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CFD Simulation and Heat Transfer Analysis of Automobile Radiator using Helical Tubes

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Abstract:- To ensure smooth running of an automotive vehicle under any variable load conditions, one of the major systems necessary is the cooling system. Automobile radiators are becoming highly power-packed with increasing power to weight or volume ratio. Computational Fluid Dynamics (CFD) is one of the important software tools to access preliminary design and the performance of the radiator. In this paper, a 55 hp engine radiator data is taken for analysis in CFD. The model is done Pro-E software and imported in ANSYS-12. Helical tubes are considered for the radiator with two different pitches like 15mm & 20mm. The comparison is done for different mass flow rates like 2.3, 2.0, 1.0, 0.5 kg/sec in helical type tubes. It is found that there is more heat dissipation rate in 15mm pitch helical tubes compared to 20mm pitch helical tubes. Maximum temperature drop & minimum pressure drop occurs in case of 0.5 kg/sec of mass flow rate. It is observed that with increased mass flow rate, there is decrease in temperature drop & increase in pressure drop.

Keywords:- CFD, ANSYS, Radiator design, Helical tubes, Mass flow rate, Coolant, Pitch, Numerical Simulations.

I. INTRODUCTION

Internal combustion engines are cooled by passing a liquid called as engine c*oolant* through the engine block. The coolant gets heated as it absorbs the heat produced in the engine. It then passes through the radiator where it loses heat to the atmosphere. It is then circulated back to the engine in a closed loop. The engine's life, performance and overall safety are ensured due to effective engine cooling. Automobile manufacturers try to ensure that the engines are compact and energy efficient by thorough optimization process in the design of all engine components, including radiators. Radiators are used for cooling internal combustion engines, piston-engine aircraft, railway locomotives, motorcycles, stationary generating plants, etc.

Hilde Van Der Vyer et al. (2003) simulated a 3-D tube-in-tube heat exchanger using Star-CD CFD software and validated the test results with the experimental work.

Witry et. al., (2003) conducted CFD analysis on radiator using implicit 3-D steady solver for incompressible condition to study shell side airflow pattern and tube side water flow pattern. The variations in overall heat transfer coefficients across the radiator ranged from 75 to 560 W/m^2-K.

Chen et al, (2001) made an experimental investigation of the heat transfer characteristics of a tube-and-fin radiator for vehicles using an experimental optimization design technique on a wind tunnel test rig of the radiator and developed the regression equations of heat dissipation rate, coolant pressure drop and air pressure drop to numerically study influence of various parameters affecting the performance.

Sridhar Maddipatla, (2001) coupled CFD and shape optimization for radiator design on a simplified 2D model. The automated mesh generated using Gambit, CFD analysis using Fluent with a k-ε turbulent model and an in-house C-code implementing a numerical shape optimization algorithm is discussed.

Yiding Cao et al. (1992) introduced heat pipe in radiator including two-phase closed thermosyphons having an effective thermal conductance much higher than that of copper.

Seth Daniel Oduro (2009) looked at the effect of sand blocking the heat transfer area of the radiator and its effect on the engine coolant through the conduct of experiments and a mathematical model developed. The results were generated using regression analysis for clay and silt soil showed that the proportional increase of temperatures at inlet and outlet due to percentage blocked area.

II. ANALYSIS OF RADIATOR USING HELICAL TUBES

Analysis is done in ANSYS-12 software with using CFX for radiator model having helical tube.

Assumptions

In order to solve the analytical model, the following assumptions are made:

Coolant flow rate is constant with no phase change. Heat conduction through the walls of the coolant tube is negligible. Heat loss by coolant was only transferred to the cooling air, thus no other heat transfer mode such as radiation was considered. Coolant fluid flow is in a fully developed condition in each tube. All dimensions are uniform throughout the radiator and the heat transfer surface area is consistent and distributed uniformly. The thermal conductivity of the radiator material is considered to be constant. There are no heat sources and sinks within the radiator. There is no fluid stratification, losses and flow misdistribution. Momentum condition: Tube wall is stationary.

Radiator Specification for Helical type tubes:

Number of tubes	: 29
Helical type tube mean diameter	: 30mm
Pitch	: 15mm & 20mm
Inner diameter of tube	: 2 mm
Outer diameter of tube	: 4 mm

Input Data

Air inlet velocity	: 4.4 m/s
Air inlet temp	: ambient temp
Coolant inlet (mass flow)	: 2.3 kg/s, 2.0 kg/sec, 1.0 kg/sec & 0.5 kg/sec.
Coolant inlet temp	: 98.75^0C
Outside temperature	: 25^0C
Flow region	: Laminar
Mass & Momentum	: Free slip wall

Overall heat transfer co efficient across the radiator ranges from 75 to 560 W/m^2-K

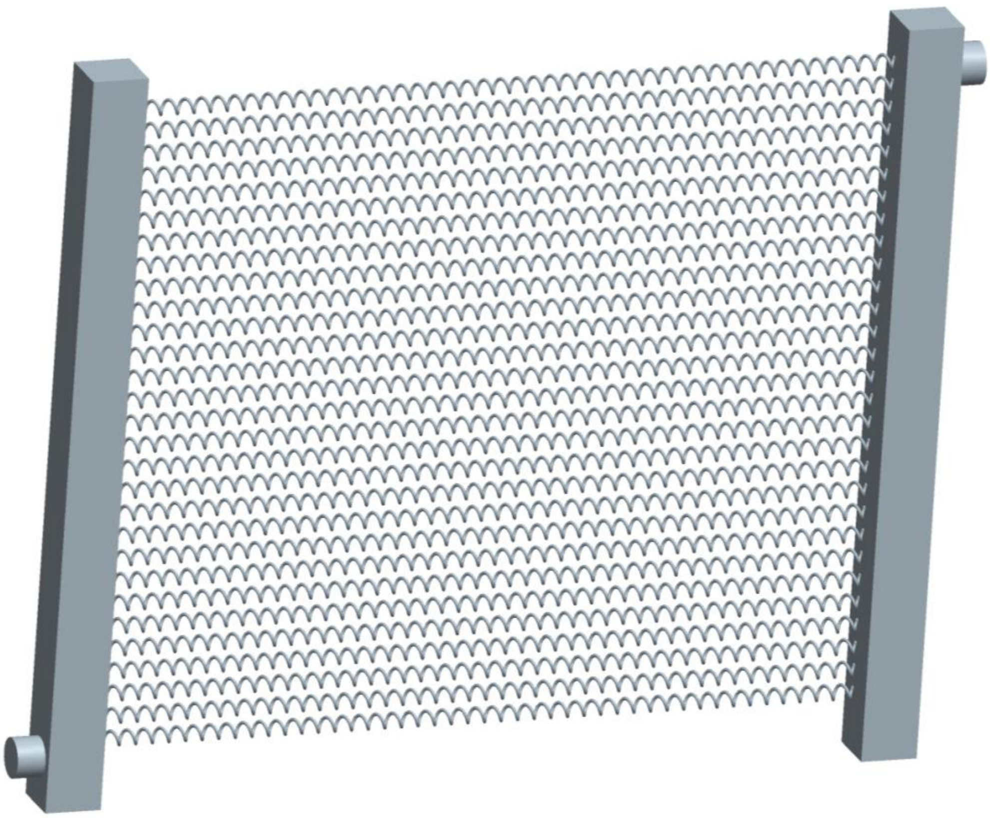

Figure 1: Helical tube radiator model making in Pro-E

The cases considered for the analysis of radiator using helical tubes are for 15mm and 20 mm pitch using ethylene glycol.

Case-1: Analysis of Helical Tube Type Radiator (Pitch-15mm)
Case 1(a): Using Ethylene Glycol Coolant (Mass Flow rate=2.3 kg/sec)

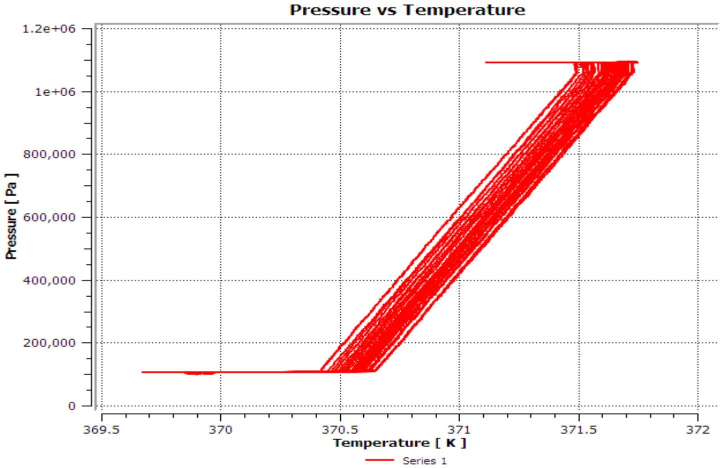

Figure 2: Flow diagram of different tubes related to the pressure & temperature In Helical type Tube (15mm pitch-Ethylene Glycol)

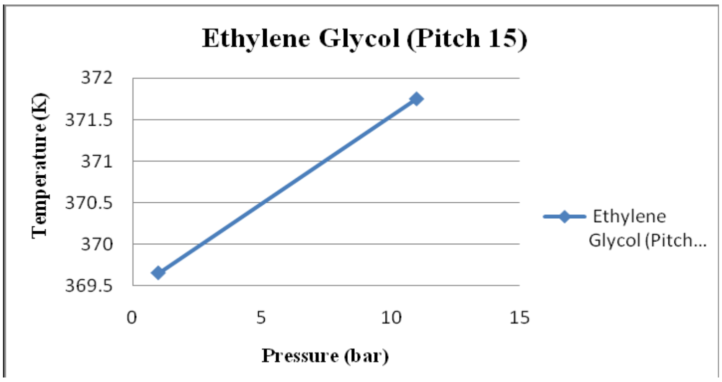

Figure 3: Inlet & Outlet Temperature VS Inlet & Outlet Pressure of Helical Tube (Ethylene Glycol)

From figure 2 & 3, it is observed that the ΔT is 2.1 K and ΔP is10 bar.

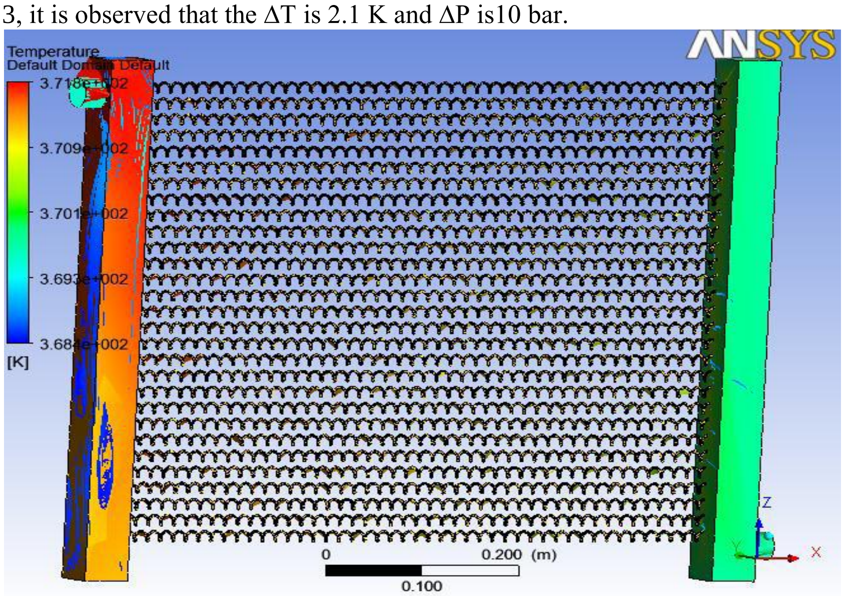

Figure 4: Temperature diagram of helical tubes used in Radiator. (Ethylene Glycol)

In figure 4 temperature range in radiator indicated with different colour. Inlet has 371.75K the maximum temperature & outlet has 369.5 K minimum temperature.

Case 1(b): Using Ethylene Glycol Coolant (Mass Flow rate= 2 kg/sec)

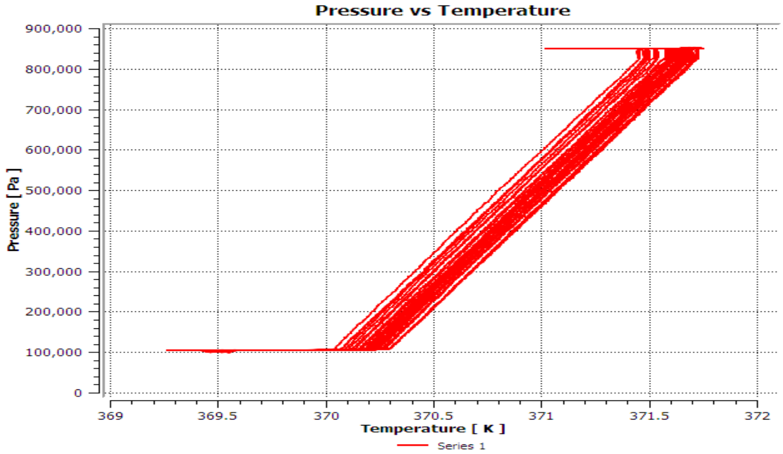

Figure 5: Flow diagram of different tubes related to the pressure & temperature in Helical type Tube (15mm pitch-Ethylene Glycol)

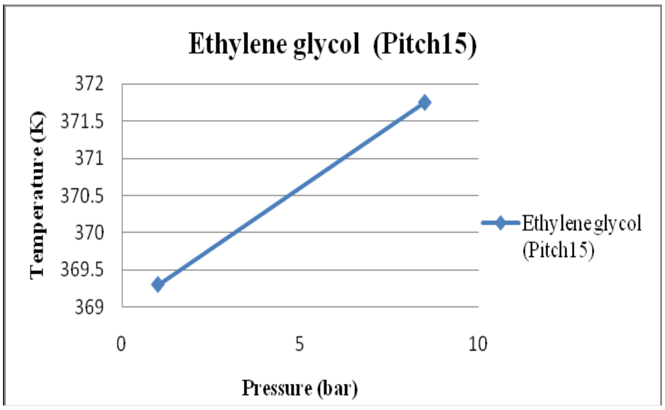

Figure 6: Inlet & Outlet Temperature Vs Inlet & Outlet Pressure of Helical Tube (Ethylene Glycol)

From figure 5 & 6, it is observed that the ΔT is 2.45 K and ΔP is7.5 bar.

Case-1 (c): Using Ethylene Glycol Coolant (Mass Flow rate = 1 kg/sec)

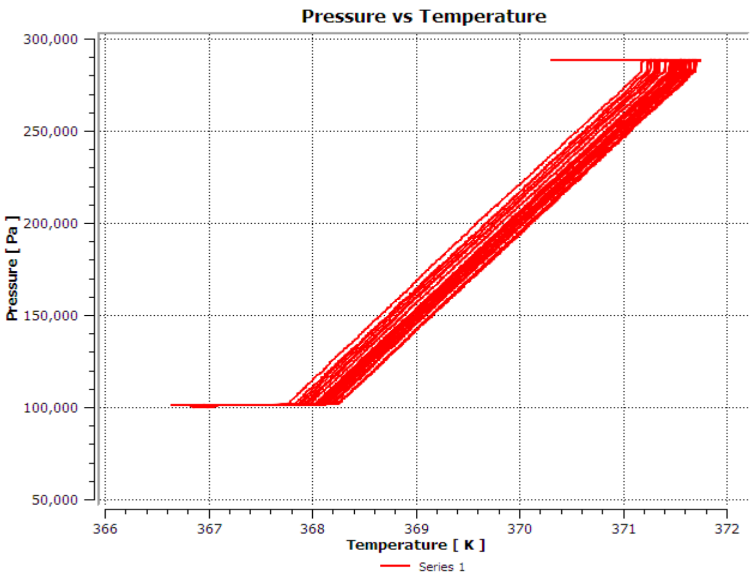

Figure 7: Flow diagram of different tubes related to the pressure & temperature In Helical type Tube (15mm pitch-Ethylene Glycol)

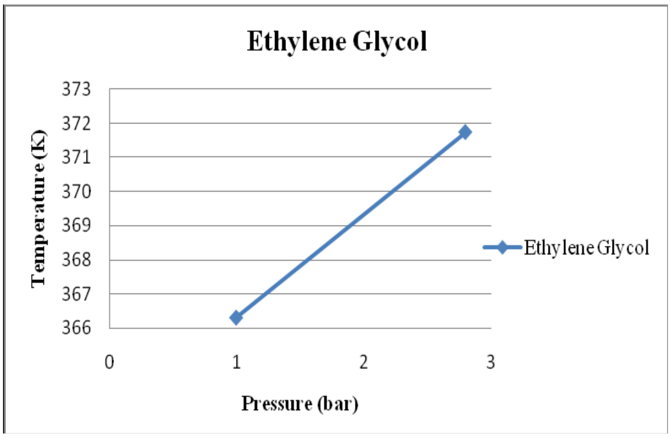

Figure 8: Inlet & Outlet Temperature VS Inlet & Outlet Pressure of Helical Tube (Ethylene Glycol)

From figure 8 & 9, it is observed that the ΔT is 5.45 K and ΔP is1.8 bar.

Case 1(d): Using Ethylene Glycol Coolant (Mass Flow Rate = 0.5 kg/sec)

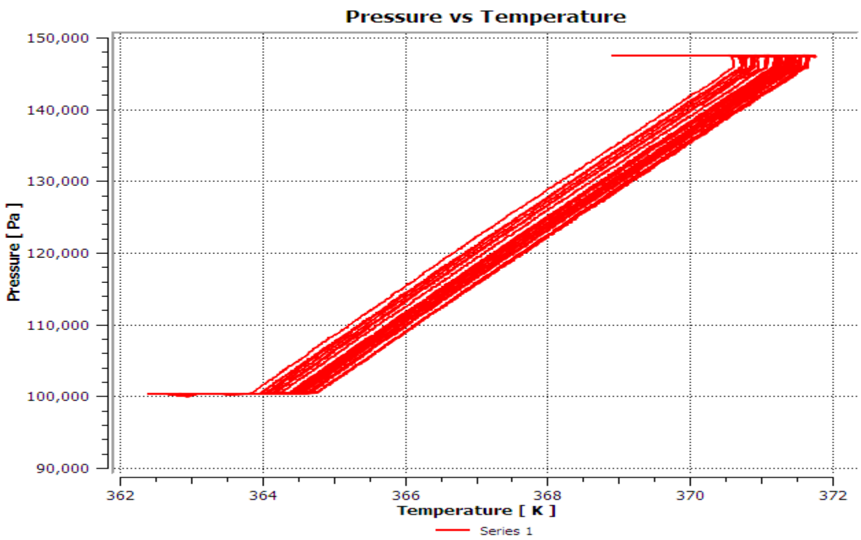

Figure 9: Flow diagram of different tubes related to the pressure & temperature In Helical type Tube (15mm pitch-Ethylene Glycol)

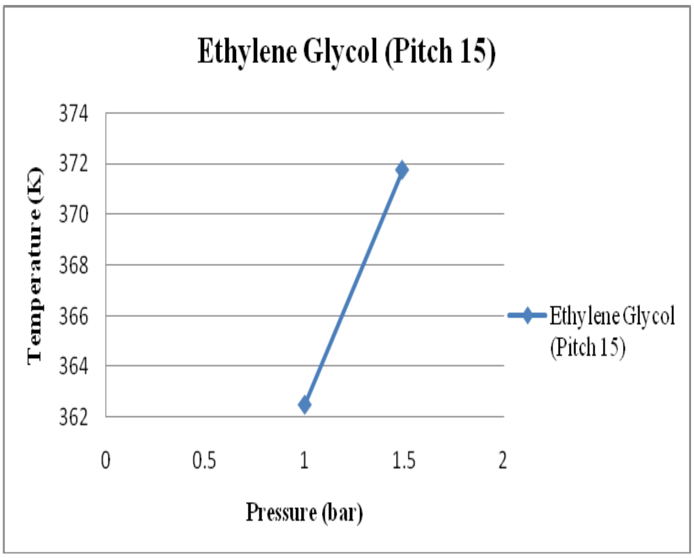

Figure 10: Inlet & Outlet Temperature VS Inlet & Outlet Pressure of Helical Tube (Ethylene Glycol)

From figure 9 & 10, it is observed that the ΔT is 9.25 K and ΔP is 0.49 bars.

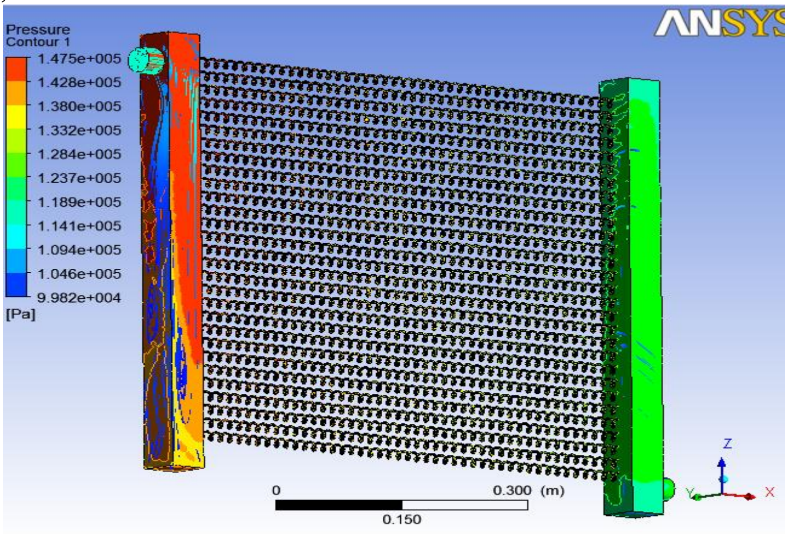

Figure 11: Pressure diagram of Helical Tubes. (Ethylene Glycol)

From above fig.11 shows the pressure distribution of radiator tubes.

Case 2: Analysis of Helical Tube type Radiator (Pitch: 20mm)
Case 2(a): Using Ethylene Glycol Coolant (Mass Flow rate = 2.3 kg/sec)

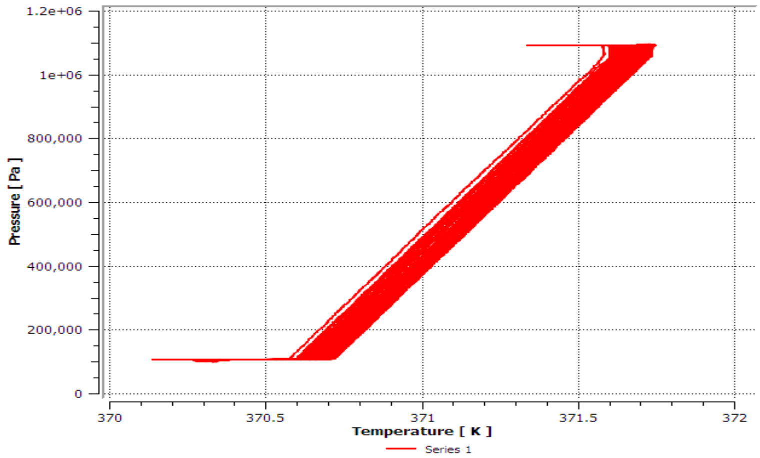

Figure 12: Flow diagram of different tubes related to the pressure & temperature in Helical type Tube (20mm pitch-Ethylene Glycol)

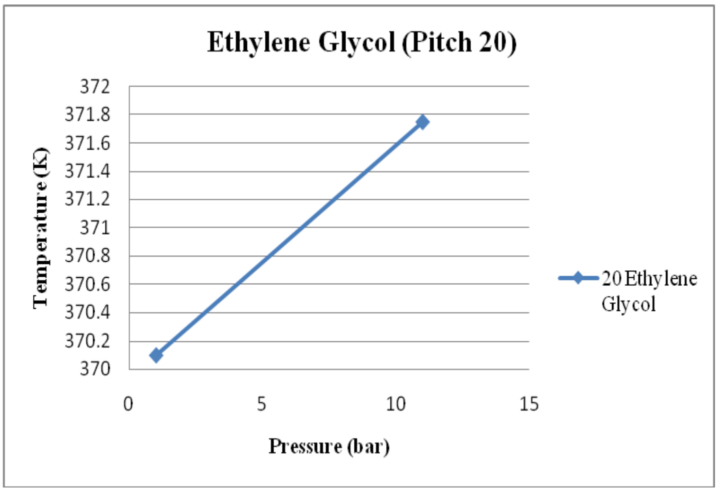

Figure 13: Inlet & Outlet Temperature VS Inlet & Outlet Pressure of Helical Tube (Ethylene Glycol)

From figure 12 & 13, it is observed that the ΔT is 1.65 K and ΔP is 10 bars.

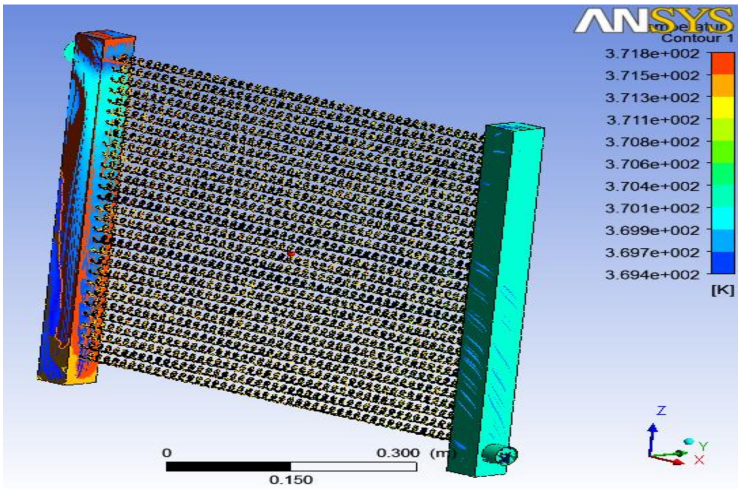

Figure 14: Temperature diagram of helical tubes used in Radiator. (Ethylene Glycol)

Figure 14 shows that temperature range in radiator indicated with different colours. Inlet has 371.75K the maximum temperature & outlet has 370.10 K minimum temperature.

Case 2(b): Using Ethylene Glycol Coolant (Mass Flow Rate = 2 kg/sec)

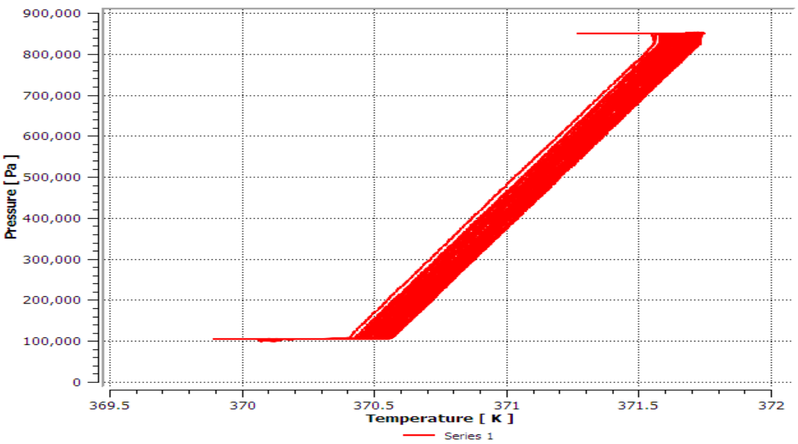

Figure 15: Flow diagram of different tubes related to the pressure & temperature In Helical type Tube (20mm pitch-Ethylene Glycol)

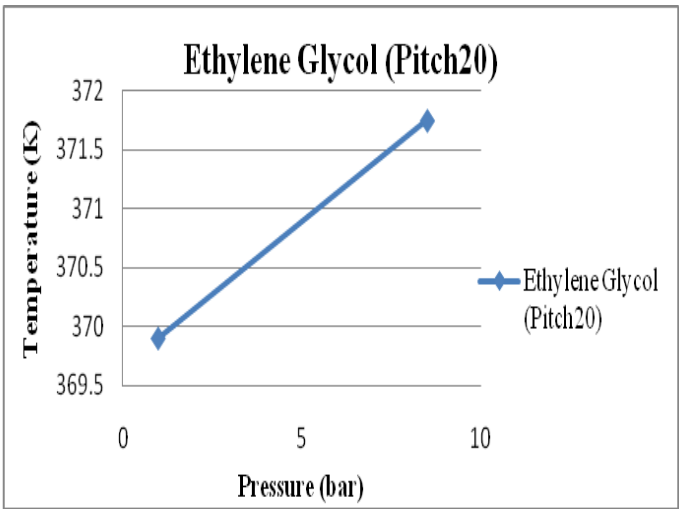

Figure 16: Inlet & Outlet Temperature VS Inlet & Outlet Pressure of Helical Tube (Ethylene Glycol)

From figure 15 & 16, it is observed that the ΔT is 1.85 K and ΔP is 7.5 bars.

Case 2(c): Using Ethylene Glycol Coolant (Mass Flow rate = 1.0 kg/sec)

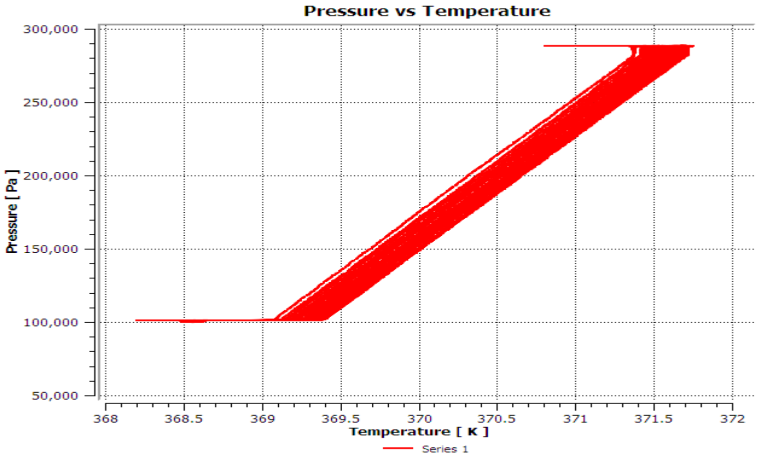

Figure 17: Flow diagram of different tubes related to the pressure & temperature In Helical type Tube (20mm pitch-Ethylene Glycol)

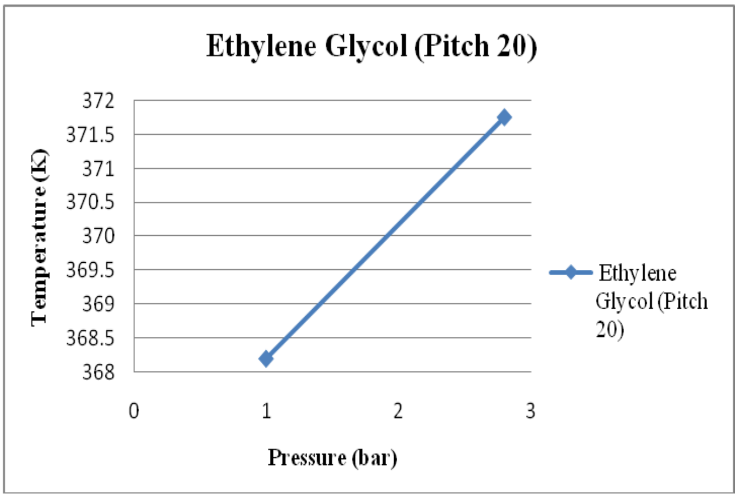

Figure 18: Inlet & Outlet Temperature VS Inlet & Outlet Pressure of Helical Tube (Ethylene Glycol)

From figure 17 & 18, it is observed that the ΔT is 3.55 K and ΔP is1.8 bar.

Case 2(d): Using Ethylene Glycol Coolant (Mass Flow rate= 0.5 kg/sec)

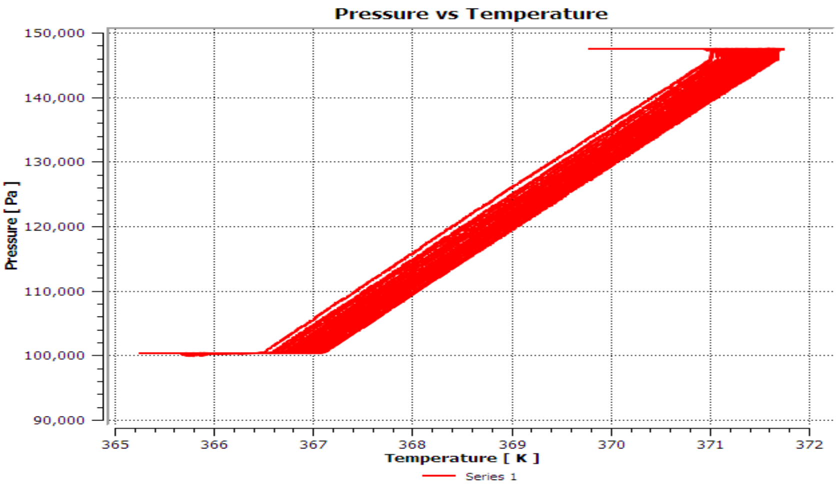

Figure 19: Flow diagram of different tubes related to the pressure & temperature In Helical type Tube (20mm pitch-Ethylene Glycol)

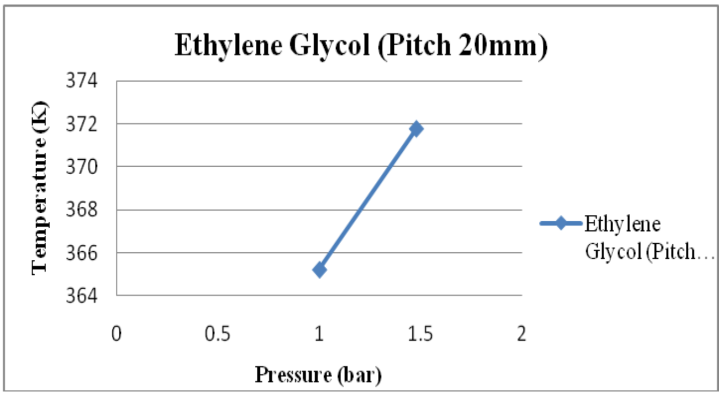

Figure 20: Inlet & Outlet Temperature VS Inlet & Outlet Pressure of Helical Tube (Ethylene Glycol)

From figure 19 & 20, it is observed that the ΔT is 6.55 K and ΔP is 0.48 bars.

The results of Case 1 are summarized in table 1. It is found that with increased mass flow rate, there is decrease in temperature drop & increase in pressure drop.

Table1: Helical Tube Radiator - Pitch 15mm-Case 1

Mass flow rate kg/sec	Inlet Temp. (K)	Outlet Temp. (K)	Inlet Pres. (K)	Outlet Pres. (bar)	Temp. Drop (bar)	Pres. Drop (bar)
2.3	371.75	369.65	11	1.0	2.1	10
2.0	371.75	369.30	8.5	1.0	2.45	7.5
1.0	371.75	366.30	2.8	1.0	5.45	1.8
0.5	371.75	362.50	1.49	1.0	9.25	0.49

The results of Case 2 are summarized in table 2. It is found that with increased mass flow rate, there is decrease in temperature drop & increase in pressure drop.

Table2: Helical Tube Radiator - Pitch 20mm- Case 2

Mass flow rate kg/sec	Inlet Temp. (K)	Outlet Temp. (K)	Inlet Pres. (K)	Outlet Pres. (bar)	Temp. Drop (bar)	Pres. Drop (bar)
2.3	371.75	370.10	11	1.0	1.65	10
2.0	371.75	369.90	8.5	1.0	1.85	7.5
1.0	371.75	368.20	2.8	1.0	3.55	1.8
0.5	371.75	365.20	1.48	1.0	6.55	0.48

Case-3: Comparison between Helical tubes used in radiator with Pitch 15mm & 20mm using Ethylene Glycol as Coolant

Case-3(a): Comparison at Mass Flow Rate = 2.3 kg/sec

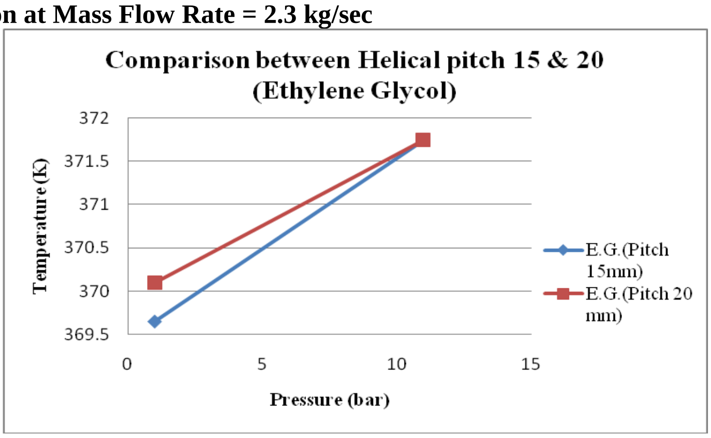

Figure 21: Comparison between helical pitch 15mm &20mm

Case-3(b): Comparison of helical at pitch 15 and 20 at m=2.0 kg/sec

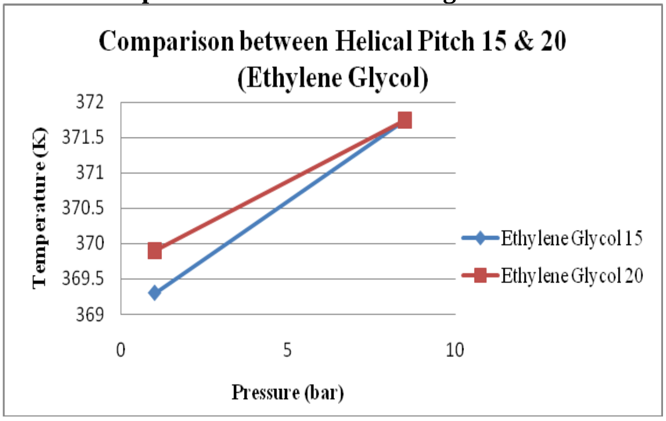

Figure 22: Comparison between helical pitch 15mm &20mm

Case-3(b): Comparison at Mass Flow Rate =1.0 kg/sec

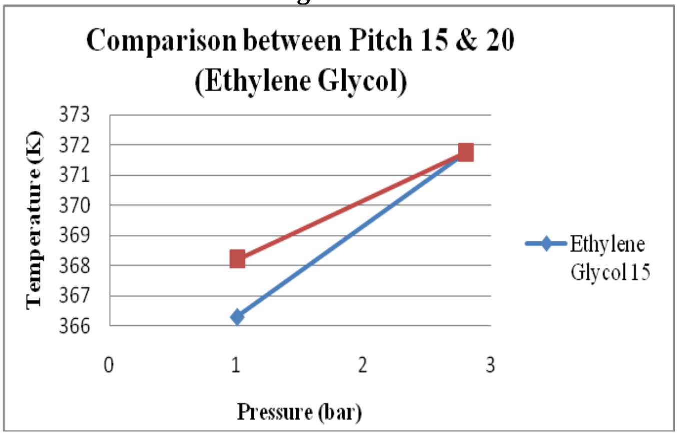

Figure 22: Comparison between helical pitch 15 &20(Ethylene Glycol)

Case-3(c): Comparison at Mass Flow Rate = 0.5 kg/sec

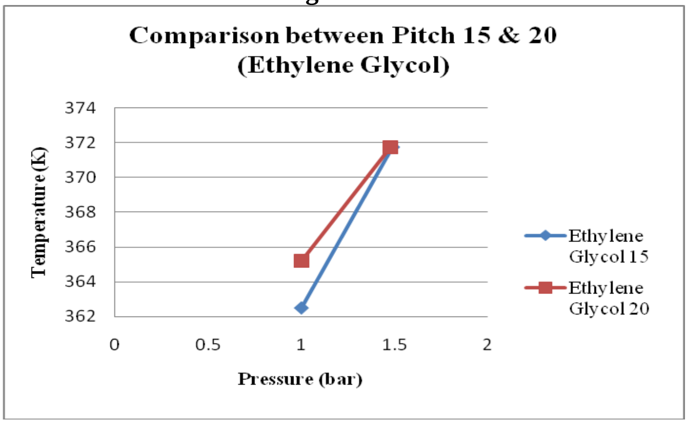

Figure 23: Comparison between helical pitch 15 &20

From the above cases of Case-3, i.e. (a), (b) and (c) it is found that compared to 20mm pitch helical tubes, 15 mm pitch has higher temperature drop.

Case 4: Comparison of different Mass Flow Rate

Case- 4(a): Comparison between different Mass Flow Rate in Helical tubes used in Radiator Considering Ethylene Glycol as Coolant and at 15mm Pitch

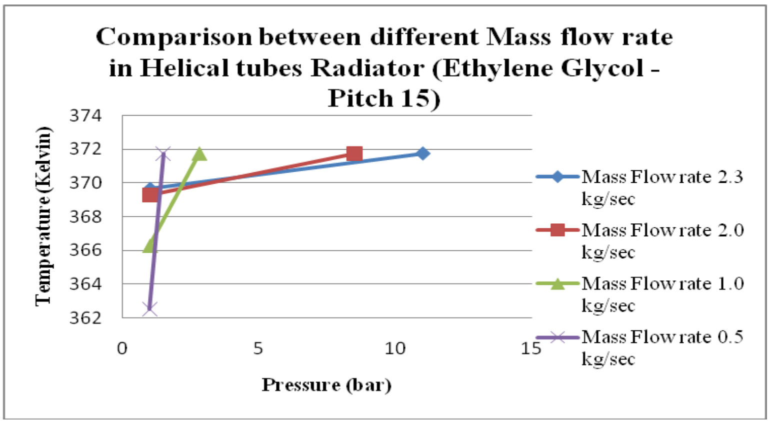

Figure 24: Comparison between different Mass Flow rate in Helical tubes Radiator (Ethylene Glycol – Pitch 15)

Case- 4(b): Comparison between different Mass Flow Rate in Helical tubes used in Radiator Considering Ethylene Glycol as Coolant and at 20mm Pitch

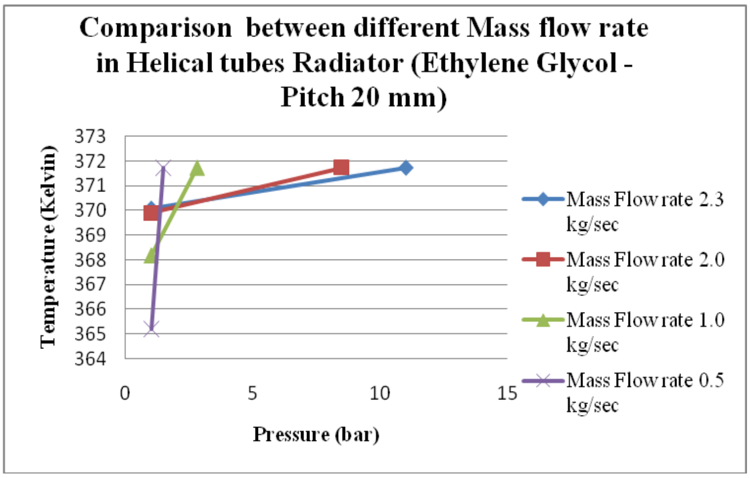

Figure 25: Comparison between different Mass Flow rate in Helical tubes Radiator (Ethylene Glycol – Pitch 20)

From the above cases of Case-4, i.e. (a), (b) it is found that for different mass flow rate like 2.3, 2.0, 1.0, 0.5 kg/sec in helical type tubes in radiator, maximum temperature drop & minimum pressure drop is observed for the case of 0.5 kg/sec of mass flow rate in helical type tubes of radiator.The figure 24 and 25 shows that temperature drop decrease with increased mass flow rate & pressure drop increased with increased mass flow rate.

III. CONCLUSION

From the result obtained for different cases it can be concluded that:

- For different pitch used in radiator like 15mm pitch & 20mm pitch in helical type tubes, 15mm pitch helical gives more temperature drop compared to 20mm pitch helical tube & also more pressure drop occurs in 15mm pitch helical tubes than with 20 mm pitch.
- Comparison between different mass flow rate like 2.3, 2.0, 1.0, 0.5 kg/sec in helical type tubes in radiator, indicate that maximum temperature drop & minimum pressure drop occur in case of 0.5 kg/sec of mass flow rate in helical type tubes of radiator.

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