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Analytical Investigation of R-407c & R-22 Flowing Through Adiabatic Helically Coiled Capillary Tube

[1]Uggirala Srinivas, [2]Mr. A. Rama Krishna , [3]B. Srinivas
M.Tech.,
MISTE., MIIW, (Ph.D.), M.TECH student B.Tech,ME,(PhD) Professor& Head,
Department of Mechanical Engineering, B V C Engineering College , Odalarevu-533210

ABSTRACT

In this thesis, the effects of the relevant parameters on the flow characteristic of R-407C and R-22 flowing through adiabatic helical capillary tubes of copper and aluminum materials were theoretically studied. The capillary tubes' diameter, coil diameter, and parameters relating to flow conditions such as inlet and outlet pressures and temperatures were the major parameters investigated.

In this thesis, the CFD analysis is to determine the heat transfer rate, pressure drop, velocity, mass flow rate and heat transfer coefficient for the fluids R-407C and R-22 with different tube and coil diameters. Thermal analysis is to determine the temperature distribution and heat flux for copper and aluminum as tube materials.

3D modeling is done inRhinoceros softwareand analysis is done in ANSYS software.

Comparing with diameters of 25mm 30mm, 40mm and 50mm of capillary tube for both Copper and Aluminum materials, it is observed that it is better to use copper capillary tube with 25mm diameter with refrigerant R22 far better for capillary tube when compared to aluminum material at various coil diameters over a refrigerant R407c.

INTRODUCTION

Capillary tube is one of the most commonly used throttling devices in the refrigeration and the air conditioning systems. The capillary tube is a copper tube of very small internal diameter. It is of very long length and it is coiled to several turns so that it would occupy less space. The internal diameter of the capillary tube used for the refrigeration and air conditioning applications varies from 0.5 to 2.28 mm (0.020 to 0.09 inches). Capillary tube used as the throttling device in the domestic refrigerators, deep freezers, water coolers and air conditioners.

Table 1: Compares the capillary length predicted by the model with the actual length of capillary tubes used in the experiment. In the model a typical value of inside surface roughness of 1.2 micron is used throughout. From the table it can be observed that the length of the capillary tube predicted by the model in majority of the cases is within the ± 10% limit of the actual value, which is quite reasonable.

Se. No.	d mm	Pitch mm	Helix Diameter mm	P_{cond} MPa	P_{evap} MPa	Sob-Cooling °C	Mass Flow Rate Kg/h	Length Predicted by model m	Actual Length m	Error in prediction (%)
1	1.62	10	66	0.91	0.21	1.0	15.12	5.14	6.0	-14.33
2	1.62	10	66	0.83	0.19	0.8	13.37	6.03	6.0	0.50
3	1.62	10	66	0.69	0.41	1.0	11.19	5.32	5.5	-3.27
4	1.62	10	66	0.63	0.36	1.1	10.71	5.41	5.5	-1.64
5	1.01	6	16	0.98	0.16	1.2	3.89	6.51	6.0	8.50
6	1.01	6	16	1.01	0.10	2.1	4.30	6.05	5.5	10.00
7	1.01	6	16	0.7	0.19	0.9	3.52	4.89	5.0	-2.20
8	1.01	6	16	0.63	0.195	1.6	3.38	4.91	5.0	-1.80
9	1.01	6	16	0.82	0.13	1.4	4.10	4.76	4.5	5.80
10	1.01	6	16	0.81	0.32	1.3	4.01	4.68	4.5	4.00

Table 1.1 Comparisons of experimental and theoretical predicted values of capillary tube length

Table 2 compares the length of helical capillary tube predicted by model for two different values of D/d ratios of 20 and 40 with the experimental value of straight capillary length for R-134a. The P/d ratio is 5 in all the cases. It can be observed that for a D/d ratio of 20 the length required is 15-30% smaller as compared to straight. For D/d of 40 the length required is

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approximately 8-25% smaller in comparison to straight and 7% larger as compared to that with D/d of 20 due to smaller curvature.

Se. No.	d mm	ε µm	P_{cond} MPa	P_{evap} MPa	Sub-cooling °C	Mass Flow Rate kg/h	$L_{straigh}$ actual by Melo [1999]
1	1.05	0.72	1.12	0.13	4.0	11.18	2.03
2	1.05	0.72	1.13	0.14	8.2	12.14	2.03
3	1.05	0.72	1.43	0.16	6.2	13.08	2.03
4	0.87	0.78	1.40	0.11	4.4	6.87	2.97
5	0.87	0.78	1.51	0.12	7.2	7.45	2.97

Table1.2: Comparison of length of helical coil predicted by model with experimental values for straight capillary

Properties	R407c	R22	Copper(Cu)	Aluminium(Al)
Density (kg/m³)	41.19	44.230	8978	2710
Specific heat (J/kg k)	1381.64	1082.1	381	871
Thermal conductivity (W/mk)	0.0954	0.1	387.6	202.4
Viscosity (kg/m s)	0.00023	0.0011832	-----	------

Table: 4.1. Table showing properties of R22,R407c, Copper and Aluminium

S.no.	Parameters	value
1	Internal diameter of capillary tube in mm	1.6
2	Pitch of helical capillary tube in mm	10
3	Diameter of capillary tube in mm	25,30,40 and 50
4	Mass flow rate in kg/s	0.4
5	Inlet pressure in Mpa	0.91
6	Inlet temperature in k	298

Table: 4.2. Table showing input details for analyzing a model

Case 1:

Analysis of Aluminium capillarytube of various diameters 25mm, 30mm, 40mm and 50mm with refrigerant R407c to obtain parameters like pressure, temperature and enthalpy for the given inlet boundary conditions such as mass flow rate, pressure and temperatures are 0.4kg/s, 0.91Mpa and 298 k. The pressure, temperature and enthalpy variation in the capillary tube of various diameters are as shown in the following figures.

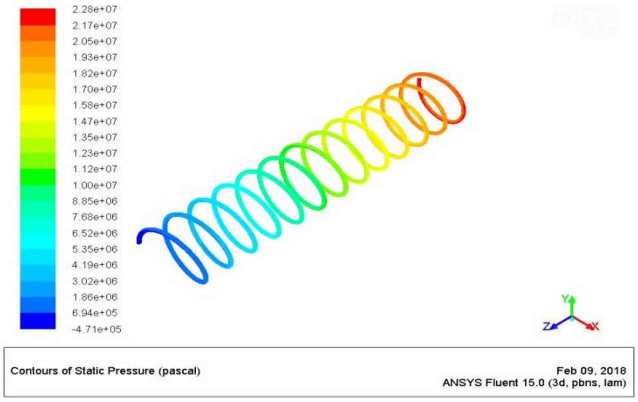

Fig 4.5: Image showing pressure analysis of aluminium helical coiled capillary tube of coil diameter 25mm of R407C

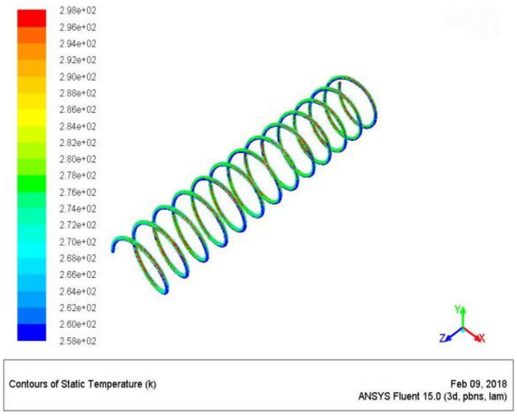

Fig 4.6: Image showing temperature analysis of aluminium helical coiled capillary tube of coil diameter 25mm of R407C

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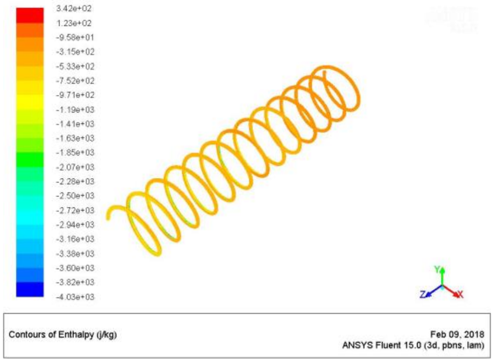


Fig 4.7: Image showing enthalpy analysis of aluminium helical coiled capillary tube of coil diameter 25mm of R407C

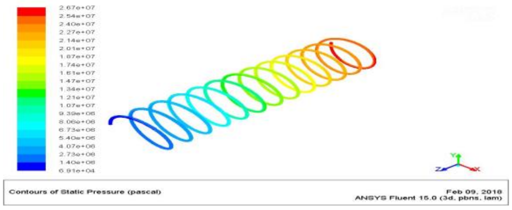


Fig 4.8: Image showing pressure analysis of aluminium helical coiled capillary tube of coil diameter 30mm of R407C

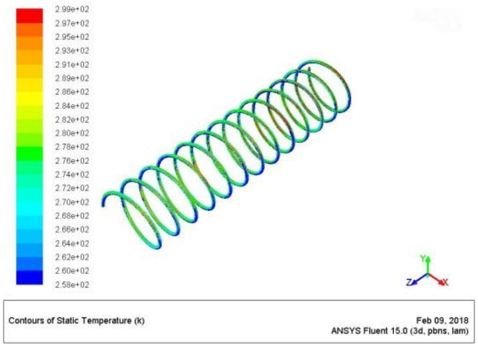


Fig 4.9: Image showing temperature analysis of aluminium helical coiled capillary tube of coil diameter 30 mm of R407C

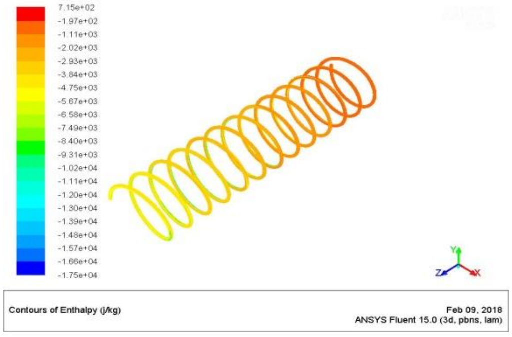


Fig 4.10: Image showing enthalpy analysis of capillary tube of coil diameter 30 mm of R407C

RESULTS

5.1. RESULTS OF ALUMINIUM CAPILARY TUBE:

Analysis of Aluminium capillary tube of various diameters 25mm, 30mm, 40mm and 50mm with refrigerant R407c and R22for the given inlet boundary conditions such as mass flow rate, pressure and temperatures are 0.4kg/s, 0.91Mpa and 298 k. The Pressure and Temperature variation at outlet in the Aluminiumcapillary tube at various diameters was tabulated below.

Aluminium capillary tube					
Fluid	Coil dia (mm)	Pressure (Mpa)		Temperature (k)	
		Inlet	outlet	Inlet	outlet
R407c	25	9.1 e^5	4.71 e^5	2.98e^2	2.65e^2
	30	9.1 e^5	4.91 e^5	2.98e^2	2.69e^2
	40	9.1 e^5	5.01 e^5	2.98e^2	2.85e^2
	50	9.1 e^5	5.06 e^5	2.98e^2	2.86e^2
R22	25	9.1 e^5	1.78e^5	2.98e^2	2.65e^2
	30	9.1 e^5	1.98 e^5	2.98e^2	2.75e^2
	40	9.1 e^5	2.01 e^5	2.98e^2	2.85e^2
	50	9.1 e^5	2.10 e^5	2.98e^2	2.85e^2

Fig 5.1: The table showing the temperature and pressure variations at outlet of refrigerants R22 and R407c at various diameters when passing through Aluminium capillary tube

5.2. RESULTS OF COPPER CAPILARY TUBE:

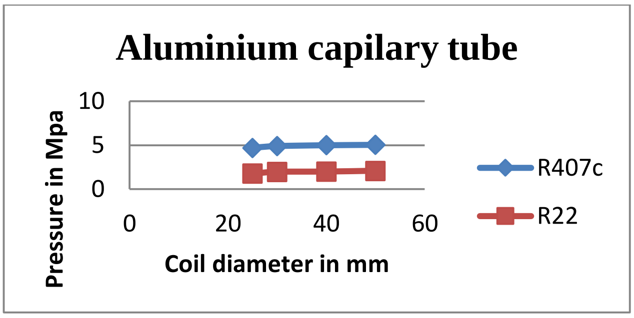
Analysis of Copper capillary tube of various diameters 25mm, 30mm, 40mm and 50mm with refrigerant R22 and R407c for the given inlet boundary conditions such as mass flow rate, pressure and temperatures are 0.4kg/s, 0.91Mpa and 298 k. The Pressure and Temperature variation at outlet in the Copper capillary tube at various diameters was tabulated below.

Copper capillary tube					
Fluid	Coil dia (mm)	Pressure (Mpa)		Temperature (k)	
		Inlet	outlet	Inlet	outlet
R407c	25	9.1 e^5	3.25 e^5	2.98 e^2	2.68e^2
	30	9.1 e^5	3.91 e^5	2.98 e^2	2.86e^2
	40	9.1 e^5	5.75 e^5	2.98 e^2	2.98e^2
	50	9.1 e^5	5.56 e^5	2.98 e^2	3.38e^2
R22	25	9.1 e^5	1.79 e^5	2.98 e^2	2.58e^2
	30	9.1 e^5	1.90 e^5	2.98 e^2	2.63e^2
	40	9.1 e^5	1.97 e^5	2.98 e^2	2.68e^2
	50	9.1 e^5	2.01 e^5	2.98 e^2	2.69e^2

Fig 5.2: The table showing the temperature and pressurevariations of refrigerants R22 and R407c at various diameters when passing through copper capillary tube

5.3. GRAPHICAL REPRESENTATION:

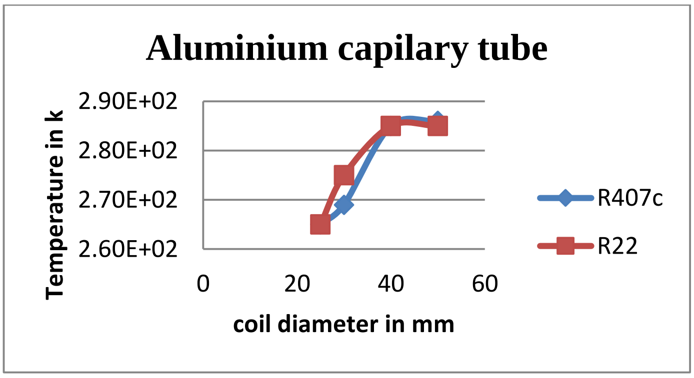
5.3.1. Pressure variation in Al capillary tube



Graph: 5.1. According to this plot, pressure varies with respect to coil diameter.

Description: Based on the results, this graph is plotted against pressure variation with change in coil diameter by using R22a (red) and R407c (blue). According to this plot while using R22a (red) pressure decreased up to 0.325Mpa when coil diameter is 25mm, In case of R407c (Blue)pressure decreased up to 0.325Mpa when coil diameter is 25mm in Aluminium capillary tube.

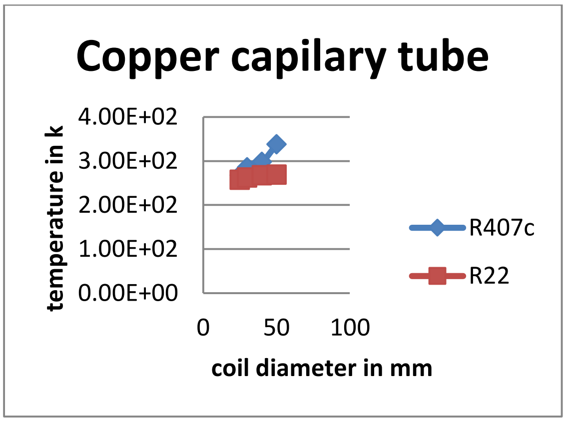
5.3.2. Temperature variation in Al capillary tube



Graph: 5.2. According to this plot, temperature varies with respect to coil diameter

Description: Based on the results, this graph is plotted against pressure variation with change in coil diameter by using R22a (red) and R407c (blue). According to this plot while using R22a (red) temperaturedecreased up to 258 k when coil diameter is 25mm, In case of R407c (Blue)temperaturedecreased up to268 kwhen coil diameter is 25mm in Aluminium capillary tube.

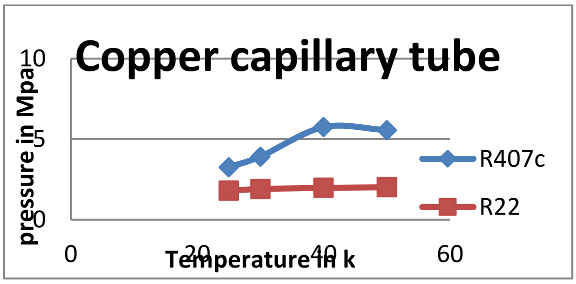
5.3.3. Pressure variation in Cu capillary tube



Graph: 5.3. According to this plot, pressure varies with respect to coil diameter.

Description: Based on the results, this graph is plotted against pressure variation with change in coil diameter by using R22a (red) and R407c (blue). According to this plot while using R22 (red) pressure decreased up to0.325 Mpawhen coil diameter is 25mm, In case of R407c (Blue) pressure decreased up to0.179 Mpawhen coil diameter is 25mm in copper capillary tube.

5.3.4. Temperature variation in Cu capillary tube



Graph: 5.4. According to this plot, temperature varies with respect to coil diameter

Description: Based on the results, this graph is plotted against pressure variation with change in coil diameter by using R22a (red) and R407c (blue). According to this plot while using R22a (red) temperaturedecreased up to 258 k when coil diameter is 25mm, In case of R407c (Blue)temperaturedecreased up to 268 k when coil diameter is 25mm in copper capillary tube.

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Hence the results of copper capillary tube with coil diameter 25 mm by using R22 is far better when compared to various coil diameters of aluminium and copper when using R22 and R407c.

CONCLUSION

In this thesis, the effects of the relevant parameters on the flow characteristic of R407C and R22 flowing through adiabatic helical capillary tubes were studied. The capillary tubes material (Aluminium and copper), tube diameter 1.15 mm, coil diameter (25,30,40 and 50mm), and parameters relating to flow conditions were investigated.

By observing the CFD analysis

- The pressure drop value when using Aluminium capillary tube 4.39 bar and max temperature drop is 33 k at coil diameter 25mm by the fluid R407c.
- The pressure drop value when using Aluminium capillary tube 7.19 bar and max temperature drop is 36 k at coil diameter 25mm by the fluid R22.
- The pressure drop value when using Copper capillary tube 5.85 bar and max temperature drop is 30 k at coil diameter 25mm by the fluid R407c

- The pressure drop value when using Copper capillary tube 7.31 bar and max temperature drop is 40 k at coil diameter 25mm by the fluid R22.

So we can conclude the copper material of coil diameter 25mm and fluid R22 better for capillary tube when compared to aluminum material at various coil diameters over a refrigerant R407c.

In earlier studies, use of alternative refrigerants plays an important role in forming problems such as global warming and ozone depletion. It is observed that R407c has zero ODP, considerably GWP, low flammable, eco-friendly refrigerant and also observed nearly the same flow characteristics of R22 observed in this thesis.

Future scope:

1. By changing pitch of the coil we can get difference results which increase refrigeration effects.
2. By using eco-friendly refrigerants basing on the applications to control pollution caused by refrigerant.
3. By changing the material of capillary tube like bronze, brass etc the properties also changes and will get desire results in the experiment.

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