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Comparative Study of Analytical & Experimental Work for Enhancement of Rate of Heat Transfer in Automotive Radiator

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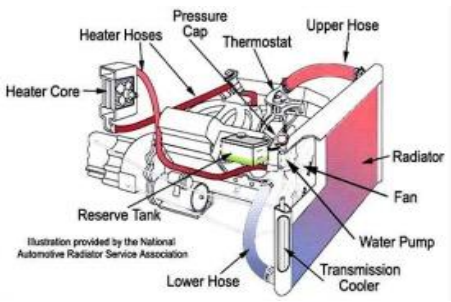
Abstract: Automotive engine cooling system takes care of excess heat produced during engine operation. It regulates engine surface temperature for engine optimum efficiency. Recent advancement in engine for power forced engine cooling system to develop new strategies to improve its performance efficiency. Also to reduce fuel consumption along with controlling engine emission to mitigate environmental pollution norms. In the performance evaluation, a radiator is installed into a test-setup and the various parameters including mass flow rate of coolant, inlet coolant temperature; etc. A comparative Analysis between different coolants is also shown. One coolant as water and other as mixture of water in Propylene glycol it is observed that that the water is still the best coolant but its Limitation is that it is corrosive and contains dissolved salts that degrade the coolant flow passage.

Keywords:Automotive engine cooling system, Radiator, ANSYS Fluent, Heat transfer, CFD Analysis.

1. Introduction

There are many new inventions that are icons of modern life. Advances like the computer, the automobile, and the harnessing of electricity are integrally linked by the need of a heat sink for the ability to function. Heat sink technology is applied in various ways for these different inventions, but it takes the form of a radiator in automobiles. Radiators are more technically known as heat exchangers, but the basic principles are very similar. To keep engines cool enough to function properly, water is pumped through the internal combustion engine and heated by the combustion process. The water then flows into the radiator and through numerous smaller tubes, which are connected to the many fins.



Engine produces heat as per the capacity of engine on that 33% of heat is to be lost through the exhaust. Insufficient dissipation space in engine can result in to the overheating of engine and can leads to metal weakening of different parts, breakdown of lubricating oil supply. To minimize the temperature and increasing the heat dissipation rate radiators are used in changing the variables to achieve the respective objectives.

Aluminum & Copper is the commonly used material for radiator. Generally Aluminum is used for heavy loaded vehicles. Another thing is that all the performance of the radiator is dependent on the air inlet temperature, mass flow rate of coolant, type of coolant, fin thickness, coolant tube type, fin type etc.

While designing of Radiator three worst conditions are to be considered High altitude we know that as high altitude is there density of fluid is less it goes direct effects on the mass flow rate of the fluid.

Radiator is a heat exchanger that removes heat from engine coolant passing through it. Heat is transferred from

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hot coolant to outside air. 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.

2. Problem Definition

The OEM client for the Sponsoring Company intends to evaluate new alternatives for radiator for its passenger car. The investigation shows that the current 'radiator', though efficient for heat transfer, offers a huge scope for achieving higher rate of heat transfer. The average output temperature for the case study (Idling equilibrium temperature) to be further reduced to feasible limits as decided by the Sponsoring Company. The constants to be considered while assessing the alternatives or the parameters being:

1. Type of radiator
2. Flow rate
3. Geometry of the core of radiator (through additions can be made on the exterior)
4. Material
5. Overall size

The variable parameters are to change or modifications are

1. Type of coolant
2. External Geometry (e.g. - fins to be added).

3. Scope/Objectives

1. Study the radiator system with changing the variants mention above.
2. Study the 3D model of the radiator with changing variable and prepared the fluid domain model for analysis purpose.
3. Conduct CFD analysis for determining the concurrence to the measured values of radiator.
4. Expedite analysis for accessing (Coolant variants) alternatives for performance.
5. Compare the result for validation of the hypothesis.

4. Methodology

The different methodologies used during project work are as follows.

4.1. Mathematical Calculation

Mathematical calculation can be completed for existing model only. With the help of empirical formulae we can find out the heat transfer rate for the given geometry. This value of the heat transfer rate can be compared with value coming from CFD results. Mathematical calculation is paly a very important role to expedite or to find the results for the thermal analysis of radiator. With the changing of the variants of radiator readings is to be noted and is utilize in to the standard formulae calculate the Heat transfer rate.

Coolant side heat transfer coefficient Calculations

1. Hydraulic diameter

$$D_{hc} = \frac{4 * A_{it}}{P_{it}}$$

2. Reynolds Number

$$R_{ec} = \frac{V_c * D_{hc}}{S_c}$$

3. Prandtl Number

$$P_{rc} = \frac{S_c * C_{pc}}{K_c}$$

4. Nusselt Number for 2300<Re<10000

$$\frac{\left[(R_{ec} - 1000) * P_{rc} * \left(\frac{EF}{2}\right)\right]}{\left\{1.07 + \left[(12.7) * \left(\frac{EF}{2}\right)^{\frac{1}{2}} * \left(P_{rc}^{\frac{2}{3}} - 1\right)\right]\right\}}$$

Where EF is Friction Factor

$$\mathrm{EF} = [1.58 * \ln(R_{ec}) - 3.28]^{-2}$$

5. Heat Transfer Coefficient $h_{c=} \frac{(N_{uc} * k_c)}{(D_{hc})}$

Air side heat transfer coefficient Calculations

1. Hydraulic diameter

$$D_{ha} = \frac{4 * C_{d*} \ A_{ra}}{A_a}$$

2. Reynolds Number

$$R_{ea} = \frac{V_{fa} * D_{ha}}{S_a}$$

3. Prandtl Number

$$P_{rc} = \frac{S_c * C_{pc}}{K_c}$$

4. Colburn factor

$$J = \frac{0.174}{R_{ea}^{\frac{2}{3}}}$$

5. Heat Transfer Coefficient

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$$h_a = \frac{(J * V_{fa} * C_{pa})}{P_{ra}^{\frac{2}{3}}}$$

Heat Rejection Calculations

1. Factor to calculate fin efficiency

$$F = \left[\frac{(2 * h_a)}{K_f * T_{hf}}\right]^{0.5} \left(\frac{F_h}{2}\right)$$

2. Temperature Effectiveness of Fin (Fin Efficiency)

$$E_f = \frac{[TanH(F)]}{F}$$

3. Total Surface Temperature Effectiveness of Fin

$$E_{ft} = 1 - \left[(1 - E_f) * \left(\frac{A_f}{A_a}\right)\right]$$

4. Overall Thermal Resistance

$$R = \left[\frac{1}{(E_{ft} * h_a) + \left\{\frac{1}{\left\{\left[\left(\frac{A_c}{C_v}\right)\right] * h_c\right\}}\right\}} + \left(\frac{T_{ht}}{K_t}\right)\right]$$

5. Over all heat Transfer Coefficient

$$U = \frac{1}{R}$$

6. Stream Heat Capacity rate for air

$$C_a = M_a * C_{pa}$$

7. Stream Heat Capacity rate for Coolant

$$C_c = M_c * C_{pc}$$

8. Stream Heat capacity rate ratio

$$C_r = \frac{Minimum of C_a or C_c}{Maximum of C_a or C_c}$$

9. Number of Transfer Units

$$NTU_{max} = \frac{\left[U * \left(\frac{A_a}{2}\right)\right]}{Minimum of C_a or C_c}$$

10. Total Heat Transfer rate

$$Q = E * Minimum of C_a or C_c * (T_{ic} - T_{ia})$$

Coolant Outlet Temperature

$$T_{oc} = T_{ic} - c_c$$

$$T_{oa} = T_{ia} - c_a$$

Parameter	Using water as a coolant			Ethylene Glycol 30% with water			Ethylene Glycol 50% with water		
Mass flow rate for coolant Kg/s	0.138	0.208	0.25	0.138	0.208	0.25	0.138	0.208	0.25
Water Inlet Temp. (K)	344	344	344	344	344	344	344	344	344
Water Outlet Temp (K)	339.32	340.32	341.18	334.19	335.20	336.20	329.22	330.21	331.21

Table: 1Mathematical Observation Table

4.2. Computational Method

Computational method is also known as numerical method. CFD analysis is comes under finite volume method as we study on behavior of fluid under different load conditions. For CFD analysis, ANSYS Fluent solver used.

CFD analysis is carried out in main three steps.

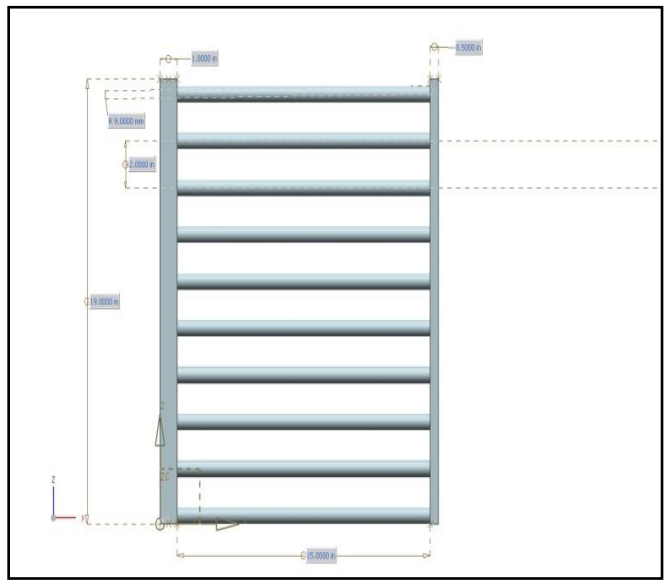

Fig.: 1 CAD Model and detail dimension of Radiator for fluid domain.

4.2.1. Pre-processing

GAMBIT software interface used for discretization. Generally volume mesh (solid meshing) with tetrahedral element used for analysis purpose. Boundary conditions are assigned to the meshed model as per working conditions such as fluid inlet, fluid outlet, air inlet, air outlet, heat transfer wall etc. Also region for different fluids are given in same interface. Then file exported to solver in .mesh format.

4.2.2.Processing for processing purpose, ANSYS Fluent 14.5 software used. In this interface, meshed model is imported then respected values are given to boundary conditions such as

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air velocity, fluid mass flow rate, inlet temp, outlet temp etc. k-epsilon model with standard wall function used for this analysis. No of iterations are carried out till the solution get converge.

4.2.3. Post-Processing ANSYS Fluent 14.5 interfaces used for post-processing purpose. In post processing, interpretation of results are done in different formats such as contour plot, velocity plot, X-Y plot, reports etc.

Observation Table

Coolant Name	Mass flow rate in Kg/s	Outlet Temp of coolant in K
Water	0.138	336
	0.208	338.3
	0.25	339.1
30% Ethylene Glycol mixed with water	0.138	331.05
	0.208	332.8
	0.25	334.1
50% Ethylene Glycol mixed with water	0.138	328.8
	0.208	329.6
	0.25	331.2

Table No. 2 Observation Table.

5. Validation

Validation is the process of determining the degree to which a model is an adequate representation of the real world based on the intended used of a model. The fundamental strategy of validation is to identify and quantify the error and uncertainty in the conceptual and computational models, quantify the numerical error in the computational solution, and also estimate the experimental uncertainty, and then make the comparison between computation and experimentation. That is, accuracy is measured in relation to experimental data, our best measure of reality. In this dissertation work first calculate the results from the computational method with the different conditions that is variants of radiator and then the results calculated from the experimentation set up of radiator for the thermal analysis. In experimentation the readings is taken as the different mass flow rate this was the changing variants of radiator.

Table No.3 Validation Result

Sr. No.	Result from CFD	Result from Experimentation	% Variations in observation
1	337.15	340.27	3.12
2	332.65	335.2	2.55
3	329.86	330.21	0.35

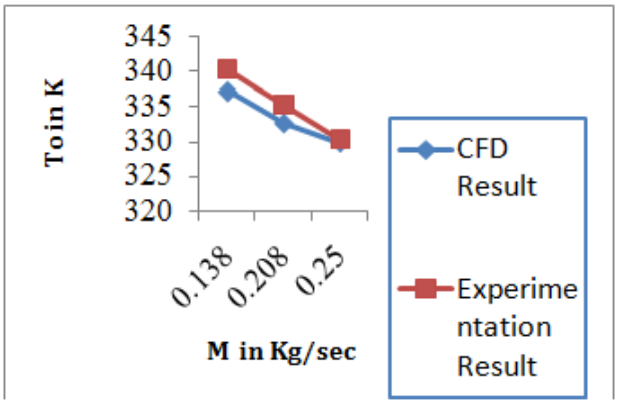

Fig. No. 2Validation Result Chart

6. Conclusion

A complete set of computational method and experimental method on automotive radiator has been presented in detail in this study. In this Computational method describes the thermal analysis is based on the finite volume method. In the experimentation output data was recorded in tabular form i. e. output temperatures. By a detail literature survey a number of recommendations have been provided for the development of a radiator as to maximize the heat transfer rate. These recommendations demand the changing in the geometrical parameter as well as the coolant composition. In this study we change the radiator variants as coolant composition and the mass flow rate of the coolant.The cooling capacity is in direct relation with the inlet temperature of hot coolant. The cooling capacity is also in direct relation with the mass flow rate of the coolant i.e. with an increase mass flow rate the cooling capacity is increase.

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