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Experimental Study of Performance Investigation of a Heavy Vehicle Automotive Radiator

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Highlights:

- Designing of a wavy and louvered fin based heavy vehicle automotive radiator.
- CFX simulation of cross flow heat transfer of nanofluids in circular tubes.
- To evaluate the fluid flow analysis and cooling capacity by estimating temperature distribution of nanofluid as coolant.

Abstract: In continuous technological development, an automotive industry has increased the demand for high efficiency engines. A high efficiency engines is not only based on its performance but also for better fuel economy and less emission rate. Researches in heat transfer have been carried out over the previous several decades, leading to the development of the currently used heat transfer enhancement techniques.
Radiator is one of the important parts of the internal combustion engine cooling system. So improving the performance and reducing cost of radiator is the necessary research. For higher cooling capacity of radiator, addition of fins is one of the approaches to increase the cooling rate of the radiator. The water and ethylene glycol as conventional coolant have been widely used in an automotive radiator in many years. With the advancement of nanotechnology, a coolant are invented which is known as "nanofluids". The Researchers found that these fluids offer higher thermal conductivity compared to that of conventional coolants. With these specific characteristics, the size and weight of an automotive car radiator can be reduced without affecting its heat transfer performance.
An automotive radiator (Wavy and Louvered fin type) model is modeled on modeling software CATIA V5 and performance evaluation is done on pre-processing software ANSYS 14.0. Present study outline that the use of fins and nano fluid may improve the performance of automotive radiator. Results have shown that the rate of heat transfer is better when nano fluid (Si C + water) is used as coolant, than the conventional coolant.

Keywords: Automotive radiator, Nano fluid, Wavy and Louvered fin, Circular tube geometry, performance parameters.

Introduction

The automotive industry is continuously involved in a strong competitive career to obtain the best automobile design in multiple aspects (Performance, fuel consumption, aesthetics, safety etc.)[1]. Reducing a vehicle weight by optimizing design and size of a radiator is a necessity for making the world green [2]. The air-cooled heat exchangers found in a vehicle (radiator, AC condenser and evaporator, charge air cooler etc.) have an important role in its weight and also in the design of its front-end module, which also has a strong impact on the car aerodynamic behaviour[1]. The growth of technology challenges, an optimization process is mandatory to obtain the best design compromise between performance, size/shape and weight [3].

Automotive radiators are heat exchangers used to transfer thermal energy from one medium to another for the purpose of cooling and heating. Improving the performance and reducing cost of radiators are necessary research. A radiator is hotter than the air surrounding it because hot water passes through the hollow tubes, an amount of heat is transferred to the air and thus the water exits at lower temperature. The first law of thermodynamics states that in steady state heat flow, all of the energy put into a system must come out again.
For higher cooling capacity of radiator, addition of fins is one of the approaches to increase the cooling rate of the radiator. It provides greater heat transfer area and enhances the air convective heat transfer coefficient. In addition, heat transfer fluids at air and fluid side such as water and ethylene glycol exhibit very low thermal conductivity. As a result there is a need for new and innovative heat transfer fluids for improving heat transfer rate in an automotive car radiator.

With these specific characteristics, the size and weight of an automotive car radiator can be reduced without affecting its heat transfer performance. This translates into a better aerodynamic feature for design of an automotive car frontal area [2]. Change in the design and dimensions of the tubes, direction of flow, materials,

concentration of nano particle, incorporation of fins and fins design and types are some methods by which the heat transfer enhancement can be done in the thermal management in the automobile industries.

In this work, a 3D compact tube fin type automotive radiator by considering different fin geometries like wavy and louvered fin is modeled on modeling software CATIA V5 and compact radiator performance is analyzed on pre-processing software ANSYS 14.0. Also the performance of a radiator has been compare by considering nano particle like Si C in a base fluid like 80% water-20% Ethylene glycol with a conventional coolant.

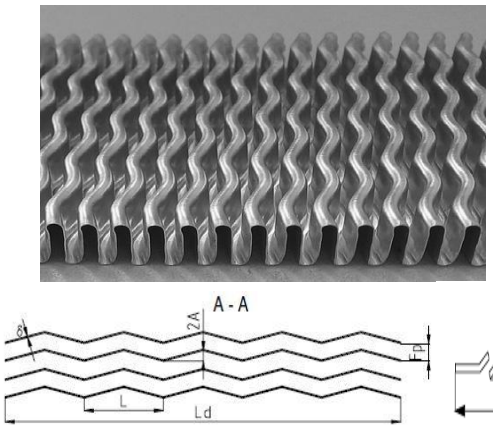


Fig.1 Geometry of wavy fin

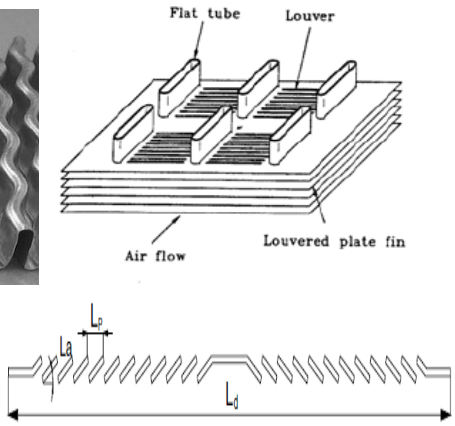


Fig.2. Louvered fin geometry

Nomenclature

A	Total heat transfer area
C	Heat capacity rate
c_p	Specific heat
D_h	Hydraulic diameter
F_h	Fin height
F_p	Fin pitch
H	Heat transfer coefficient
K	Thermal conductivity
L_d	Fin length
Q	Heat transfer rate
ṁ	Mass flow rate
T	Fin thickness
T	Temperature
u	Fluid velocity
U	Overall heat transfer coefficient

Abbreviations

a	Air
f	Fin
i	Inlet
o	Outlet
bf	Basefluid
nf	Nanofluid
np	Nanoparticles
Si	Silicon Carbide

1. Geometric Modeling

2.1 Problem Geometry Wavy fin Radiator

A compact automotive radiator is a type of heat exchanger, is made of four major components as coolant inlet tank, outlet tank, pressure cap and core. The main subcomponents of the core are tubes and fins. Circular tubes are more effective for automotive engine applications due to their low drag compared with elliptical tubes.

The design is a circular tube and wavy fin based automotive radiator which is designed for getting high cooling rate with nanofluids. There is no. of circular tubes which are arranged in parallel design use for the support of fins as well as contain the necessary volume of coolant.

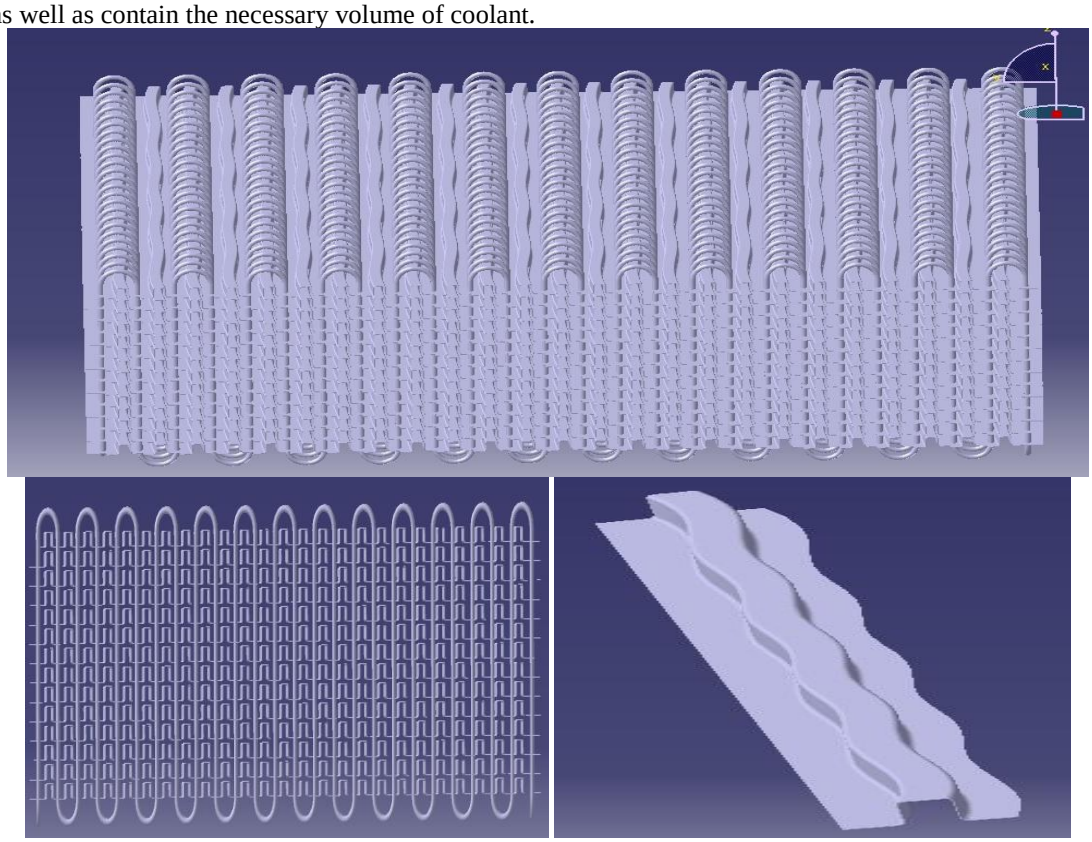
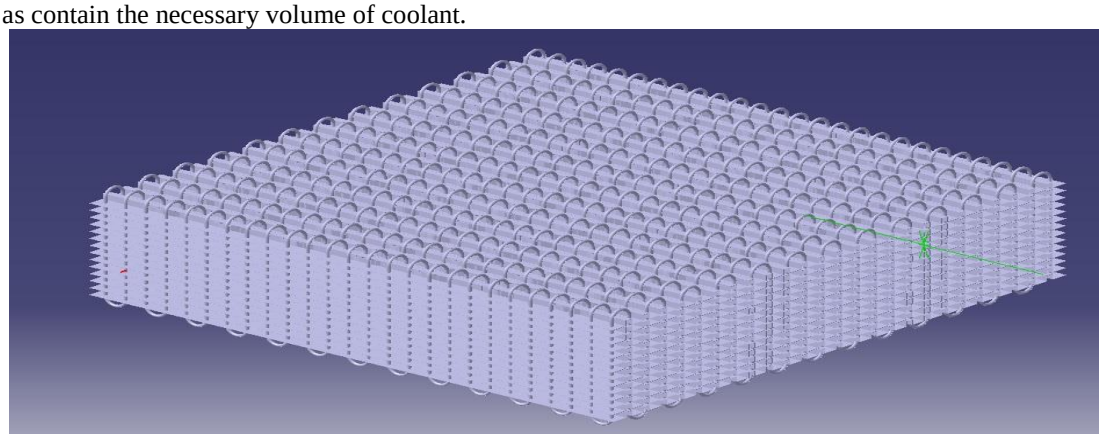


Fig.3 Isometric and front view of wavy fin automotive radiator

2.2 Problem Geometry of louvered fin Radiator

The design is a circular tube and louvered fin based radiator which is designed for getting high cooling rate with nanofluids. There is no. of circular tubes which are arranged in parallel design for the support of fins as well as contain the necessary volume of coolant.



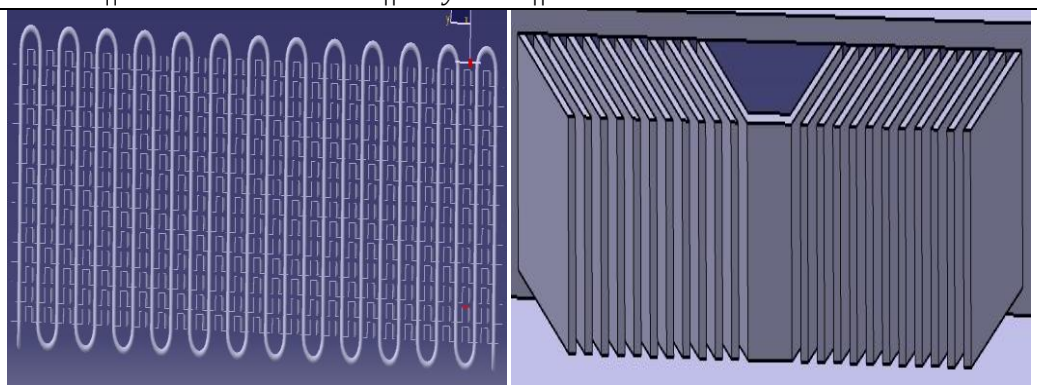


Fig.4 Isometric and front view of louvered fin automotive radiator

2. Mathematical Modeling

The governing equations are assumed to be steady state for in compressible fluid and the fluid inside the tube has Newtonian behaviour. The density of the water and ethylene glycol-based nanofluids is almost constant under pressure. Ambient temperature and an air velocity through the air cooled exchanger are assumed to constant. Inlet velocity and temperature of the circular tube is uniform. Thermal equilibrium is established between the Nanoparticles and the base fluid. The wall resistance and fouling factors are taken as negligible.
The following assumptions have been made for analysis:

1) The fin material is homogeneous and isotropic.
2) The temperature at any cross section of the fin is uniform i.e. t=t(x) only.
3) Properties of nanofluid as well as air assumed to be constant.
4) Heat flow is Steady state flow.
5) All the heat rejected from nanofluid absorbed by air flow through radiator.
6) There is no heat generation.
7) Contact thermal resistance is negligible.

3. Input Parameters

The radiator which is considered in the study, is mounted on the present turbo-charged diesel engine, is cross flow compact heat exchanger with unmixed flow. Radiator consists of 625 tubes make of brass and 346 continuous fins made of Aluminum alloy whose thermal conductivity is 177 W/m K. The common geometrical factors and operating conditions are described in the tables 1 and 2. The geometric parameters for louvered fin are given in table 3 and for wavy fin in table 4. Properties of base fluid and air are given in Table 5. Properties of nano particle are given in table 6.

Table 1: Fluid parameters and Normal Operating conditions

S.No.	Description	Air	Coolant
1.	Fluid mass rate	16 Kg/s	8 Kg/s
2.	Fluid inlet temperature	35℃	68℃
3.	Core Width	60 cm	
4.	Core height	60 cm	
5.	Core depth	1.7 cm	

Table 2: Surface core geometry of flat tubes and fins

S.No.	Description	Air side	Coolant side
1.	Fin metal thickness	0.025 cm	
2.	Hydraulic Diameter	0.351 cm	0.373 cm
3.	Total heat transfer area	886	138
4.	Fin area	0.845	

Table 3: Specification of multi-louvered fin parameters

S. No.	Description	Fin Dimension
1.	Louver angle (L_a)	28°
2.	Fin pitch (F_p)	2 mm
3.	Louver pitch (L_p)	1.2 mm
4.	Fin height (F_h)	8 mm

5.	Louver height (L_h)	6.5 mm
6.	Fin length (L_d)	36.6 mm

Table 4: Specification of Wavy fin parameters

S. No.	Description	Fin Dimensions
1.	Fin pitch (F_p)	2 mm
2.	Fin height (F_h)	8 mm
3.	Louver depth (L_d)	36.6 mm
4.	Fin depth (2A)	1.5 mm
5.	Fin length (L)	10.8 mm

Table 5: Thermal physical properties of base fluid (80% water-20% Ethylene glycol) and air

S.No.	Thermal physical properties	Base fluid	Air
1.	Density (kg/m^3)	1008	1.1614
2.	Specific heat (J/kg K)	4020	1007
3.	Viscosity (N-s/m^2)	0.0019	0.00001846
4.	Conductivity (W/m K)	0.58	

Table 6: Thermal physical properties of Nanoparticles

S.No.	Thermal physical properties	Silicon Carbide (Si C)
1.	Density (kg/m^3)	3160
2.	Specific heat (J/kg K)	1340
3.	Conductivity (W m/K)	350

4. Simulation Process

For implementing the analysis, pre-processing software ANSYS 14.0 is used for the compact heat exchanger. This software is useful in analyzing the fluid properties at operating temperatures is estimating the velocity and temperature distribution of coolant and air of cross flow automotive radiator. Numerical simulation approach is adopted using the theory of three-dimensional computational fluid dynamics and flow direction is studied with the help of CFX. With this approach, it was able to generate three dimensional patterns for temperature and pressure of coolant and air, inside and outside the radiator respectively.

As the model analysis is difficult with available resources, 625 tubes model is reduced to 16 tubes model which gives the same result, in the specific ratio. The radiator model is imported from CATIA to ANSYS through a Neutral file format STEP. Imported model contains only single volume of radiator with fins. For the analysis of the radiator model, we need volume of coolant and air flow. Coolant volume is created by selecting all the inner surfaces of the radiator where the coolant flows.

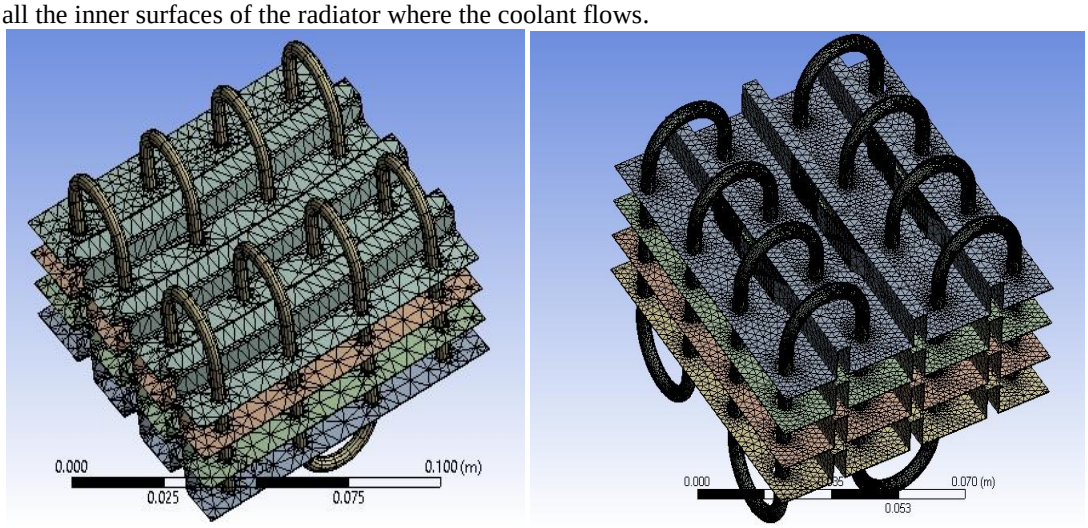


Fig.5 Meshing of a small section of radiator (Wavy and Louver fin)

5. Results

The variation of cooling capacity with air mass flow rate from 15 to 20 kg/s is shown in fig.14 keeping constant average values for other input data(m_c=8 kg/s, T_{ai}=35°C,T_{nfi}=68°C). It has been found that with increase in mass flow rate of air, cooling capacity goes on increasing because of increasing heat transfer coefficient. Also, cooling capacity of nanofluids having base fluid of 80% water-20% EG is much higher as compared to 80% water-20% EG mixture only.

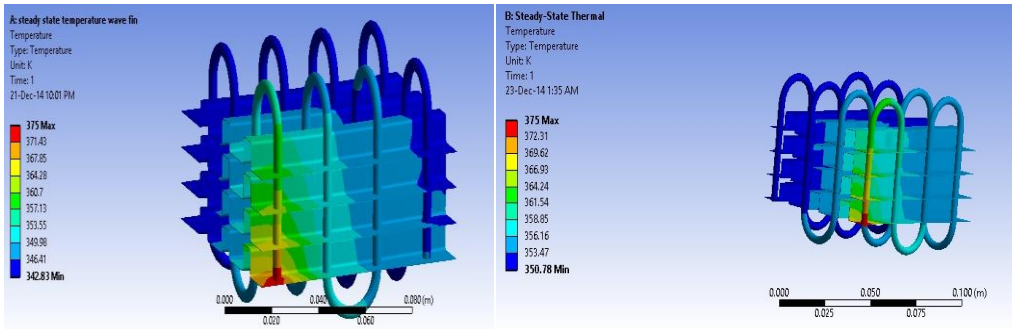


Fig.6 The variation of coolant (Si C) temperature (K) for wavy and louver fin

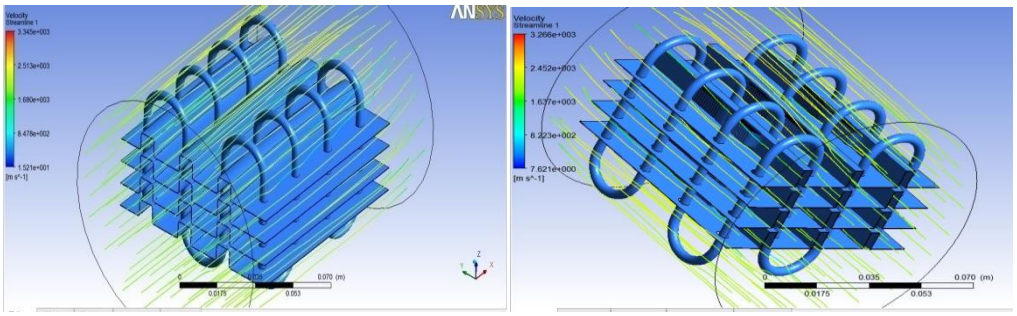
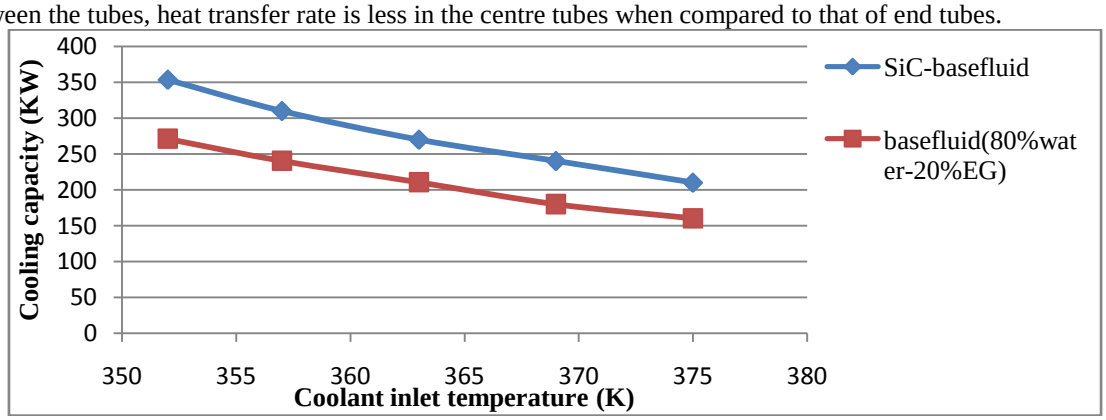


Fig.7 Air flow variation through the wavy and louver fin radiator

As heat transfer rate is more in tubes when coolant just enters. As the air flow rate is very less in between the tubes, heat transfer rate is less in the centre tubes when compared to that of end tubes.



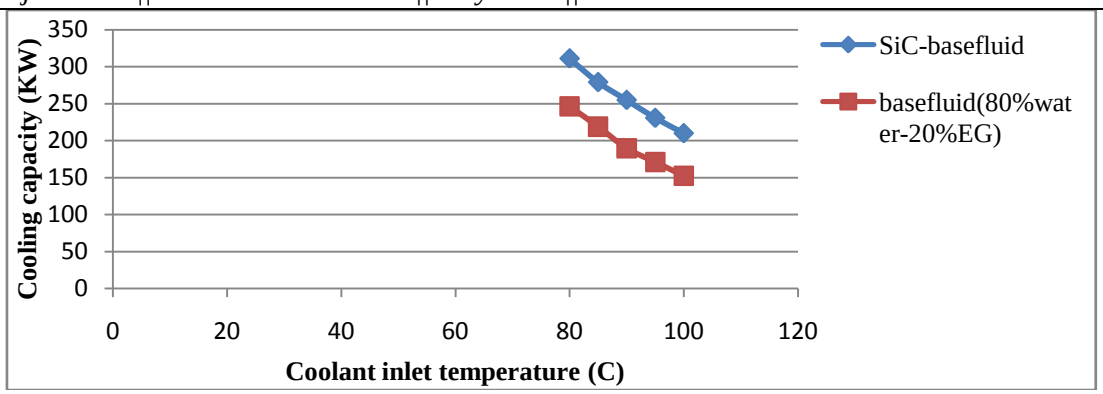
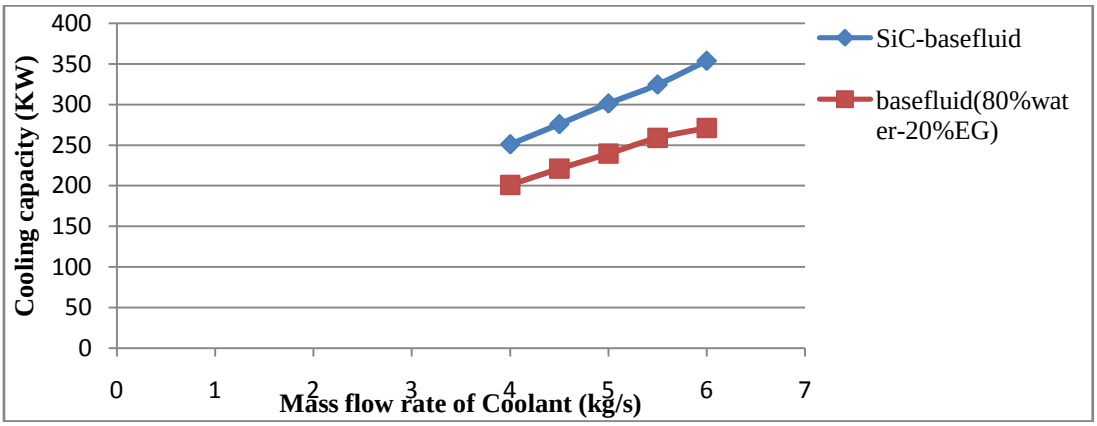


Fig.8 Effect of coolant inlet temperature on cooling capacity



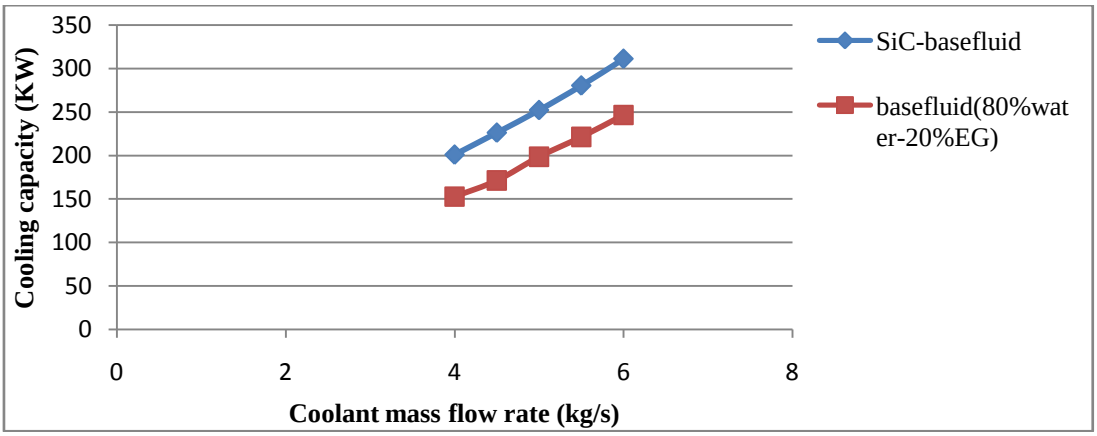


Fig.9 Effect of mass flow rate of coolant on cooling capacity

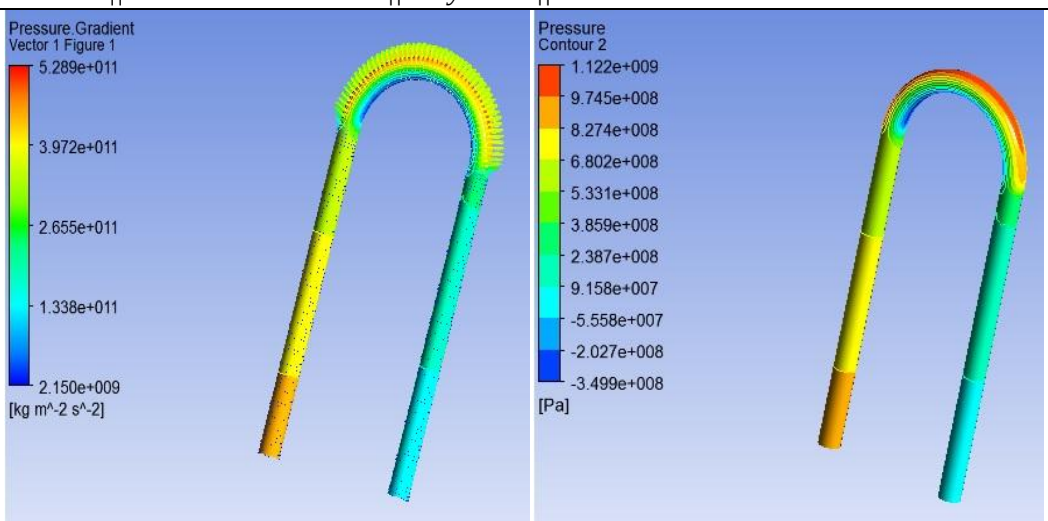


Fig.10 Contours of pressure distribution of coolant through tube

6. Discussion

Table 7 shows the comparison of Cooling capacity (KW) of circular tube radiator having different fin geometry using nano particle (Si C) in a base fluid (80% water-20%EG) with inlet conditions.

S. NO.	Types of geometry	Si C Base fluid	Only base fluid
1.	Wavy fin	353.76	271.27
2.	Louvered fin	311.28	246.57

Table 7: Comparison of cooling capacity (KW)

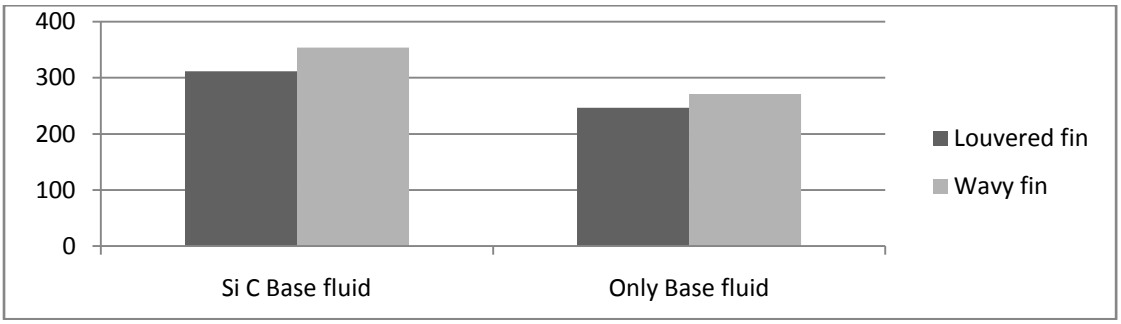


Fig.11 Comparison of cooling capacity (KW)

7. Conclusion

A detailed studies on compact automotive radiator has been done by using CAE based tools as CATIA V5 and ANSYS 14.0 using nanofluid Si C in a base fluid 80%water-20%EG as a coolant for louvered fin and wavy fin geometries. By obtaining results and comparison, the conclusion has been done;

- Cooling capacity increases with increase in mass flow rate of air and coolant.
- Reduction in cooling capacity with the increase in inlet air temperature while cooling capacity increases with the increase in inlet coolant temperature.
- Cooling capacity of radiator using nanofluid as coolant is much higher than radiator using base fluid alone.
- The pressure drop also increases with the increase in air and coolant mass flow rate through radiator.
- About 8% increment in cooling capacity with the use of wavy fin heat exchanger as compared to louvered fin heat exchanger.

However, continued studies in various aspects for a better design of the radiator are suggested as;

- Experimental set up will be prepared for different fin geometry and comparison of this result will be done with experimental data.

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