# PROJECT REPORT
# ON

# DESIGN AND ANALYSIS
# OF
# AUTOMOBILE RADIATOR

Submitted in partial fulfillment of the requirements for the award of the degree of

**BACHELOR OF TECHNOLOGY**
In
**Mechatronics Engineering**


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Harnessing Energy through Knowledge

Department of Mechanical Engineering
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# CERTIFICATE

Certified that the project work entitled "Design and analysis of automobile radiator" is a bonfide work carried by :

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in partial fulfillment for the award of Bachelor of Technology in Mechatronics Engineering of University of Petroleum & Energy Studies during the academic session 2014-15. It is further certified that the corrections/suggestions indicated for Internal Assessment have been incorporated. The project report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said degree.



Signature of Mentor

Name of Mentor
Prof. Deepak Kumar

# DECLARATION

We Shubham Bisht,Abhishek Bourai and Shivam Ghildiyal bearing the Roll No: R880211045, R880211003 & R880211043 respectively hereby declare that this Project work entitled "Design and analysis of automobile radiator" was carried out by us under the guidance and supervision of Prof. Deepak Kumar. This Project work is submitted to University of Petroleum & Energy Studies in partial fulfillment of the requirement for the award of Bachelor of Technology in Mechatronics Engineering during the Academic year 2014-15. We also declare that, we have not submitted this dissertation work to any other university for the award of either degree or diploma

Place: Dehradun

Date: 15 April 2015

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We are indebted to those people across the globe who has shared their knowledge and perspectives in the form of online tutorials, forums and other resources which helped us to a great extend whenever we met with technical obstacles during this endeavour. We wish to avail this opportunity to express a sense of gratitude and love to all our friends and our family for their unwavering support, strength, help and in short for everything they have done during the crucial times of the progress of our project.

Last but not the least we thank God almighty for his blessings and guidance without which this project wouldn’t have been reality.

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# CHAPTER 5: ABSTRACT

The demands for engine cooling systems have risen dramatically over the past two decades. Factors that have driven this rising demand are an increase in the number of fluids that need cooling, a push for higher power output, and the implementation of stricter emissions regulations. As both initial capital costs and operating costs continue to increase for cooling systems, so has the awareness of the importance of properly optimizing these systems.

This work is focused on the radiator design for automobile, which includes modeling, simulation and analysis of heat transfer and fluid flow in the heat exchanger. The developed models are validated by experimental data from the literature. Based on the simulation results, the heat exchanger would be optimized in terms of thermal performance and flow resistance.

Automobile radiator is designed from the conventional dimensions of the car Opel Astra. The Design is analyzed by using concepts of Computational Fluid Dynamics (CFD) and developing mathematical model consisting of the necessary boundary condition required to solve the heat transfer problem. Software analysis of the problem is carried out on ansys software to generate the reports used to analyze the solution.

# CHAPTER 6: INTRODUCTION

## 6.1 Background Study:

In recent years the number of vehicles being used has constantly increased. For instance, the number of registered trucks and buses increased from 138 million to 274 million between 1990 and 2008 in the world. The increasing number of vehicles causes more energy/fuel to be consumed and more carbon dioxide ($CO_2$) to be released to the environment. 29.2 % of the total energy in USA are consumed by the transportation section (medium/heavy trucks used 18.7 % of energy in transportation) in 2008. Furthermore, 31.2 % of $CO_2$ emission was from the transportation section (67.9 % from medium/heavy trucks and buses) in USA [1]. On the other hand, the oil price is increasing all the time. Strong legislations on emissions have been introduced as well. All these factors require innovations in the vehicle industry. Many technical developments have been introduced to meet the requirements on low fuel consumption and $CO_2$ emission in vehicles. Concerning the energy distribution (as shown in Fig. 1) in the vehicle, only around 35 % of the total fuel energy finally becomes mechanical work which is used for driving the vehicle. However, 30 % of the total energy input is brought away by the coolant of the engine cooling system, and another 35 % of the energy is lost to the exhaust gases. If one could optimize the energy wasted in the coolant or the exhaust gases, the fuel consumption and the $CO_2$ emission (This is also proportional to the fuel consumption.) could be reduced.

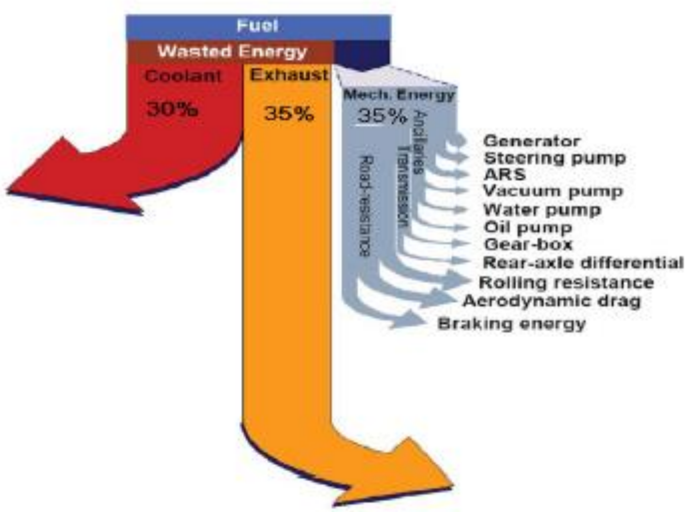



Fig1. Energy Distribution in a vehicle

## 6.2 Problem Statement:

One third of the engine energy is lost to the exhaust gases. Johnson [2] found out for a typical 3.0 liter gas engine with a maximum mechanical output power of 115 kW, the total waste heat dissipated can be from 20 kW to as much as 400 kW across the range of a typical engine operation. The corresponding energy efficiency of the vehicles might be from 30 % to 15 %. If the exhaust gases enter into the surroundings directly, they will not only waste energy but also cause heat pollution of the environment. Reusing the waste heat of the exhaust gas has a great potential for reducing the fuel consumption of vehicles. There are several methods to reuse the energy of the exhaust gases.

These methods include:

(1) The waste heat is used to heat the passenger compartment in the winter;

(2) The waste heat can be used in absorption cooling, which is attractive for the tractor-trailer refrigeration and bus air conditioning systems;

(3) The waste heat from exhaust gases is reused to generate electricity by using a thermoelectric device (3 -8 % fuel saving is offered by a thermoelectric generator [3]).

However, due to development of electric or hybrid electric vehicles and fuel cell vehicles, less and less exhaust gases are dissipated from the vehicles. In this case, more heat has to be brought away by the engine cooling system than before (the engine efficiency is assumed similar). Furthermore, the working temperature of batteries (electric vehicles) is around 55 degree [4], and the operating temperature of lymer Electrolyte Membrane Fuel Cells (used for fuel cell vehicles) is around 65 degrees. These temperatures of electric vehicles or fuel cell vehicles are much lower than that of a combustion engine vehicle (the working temperature is around 90 degree). Due to the low working temperature of electric or fuel cell vehicles, the size of the heat exchanger (HEX) has to be increased. However, there is space limitation in vehicles. Thus, the cooling issues become more serious than before. If the engine cooling system cannot bring away the heat quickly, the engine working temperature will increase. More fuel will be consumed and the life time of the engine will be reduced due to the high working temperature in the engine. Contrarily, a good engine cooling system can reduce the time of the engine start and warm up processes, in which the engine reaches its optimal working temperature [5]. A lot of hydrocarbon (HC) and carbon monoxide (CO) are produced during the starting and warming up period. Thus, an efficient engine cooling system is significantly important for the fuel consumption of vehicles.

Automotive engine cooling system takes care of excess heat produced during engine operation. It regulates engine surface temperature for engine optimum efficiency. Most automotive engine cooling systems consist of the radiator, water pump, cooling fan, pressure cap and thermostat. Radiator is the prime component of the system. Radiator is a heat exchanger that removes heat from engine coolant passing through it. Heat is transferred from hot coolant to outside air. Radiator assembly consists of three main parts core, inlet tank and outlet tank. Core has two sets of passage, a set of tubes and a set of fins. Coolant flows through tubes and air flows between fins. The hot coolant sends heat through tubes to fins. Outside air passing between fins pickups and carries away heat.

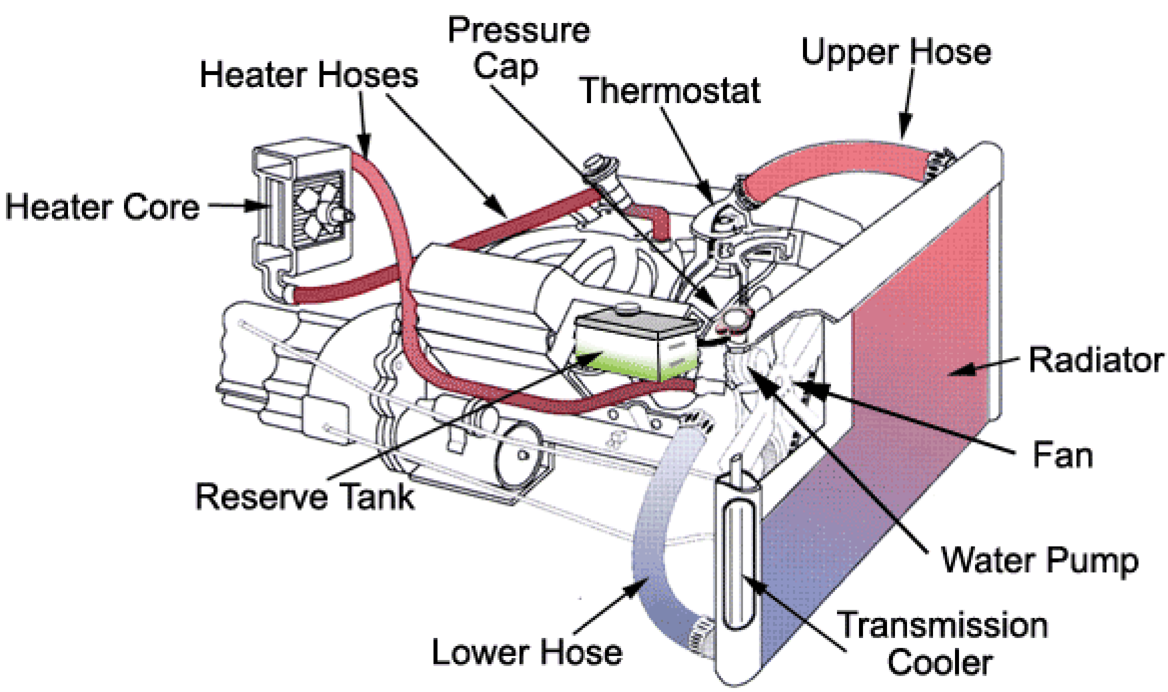



Fig.2 Schematic layout of Engine Cooling System

Performance of engine cooling system is influenced by factors like air and coolant mass flow rate, air inlet temperature, coolant fluid, fin type, fin pitch, tube type and tube pitch etc. While designing cooling system three worst conditions considered based on above parameters.

High altitude: At high altitude, air density becomes low and hence affects air mass flow rate.

Summer conditions: During summer surrounding air is hot i.e. air inlet temperature is more.

Maximum power: Engine condition producing maximum power like when vehicle is climbing uphill, maximum heat rejection is required during this condition. To compensate all these factors radiator core size required may be large.

# CHAPTER 7: OBJECTIVES

The overall aim of this project is to develop a new cooling system to satisfy the increasing cooling power in vehicles. The work to be done during the duration of this project is as follows:

1. Design of an automobile radiator influenced from the dimensions provided by the pre-existing available automobile radiator.
2. Developing the mathematical model with the set of boundary conditions required to solve the problem.
3. Analysis of various parameters which can improve the performance of the radiator.
4. Thermal and Fluent analysis of the design to gather results.

# CHAPTER 8: LITERATURE REVIEW

The demand for more powerful engines in smaller hood spaces has created a problem of insufficient rates of heat dissipation in automotive radiators. Upwards of 33% of the energy generated by the engine through combustion is lost in heat. Insufficient heat dissipation can result in the overheating of the engine, which leads to the breakdown of lubricating oil, metal weakening of engine parts, and significant wear between engine parts.

To minimize the stress on the engine as a result of heat generation, automotive radiators must be redesigned to be more compact while still maintaining high levels of heat transfer performance.

In an automobile, fuel and air produce power within the engine through combustion. Only a portion of the total generated power actually supplied to the automobile with power, the rest is wasted in the form of exhaust and heat. If this excess heat is not removed, the engine temperature becomes too high which results in overheating and viscosity breakdown of the lubricating oil, metal weakening of the overheated engine parts, and stress between engine parts resulting in quicker wear, among the related moving posts . A cooling system is used to remove this excessive heat. Most automotive cooling systems consist of the following components: radiator, water pump, electric cooling fan, radiator pressure cap, and thermostat.



Of these components, the radiator is the most prominent part of the system because it transfers heat. As coolant travels through the engine's cylinder block, it accumulates heat. Once the coolant temperature increases above a certain threshold value, the vehicle's thermostat triggers a valve which forces the coolant to flow through the radiator. As the coolant flows through the tubes of the radiator, heat is transferred through the fins and tube walls to the air by conduction and convection.

## 8.1 Automotive Radiator

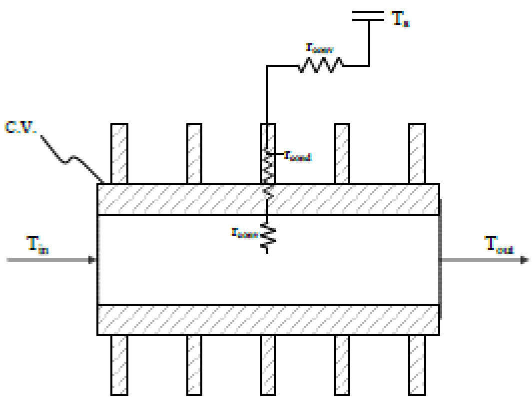
A radiator is a type of heat exchanger. It is designed to transfer heat from the hot coolant that flows through it to the air blown through it by the fan. Most modern cars use aluminum radiators. These radiators are made by brazing thin aluminum fins to flattened aluminum tubes. The coolant flows from the inlet to the outlet through many tubes mounted in a parallel arrangement. The fins conduct the heat from the tubes and transfer it to the air flowing through the radiator. The tubes sometimes have a type of fin inserted into them called a turbulator, which increases the turbulence of the fluid flowing through the tubes. If the fluid flows very smoothly through the tubes, only the fluid actually touching the tubes would be cooled directly. The amount of heat transferred to the tubes from the fluid running through them depends on the difference in temperature between the tube and the fluid touching it. So if the fluid that is in contact with the tube cools down quickly, less heat will be transferred. By creating turbulence inside the tube, all of the fluid mixes together, keeping the temperature of the fluid touching the tubes up so that more heat can be extracted, and all of the fluid inside the tube is used effectively. Radiators usually have a tank on each side, and inside the tank is a transmission cooler. From fig. 2 the inlet and outlet shown where the oil from the transmission enters the cooler. The transmission cooler is like a radiator within a radiator, except instead of exchanging heat with the air, the oil exchanges heat with the coolant in the radiator.

The pump sends the fluid into the engine block, where it makes its way through passages in the engine around the cylinders. Then it returns through the cylinder head of the engine. The thermostat is located where the fluid leaves the engine. The plumbing around the thermostat sends the fluid back to the pump directly if the thermostat is closed. If it is open, the fluid goes through the radiator first and then back to the pump.

There is also a separate circuit for the heating system. This circuit takes fluid from the cylinder head and passes it through a heater core and then back to the pump. On cars with automatic transmissions, there is normally also a separate circuit for cooling the transmission fluid built into the radiator. The oil from the transmission is pumped by the transmission through a second heat exchanger inside the radiator, as shown in fig.2.

Most commonly made out of aluminum, automobile radiators utilize a cross-flow heat exchanger design. The two working fluids are generally air and coolant (50-50 mix of water and ethylene glycol). As the air flows through the radiator, the heat is transferred from the coolant to the air. The purpose of the air is to remove heat from the coolant, which causes the coolant to exit the radiator at a lower temperature than it entered at. The benchmark for heat transfer of current radiators is 140 kW of heat at an inlet temperature of 95 °C. The basic radiator has a width of 0.5-0.6 m (20-23“), a height of 0.4-0.7 m (16-27”), and a depth of 0.025-0.038 m (1-1.5”).

These dimensions vary depending on the make and model of the automobile. For current radiator designs, a common configuration is to use parallel tubes which have aluminum fins attached to them. In these designs, there are basically three modes of heat transfer: conduction between tube walls and fins, and two modes of convection. One mode of convection is due tothe coolant flowing in the tubes and the second is caused by the air flowing through the radiator. Associated with each type of heat transfer is a thermal resistance which obstructs the heat transfer rate. These resistances are summarized in Figure 3 below.




$$r_{cond} = \frac{R_{cond}}{L_{pipe}} \quad \text{(Eq. 1)}$$

$$R_{cond} = \frac{L_{fin}}{k_{fin} A_{fin}} \quad \text{(Eq. 2)}$$

$$r_{conv} = \frac{R_{conv}}{L_{pipe}} \quad \text{(Eq. 3)}$$

$$R_{conv} = \frac{1}{h A_{S.A.}} \quad \text{(Eq. 4)}$$

Fig. 3: A control Volume Thermal Circuit Diagram



Here, Tin represents the inlet fluid temperature, Tout represents the outlet fluid temperature, and Ta represents the ambient air temperature. As shown by Eq. 1, thermal resistance due to conduction per unit length (rcond) is equal to the total resistance due to conduction (Rcond) divided by the length of the pipe (Lpipe). Eq. 2 provides the definition for Rcond. In this equation, Lfin is the length of the fin, kfin is the thermal conductivity associated with the fin material, and Afin is surface are associated with conduction. In this case, it would represent the bottom surface area of the fin. In Eq. 3, rconv is equal to the total resistance due to convection (Rconv) divided by the length of the pipe. Here, Rconv is equal to 1 divided by product of the convective coefficient associated with the air (h) and the surface area exposed to the air (AS.A.). This can be seen by Eq. 4.

In current radiator designs, the largest thermal resistance is caused by the convective heat transfer (Rconv ) that is associated with the air. This comprises of over 75% of the total thermal resistance. The second largest thermal resistance is caused by the convection that is associated with the fluid. Together, these resistances comprise of over 97% of the total thermal resistance [7]. Since there is a large thermal resistance associated with the air, the increased heat transfer cannot be observed. Therefore, there is a need to design a radiator that reduces the percentage of thermal resistance associated with the air.

Limitations

Current radiator designs are extremely limited and have not experienced any major advancement in recent years. As described above, the main problem is that current radiators experience a large resistance to heat transfer caused by air flowing over the radiator. Current radiators also experiences head resistance, are very bulky, and impose limitations on the design of the vehicle.

## 8.2 Cooling System and Antifreeze

An automobile’s cooling system is the collection of parts and substances (coolants) that work together to maintain the engine’s temperature at optimal levels. Comprising many different components such as water pump, coolant, a thermostat, etc, the system enables smooth and efficient functioning of the engine at the same time protecting it from damage. While it’s running, an automobile’s engine generates enormous amounts of heat. Each combustion cycle entails thousands of controlled explosions taking place every minute inside the engine. If the automobile races on and the heat generated within isn’t dissipated, it would cause the engine to self-destruct. Hence, it is imperative to concurrently remove the waste heat.

While the waste heat is also dissipated through the intake of cool air and exit of hot exhaust gases, the engine’s cooling system is explicitly meant to keep the temperature within limits. The cooling system essentially comprises passages inside the engine block and heads, a pump to circulate the coolant, a thermostat to control the flow of the coolant, a radiator to cool the coolant and a radiator cap controls the pressure within the system. In order to achieve the cooling action, the system circulates the liquid coolant through passages in the engine block and heads. As it runs through, the coolant absorbs heat before returning to the radiator, to be cooled itself. Next, the cooled down coolant is re-circulated and the cycle continues to maintain the engine’s temperature at the right levels.

The term engine coolant is widely used in the automotive industry, which covers its primary function of convective heat transfer. When used in an automotive context, corrosion inhibitors are also added to help protect vehicles’ cooling systems, which often contain a range of electrochemically incompatible metals (aluminum, cast iron, copper, lead solder, etc).

Antifreeze was developed to overcome the shortcomings of water as a heat transfer fluid. In most engines, freeze plugs are placed in the engine block which could protect the engine if no antifreeze was in the cooling system or if the ambient temperature dropped below the freezing point of the antifreeze. If the engine coolant gets too hot, it might boil while inside the engine, causing voids (pockets of steam) leading to the catastrophic failure of the engine. Using proper engine coolant and a pressurized coolant system can help alleviate both problems. Some antifreeze can prevent freezing till - 870C.

**Methanol :**

Methanol, also known as methyl alcohol, carbonyl, wood alcohol, wood naphtha or wood spirits, is a chemical compound with chemical formula CH3OH (often abbreviated MeOH). It is the simplest alcohol, and is a light, volatile, colourless, flammable, poisonous liquid with a distinctive odor that is somewhat milder and sweeter than ethanol (ethyl alcohol). At room temperature it is a polar liquid and is used as an antifreeze, solvent, fuel, and as a denaturant for ethyl alcohol. It is not very popular for machinery, but it can be found in automotive windshield washer fluid, de-ices, and gasoline additives to name a few.

**Ethylene glycol :**

Ethylene glycol (IUPAC name: ethane-1, 2-diol) is an organic compound widely used as an automotive antifreeze and a precursor to polymers. In its pure form, it is an odorless, colorless, syrupy, sweet tasting liquid. However, ethylene glycol is toxic, and ingestion can result in death. Ethylene glycol solutions became available in 1926 and were marketed as “permanent antifreeze,” since the higher boiling points provided advantages for summertime use as well as during cold weather. They are still used today for a wide variety of applications, including automobiles. Being ubiquitous, ethylene glycol has been ingested on occasion, causing ethylene glycol poisoning. Coolant containing ethylene glycol should not be disposed of in a way that will result in it being ingested by animals, because of its toxicity. Many animals like its sweet taste. As little as a teaspoonful can be fatal to a cat, and four teaspoonfuls can be dangerous to a dog. In some places it is permitted to pour moderate amounts down the toilet, but there are also places where it can be taken for processing.

**Propylene glycol:**

Propylene glycol, on the other hand, is considerably less toxic and may be labeled as “nontoxic antifreeze”. It is used as antifreeze where ethylene glycol would be inappropriate, such as in food processing systems or in water pipes in homes, as well as numerous other settings. It is also used in food, medicines, and cosmetics, often as a binding agent. Propylene glycol is “generally recognized as safe” by the Food and Drug Administration (FDA) for use in food. However, propylene glycol-based antifreeze should not be considered safe for consumption. In the event of accidental ingestion, emergency medical services should be contacted immediately.

Propylene glycol oxidizes when exposed to air and heat. When this occurs lactic acid is formed. [6]. If not properly inhibited, this fluid can be very corrosive. Protodin is added to propylene glycol to act as a buffer, preventing low pH attack on the system metals. It forms a protective skin inside the tank and pipelines which helps to prevent acid attack that cause corrosion. Besides cooling system breakdown, biological fouling also occurs. Once the bacterial slime starts, the corrosion rate of the system increases. In systems where a glycol solution is maintained on a continuous basis, regular monitoring of freeze protection, pH, specific gravity, inhibitor level, color and biological contamination should be checked routinely. Propylene glycol should be replaced when it turns reddish in color.

**Functions of Antifreeze:**

Engine antifreeze and additive mixture for automobile radiator are meant to:

1. Reduce cooling system corrosion

Every automotive cooling system will corrode eventually, but this mixture of antifreeze and additive will make the overall process of corrosion slow therefore, increasing the life of cooling system.

2. Reduce cavitation

In large diesel engines, air or tiny bubbles in the coolant can cause serious problems or engine overheating. So, for a diesel vehicle, it is highly recommended that a cavitation reducing engine coolant must be used.

3 Buffer the acidity of your engine coolant

The more acidic an engine coolant, the more quickly it can corrode and damage the cooling system and automobile radiator.



4 Raise the boiling point of the engine coolant

A higher boiling temperature means that the coolant can cool better as the engine gets hotter. It also reduces the chance of blowing a head gasket.

# CHAPTER 9 : METHODOLOGY

## 9.1 Concepts for Performance Enhancement

1. Use of Carbon Graphite foam fin:

Using graphite foam as a thermal material for HEXs in vehicles: Nowadays aluminum HEX is very common in the vehicle industry. Due to the increasing cooling power and the space limitation in vehicles, a highly compact HEX has to be developed. Graphite foam has even higher thermal conductivity (solid thermal conductivity is around 1700 W/m·K), large Specific surface area (5000-50000 m2/m3), and low density (0.2-0.6 g/cm3)[8]. These characteristics imply that graphite foam is a good potential thermal material for HEXs (instead of the conventional aluminum HEX). The carbon-foam fins can be seen in Figure 4 below.

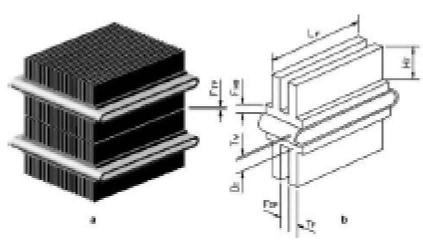




Fig.4 Carbon Foam Fin

2. Use of Microheat Exchangers:

In this case study, a possible improvement to the automobile radiator was seen through the analysis of micro heat exchangers. These heat exchangers incorporated the use of micro-channels and were fabricated from plastic, ceramic, or aluminum. The micro heat exchanger can be seen in Figure 5 below:

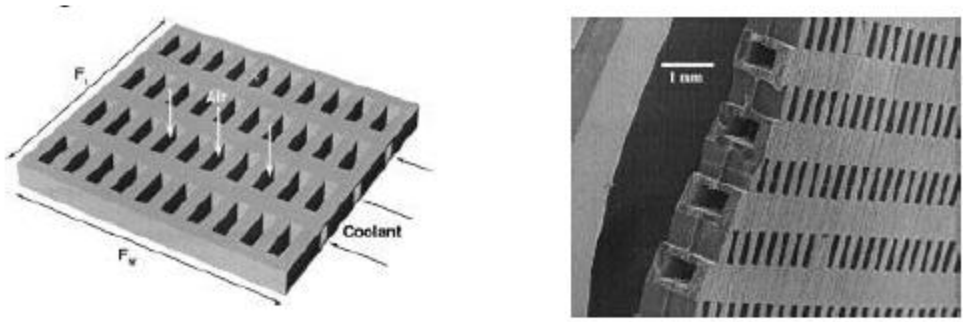



Fig.5 Microheat Exchangers

When compared to several automobile radiators, the micro heat exchanger outperformed them in a couple of areas. One area was on a heat transfer rate to volume basis in which the micro heat exchanger was better by more than 300%. Another area was a heat transfer rate per mass basis.

In this area, the micro heat exchanger showed improvement of about 200%. These improvements were achieved by limiting the flow to smaller channels which increased the surface area/volume ratio and reduced the convective thermal resistance associated with the solid/fluid interface. However, in this study, the automobile radiators did outperform the micro heat exchanger on a heat transfer rate per frontal area basis. Here, the micro heat exchanger showed a reduction of over 45%. However, it is possible to construct a micro heat exchanger that has the same heat transfer rate/frontal area as current automobile radiators by using a more conductive material and reducing the spacing between the fins [9]. Therefore, when compared to automobile radiators, the use of micro heat exchangers allows the same amount of heat to be dissipated with a reduced volume and weight.

3. Changing the position of heat exchangers:

Due to the space limitation in vehicles, it is extremely difficult to increase the size of the heat exchangers (HEXs) to bring away the increased heat from the vehicles. Removing the HEX from the front of the vehicles to the roof of vehicles, might increase the possibility to increase the size of the HEX. However, when the HEX is placed at the roof, a new configuration of the HEX has to be introduced to accommodate the HEX position change. Based on the air fluid direction and the engine coolant direction, a countercurrent flow HEX is introduced at the roof position, to replace a cross flow HEX.

4. Use of Nano fluids:

In this case study, coolants used as Nano fluids like cuo/water, water/ethyl one glycol for better radiator performance using Computational Fluid Dynamics (CFD). Nano fluids give higher heat transfer rate than base fluids[10]. This case study is CFD simulation of the mass flow rate; fluid flow and heat transfer of shell and tube heat exchanger (radiator) at various coolants (Nano fluids). In the literature research, CFD used to simulate flow and heat transfer in tube and fin heat exchanger.

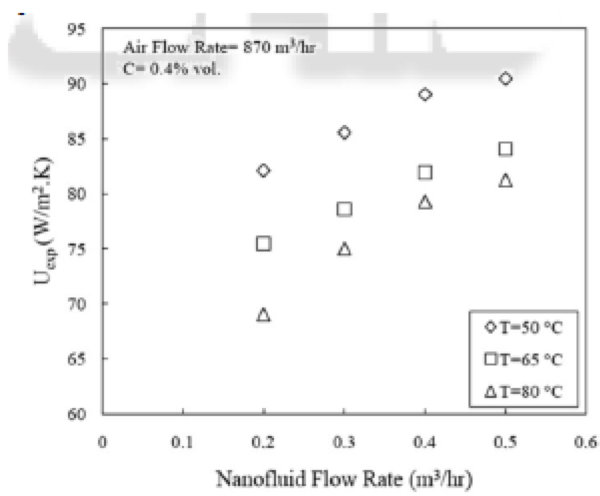



Fig. 6: Effect of Nano fluid volumetric flow rate on the overall heat transfer coefficient of CuO/water Nano fluid in the radiator.

It is shown that the overall heat transfer coefficient significantly increases with increasing flow rate of nanofluid. For example, at the air flow rate of 870m³/h, nanofluid concentration of 0.4 vol.%, and nanofluid inlet temperature of 80°C, for large particles. The maximum value of the overall heat transfer coefficient with nanofluid, effect of each operating parameter on the overall heat transfer coefficient and the optimum values of each parameter are analyzed by CFD simulation.

5. Spiral Radiator:

The Spiral Radiator helps in improving the heat dissipation through the radiator. The Radiator consists of spiral tube with fluid inlet at the center of the radiator rotating with the drive axle of automobile connected through a series of gear train which help in controlling the speed. The coolant is pushed centrifugally throughout to the corners thereby increasing the fluid velocity and decreasing the convective resistance .

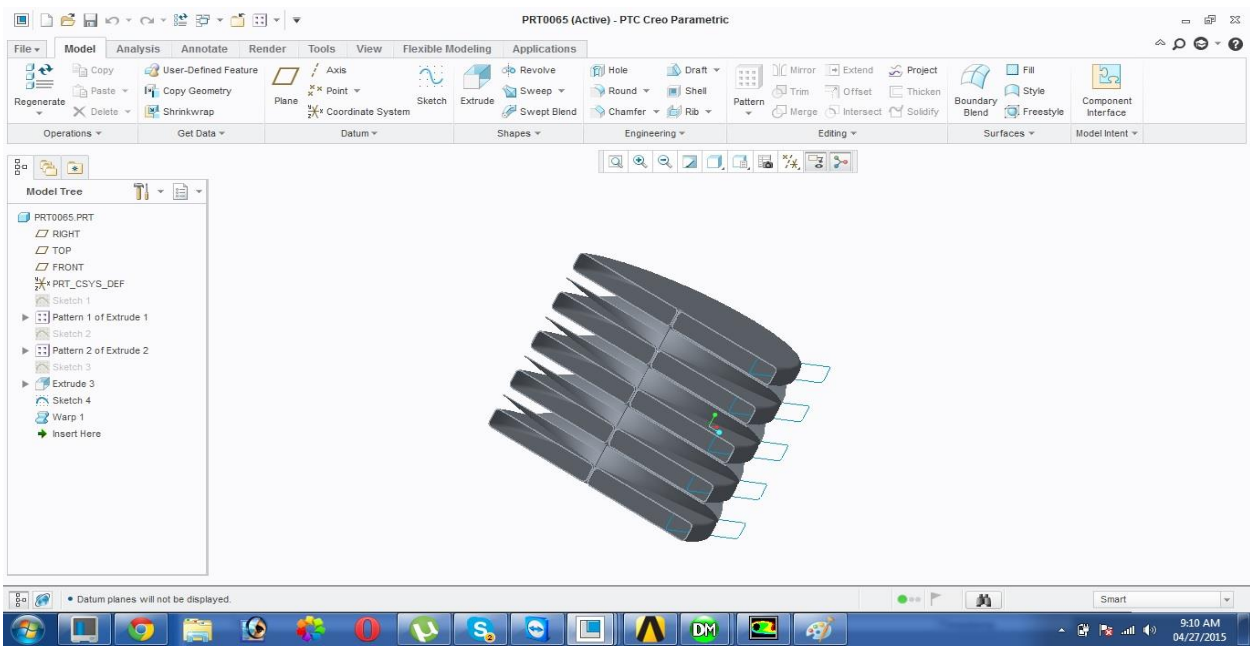



Fig 7. Cut out section of Spiral radiator design

## 9.2 Mathematical Modelling

The heat transfer for the radiator design can be modelled using FEM approach. The flow variables for the modelled element are used to interpolate the variables inside the nodal conditions.

Boundary conditions: T=50˚C (at inlet)

$$-k\frac{\partial T}{\partial n} = h(T - Tf)$$ (Heat conducted through convection)

Heat convection equation of 3D unsteady state system is given by:

$$\frac{d^2T}{dx^2} + \frac{d^2T}{dy^2} + \frac{d^2T}{dz^2} = \frac{1}{\alpha}\frac{dT}{d\tau}$$

Where α= thermal diffusivity

$$\alpha = \frac{k}{Cp}$$

In FEM, the governing equation becomes:

$$\iiint W_{\mathrm{i}}(k\nabla^2 T + Q)\, dxdydz = \frac{1}{\alpha}\int \frac{dT}{d\tau}$$

$W_{\mathrm{i}}$ can be replaced by interpolation constant $N_i$,

$$\iiint N_{\mathrm{i}}(k\nabla^2 T + Q)\, dxdydz - \frac{1}{\alpha}\int \frac{dT}{d\tau} = 0$$

Q=0; as internal heat generation is zero,

$$\iiint N_{\mathrm{i}}(k\nabla^2 T)\, dxdydz - \frac{1}{\alpha}\int \frac{dT}{d\tau} = 0$$

Applying gauss Divergence Theorem on above equation, we get:

$$\iiint N_{\mathrm{i}}\nabla.(k\nabla T)\, dxdydz - \frac{1}{\alpha}\int \frac{dT}{d\tau} = 0$$

$$\iiint \nabla.(N_{\mathrm{i}}k\nabla T)\, dxdydz - \iiint (\nabla N_{\mathrm{i}}).(k\nabla T)\, dxdydz\ - \frac{1}{\alpha}\int \frac{dT}{d\tau} = 0$$

The volume integral is converted into space integral

$$\iint k\left(\frac{\partial N_i}{\partial x}\frac{\partial T}{\partial x}+\frac{\partial N_i}{\partial x}\frac{\partial T}{\partial x}\right)dxdy-\oint N_i K\frac{\partial T}{\partial n}dl-\oint \frac{1}{\alpha}\frac{\partial T}{\partial \tau}=0$$

Now applying boundary conditions

$$\iint k\left(\frac{\partial N_i}{\partial x}\frac{\partial T}{\partial x}+\frac{\partial N_i}{\partial x}\frac{\partial T}{\partial x}\right)dxdy-\oint N_i h\,(T-Tf)-\oint \frac{1}{\alpha}\frac{\partial T}{\partial \tau}=0$$

The above equation represents the heat governing equation of the radiator design.

## 9.3 Computational Dynamics

ANSYS, Inc. is an engineering simulation software (computer-aided engineering, or CAE) developer headquartered south of Pittsburgh in the business park in Cecil Township, Pennsylvania, United States. One of its most significant products is Ansys CFD, a proprietary computational fluid dynamics (CFD) program. ANSYS CFD allows engineers to test systems by simulating fluid flows in a virtual environment — for example, the fluid dynamics of ship hulls; gas turbine engines (including the compressors, combustion chamber, turbines and afterburners); aircraft aerodynamics; pumps, fans, HVAC systems, mixing vessels, hydro cyclones, vacuum cleaners, etc. The project included CFD analyses of the conventional radiator and a new concept based on spiral radiator. First the Steady state analysis of the conventional radiator is done as shown below:

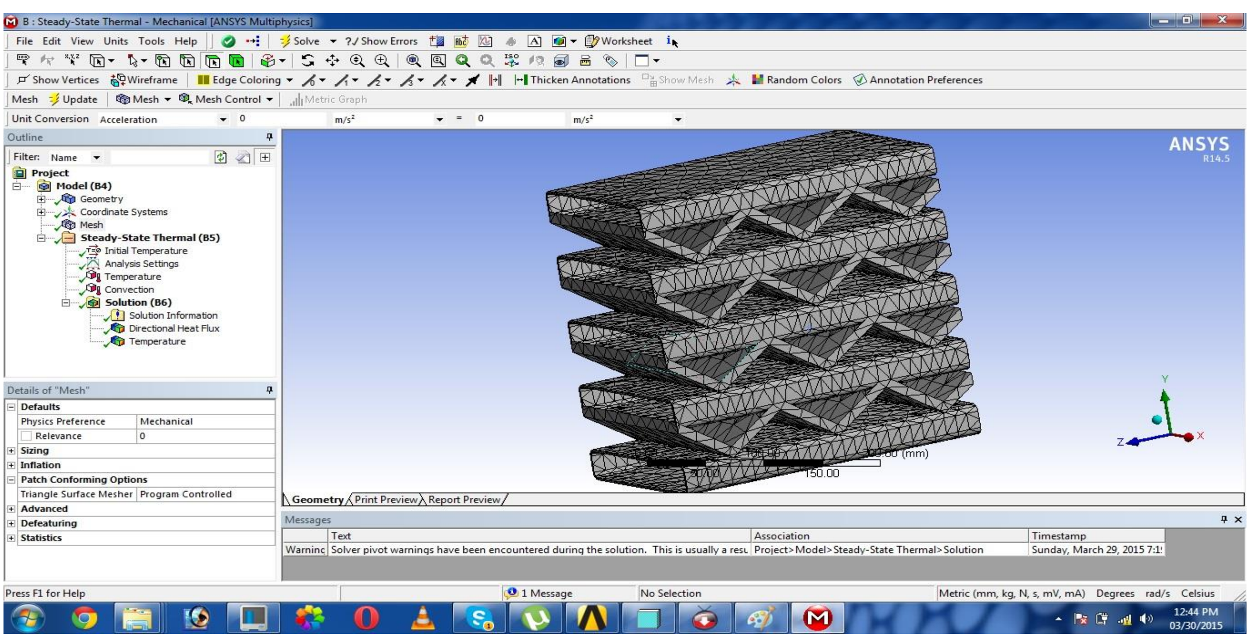



Fig8: Generation of meshing in the cutout section of the radiator

Meshing is generated on the cutoff portion of the model and is solved to obtain the temperature and heat flux distribution as shown above and can be referenced from the annexure 1.

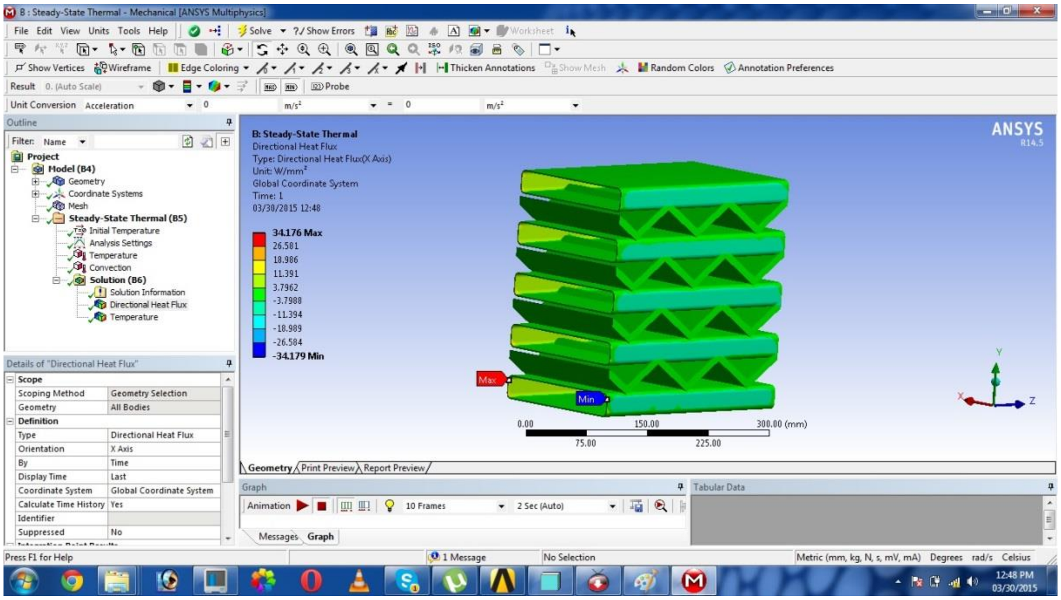



Fig 9: Heat flux distribution

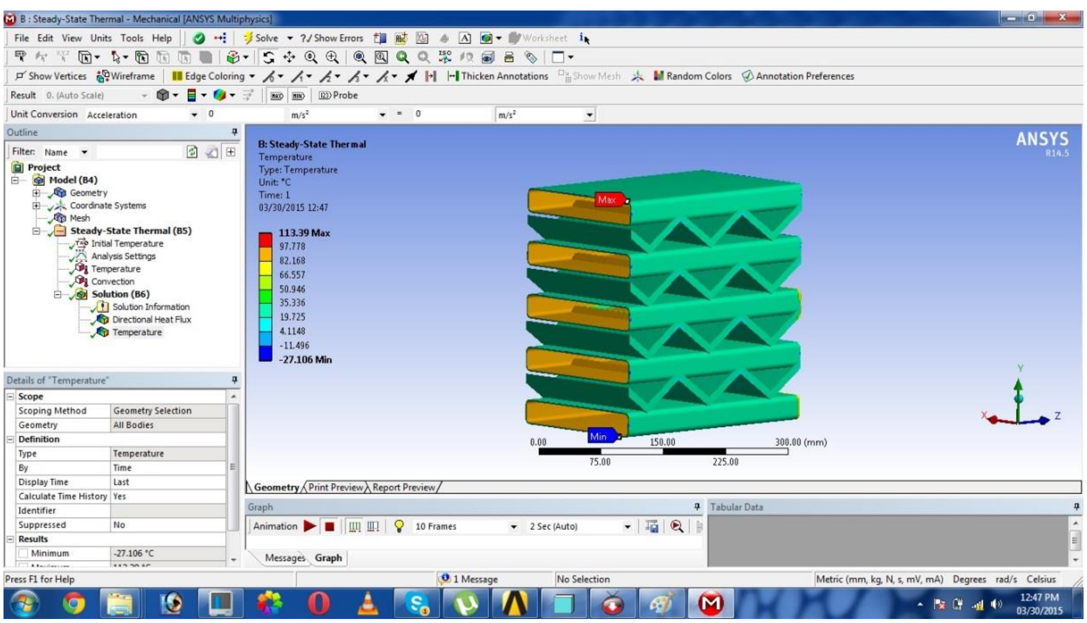



Fig 10. Steady State Temperature Distribution.

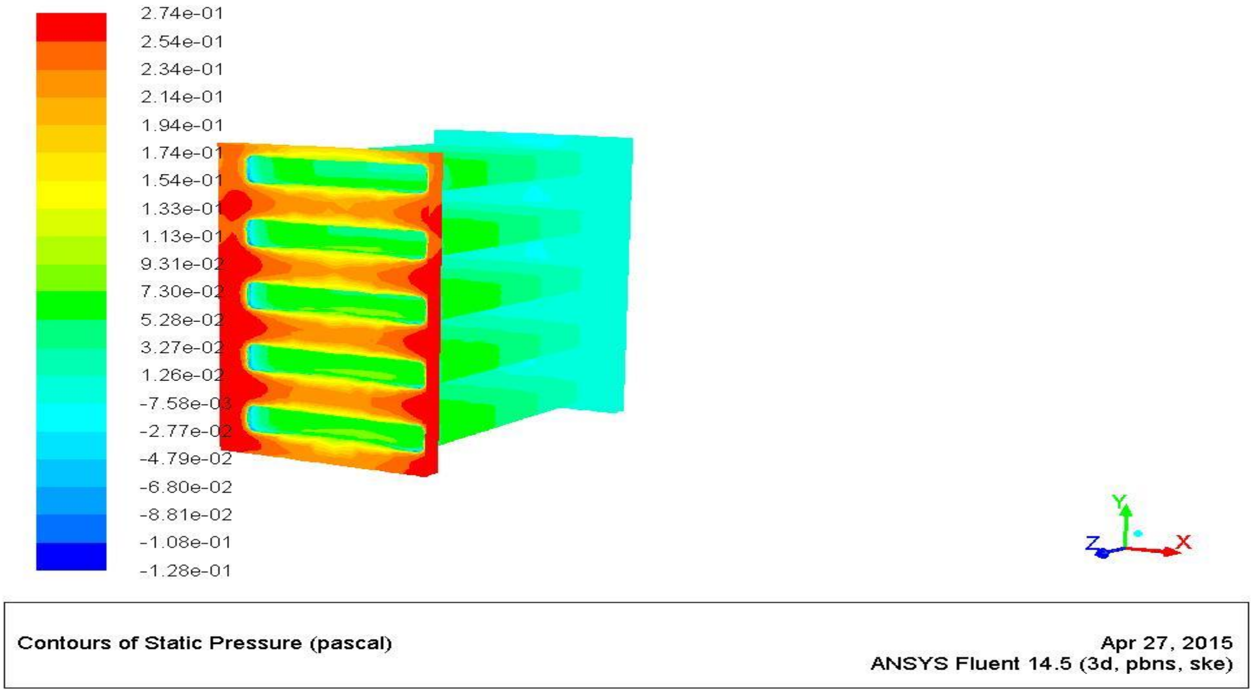



Fig.11 : Contours of Static Pressure (pa)

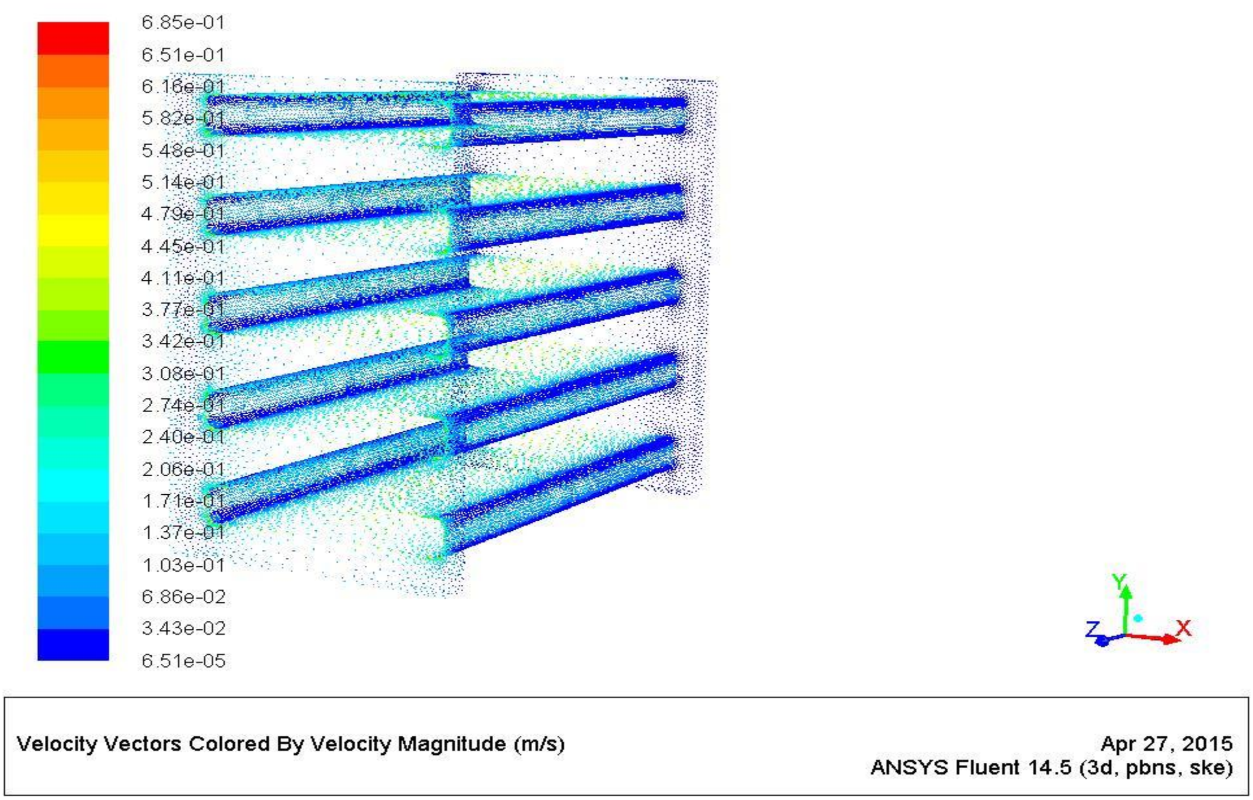



Fig. 12: Velocity Profile

## Analysis of Spiral radiator:

The analysis of spiral radiator using ANSYS 14.0 was performed .It consisted of Steady state thermal analysis of Spiral Radiator and fluent analysis of the radiator . The entire process is as follows :

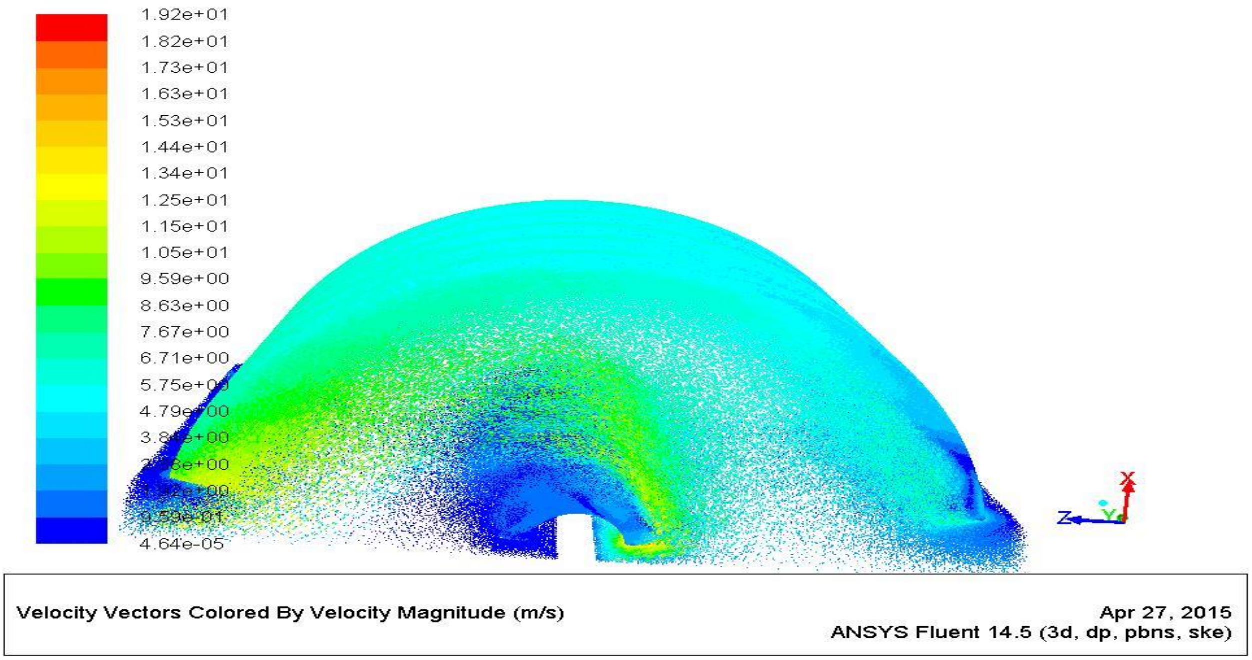



Fig 13: Velocity Profile Spiral Radiator

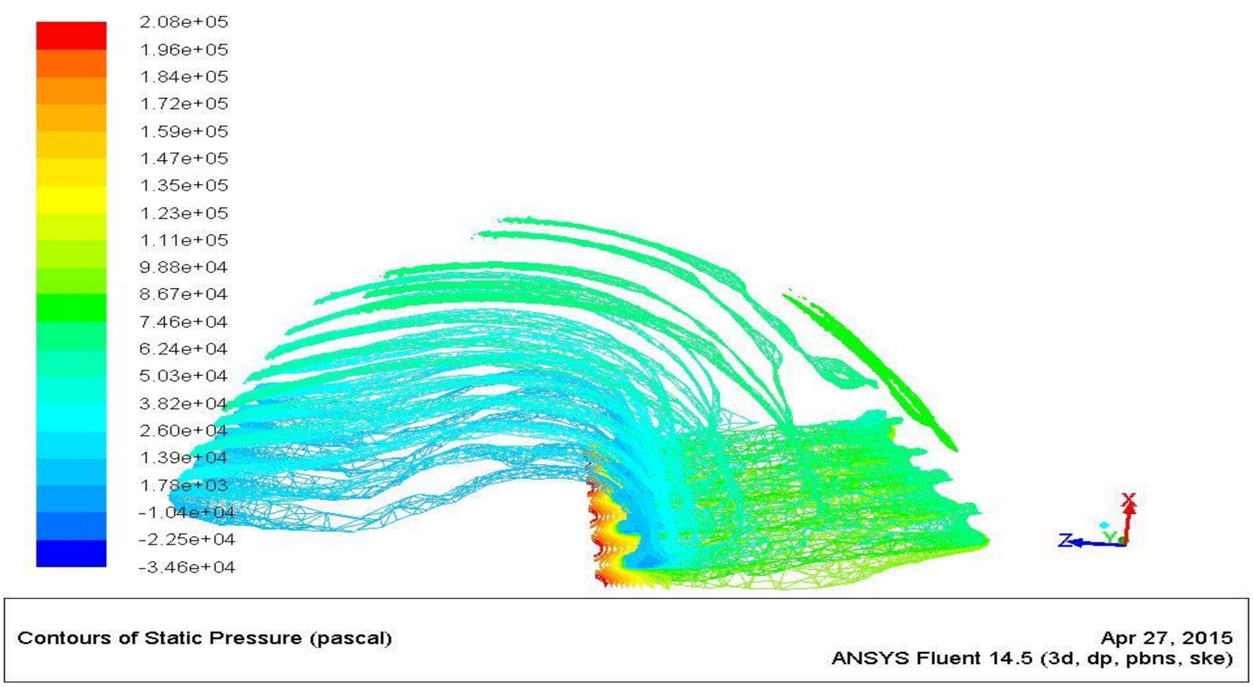



Fig 14: Contours of Static Pressure

# CHAPTER 10: RESULTS AND CONCLUSIONS

The objective of the study , design and simulation of the Radiator system of an automobile was successfully performed. The simulation and analysis of radiator was completed in ANSYS 14.0 .Optimal results were found after the complete analysis of the two radiators ie.. Conventional and Spiral. The two radiators were compared based on their net heat flux analysis .

**FOR CONVENTIONAL RADIATOR :**

Maximum Heat flux generated = 97.706 W/mm^2

**FOR SPIRAL RADIATOR :**

Maximum Heat Flux Generated = 222 w/mm^2

Thus the percentage increase in heat flux is given as :

% increase = (heat flux of conventional radiator – heat flux of Spiral radiator )* 100 /heat flux of conventional radiator

Thus % increase = 127.2122 %

Thus , based on the above data we can conclude that the spiral radiator is more efficient than the conventional radiator .

# CHAPTER 11: REFERENCES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