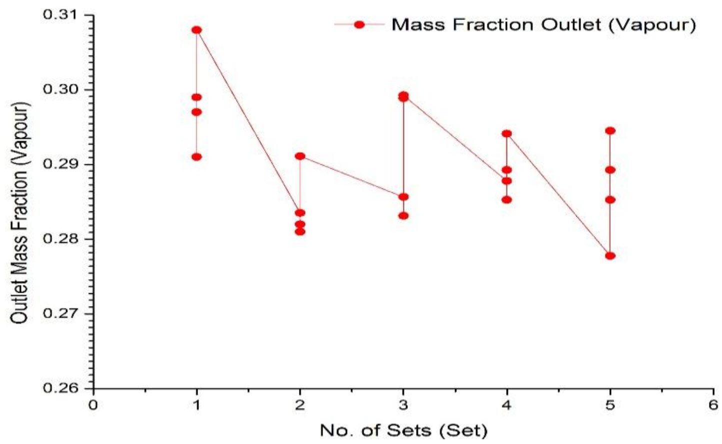


Fig 11: Comparison of predicted sets results according to outlet mass fraction (vapour)

Above figure 11 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 11 indicates that the comparison the results between number of sets has been predicted according to the outlet mass fraction (vapor) 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 vapour is increases.

V. CONCLUSION

- 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 R512a is easily flow when pipe diameter is small or less as compare to R22. Hence present investigation also reduces the size assembly and cost.
- Difference between literature Y Raja Kumar et. al., [4] and present work of mass fraction of liquid has 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.
- Difference between literature Y Raja Kumar et. al., [4] 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.
- In present investigation concluded that the replacing of R22 refrigerant to R512a is best for capillary device. It is also investigating the pressure drop is 0.7044% more efficient as compare to literature work Y Raja Kumar et. al., [4].
- In present investigation the temperature is decreased 1.15% more as compare to literature work Y Raja Kumar et. al., [4].
- Analysis has been done for mass fraction of liquid and vapour formed in capillary tube in literature Y Raja Kumar et. al., [4] and present work ANSYS 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., [4] and vapour mass fraction in present work is 3.78% more as compare to literature work Y Raja Kumar et. al., [4].
- It is concluded that after 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 set the 40 turns and diameter of tube is 1.25mm is preferable.
- Also concluded that comparison the results between number of sets has been predicted according to the outlet mass fraction (vapor) 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 vapour is increases. The above results or comparison is shows that the prediction set 1 is preferable. Also in this set the 40 turns and diameter of tube is 1.25mm is preferable.
- For a large cold storage, the operation costs are 20-30% lower with R512a than R22 and also R134a.
- The neural network tool is gives the optimized result of the tube diameter which work between the operating conditions.

VI. REFERENCES

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