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Modeling and Fluid Flow Analysis of Wavy Fin Based Automotive Radiator

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Highlights

- ✓ Modeling of Wavy fin based Heavy vehicle automotive radiator.
- ✓ CFX simulation of cross flow heat transfer of nanofluids in circular tubes.
- ✓ Compare the cooling capacity by estimating temperature distribution of nanofluid as coolant to water/EG as base fluid alone.

Abstract:
In continuous technological development, an automotive industry has increased the demand for high efficiency engines. A high efficiency engines in not only based on its performance but also for better fuel economy and less emission rate.
Radiator is one of the important parts of the internal combustion engine cooling system. The manufacturing cost of the radiator is 20 percent of the whole cost of the engine. So improving the performance and reducing cost of radiators are necessary research. For higher cooling capacity of radiator, addition of fins is one of the approaches to increase the cooling rate of the radiator. 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, known as “Nano fluid” for improving heat transfer rate in an automotive radiator. Recently there have been considerable research findings highlighting superior heat transfer performances of nanofluids about 15-25% of heat transfer enhancement can be achieved by using types of nanofluids. 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 fin type) model is modeled on modeling software CATIA V5 and performance evaluation is done on pre-processing software ANSYS 14.0. The temperature and velocity distribution of coolant and air are analyzed by using Computational fluid dynamics environment software CFX. 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, Nanofluid, Wavy fin and circular tube geometry, performance parameters.

I. Introduction

As a type of compact heat exchanger, plate fin heat exchangers are used in a wide variety of applications. Typical among these are automobile radiators, air conditioning evaporators and condensers, charge air coolers, electronic cooling devices and cryogenic exchangers to meet the demand for saving energy and resources. To reduce the size and weight of heat exchangers, various augmented surfaces have been developed to improve the air side heat transfer performances. Typical fin geometries are plain fins, wavy fins, offset fins, perforated fins, pin fins and louvered fins. For the complex geometries, which are usually set up in a cross flow arrangement, with wavy fin geometry in a compact automotive radiator. Heat exchangers are used either individually or as components of a large thermal system, in a wide variety of commercial, industrial and household applications, e.g. power generation, refrigeration, ventilating and air-conditioning systems, process, manufacturing, aerospace industries, electronic chip cooling as well as in environmental engineering. The improvements in the performance of the heat exchangers have attracted many researchers for a long time as they are of great technical, economical, and not the least, ecological importance.

Incessant technological development in automotive industries has required for high efficiency engines. A high efficiency engine is not only based on the performance of radiator but also depends on better fuel economy and less emission rate. Reducing the vehicle weight by optimizing design and size of a radiator is a capital feature. Addition of fins is one of the approaches to increase the heat transfer rate of radiator, provides greater heat transfer area and enhances the air convective heat transfer coefficient. The typical tube geometry uses in the compact automotive radiator, are flat, circular and elliptical in shape.

The conventional method of increasing the cooling rate is to use extended heat transfer surfaces for exchanging heat with a heat transfer fluid. However, this approach requires an undesirable increase in the size of the thermal management system. In addition, the inherently poor thermo physical properties of conventional heat transfer fluids such as water, ethylene glycol (EG) or engine oil (EO) greatly limit the cooling performance. Thus, conventional methods for increasing heat dissipation are not suitable to meet the demand of these high technology industries. There is therefore, a need to develop advanced cooling techniques and innovative heat transfer fluids with better heat transfer performance. At room temperature, metallic solids possess an order-of-magnitude higher thermal conductivity than fluids. This new class of heat transfer fluids (nanofluids) is engineered by dispersing nanometer-sized (one billionth of a meter) solid particles, rods or tubes in traditional heat transfer fluids. Thus, nanofluids have attracted great interest from the research community due to their potential benefits and applications in numerous important fields such as microelectronics, transportation, manufacturing, medical, and HVAC.

The purpose of the paper is to predict the flow behaviour and temperature distribution of a Wavy fin tube cooling units with nanofluids (Si C based fluid) and to calculate and compare the loss in temperature in conventional and nanofluids (Si C based fluid) as coolant in the radiator model with CFX analysis.

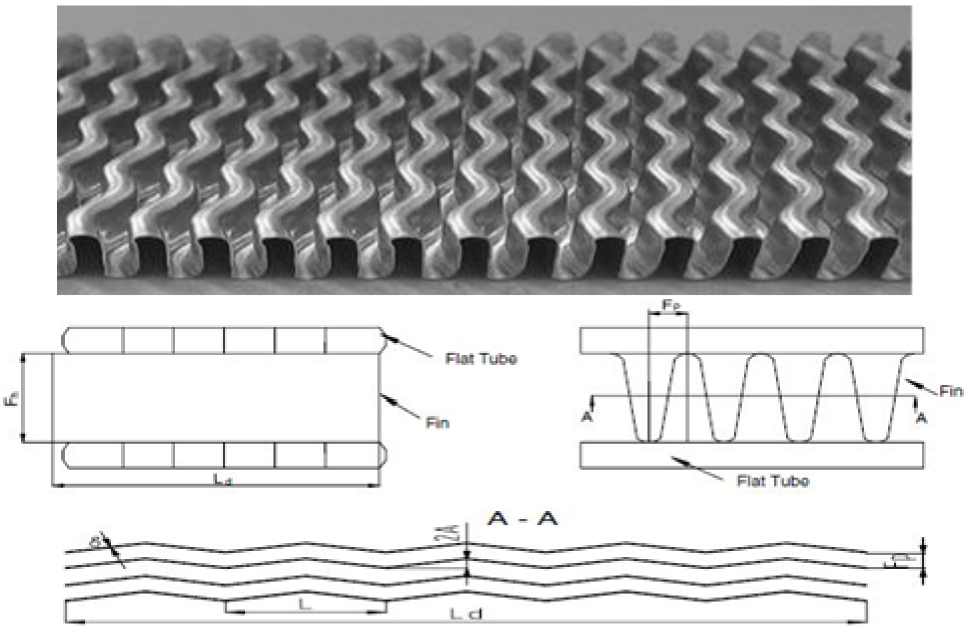


Fig.1 Geometry of wavy fin

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
$\dot{m}$	Mass flow rate

T	Fin thickness
T	Temperature
u	Fluid velocity
U	Overall heat transfer coefficient
Si C	Silicon Carbide

Greek symbols

P	Density, kg/m^3
σ	Minimum free flow area
ν	Viscosity, m^2/s

Abbreviations

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

II. Mathematical Modeling

2.1 Problem geometry

The Heavy vehicle automotive radiator is a type of compact 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.

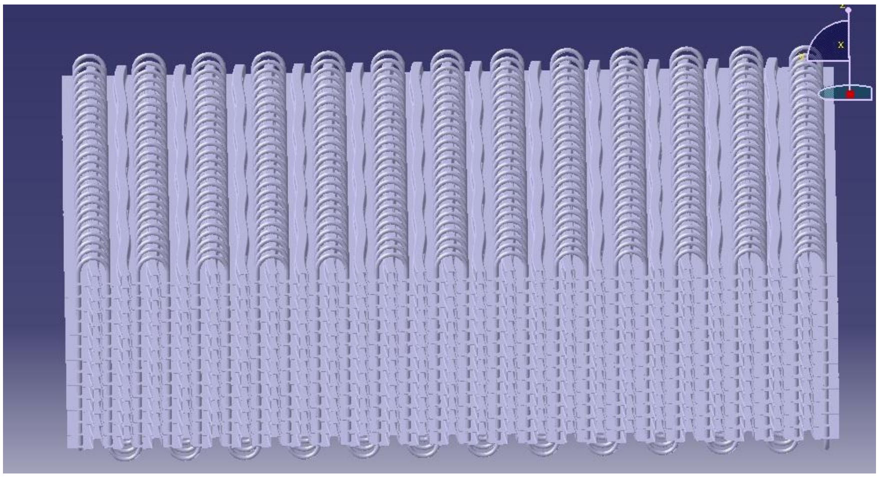
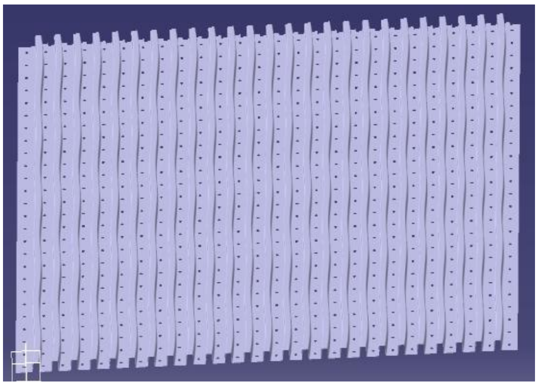


Fig.2 Isometric view of Wavy fin based compact radiator on CATIA



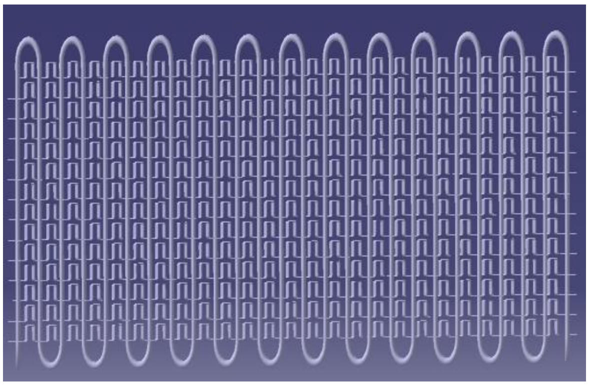


Fig.3 Front view of wavy fin and circular tubes on CATIA

2.2 The governing equations

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) Properties of nanofluid as well as air assumed to be constant.
2) Steady state process.
3) All the heat rejected from nanofluid absorbed by air flow through radiator.

2.2.1 Calculation of heat transfer rate (for conventional fluids)

Heat transfer rate on air side;

$$Q = h_a\ A\ \Delta T = h_a\ A\ (T_{h2}\text{-}T_{h1})$$

Heat transfer rate on water side;

$$Q = m\ c_p\ \Delta T = m\ c_p\ (T_2\text{-}T_1)$$

Mass of water through each tube;

$$\dot{m} = \rho\ A\ V$$

$$\text{Volume (V)} = l\times b\ \times w$$

Pressure loss on tube;

$$(4\Delta T) = \frac{4flv^2}{2g}$$

$$\text{Friction factor} = \frac{0.079}{Re^{0.25}}$$

$$\text{Reynolds number (Re)} = \frac{VD}{\nu}$$

2.2.2 Calculation of heat transfer rate (for nanofluid)

Heat transfer rate for nanofluid

$$Q = h_{\ nf}\ A\ \Delta T = h_{\ nf}\ A\ (T_{c2}\text{-}T_{c1})$$

Heat transfer coefficient for nanofluid

$$Nu = \frac{h_{exp}\ d_{hy}}{k} = \frac{m c_p (T_{in} - T_{out}\ )}{A(T_1 - T_2)}$$

$$Nu = Re^{0.8}Pr^{0.3} \qquad \text{(Dittus - Boelter Equation)}$$

If friction factor will be consider;

$$Nu = \frac{\left(\frac{f}{8}\right)(Re - 1000)Pr}{1 + 12.7\left(\frac{f}{8}\right)^{0.5}\left(Pr^{\frac{2}{3}} - 1\right)} \qquad \text{(Gnielinsky Equation)}$$

$$\text{Friction factor (f)} = (0.79\ln Re\text{-}1.69)^{-2}$$

III. Input parameters

The radiator which is considered is mounted on the present heavy vehicles diesel engine is, cross flow compact heat exchanger with unmixed fluids. Radiator consists of 644 circular tubes whose diameter is 0.35cm (Air side) and 0.37 cm (coolant side), make of brass and 346 continuous fins of 0.25 mm thick, made of aluminum alloy whose thermal conductivity is considered as 177 W/m K. For designing and performance analyses of compact automotive radiator (Wavy fin type) using nanofluid as coolant (Si C + water) whose thermal conductivity is 350 W/m K. The following parameters are given as;

Table 1: Fluid parameters and Normal Operating conditions:

S. No.	Description	Air	Coolant
1.	Fluid mass rate	20 Kg/s	6 Kg/s
2.	Fluid inlet temperature	35 ℃	95 ℃
3.	Core Width	60 cm	
4.	Core height	60 cm	
5.	Core depth	1.7 cm	

Table 2: Specification of Wavy fin parameters:

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

IV. 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.

Continuum type of air and coolant are set to fluid and radiator is set to solid. Inlet and outlet areas of coolant (inside the radiator) and air (outside the radiator) have been assigned which are further used in CFX.

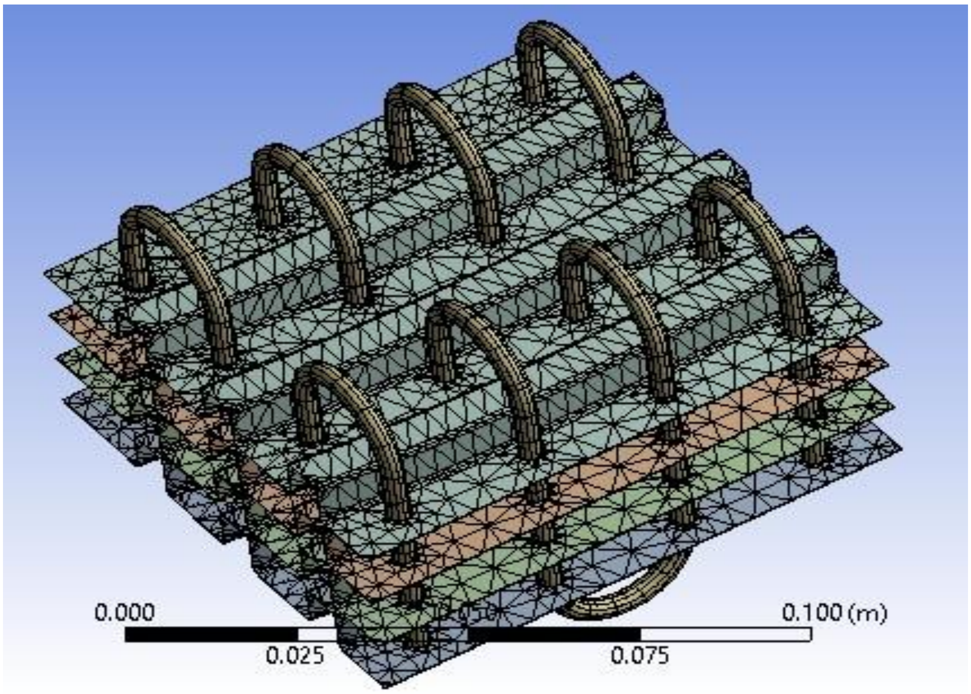


Fig.4 Meshing of a section of radiator on ANSYS

V. Results and Discussion

The simulation results obtained show reasonable variation in the temperature as expected. A drop in temperature of the coolant from 375 K to 342 K.

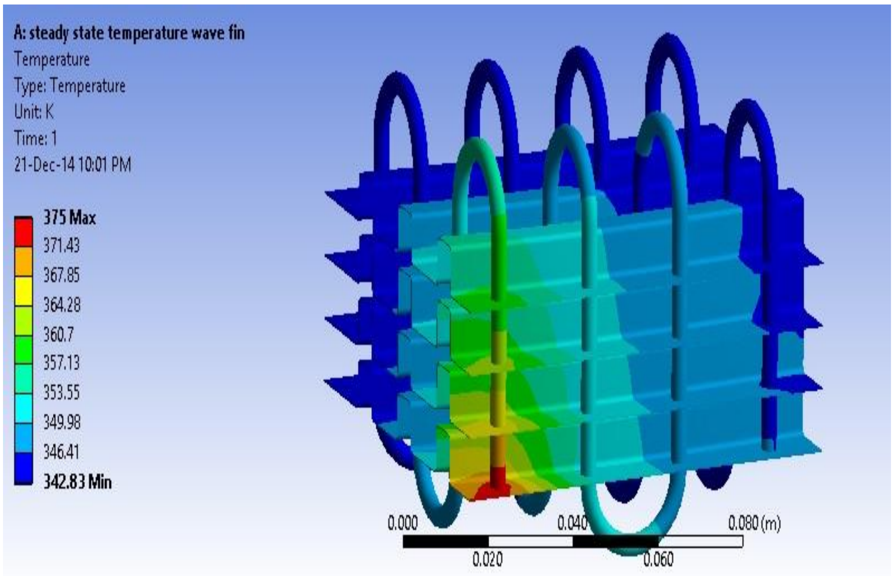


Fig.5 The variation of coolant (Si C) temperature in K

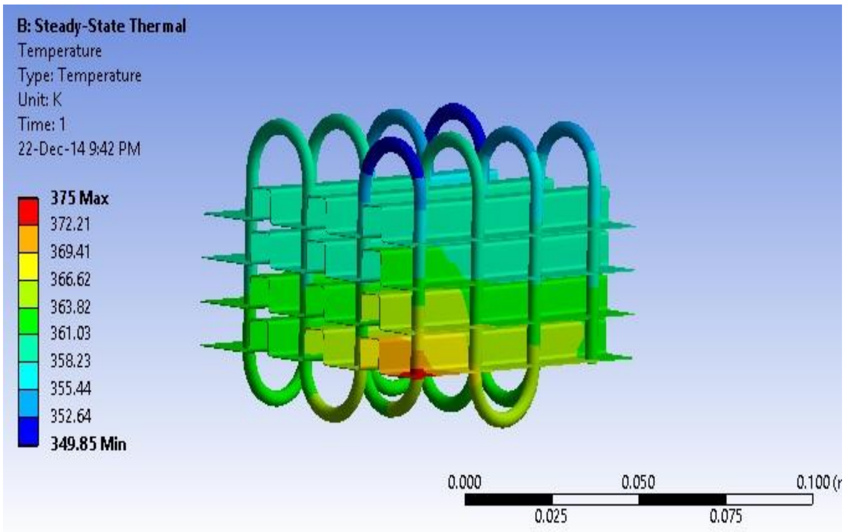


Fig.6 The variation of coolant (water) temperature in K

The loss in temperature across the tube length for the water as coolant and nano fluid as coolant are shown below. Where the drop in temperature with water as coolant is from 375 to 349 i.e. 26℃ and with nano fluid as coolant, it is 375 to 342 i.e. 33℃. So by this it has been shown that heat transfer of nano fluid is better than that of water as coolant in compact radiator.

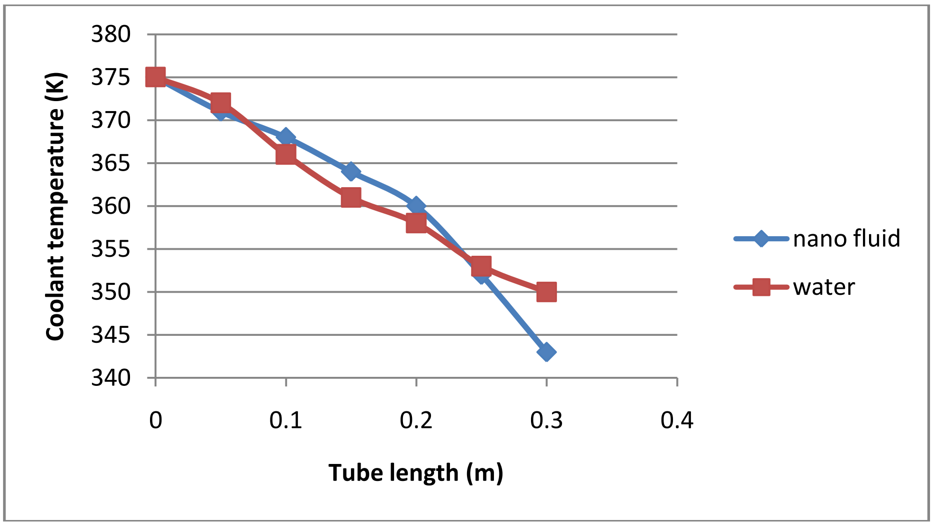


Fig.9 Loss in temperature of coolant with nanofluid and water

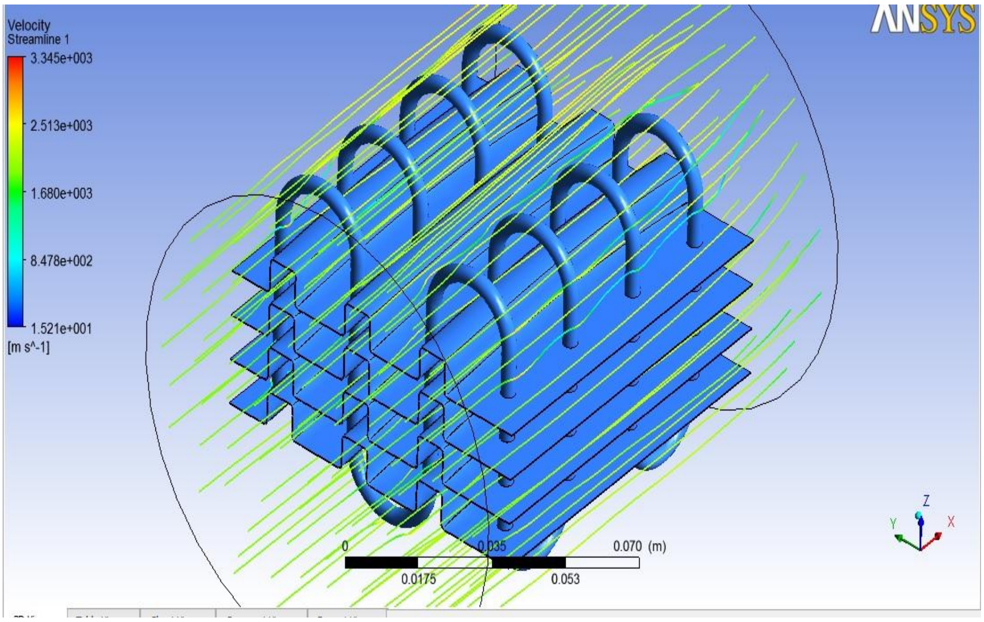


Fig.8 Air flow variation through the radiator

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.
Due to friction in the tubes, there will be loss of pressure across the tubes. As there are number of tubes and in each tube input pressure and output pressure vary from each other, we get a graph of pressure variation along the tube length.

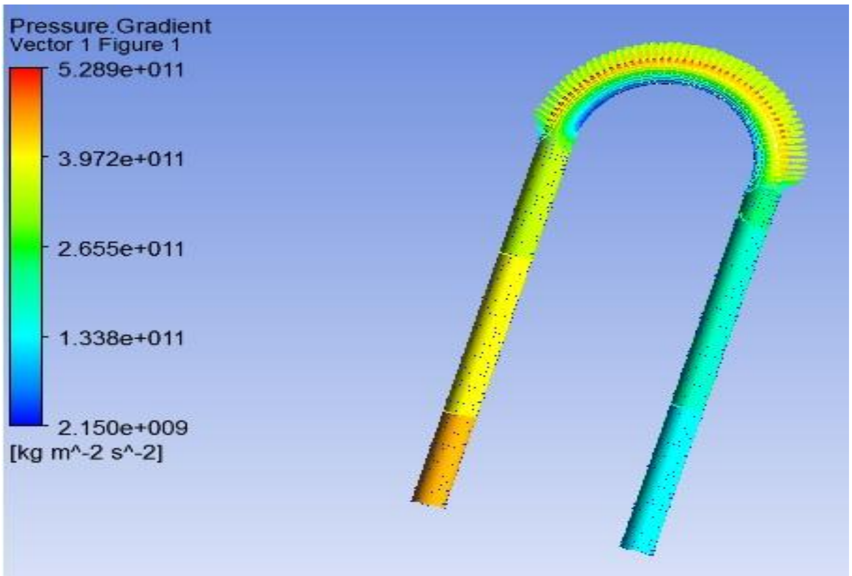


Fig.9 Pressure distribution of the coolant through tube length

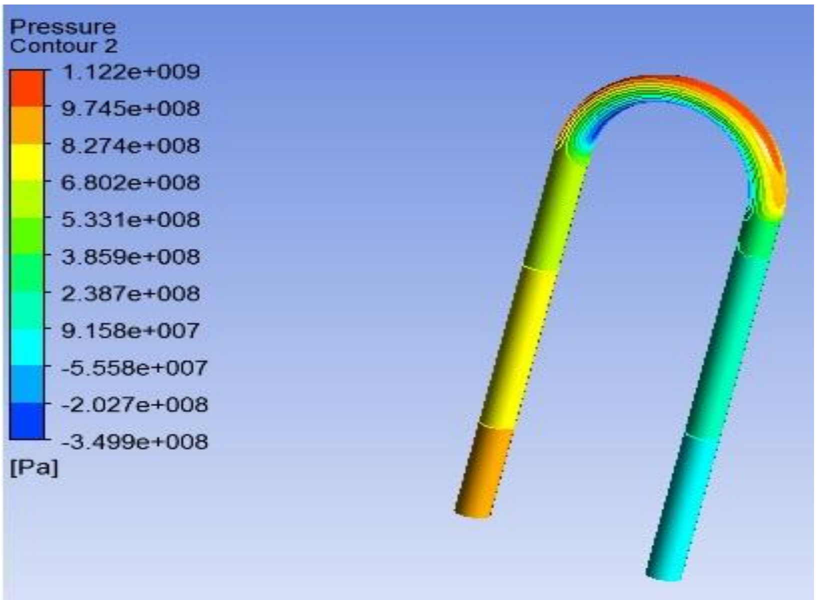


Fig.10 Contours of pressure distribution of coolant through tube

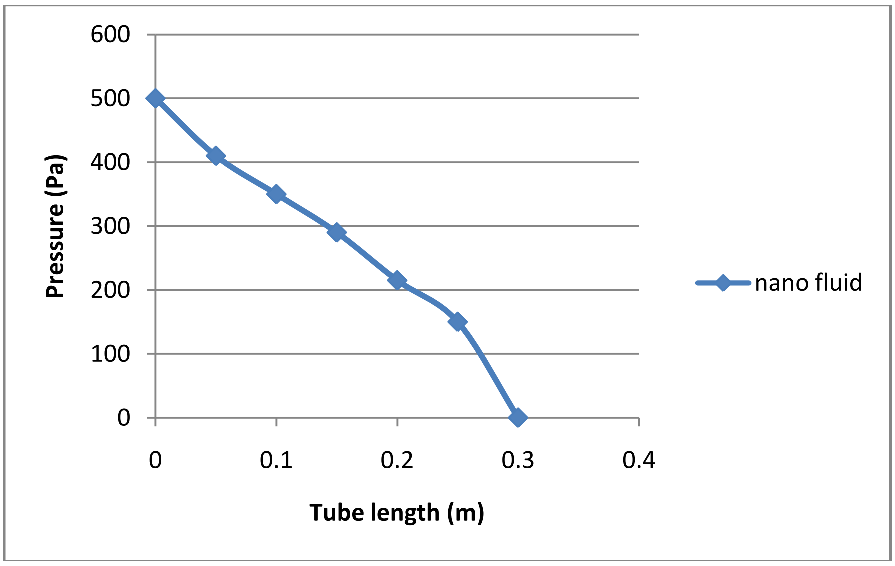


Fig.11 Loss in pressure of coolant

VI. Conclusion

The fluid flow and heat transfer analysis of the automotive radiator with nano fluid is successfully carried out. The variations in the pressure, temperature and velocity in the direction of coolant flow and air flow is analyzed. The study forms a foundation for the fluid flow analysis of an automotive radiator with nano fluid. With the computational time and available resources, the results obtained are to be satisfied. It is obtained that temperature drop of conventional coolant is 26℃ and for nanofluid as coolant, is 33℃ and pressure drop of 528 Pa in the coolant. So when compared for conventional coolant (water), the heat transfer rate is higher when nanofluid is used as coolant on same radiator model.

As we can find that we can reduce the size of the radiator by using nanofluid as coolant to obtain higher cooling capacity by which we can optimize the size, weight and cost of automotive vehicles in recent years.

Based on results and comparisons, following conclusions are obtained;

- ✓ 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.
- ✓ The pressure drop also increases with the increase in air and coolant mass flow rate through radiator.
- ✓ About 5% increment in cooling capacity with the use of nanofluid as coolant in Wavy fin heat exchanger as compared to Conventional coolant.

However, a continued study 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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