**International Journal of Mechanical Engineering and Technology (IJMET)**
Volume 9, Issue 12, December 2018, pp. 671–680, Article ID: IJMET_09_12_068
Available online at http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=9&IType=12
ISSN Print: 0976-6340 and ISSN Online: 0976-6359



# REVIEW ON CONTEMPORARY TRENDS IN RADIATOR DESIGN AND TESTING OF AUTOMOBILE RADIATORS

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## ABSTRACT

*As the modern era demands of communication by means of transportation, the demand for automobiles has risen to peaks. Consequently, it has become a great difficulty for the manufacturers to give an efficient and powerful engine for the necessity of the customer. The transmission system, fuel/air supply system, lubrication system, air/coolant cooling system etc. and various other system affects the performance of the engine. Hence, it is necessary for considering these performance attributes by designing an engine for better performance, where the cooling system plays a major role. Designing, maintaining and testing of engine cooling system must be maintained properly for better performance of the engine. This review focuses on the design of radiators to improve automobile radiator efficiency and testing of radiators. Many varieties of research papers have worked on the variety of methods that the radiator efficiency changes at the variation of mass flow rate by use of tubes, core, different nanofluids (coolants) and fan. In this literature study, it will be seen that different methods are used to increase the radiator's efficiency, among them radiator coolant is the most used one to improve the radiator's efficiency by addition of nanoparticles in coolant and modification of radiator's tube and fan.*

**Keywords:** Flow Rate, Radiator, Nano particles, Cooling System, Heat Dissipation Rate, Pressure Drop.

**Cite this Article:** Nagarjun Vinukonda and Vinod Kumar Sharma, Review On Contemporary Trends In Radiator Design and Testing of Automobile Radiators, International Journal of Mechanical Engineering and Technology, 9(12), 2018, pp. 671–680.
http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=9&IType=12

# 1. INTRODUCTION

Engine cooling system of the automobile will take charge of waste heat generated in the course of operation of the engine and regulate the temperature at the surface of an engine for better performance. Majorly, the engine cooling system of the automobiles is composed of the cooling fan, pressure cap, radiator, water pump and thermostat where the systems main component is radiator as shown in Figure 1. The radiators heat exchanger will discard the heat generated in the coolant of an engine while sending it through the radiator. This heat is transported to ambient air. Its assembly is composed of 3 important parts outlet tank, core and inlet tank. There are 2 sets of passage for core i.e. a set of fins and tubes. The coolant will flow passing along the airflow and tubes among the fins and hot coolant will then send heat across tubes to fins. Ambient air which is moving across pickups of fins will carry heat away. If radiator doesn't cool down the engine, a variety of complications like cylinder deformation, knocking, etc. will occur. In order to increase the performance of an engine, the cooling system should work precisely which makes the radiator must work perfectly. The optimization of air flow has an important part in heat transfer through convection while designing several sections (grills, radiator cover, core, fins, etc.).

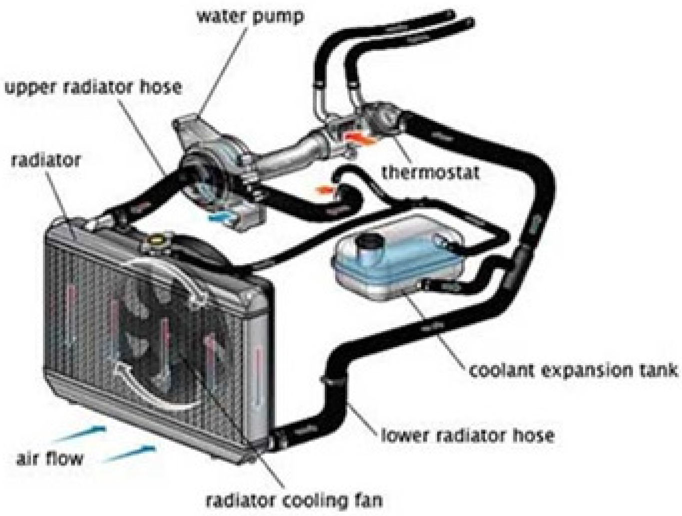


**Figure 1** Radiator with its Components.

IC engine cooling system utilizes either liquid or air to discard the unrequired heat generated. For special or small basis engines, cooling of air causes for a comparatively easy system and lightweight. The liquid cooling systems of the engine which are further complicated in circulating will discard unrequired heat to the air, but circulating fluid which would be air or liquid will improve the heat transfer from internal parts of an engine [1].

First, the coolants flow through this passage in the engine block and pick up the heat from the engine as shown in Figure 2. The liquid which is heated passes through a rubber hose and goes towards the radiator. Then, the compartment of an engine in the car which intakes the air stream will cool this liquid. This is how the cooling system works. An equipment called thermostat which is located in between the radiator and engine and will ensure the coolant always maintains above an optimum level of temperature. When the temp of coolant tumbles lower than the optimum temp, the coolant's flow will be blocked by the thermostat into the radiator and this forces the liquid through a bypass which directs back to the engine. In order to avert the boiling of coolant, the engine cooling network is sketched such that it can be pressurized which makes coolants boiling point to increase substantially under applied pressure.

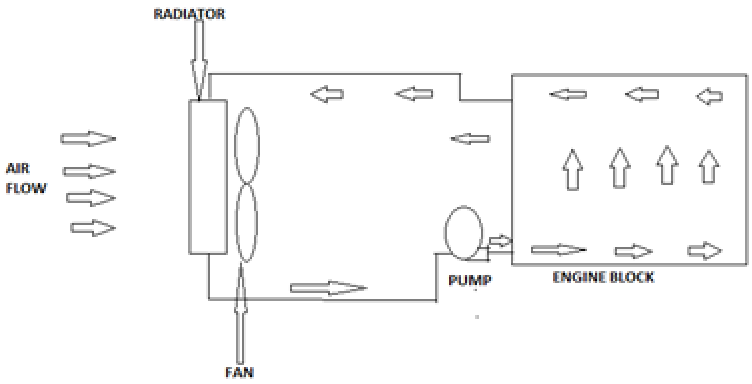


**Figure 2** Block diagram of radiator intake.

## TESTING OF RADIATORS [2]

There are 3 types of methods that are employed for testing: analytical and experimental, computational methods.

***1. Analytical Methods:***

The radiator effectiveness could be calculated using any of the underneath methods:

a. Log Mean Temperature Difference method (LMTD)

b. Number of Heat Transfer Units method (NTU)

a. Log Mean Temperature Difference:

By use of this method, the exact magnitude for an area of the heat transfer on the core of radiator is calculated here for achieving the required outlet temperatures under the specific radiator operating conditions.

b. The Number of Heat Transfer Units:

When the size and shape of a radiator, the discharge rate of coolant flow and temperatures of the inlet for both coolant and air fluids are known for a specific radiator this method is more accurate than LMTD method. Here each parameter has its own importance where the performance is affected. Here the outlet temperature and heat transfer rate are also calculated where it includes calculation of many units-less(dimensionless) attributes (parameters) while consisting of NTU, Capacity Ratio (Cmin/Cmax) and Effectiveness (ε).

***2. Experimental Methods [3]:***

On road and wind tunnel testing is used for Test assessment of car. On road-testing helps to directly assess the true behavior of cooling system effectiveness of engine by giving appropriate airflow at "real" conditions to the under of vehicle. The estimation of flow conditions on on-road is made under-regulated surroundings by including no movement of vehicle w.r.t air. The regulation of tests will be more advantageously, time-viably and well approximated by the wind tunnel testing. There are two types of wind tunnels: aerodynamic wind tunnels and climatic wind tunnels. For better exterior surface aerodynamics i.e. for testing the variations of moments and forces on the car and wind noise the usage of aerodynamic wind tunnels takes place. For creating the thermal characteristics experience on the road i.e. giving the capacity for regulating surrounding humidity and air temperature by making artificial rain, etc. and simulating engine loads on a chassis dynamometer climatic wind tunnels are used, which are generally not as good as aerodynamic wind tunnels in flow quality.

## 1.2. TERMINOLOGY USED:

For the purpose of this review, the following definitions should apply,

A. Heat Dissipation Rate of Coolant (Qw)

It is the quantity of heat which coolant loses under test conditions, units (KJ/s).

B. Heat Dissipation Rate of Air (Qa)

The rate which the heat is dissipated by the cooling air, units (KJ/s).

C. Inlet Temperature Difference

Temperature dissimilarity between the inlet temp of air and water. Units degree Celsius.

D. Flow Rate of Coolant (mw)

It is a rate of flow of coolant which goes through the radiator is represented in (Kg/s).

E. Flow Rate of Air (ma)

It is a rate of flow of air which goes through the radiator is represented in (Kg/s).

F. Upstream End

The air is allowed to enter into an area before radiator. This is called upstream end.

G. Downstream End

The air is allowed to exit from an area after radiator. This is the downstream end.

## 1.3. THERE ARE TWO TYPES OF TEST APPARATUS:

### *A. Waterside Circuit:*

Here the rate of heat rejection from the hot water tank should balance the rate of dissipation of heat and should be alterable in the domain of heat dissipation. The hot water tank here is sketched to avert vapor and air locking and the water pump could be attached to any side of the outlet or inlet pipe of the radiator. Here, in the waterside circuit of the radiator, it is armed with separators for averting the mixing of vapor and air.

### *B. Airside Circuit (wind tunnel):*

Here the attachment of tube across the radiator and wind tunnel main body should be exchangeable for eliminating imbalance in shape and radiator size. This arrangement should include fan, throttle devices, shutter, cone etc. here the passing of flow in radiator should be adjustable. Radiators front should receive a parallel and uniform air flow. Hence the attaching tube shape should be designed in such a manner.

### *C. Measuring Equipment:*

Some of the normally used measuring equipment's are:

1. Water Flow Meter: it has a better approximation of +1% of max scale.
2. Airflow Meter: it should be based on the pitot tube. The inclined type manometer of 1 mm on 30˚or such vertical column should be the least scale requirement of liquid column which is to be taken here.
3. Pressure Gauges: When considering waterside least of 1.2 mm or better approximation for the liquid mercury column gauge should be taken. When considering airside in the measurement of pressure loss, least of 1.2 mm or better approximation for the liquid column should be taken. Fortin's barometer shall be used for measuring atmospheric pressure.

4. Thermometers: For temperature measuring thermometers should be used having at least +/- 0.1˚C of better approximation for waterside and 1˚C of better approximation for the airside. For humidity and room temperature, a dry and wet bulb thermometer should be used.

## 2. LITERATURE REVIEW:

***(i) N. Galanis, G. Roy, C.T. Nguyen and C. Gauthier (2007) [4]:***

Here the magnification of heat transfer delivered by a specific nanofluid i.e. water and Al2O3 composition have been experimentally studied for the cooling of microprocessors and other heated electronic components which is the work of water closed system. The use of Nano-fluid was addressed to be advantageous from the data obtained for Nano-fluid and distilled water with various component concentrations about 2.2% and 0.95%. with respect to distilled water, the heat transfer improvement was observed for a 4.5% concentration.

***(ii). John Vetrovec (2008) [5]:***

By use of passive heat load accumulator which normalizes out peak heat loads of the engine cooling system with heat load averaging capacity was evaluated through this paper. During reduced heat load condition, the phase change material will store the heat generated during peak which is called heat load accumulator. During a cold engine start the reduced emissions of harmful pollutants and faster engine warm-up was done by translating heat load to a smaller coolant inventory which by averaging allows relaxation of cooling system and substantial reduction of system size and weight, which was done by losing phase change of PCM (Phase Change Material) from liquid to solid or vice versa, which would result in same heat rejection and reduction in load on cooling system for compact heat exchanger. The accumulator can be adjusted to replace a portion of ECS (Engine Cooling System) coolant lines, when faster warm up's and high transient loads at cold engine start was handled by the system which results in concept of down-sizing of ECS volume and weight when 1) handling of high-transient loads by surpassing a full-size ECS. 2) Under typical heat load conditions, comparable to a full-size ECS offering a heat load-handling performance.

***(iii) S. Cheong, Y. Kwon, Y. Hwang, D. Kim, and Y. Cho (2009) [6]:***

A straightforward circular tube which is having turbulent and laminar flow with a constant heat flux of convective heat transfer coefficient was studied, whose performances are affected by nanofluids in this paper. The coefficient of heat transfer by convection of alumina nanofluid is improved in correspondence to base sample fluid by 20% & 15% in turbulent and laminar flow correspondingly. Through their research, they also made an observation that in turbulent flow, thermal conductivity plays a major role and in the laminar flow, the thermal boundary layer plays a major role. There is no enhancement in the coefficient of heat transfer by convection for amorphous molecules of nanofluids.

***(iv). A.H. Mamun, K.Y. Leong, S.N. Kazi and R. Saidur (2010) [7]:***

This paper outlines the effect on cooling capacity while using nanofluid based coolant in engine cooling system. Through this, it was discovered that nano-fluid increases heat transfer which has higher thermal conductivity than base coolant which blends of 50%/50% ethylene glycol and water. When same heat transfer occurs compared to base one of the radiator, its core area can be reduced. Ethylene glycol as a coolant in the radiator when used compared to the nanofluid, the thermal performance of a radiator is raised by increasing power of pumping.

***(v). M. Seifi Jamnani, S.M. Peyghambarzadeh, S.M. Hoseini and S.H. Hashemabadi (2011) [8]:***

This paper researches about the experimental comparison of heat transfer by forced convection of Nano-fluid which is water based to that of pure water in the radiator of the automobile. Where on the addition of Al2O3 nanoparticles into the water, 5 distinct level of quantity magnitude of Nano-fluids in the domain of 0.2-1 vol. % was made, where the sample functional liquid goes into the radiator consisting of 34 vertical tubes which have the elliptical cross-section and with constant speed inside the tube bank the air creates a cross flow. To have the fully turbulent regime the flow rate of the liquid is been modified in the domain of 2-5 lit/min. On the other hand, by fluctuating the temperature in the domain of 37-490oC the effect of fluids inlet temperature to that of radiator on coefficient of heat transfer is been studied, which results the improvement in heat transfer effectiveness by increasing the circulating rate of fluid while the inlet temperatures of fluid to that of radiator has adverse effects. In correspondence with pure water, the efficiency of heat transfer can be enhanced by the application of Nano-fluid at low concentrations, up to 45%.

***(vi) Komalangan Krishnakumar, Navid Bozorgan and Nariman Bozorgan (2012) [9]:***

A numerical study on coolant i.e. CuO-water nanofluid with a given pumping power and heat exchange of copper oxide water capacity was described in this article. Under turbulent flow conditions, the overall convective local coefficients of heat transfer of nanofluid at distinct volume fractions (2% to 0.1%) and effects of speed of automobile on the radiator's efficiency were researched. The nanofluid's total coefficient of heat transfer is much better than the coefficient of heat transfer of water was described in the numerical analysis. Here and hence, it is concluded that the total area of heat transfer of the radiator can be decreased.

***(vii) D.H. Lee, L.D. Tijing, B.C. Pak and B.J. Baek (2013) [10]:***

By the utilization of twisted and straight internal fin inserts the heat transfer enhancement was researched under this article and the pressure drop and characteristics of heat transfer results on horizontal 2 tubes with coil-wire insert were concluded. The hot and cold water mass flow rates effect directly the heat transfer rate and coefficient of heat transfer. It is seen that as Re raises the coil-wire insert effect on the magnification of heat transfer leads to reduce.

***(viii) Tun-Ping Teng, Hwa-Ming Nieh and Chao-Chieh Yu (2014) [11]:***

The article here presents to magnify the performance of dissipation of heat for an air-cooled radiator by use of titanium (TiO2) and alumina (Al2O3) Nano-coolant, whereby use of the Nano-fluid and 0.25 wt. % chitosan dispersant is constituted with 1:1 volume ratio of ethylene glycol (EG). A 2-step fabrication process is used to yield distinct level of magnitude of its quantity for Al2O3 and TiO2/water (W) Nano-fluid to form NC1 to NC6 (Nano Coolant). Here with distinct level of magnitude of quantity for nanoparticles and its sample temperatures, tests are organized to calculate the specific heat, viscosity and thermal conductivity of the nano-coolant and with help of that nano coolant the capacity for dissipation of heat, drop of pressure, and power for pumping at distinct volumetric flow rates and temperatures are used for evaluation. The results observed are, as there is raise in TiO2 nano coolant volumetric flow rate and concentration, the average EF enhanced percentage raises and the efficiency factor (EF) and heat dissipation capacity of nano coolant are greater than EG/W (Ethyl glycol-water), and that of TiO2 nano coolant is also greater than Al2O3 nano coolant.

***(ix) JP Yadav and Bharat Raj Singh (2015) [12]:***

This article reviews the variation of parameters like inlet coolant temperature, its mass flow rate; etc. and installation of the radiator into a test-setup to review a differential analysis between different coolants. The coolant used here is composed of water and propylene glycol in a ratio of 40:60 and other is water alone. It resulted that due to the corrosiveness of water and containment of dissolved salts decreased the quality of coolant flow passage and its limitation occurs to water independent of its results in the best coolant. From the tests that have been followed in this paper, it is concluded that:

1. The cooling capacity and effectiveness will raise with raise in the rate of coolant flow in radiator more for water than the mixture.

2. Cooling Capacity and Output Temperature is more for water and mixture respectively for given Input Temperature of Radiator for both with and without Fan.

***(x) P. Mounika1 and Rajesh K Sharma (2016) [13]:***

Here as the vehicle moves from its rest position to a certain speed, the radiator is analyzed for a small segment for the several speeds of air striking the radiator. With ethylene glycol as the coolant, the experiment is done for a range of 15 kmph to 75 kmph speed of the air striking the radiator. After the analysis, the coefficient of heat transfer of ethylene glycol and the air is assessed and further, the gross coefficient of heat transfer is estimated. From the analysis done it can be concluded that:

1. Nusselt number of the air is estimated, as the Reynolds number of the air increases, the Nusselt number increases from 69 % to 125 %.

2. The coefficient of heat transfer values is raised by 125% when the velocity of the air striking the radiator changes.

3. It is also seen that, at a greater velocity of air striking the radiator, the Reynolds number is higher and as a result of it the efficiency of the fins is reduced slightly. The efficiency of the fins reduces by 6.1% when there occurs a change in Re (Reynolds number) from 14000 to 71000.

4. The gross coefficient of heat transfer is the function of the coefficient of heat transfer of air and the coolant used (ethylene glycol). As the Reynolds number raises from 14000 to 71000, there is a 91 % rise in the gross coefficient of heat transfer.

5. The generation of heat in engine parts increases significantly with an increase in speed of the vehicle when engines run at high values of rpm. Therefore, to dissipate the heat to the atmosphere the cooling process at higher speed should be effective. It can be concluded by this study that at greater speeds with a slight compromise in the decrease in the efficiency of the given number of fins attached and used in the radiator, the dimensioned radiator works properly.

***(xi) Nikhil S. Nagulkar1 and S. M. Lawankar (2017) [14]:***

This research paper works on measuring the coefficients of heat transfer in the radiator of an automobile with 2 different functional liquids: $Al_2O_3$ EG/W based Nanofluid(NF) and $ZrO_2$ EG/W based NF by experimental methods and at different magnitudes of the level and the underneath presumptions are created from the analysis.

1. The extent of enhancement of heat transfer is contingent upon the magnitude of nanoparticle constituted with base fluid the enhancement.

2. On comparison of those 2 NF's, we obtain enhancement 16.2% of heat transfer. The heat transfer coefficients were got by use NF as a substitute of base fluid which would make the functional fluid in the radiator of an automobile to be less compared to it.

3. The magnification of coefficient of heat transfer is done by raising the flow rate of the functional fluid (or similarly Re) for both of ZrO2 and Al2O3 nanoparticle EG/W based NF's.

4. On inclusion of nanoparticles, the thermal conductivity of base fluid was enhanced significantly. Also, the temperature was observed as a strong factor of thermal conductivity. From 0.1% to 0.3% increase in the volumetric concentration of base fluid by addition of Al2O3 Nano-particles, an enhancement of 7% in thermal conductivity is noticed at 70°C while it was 5% at 80°C. For ZrO2 from 0.1% to 0.3% of volumetric concentration, the denseness of nanofluid is faintly larger than the base fluid.

5. Here it is observed that with a rise in the nanofluids volume concentration, the specific heat of ZrO2 and Al2O3 Nano-fluids decreases. And also with the rise in temperature of nanofluid, the nanofluids specific heat raises and the same can be observed.

## 3. CONCLUSION

From the review of the literature, it can be analyzed the Automobile radiator cooling system is very important in an internal combustion engine. From the literature survey, different findings are concluded.

1. By insertion of a heat pipe in radiator core the radiator efficiency increases.
2. Ethyl glycol-water (EG/W) has the efficiency factor (EF) and heat capacity dissipation lower than that of nano coolant, and EF for TiO2 NC is higher than Al2O3 NC. With enhancing Nano-fluid volumetric flow rate, the gross coefficient of heat transfer will increase [15].
3. With the rise in the mass flow rate of coolant air, the effectiveness and capacity of cooling increase and the gross coefficient of heat transfer reduces with raise in the inlet liquid temperature.
4. With the rise in inlet temperature of the Nano-fluid the gross coefficient of heat transfer decreases.
5. In comparison to conventional automotive engine coolant, Nano-fluid gives greater properties of heat-transfer.
6. The necessary power for pumping decreases with the use of Nano-fluid in the radiator.
7. The heat transfer behavior of the Nano-fluid is greatly influenced on the quantity level of particles, the condition of flow and also influenced on temperature.
8. Water along is a good coolant but the corrosion problem by the use of water make it avoidable.

## 4. FUTURE SCOPE

1. For the better efficiencies of engine radiators modification is required. The design of the radiator will enhance to get very efficient in the near future. At the minimum input, the maximum output can be provided by new edition vehicles such that the use of radiators is so flexible. Hence, for the less heat production, better performance and good efficiencies changes in the coolant, fan, radiator tube etc. will change with time to time are able to be managed. In sense of performance and look there may be a requirement of modification or change. I assume the efficiency of a car radiator can be increased by: Raising the amount of airflow, Increasing the area of the cooling fins, Increasing the frontal area, Increasing the water flow through the radiator, moving to a waterless system, etc. by to these parameters we may increase the efficiency of radiators [16].

2. Fin geometry: Efficiency of radiator depends on many factors and one of them is fine geometry. If you change the angle of fins with respect to your fan even by a few degrees, it is

going to block the amount of air passing through fins and hence reducing the efficiency of the radiator. So it's better you keep the fins perpendicular to the plane of your fan (i.e. the angle at which the air is blocked max) so that maximum amount of air can pass through the fins.

The heat transfer can be increased by the large angle of louver fin and small spacing of fin up to an optimum level. [17].

3. Increasing turbulence of coolants: On installation of turbulence promoters, the efficiency of the radiator can be increased. In a paper, the involvement of circular contour outlined turbulence promoters in non-staggered, staggered and inclined positioning were evaluated and calculation of Nusselt number viewed the non-staggered sketches achieved the largest rates of heat transfer and the better volume factor was gained in the staggered positioning.

4. Use of carbon-foam fins: Here the gross bigness of radiator can be decreased with raising the magnitude of exposed surface area to the air because of carbon foam thermal properties i.e. k = 165-178 W/mK carbon foam with 65% permeability and raising the magnitude of heat discarded and hence reducing air-side resistance with the replacement of aluminum fins with carbon foam channels. The corrugation pattern of carbon foam pressurizes the air across the carbon foam and pushes air into the slots. The tubes arranged in the parallel design and the end caps made of aluminum provide structural support and contains the necessary volume of coolant, which makes it a simple design that meets customer requirements [18].

5. To increase its cooling is to replace it with a larger unit. This is often done by changing the core (the center with the vanes) to a thicker core while preserving the tanks (the solid parts on the top/bottom or sides). It can't be done in all cases, as in many cars, the thickness of the radiator is precisely tailored to the location where it is mounted. But there are plenty of cases where a competent radiator shop could recover an existing radiator with a thicker core, and in some cases, larger tanks as well.

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