Performance Analysis of Automobile Radiator

Jeevananth P[1], Prithivi Raaj S[2], Theyagarajan S[3], Vionth Kumar J[4]

[1,2,3]Student, Mechanical Engineering, BIT sathyamangalam, Tamil Nadu
[4]Asst.Professor, Mechanical Engineering, BIT sathyamangalam, Tamil Nadu

---

Abstract - *An automobile radiator is a component of an automotive cooling system which plays a major role in transferring the heat from the engine parts to the environment through its complex system and working. It is a type of cross flow heat exchanger which is designed to transfer the heat from the hot coolant coming from the engine to the air blown through it by the fan. A small segment of the radiator is analyzed for the various speed of the air striking the radiator as the vehicle moves from its rest position to a certain speed. The heat transfer processes takes place from the coolant to the tubes then from the tubes to the air through the fins. After the analysis is carried out, the heat transfer coefficient of air and ethylene glycol is estimated and further overall heat transfer coefficient is calculated.*

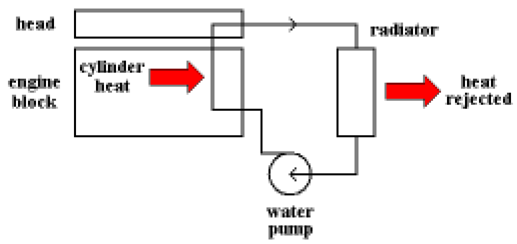
***Key Words*: Automobile radiator, velocity, convection, fins, heat transfer coefficients.**

1. INTRODUCTION

An automobile travels at various ranges of velocities. The faster it travels, the more power engine needs to generate and hence the better the cooling process has to be. The coolant(ethylene glycol) coming from the engine passes through the tubes of the radiator where the heat transfer from the coolant to the surrounding takes place through heat transfer processes, mainly conduction and convection. Thus, the velocity of the air striking the radiator becomes a crucial parameter during the cooling phenomenon through the fins.

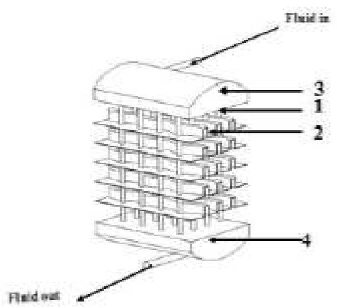
Oliet et al. [1], studied different factors which influence radiator performance. It includes air and coolant flow, fin density and air inlet temperature. Yadav and Singh [2], in their studies also presented parametric study on automotive radiator. The various parameters including mass flow rate of coolant, inlet coolant temperature; etc. are varied. Mazen Al- Amayreh[3],in his study, tested the thermal conductivities of ethylene glycol + water, diethylene glycol + water and triethylene glycol + water mixtures, measured at temperatures ranging from 25°C to 40°C and concentrations ranging from 25 wt. % glycol to 75 wt.% glycol. Trivedi and Vasava [4], illustrated the effect of Tube pitch for best configured radiator for optimum performance. Heat transfer increases as the surface area of the radiator assembly is increased. Chavan and Tasgaonkar [5], explained conventional radiator size is rectangular which is difficult for circular fan to cover whole surface area. It creates lower velocity zones at corners giving less heat transfer. Leong et all [6], described use of nanofluid based coolant in engine cooling system and its effect on cooling capacity. It is found that nano-fluid having higher thermal conductivity than base coolant like 50%/50% water and ethylene glycol. John Vetrovec [7], carried work on engine cooling system with heat load averaging capacity using passive heat load accumulator. Salah et all [8], discussed about hydraulic actuated cooling system. Actuators can improve temperature tracking and reduce parasitic losses. Cengel [9], said that the common definition for cross flow heat exchanger is where both hot and cold fluid travel perpendicular to each other. Kishore [10], in his thesis dealt with enhancement of heat transfer for both laminar and turbulent flow conditions and derived the equations for Nusselt number and friction factor. Sarma et al. [11] in their article discussed the momentum effects and heat transfer induced effects in evaluating the correlations for heat transfer and friction factor. They said that the turbulence introduces the need for evaluating the momentum and thermal eddy diffusivities. K.Balanna and P.S.Kishore in their paper written about the evaluation of heat transfer and friction factor on wavy fin of an automotive radiator.

2. DESCRIPTION AND WORKING OF THE RADIATOR:



LINE DIAGRAM OF HEAT TRANSFER THROUGH COOLING SYSTEM

The radiator is part of the cooling system of the engine Automobile radiators utilize mostly a cross flow heat exchanger. The two working fluids are generally air and coolant. 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. Coolant is passed through engine, where it is absorb heat. The hot coolant is then feed into tank of the radiator. From tank of radiator, it is distributed across the radiator core through tubes to another tank on opposite side of the radiator. As the coolant passes through the radiator tubes on its way to the opposite tank, it transfers much of its heat to the tubes which, in turn, transfer the heat to the fins that are lodged between each row of tubes. The radiator acts as a heat exchanger, transferring excess heat from the engine's coolant fluid into the air. The radiator is composed of tubes that carry the coolant fluid, a protective cap that's actually a pressure valve and a tank on each side to catch the coolant fluid overflow. In addition, the tubes carrying the coolant fluid usually contain a turbulator, which agitates the fluid inside. This way, the coolant fluid is mixed together, cooling all the fluid evenly, and not just cooling the fluid that touches the sides of the tubes. By creating turbulence inside the tubes, the fluid can be used more effectively.



RADIATOR CORE GEOMETRY

1) Tube
Radiator consists of circular tubes whose diameter is 0.59 cm (air side) and 0.56 cm (coolant side), number of tubes are arranged in parallel as shown in Fig.1. The fluid circulates through the tubes which take out the heat from the engine cylinder.
2) Wavy Fin Continuous fins of thickness, made of aluminum is taken 3) Upper and Lower Cover

The upper and lower radiator covers are surrounded on top and bottom of radiator

3. THERMAL ANALYSIS OF THE PROBLEM:

The performance parameters like heat transfer coefficient and efficiency are to be analyzed for different set of values of velocity of the automobile (i.e., velocity of air)

3.1 ASSUMPTIONS:

Heat transfer analysis of a radiator in an automobile radiatorin an automobile engine is done by considering the following assumptions.

1. The radiator operates under steady-state conditions that is constant flow rate and coolant temperatures at the inlet and within the radiator are independent of time.
2. There are no thermal energy sources and sinks in radiator walls or coolant.
3. Either there are no phase changes in the coolant stream flowing through the exchanger
4. The specific heats of ethylene glycol and air are constant throughout the radiator.
5. The fluid flow rate is uniformly distributed through the radiator on each fluid side in each pass. No flow stratification, flow bypassing or flow leakages occur in any stream
6. Kinetic energy and potential energy changes are negligible

3.2 HYDRAULIC DIAMETER:

The hydraulic diameter must be used because it is a non-circular cross section. The hydraulic diameter can then be used to estimate the Reynolds number. The equation for the hydraulic diameter calls for the wetted perimeter of the tubes. However, the difference in the outer and inner tube dimensions is so negligible that the outer perimeter is used for convenience.

Hydraulic diameter,

$$D_{hyd} = \frac{4A_{tube}}{P_{tube}} \qquad (1)$$

Where
A_{tube} = Area of the radiator tube
P_{tube} = Perimeter of the radiator tube

3.3 NUSSELT NUMBER

The Nusselt number was found for a rectangular cross section for fully developed laminar flow. The ratio of width over height of the tube is used.

$$Nu_{eg} = 0.023 \times Re^{0.8} \times Pr^{0.4} \qquad (2)$$

Where,

$$R_{eg} = \frac{D_{hyd} \times \rho \times v}{\mu}$$

R_{eg} = Reynolds number of ethylene glycol
Pr_{eg} = Prandtl number of ethylene glycol

EXTERNAL FLOW OF AIR

The air flows from the fan across the radiator tubes and through the fins utilizing convective heat transfer. In reality, the flow of air over the tubes will be slightly different due to the fluid flowing around the first tube before reaching the second tube, so calculating the heat transfer coefficient would be very difficult. To simplify the calculations, the flow is assumed to be the same over both tubes. Also, because the height to width ratio of the tubes is so small, the air will be assumed to be flowing on both sides of a flat plate.

3.4 VELOCITY

$$V_{air} = \frac{Q_{air}}{A_{radiator} - N_{tube} H_{tube} L_{radiator}} \quad (3)$$

Here,

Q_{air} = Total air volumetric flow rate

$A_{radiator}$ = Area of the radiator

N_{tube} = Number of tubes

H_{tube} = Height of the tube

$L_{radiator}$ = Length of the radiator

3.5 REYNOLDS NUMBER

$$Re_{air} = \frac{V_{air} \quad W_{fin}}{\nu_{air}} \quad (4)$$

Here,
V_{air} = Velocity of air
W_{FIN} = Width of the fin
ν_{air} = Kinematic viscosity of air

3.6 NUSSELT NUMBER

Looking at the geometry of the tubes, it can be assumed that the flow of air is similar to parallel flow over a flat plate. Since the flow never reaches the critical Reynolds number for a flat plate, Re = 0.5×10^6, it is said to be laminar for the entire process.

$$Nu_{air} = .664 \, Re_{air}^{\frac{1}{2}} Pr_{air}^{\frac{1}{3}} \quad (5)$$

Where
Re_{air} = Reynolds number of air
Pr_{air} = Prandtl number of air

3.7 CONVECTIVE HEAT TRANSFER COEFFICIENT FOR AIR FLOW

$$h_{air} = \frac{Nu_{air} \times k_{air}}{W_{tube}} \quad (6)$$

Where,

Nu_{air} = Nusselt number of air

k_{air} = Thermal conductivity of air
W_{tube} = Width of the tube

3.8 FIN DIMENSIONS AND EFFICIENCY

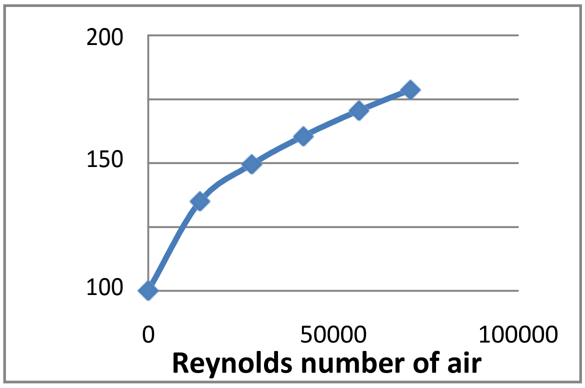
The geometry of the fins on the radiator is sinusoidal. The troughs of the fins touch the lower adjacent tube and the peaks of the fins touch the upper adjacent tube. The heat from the tubes emanates through the fins. The fins and tubes are then cooled by the air from the fan, which is traveling across the radiator. To simplify the geometry for the ease of calculations, the fins are assumed to be straight instead of sinusoidal. This is a minor transition in geometry since the shape and position of the actual fins are so close to the straight configuration. The following formulas are given below to calculate the fin efficiency

$$\eta_{fin} = \frac{\tanh(m L_c)}{m L_c}$$

Where,
Lc = Characterstic length of the fin

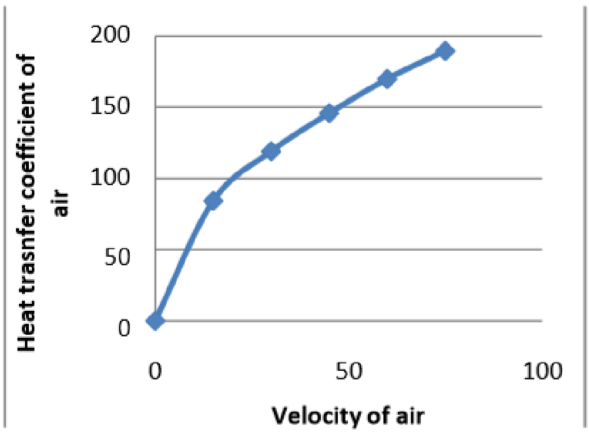
4. RESULTS AND DISCUSSIONS:

Graphs are drawn between different parameters from the values that we derive from the calculations



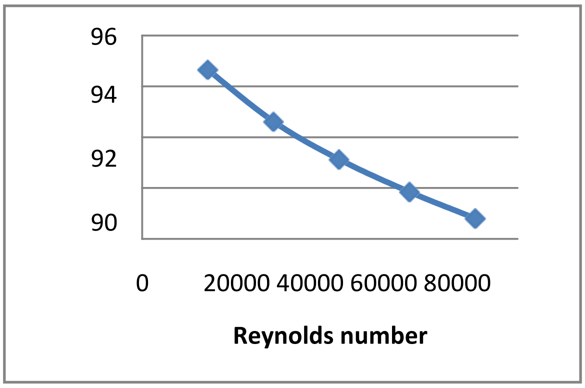
4.1 NUSSELT NUMBER OF AIR vs REYNOLDS NUMBER OF THE

The graph is plotted between Nusselt number on Y-axis and Reynolds number of air on X-axis. The graph clearly shows that as the Reynolds number of the air increases the Nusselt number also increases



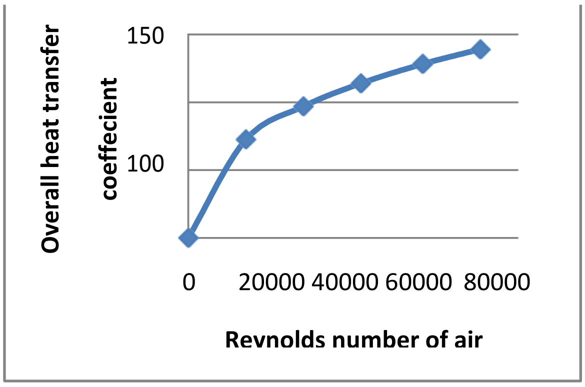
4.2 HEAT TRANSFER COEFFICIENT OF AIR vs VELOCITY OF AIR

In the graph, Heat transfer coefficient of air (W/m2k) is plotted against velocity of air (kmph).



4.3 EFFICIENCY OF THE FINS vs. REYNOLDS NUMBER OF THE AIR

The graph shows the variation of efficiency of the fins with the Reynolds number of the air that strikes the radiator at different velocities. When an automobile travels at a very faster rate, huge amount of heat is generated in the engine and its parts. The fins used in the radiator play a crucial role in helping the radiator to dissipate the heat. As we can see from the graph with increase in Reynolds number the efficiency of the fins decreases, but the decrement is very small and it is still very useful for the cooling of the radiator.



4.4 OVERALL HEAT TRANSFER COEFFICIENT vs REYNOLDS NUMBER OF AIR

A graph is plotted between overall heat transfer coefficient and Reynolds number on. From the graph, it is seen clearly that the value of overall heat transfer coefficient increases as the Reynolds number increases. Overall heat transfer coefficient depends upon the heat transfer coefficient of the air and the coolant used (ethylene glycol).

5. CONCLUSIONS

Heat transfer analysis of an automobile radiator is done for the range of 15 kmph to 75 kmph speed of the air striking the radiator with ethylene glycol as coolant and conclusions obtained are as follows:

1. Nusselt number of the air is calculated, as the Reynolds number of the air increases, the value of Nusselt number increases from 69 % to 125 %.
2. The heat transfer coefficient values are increased by 125 % when the velocity of the air striking the radiator changes.
3. It is also observed that, at higher 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. Efficiency of the fins reduces by 6.1% when the Reynolds number changes from 14000 to 71000.
4. Overall heat transfer coefficient is the function of the heat transfer coefficient of the air as well as the coolant used (ethylene glycol). As the Reynolds number increases from 14000 to 71000, there is 91 % increase in the overall heat transfer coefficient.
5. When engines run at high values of rpm to increase the speed of the vehicle, the heat generated in the parts of the engine also increases drastically. Hence, at higher speed the cooling process should also be effective in order to dissipate the heat to the atmosphere. It can concluded by this analysis that, even at higher speed the given dimensioned radiator with given number of fins attached to it works properly with slight compromise in the decrease in efficiency of the fins used in the radiator.

6. NOMENCLATURE

L	Lemgth, m
H	Height, m
W	Width, m
D	Diameter, m
A	Cross-sectional area, m2
P	Perimeter, m
V	Velocity, m/s
Q	Volumetric flow rate, m3/s
N	Number
Re	Reynolds number
h	Convective heat transfer coefficient, W/m2-K
Nu	Nusselt number
k	Thermal conductivity, W/m-K
Pr	Prandtl number
m	Coefficient for calculating efficiency
UA	Overall heat transfer coefficient

6.1 GREEK SYMBOLS

μ	Dynamic viscosity
ν	Kinematic viscosity
η	Efficiency

6.2 SUFFIXES

eg	Ethylene glycol
f	Fin
b	Base
hyd	Hydraulic
rad	Radiator

REFERENCES

1. C. Oliet, A. Oliva, J. Castro, C.D. Pe rezSegarra, ―Parametric Studies on Automotive Radiators‖, Applied Thermal Engineering, 27, 2007

2. JP Yadav and Bharat Raj Singh, ―Study on Performance Evaluation of Automotive Radiator‖, S- JPSET : ISSN : 2229-7111, Vol. 2, Issue 2, 2011

3. Mazen Al-Amayreh, ―Experimental Study of Thermal Conductivity of Ethylene Glycol Water Mixtures‖, European Journal of Scientific Research, Vol.44 No.2, 2011

4. P. K. Trivedi, N. B. Vasava, ―Effect of Variation in Pitch of Tube on Heat Transfer Rate in Automobile Radiator by CFD Analysis‖, International Journal of Engineering and Advanced Technology (IJEAT)ISSN: 2249 –8958, Volume-1, Issue-6, 2012

5. Prof. D. K. Chavan, Prof. Dr. G. S. Tasgaonkar, ―Thermal Optimization of Fan Assisted Heat Exchanger (Radiator) by Design Improvements‖, International Journal of Modern Engineering Research (IJMER),Vol.1, Issue 1, 2011

6. K.Y. Leong, R. Saidur, S.N. Kazi, A.H. Mamun, ―Performance Investigation of an Automotive Car Radiator Operated with Nanofluid-Based Coolants (Nanofluid as a Coolant in a Radiator)‖, Applied Thermal Engineering, 30, 2010

7. John Vetrovec, ―Engine Cooling System with a Heat Load Averaging Capability‖, SAE International, 2008

8. M.H. Salah, P.M.Frick, J.R.Wagner, D.M.Dawson, ―Hydraulic Actuated Automotive Cooling Systems— Nonlinear Control and Test‖, Control Engineering Practice, 17, 2009

9. Y.A.Cengel, Heat Transfer , Tata Mcgraw- Hill publications, New Delhi, 2011

10. P.S. Kishore, Experimental and theoretical studies of convective momentum and heat transfer in tubes with twisted tape inserts, Ph.D. Thesis, Andhra University,Visakhapatnam, India, 2001.

11. P.K.Sarma, C.Kedarnath, V.Dharma Rao, P.S.Kishore, T.Subrahmanyam and A.E.Bergles, ―Evaluation of Momentum and Thermal Eddy Diffusivities for Turbulent Flow in Tubes‖, Published in International Journal of Heat and Mass Transfer, Vol.53, Issues 5-6, pp. 1237-1242, Feb., 2010.

12. Evaluation of Heat Transfer and Friction Factor on Wavy Fin Automotive Radiator (IJSRD/Vol. 3/Issue 08/2015/037)