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Design and Performance Analysis of Automotive Radiator using Computational Fluid Dynamics

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ABSTRACT

Automotive radiator is a device of heat exchange to transfer heat energy from one medium to the environment. It consists a lot of parallel thin-wall tubes which allow water (medium of heat exchange) to pass through and the heat from the hot water is dissipated to the air stream which created by radiator's fan. The total heat transfer area of automotive radiator is typically high which contributed by the thin waved-shape fins sandwiched between the tubes. Most of the tubes and fins 18 are fabricated by metal which has high heat conductivity such as aluminum and copper to enhance the rate of heat conduction within tubes and fins. With higher rate of heat conduction, more heat energy can be dissipated to the environment. Therefore, automotive radiator has a very high heat transfer profile. In this study, automotive radiator is the key component which also the last stages of heat dissipation to the environment. The proposed work relates to an improved heat exchanger (Radiator) design for either heating or cooling of a fluid. Also, it deals with the work particularly which relates to an improved fan assisted air-cooled heat exchanger used in Automobiles, Internal Combustion (IC) engines, Refrigeration system, and Power plants.

Keywords— *Ansys, CAE, CFD, Radiator*

I. INTRODUCTION

1.1 HEAT EXCHANGERS IN AUTOMOBILES

Various heat exchangers employed in modern automobiles are,

- Radiator
- Transmission Oil Cooler
- Engine Oil Cooler
- Evaporator
- Condenser
- Engine water Jackets
- Exhaust Gas Cooler
- Turbo intercooler

1.2 COOLING SYSTEMS

During combustion in the IC engines, temperature of hot gases in the cylinder approaches to 2700 K. Such high temperatures are not suitable for the proper working of the engine and have adverse effects such as seizing of the piston- cylinder or damage to any other engine parts. Hence the temperature has to be brought down to 180-200 oC at which the engine will work efficiently. Overcooling is also not desirable as it decreases the thermal efficiency (ηth). Hence main aim of the cooling system is to maintain the engine running at the most efficient operating temperature. There are two types of cooling systems namely:

1. Air Cooled Systems
2. Liquid or Water Cooled Systems

It mainly consists of a Radiator, Thermostat valve, Water pump, fan etc. Working of the system is self explanatory. In the central section it consists of a central radiator core. The upper section contains upper tank and lower section contains lower tank. The upper tank is connected to water outlet from engine through hose pipes. Lower tank is connected to engine jackets inlet through hose pipes. Generally used central cores have 2 designs viz. Tubular and Cellular. Thermostat: It prevents cooling liquid below 75oC to enter the radiator. Hence the engine attains maximum efficient operating only. It has a bellow with alcohol in it. This alcohol evaporates causing the bellow to expand which in turn operates the butterfly valve and allows the liquid to flow into the radiator. Liquid Pump: To circulate liquid coolant into the system. Fan: It draws air and blows it over the radiator.

1.3 Power consumed by fan

The automobile radiator sometimes needs additional airflow through it to prevent the engine from overheating.

This usually occurs at idle and slow speed. At higher vehicle speeds, the air flows through the radiator by the forward motion of vehicle provide all the cooling that is needed. An engine fan or cooling fan pulls the additional air through the radiator. The fan may be either a mechanical fan or an electric fan. Engines mounted longitudinally in rear-drive vehicles usually have a mechanical fan that mounts to the water pump shaft. The fan is made of sheet steel or molded plastic. It has four to seven blades and turns with the water pump impeller. A fan shroud around the fan directs the airflow. This increases the efficiency of the fan. Transverse engines in front-drive vehicles usually have an electric fan. An electric motor turns the blades. A thermostatic switch turns on the fan only when needed. Generally, the switch turns on the fan when the coolant reaches 700 – 800 C. It turns off the fan if the coolant drops below this temperature. Any saving in the fan power is directly the saving of precious fuel. On the experimental trial setup of Petrol Engine and Diesel Engine, trials are conducted in the college laboratory with fan and without fan. It is observed that power consumed by the fan is of considerable magnitude and is about 2% to 5% of total power developed by the engine [4]. Any saving in the fan power is directly the saving of precious fuel. Also BHP of the engine will be mentioned by the manufacturer or it can be calculated. Fan HP can be calculated from the formula.

$P_{hp} = Q \times \Delta P \times S/6355.827$ …(1)

Where, P_{hp} = Horse Power of air

S = Specific gravity of air.(=1.0)

ΔP = total change in pressure

$P_{BP} = Q \times \Delta P / \eta \times 6355.827$ …(2)

Where η = efficiency.

It is observed that,

1) For open air engine – For power consumption 2 to 4% of engine power.

2) In case of closed engine – power consumption is 4 to 6% of engine power.

Also it is observed from following examples that,

a) Cummins engine make, 1645 BHP required 42 HP for fan i.e. 2.55% of engine power.

b) Cummins engine make, 600 BHP required 17 HP for fan i.e. 2.83% of engine power

1.4 Literature

Chavan.D.K.., et all [1] In this paper "Thermal Optimization of Fan assisted Heat Exchanger (Radiator) by Design Improvements" proposed to develop and test the circular radiator. The present heat exchangers/radiators are rectangular in shape. But the air blown by the fan is circular in area, developing low velocity area in the corners. Therefore circular radiators which are compact are proposed to be developed and tested to improve the efficiency. He said that significant work has to be done in this area. Hamid Nabati., et all [2] "Optimal Pin Fin Heat Exchanger Surface" represented the results of numerical study of heat transfer and pressure drop in a heat exchanger that was designed with different shape pin fins. The heat exchanger used in his research consists of a rectangular duct fitted with different shape pin fins, which were heated from the lower plate. The pin shape and the compact heat exchanger (CHE) configuration were numerically studied to maximize the heat transfer and minimize the pressure drop across the heat exchanger. A three dimensional finite volume based numerical model using FLUENT© was used to analyze the heat transfer characteristics of various pin fin heat exchangers. Rahul Tarodiya.,et all [3] carried out Energetic analyses as well as theoretical performance analyses of the flat fin tube automotive radiator using nanofluids as coolants to study its performance improvement. Effects of various operating parameters using Cu, SiC, Al2O3 and TiO2 nanofluids with 80% water-20% ethylene glycol as a base fluid were presented in this article. Use of nanofluid as coolant in radiator improves the effectiveness, cooling capacity with the reduction in pumping power. Ahmed F. Khudheyer.,et [4] all Carried out Three-dimensional CFD simulations to investigate heat transfer and fluid flow characteristics of a two-row plain fin-and-tube heat exchanger using Open FOAM, an open-source CFD code. Heat transfer and pressure drop characteristics of the heat exchanger were investigated for Reynolds numbers ranging from 330 to 7000. Model geometry is created, meshed, calculated, and post-processed using open source software. Fluid flow and heat transfer are simulated and results compared using both laminar and turbulent flow models (k-epsilon, and Menter SST k-omega), with steady-state solvers to calculate pressure drop, flow, and temperature fields. K.Ganesan., et all [5] This paper throws light on parameters optimization flow changes analysis which influences radiator performance along with reviews some of the systematically with new modern approaches to enhance radiator performance analysis with design and numerical analysis of water heating conductivity to transient analysis single sample tube in different copper graded material analysis in flow passing through the water comparing to the better cost effective and material data its analyzed using in ansys 14.5 version. Gita.R., et all [6] In this paper solid modeling of radiator was developed in Solid works and then this solid model was transferred to ANSYS Workbench mesh module for meshing. After completing meshing, it was transferred to ANSYS CFX to analyse the Effect of Percentage of Coolant and Water Mixture for Cooling In Automobile Radiator. The thermal performance of an automotive radiator plays an important role in the performance of an automobile's cooling system and all other associated systems. For a number of years, this component has suffered from little attention with very little changing in its manufacturing cost, operation and geometry. Vishwa Deepak Dwivedi et all [7] To improve the performance of an automotive radiator, he presented the Design and Performance Analysis of Louvered Fin Automotive Radiator using CAE Tools In this study outline that the nano fluids may effectively use as coolant in automotive radiators to improve the performance. The temperature and velocity distribution of coolant and air were 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.

II. METHODOLOGY

2.1 Factors affecting radiator performance

a) Air Turbulence: Increased air turbulence improves the heat convection process.

b) Air velocity: Increasing the velocity of the air over the radiator improves heat dissipation.

c) Radiator Tubes: Making smaller tubes and increasing the total amount of tubes, decreases the time taken to transfer the same amount of heat by increasing the surface area of tubes.

d) Surface Area (Fins): Increased surface area of the fins improves heat transfer process.

e) Surface Area (Total): Increase the overall surface area of the radiator for better heat transfer.

2.2 Existing rectangular / square and proposed radiator

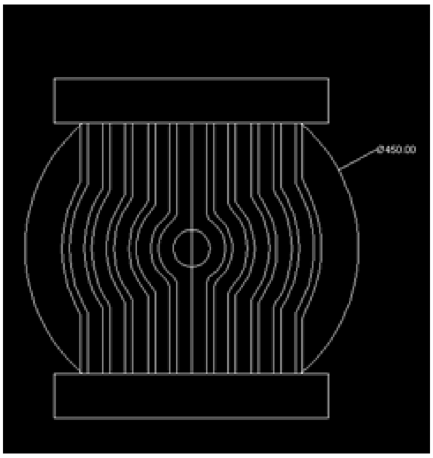

Fig.1 Existing heat exchanger (Rectangular Radiator)

A square-shaped heat exchanger with a fan provided to deliver air in a circular area shown in Fig.1.4. If the length and breadth of the heat exchanger is equal to D, the effective area of such heat exchanger will be equal to D2. While the flow of air from the fan (without shroud) will be of area (π/4) D2 = O.76 D2. The difference in the area of the square and the circle would be {D2 - (π/4) D2} = 0.24 D2.

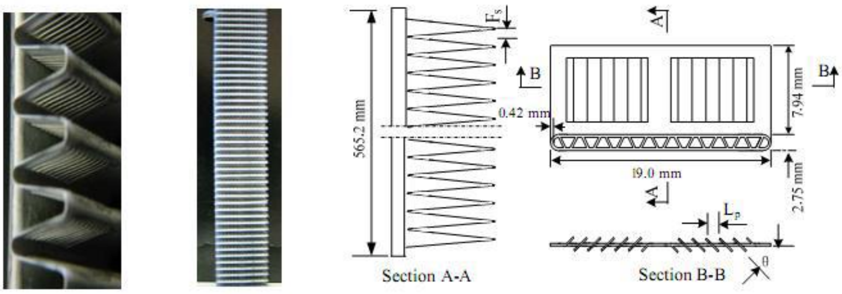

Fig.2. Structure of the test heat exchanger [9]

III DESIGN SPECIFICATIONS

Size of the radiator =500mmx100mm

Diameter of the tube (o.d)=12.5mm

Diameter of the tube (i.d)=10mm

No. of tubes=20

Height of the radiator=460mm

Material used for tubes= Aluminum

Total Mass flow rate of coolant-2.45kg/sec

3.1 Physical Properties

Density: 2.7 g/cm3

Melting Point: Approx 580°C

Modulus of Elasticity: 70-80 GPa

Poissons Ratio: 0.33

3.2Thermal Properties of aluminum 6061

Co-Efficient of Thermal Expansion (20-100°C): 23.5x10-6 m/m.°C

Thermal Conductivity: 173 W/m.K

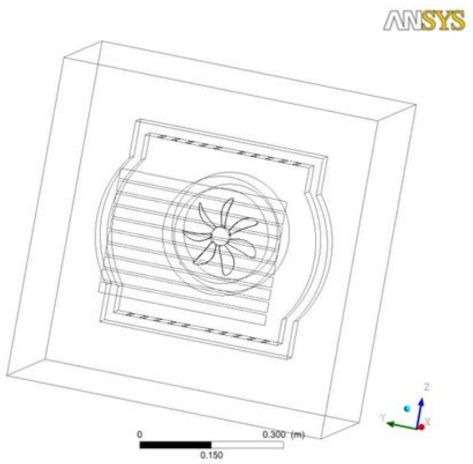

Fig.3 Geometry of model

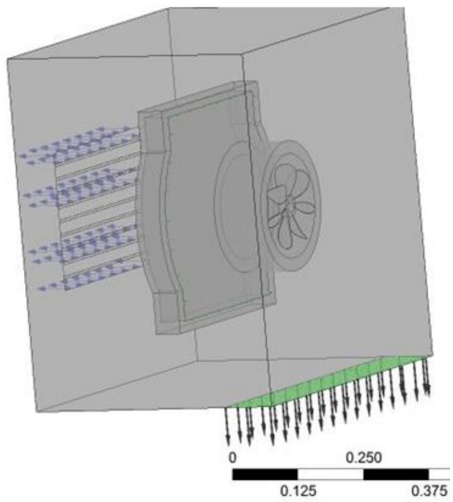

Fig.4 Boundary conditions of model

IV RESULTS AND DISCUSSION

4.1 Case 1 Flow around radiator with porous media by using Body Force Model method

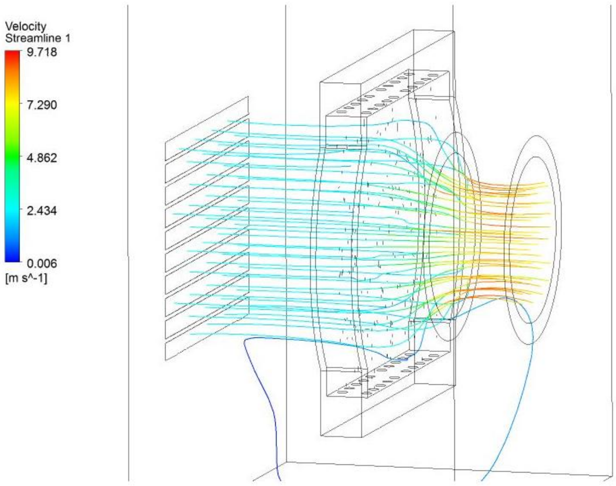

Fig.4 Velocity stream lines in Radiator using body force model with out fan

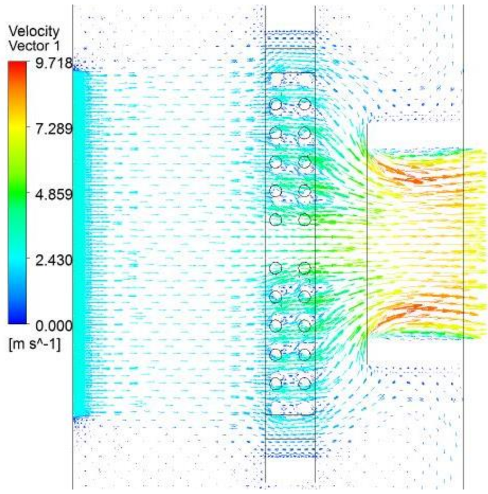

Fig.5 Velocity vectors in Radiator using body force model without fan

4.2 Case 2 Flow around radiator with porous media by using Fan

The use of fan reduces the size and the cost of the equipment, which makes it more compact. Hence, fan assisted air cooled heat exchangers are more popular than others. In known air-cooled heat exchangers, the fan either forces or draws the air through the heat exchanger, some of which are described herein below by way of examples. In present system, the fans are placed behind the heat exchangers to force/ draw the atmospheric air. These exchangers use a shroud. This directs the air over the entire area of the heat exchanger. A study was undertaken to find out the distribution of airflow and variation of its velocity, pressure and temperature.

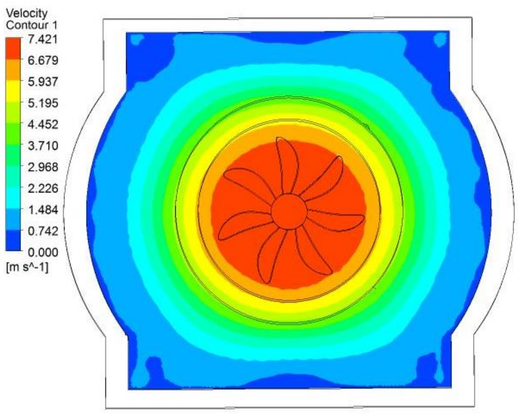

Fig.6 Velocity contours in radiator using fan

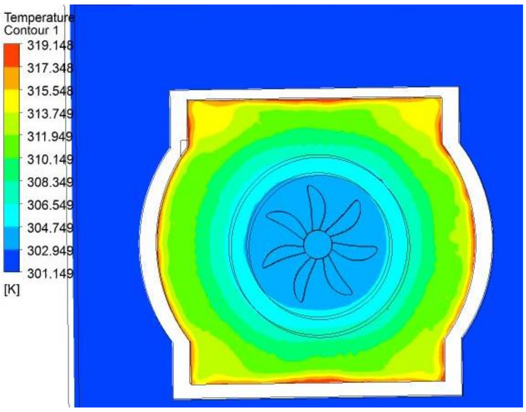

Fig.6 Temperature contours in radiator using fan

The velocity of air generated by the fan is not constant along its radial direction. It is observed to be increased to maximum at centre and gradually decreed to zero at corners. It can be observed that low velocity or stagnation zones are created in the corners hence may be eliminated and circular radiator is proposed for optimum efficiency Fins are the most important component of any heat exchanger. They are used to transfer the heat generated inside the heat exchanger to the surroundings reducing inside fluid temperature. Factors influence the temperature of the engine, including radiator size and the type of radiator fan. The simulation results obtained showed in Fig.4.7 reasonable variation in the temperature as expected. A drop in temperature of the coolant from 319 K to 301 K is observed

V CONCLUSIONS

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

- For different cases used to study the radiator performance: Indicate that maximum temperature drop & minimum pressure drop occur in case of radiator with fan of having circular section.

- The addition of fan and change in shape has the potential to improve auto motive and heavy-duty engine cooling rates.
- Help in a reduced-size cooling system by removing heat from engine.
- Smaller and lighter radiators, which in turn plus point almost every aspect of vehicle performance and lead to increased, fuel economy.

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