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Design and Modification of Radiator in I.C. Engine Cooling System for Maximizing Efficiency and Life

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Abstract

Background/Objectives: Engine produces high amount of heat while running. This can raise the engine temperature to very high level and can damage or seize the engine components. Hence for the safety of engine components, it needs to run at much lower temperature, which is called engine working temperature. **Methods/Statistical Analysis:** Radiator plays a vital role in engine cooling system. When increasing the cooling efficiency of radiator causes increase the life time of engine. The efficiency of the radiator can be increased by changing the surface area or dimension of the tube or increasing the number of fins/tubes. The heat transfer rate for the existing radiator could be analyzed. **Findings:** After analyzing the existing radiator, the new radiator has been designed. Two flat plates are placing inside the tube which acts as the nozzle. Hence, nozzle velocity increases and pressure decreases. Pressure is directly proportional to temperature. **Application/ Improvements:** Thus, the temperature of coolant inside the radiator decreases. As a result efficiency of the proposed radiator is increased 5.37% when comparing with existing method.

Keywords: Cooling System, I.C. Engine, Performance, Radiator

1. Introduction

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 order to improve the cooling effect in the cooling system heat transfer must be improved. The better heat transfer depends upon the surface area of the radiator. At the same time we must be considered the customer expectation that is size of the radiator according the size of the vehicles. So, it is needed to design the radiator tubes to satisfy both high heat transfer as well as optimum size of the radiator for customer expectation.

The different factors are influencing in the functions of radiator. Radiator incorporated with atmosphere air, flow of the coolant present in the system, density of the cooling fins as well as temperature of the air intake into the system. It is identified that when the atmospheric air and the mass flow rate of the coolant raising the cooling capacity of the radiator be increases[1,2]. When deviating the geometrical size of the cooling fins from its optimum

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the effect of cooling be reduces[3]. Surface dimples of the cooling fins endorse the turbulent mixing in the flow along with increasing heat transfer[4]. The thermal conductivity of the ethylene glycol+water, diethylene glycol+water and triethylene glycol+water mixtures, measured temperatures ranging from 25°C to 40°C in addition to concentrations from 25 wt. % glycol to 75 wt.% glycol. Raising concentration of glycol causes for reducing the thermal conductivity[5].

The circular design of radiators which are made with compact, low cost, better performance as well as least power required for rotating fan and higher mass of airflow[6].

When reducing the individual channel diameter cases reducing the mass flow rate. When maximizing the individual diameter lead to make turbulent flow[7]. Compact heat exchangers could be translating higher energy by means of effective as well as low cost when comparing other kinds of heat exchangers[8]. Two approaches that are passive and active considered while designing compact heat exchangers for increasing cooling performance as soon as not affect its pressure[9]. When experiencing lower coolant temperature, greater depth of the air flow, smaller pitch of the cooling fins causes pressure drop in the cooling system[10]. The volume of the flow rate and also the type of the working fluid are the major peculiarity that will be tested by using this radiator test rig, causing the changes in the rate of the heat transfer. Such phenomena created to replicate the same system applied in the real automobile system where it would cost in very large scale if those analyses and experiments carried out in that engine bay[11].

In this research work a new radiator is designed after analyzing the existing radiators. Two flat plates are placing inside the tube which acts as the nozzle. Hence, nozzle velocity increases and pressure decreases. Pressure is directly proportional to temperature.

2. Cooling System in I.C. Engine

Engine produces high amount of heat while running. This can raise the engine temperature to very high level and can damage or seize the engine components. Hence for the safety of engine components, it needs to run at much lower temperature, which is called engine working temperature. Engine cooling system keeps the engine running at its working temperature by removing excess heat. Coolant is mixture of water and antifreeze which flows through the engine cooling system to absorb the excess heat and dissipate it through radiator. Engine coolant is mixture of Antifreeze and Water. It is generally mixed in 30:70 to 50:50 ratio depending on weather conditions in which vehicle is used. 50% of Antifreeze is used in conditions where the temperature falls below -15o Centigrade. 30% of Antifreeze is used in conditions where the temperature does not fall below -15o Centigrade. Antifreeze is mixture of Glycol and Additives. It has anti rust properties to avoid rusting of engine passages. It has very low freezing temperature to avoid freezing in extreme cold conditions. The schematic of liquid cooling system is shown in Figure 1.

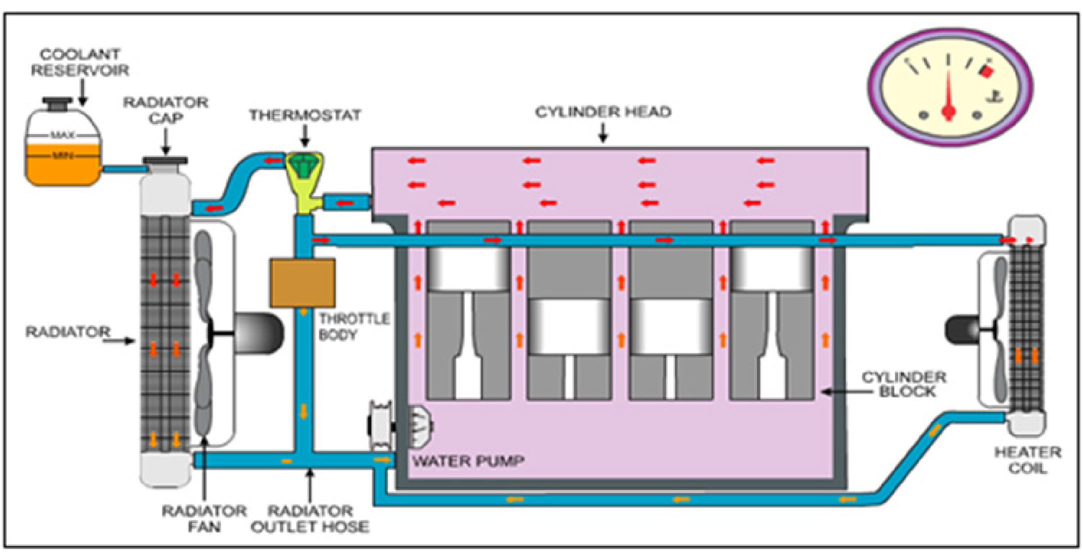

Figure 1. Images of (a)existing and (b) modified radiator tubes

2.1 Radiator

Radiator otherwise called as heat exchanger with the purpose of take out heat from engine. Here heat is transmitting through coolant liquid medium to atmosphere. It consists of core, top and bottom tank. Core is designed with two sets of passageway, one set of tube as well as fin. Liquid coolant is flows inside the fins as soon as air gets flow its outer surfaces. The heat presents in the engine is absorbing by the coolant and carrying via radiator then exchange to atmosphere.

2.2 Radiator Cap

Radiator cap maintains a constant high pressure in the cooling system, which increases the boiling temperature of engine coolant. The increased temperature helps in easy dissipation of heat to atmosphere because of higher difference in radiator temperature and ambient temperature. It contains two valves. High pressure valve maintains the pressure in the system. It opens to release the coolant to coolant reservoir if pressure increases more than a limit. Low pressure valve or vacuum valve opens to allow the flow of coolant back to radiator when engine cools down.

2.3 Coolant Reservoir

Coolant reservoir stores the coolant which flows out from radiator cap when engine temperature and coolant pressure rises. It also allows the flow of coolant back to radiator when engine cools down. This avoids the loss of coolant and frequent top ups.

2.4 Radiator Cooling Fan

Cooling fan maintains the flow of air through the radiator to dissipate the excess heat of engine to atmosphere. There are two types of cooling fans, mechanical fan and electrical fan. Mechanical fan is generally connected to engine crankshaft through a belt and set of pulleys. Electrical fan has a electric motor which is controlled either by a fan switch installed on radiator tank or by ECM which turns it ON or OFF with the help of coolant temperature sensor.

2.5 Radiator Hose

Hoses connect the components of cooling system that is top and bottom radiator tanks to the engine coolant passages. They also connect the heater coil to the system.

2.6 Water Pump

Water pump circulates the coolant by pushing it through engine passages and radiator. It is usually mounted on cylinder block and powered by engine through the belt.

2.7 Thermostat Valve

Thermostat valve allows the flow of coolant to radiator only when working temperature is attained after starting the engine. This helps engine to attain working temperature quickly. It also avoids overcooling of engine and resulted fuel wastage.

2.8 Radiator Cooling Fins

Radiator cooling fins are increases the total surface area of the metal body which provides cooling effect and hence, improve the efficiency to maximum cooling effect. It also speeds up the transfer of heat energy.

3. Heat Transfer Analysis of Proposed Radiator

The images of existing and modified radiator tubes are shown in Figure 2 (a) and (b) respectively.

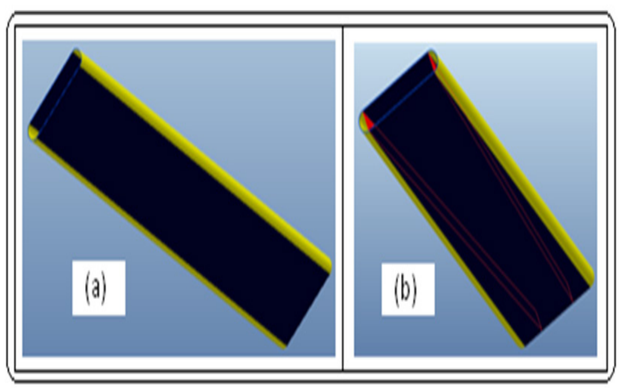

Figure 2. Schematic of liquid cooling system.

CAD modeling of the proposed radiator front, side and top views are shown in Figure 3 (a), (b) and (c) respectively.

The tube and nozzle dimensions of proposed radiator are shown in Figure 4 (a) and (b) respectively.

Specific heat ratio is

$\gamma = c_p / c_v$

To find c_v

c_p of water = 4186 kJ/kg°c

$R = 461.5 J/kgK$
$R = c_p - c_v$
$C_v = 4186 - 461.5$
$C_v = 3724.5$

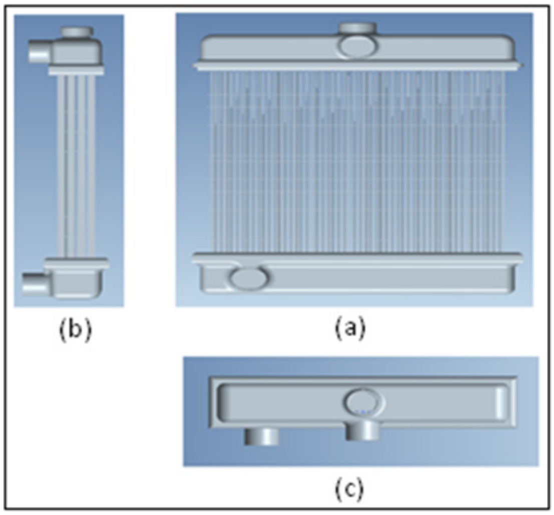

Figure 3. CAD modeling of the proposed radiator (a) front (b) side and (c) top views.

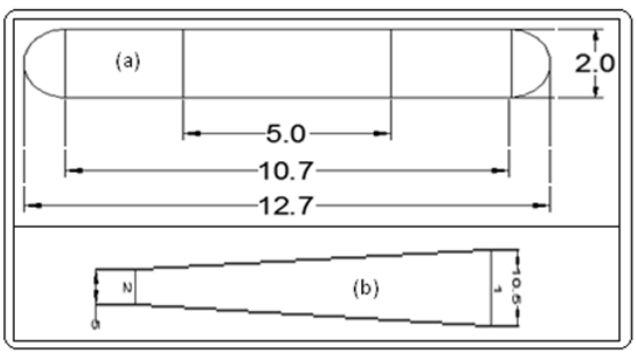

Figure 4. (a) Tube and (b) Nozzle dimensions of proposed radiator

To find γ

$\gamma = c_p / c_v$
$= 4186 / 3724.5$
$\gamma = 1.3$

Mach No (M) = c / a
$a = (\gamma R T)^{0.5}$
$a = (1.3 \times 461.5 \times 363)^{0.5}$ (T = 90°c = 363K)
$a = 466.67$ m/s
$c = 9.81$ m/s
$M = c / a$
$M = 9.81 / 466.67 = 0.021$

For $\gamma = 1.3$ and M = 0.021 (isentropic flow)[11]

$p_1/p_{01} = 0.999$
$T_1/T_{01} = 0.999$

Temperature at Point 2

$P_1 = \rho g h$
$= 1000 \times 9.81 \times 394e\text{-}3$
$P_1 = 3865.1 N/m^2$
$P_1 = 0.03865 \times e5 N/m^2$
$P_1 / P_{01} = 0.999$[11]
$P_{01} = P_1 / 0.999$
$P_{01} = 3865.1 / 0.999$
$P_{01} = 3868 N/m^2$
$P_{01} = 0.03868 e5 N/m^2$
$T_1/T_{01} = 0.999$[11]
$T_{01} = 363 / 0.999$ (T_1 = 90°c = 363K)
$T_{01} = 363.36$ K
(For γ =1.3, M=0.021) [11]
$A_1 / A^* = 29.268$
$A_1 = l \times b$
$= 10.7 \times 1.8$
$= 1.926 e\text{-}5 m^2$
$A^* = A_1 / 29.268$
$A^* = 6.58 e\text{-}5 m^2$
$A_2 = l \times b$
$= 5 \times 1.8$
$A_2 = 9e\text{-}6 m^2$
$A_2 / A^* = (9e\text{-}6) / (6.58e\text{-}5)$
$A_2 / A^* = 13.67$
$M_2 = 0.04$
For M_2=0.04 (isentropic flow) [11]

$T_2 / T_{02} = 0.985$
$P_2 / p_{02} = 0.998$

$T_2 = 0.985 \times T_{02}$
$T_2 = 0.985 \times 363.36$ ($T_{02} = T_{01} = 363.36K$)
$T_2 = 357.9$ K

Heat Transfer Due To Ambient Air

Length of tube with fin contact, $L = 90 \times 0.1 e\text{-}3$
$L = 0.009m$
Length of tube without fin contact,
$L_0 = 0.394 - 0.009$ m
$L_0 = 0.385m$

Heat Transfer with Fins

$U = 1 / RA$
$h_a = 464.096 W/m^2k$

$h_w = 4500$ W/m^{2}k
$K_b = 110.7$ W/mk
(Thermal conductivity of brass)
$K_c = 386$ W/mk
(Thermal conductivity of copper)
K_w at $90^0 = 0.67$ W/mk

The resistant circuit of radiator tube with fins is shown in Figure 5.

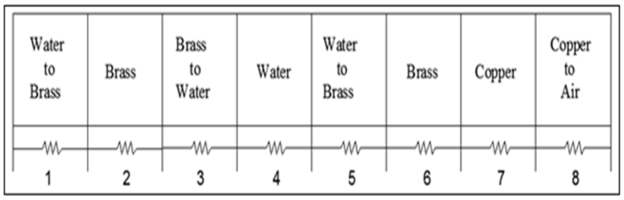

Figure 5. Resistant Circuit of Radiator Tube with Fins

Convection from water to brass
$1 / h_w A_1$
$A_1 = 2\,l + 2\,b$ (Area of inner tube)
$A_1 = (\,(2 \times 10.5\text{ e-3}) + (2 \times 1.8\text{ e-3}))$
$A_1 = 0.0246$ m^2
$1 / h_w A_1 = 1/4500 \times 0.0246$
$1 / h_w A_1 = 9.033 \times$ e-3

Conduction In brass plate
L/KA
$A_2 = (2l + 2b) - A_1$
$A_2 = ((2 \times 10.7\text{e-3}) + (2 \times 2\text{e-3})) - 0.0246$
$A_2 = 0.0254$m^2
$L / K_b A_2 = 9\text{ e-3} / (110.7 \times 0.0254)$
$L / K_b A_2 = 3.2008$ e-3

Convection from brass to water
$1 / (h_w A_2)$
$A_2 = 0.0254$ m^2
$1 / (h_w A_2) = 1 / (4500 \times 0.0254)$
$1 / (h_w A_2) = 8.748$ e-3

Conduction in water
$L / K_w A_3$
$A_3 = 2\,\pi r l$
$A_3 = 2\,\pi \times 0.9\text{ e-3} \times 9\text{ e-3}$
$A_3 = 5.654$ e-3
$L / (K_w A_3) = 9\text{ e-3} / (0.67 \times 5.654\text{ e-3})$
$L / (K_w A_3) = 9.044$ e-3

Convection from water to brass
$1 / (h_w A_3)$
$A_3 = 5.089$ e-5
$1 / (h_w A_3) = 1 / (4500 \times 5.089\text{ e-5})$
$1 / (h_w A_3) = 0.0393$

Conduction in brass plate
$L / k_b A_4$
$A_4 = 0.0276$ m^2
$L / (K_b A) = (9\text{ e-3}) / (110.7 \times 0.0276)$
$L / (K_b A) = 2.945$ e-3

Conduction in fins
$L / K_c A$
$A_5 = (2\,l + 2\,b)$
$A_5 = (2 \times 14.75\text{ e-3} + 2 \times 11.75\text{ e-3})$
$A_5 = 0.053$
$L / (k_c A_5) = 9\text{ e-3} / (386 \times 0.053)$
$L / (k_c A_5) = 4.39$ e-4

Convection from fin to air
$1 / h_a A_5$
$A_5 = 0.053$ m^2
$1 / h_a A_5 = 1 / (464.096 \times 0.053)$
$= 0.0406$
$R = 1 / (h_w A_1) + L / (k_b A_2) + 1 / (h_w A_2) + L / (K_w A_3) + 1 / (h_w A_3) + L / k_b A_4 + L / k_b A_4 + 1 / h_a A_5$
$R = 9.033\text{ e-3} + 3.2008\text{ e-3} + 8.748\text{ e-3} + 9.044\text{ e-3} + 0.0393 + 2.945\text{e-3} + 4.39\text{e-4} + 0.0406$
R with fins = 0.1133

Cross Flow Heat Exchanger (Both Fluid Unmixed) Temperature
Thermostat opening temperature: 90°C
Entry temperature of hot fluid into radiator, $(T_1) = 90$°C
Atmospheric temperature: 30°C
Entry temperature of cold fluid, $(t_1) = 30$°C

To Find
Exit temperature of hot fluid from radiator (T_2)
Exit temperature of cold fluid from radiator (t_2)

Cross flow heat exchanger (Both fluids unmixed)
Effectiveness = 1-exp ((exp(-NCn) – 1)/Cn)

Cold Fluid

Specific heat of cold fluid (c_{pc}) = 1.005 KJ/kg K
Mass flow rate of cold fluid (m_c) =4.63kg/s

Hot Fluid

Specific heat of hot fluid (c_{ph}) = 4.718 KJ/kg K
Mass flow rate of hot fluid (m_h) = 1.09 kg/s

To find specific heat ratio

specific heat capacity $C_{cold} = m_c \times c_{pc}$
$= 4.63 \times 1.005 \times 10^3$
= 4656W/K.

Specific heat capacity $C_{hot} = m_h \times c_{ph}$
$= 1.09 \times 4.718 \times 10^3$
= 5173W/K.

C_{min} = 4656W/K.
C_{max} = 5173W/K.
$C = C_{min} / C_{max}$ =4656/5173
C= 0.9
U = 1/RA
U = 1/(0.888×0.011137)
U = 342.769 W/m2K

Overall Heat Transfer Coefficient, U = Heat Transfer per Tube × No. of tubes

U = 342.769 × 186
U = 63755.05 W/m2K

No of Transfer units (NTU) = UA / C_{min}
NTU, (N) = (63755.05×0.011137)/4656
(N) = 0.1525
$n = (N)^{-0.22}$
$n = (0.1525)^{-0.22}$
n = 1.5124

Cross Flow Heat Exchanger

Effectiveness, ε = 1-exp((exp(-(N)Cn)-1)/Cn)
=1-exp((exp(-0.1525×0.9×1.5124)-1)/(0.9×0.1525))
= 0.128
$= (T_1 - T_2) / (T_1 - t_2)$
$= (90 - T_2) / (90 - 30)$
$0.128 = (90 - T_2) / 60$
T_2 = 82.32°C

Exit temperature of hot fluid from radiator is 82.32°C.
Heat lost by hot body = Heat gained by cold body
$m_h \times c_{ph} \times (T_1 - T_2) = m_c \times c_{pc} \times (t_2 - t_1)$
$1.09 \times 4.187 \times 10^3 \times (90 - 82.32) = 4.63 \times 1.005 \times (t_2 - 30)$
t_2 = 37.53°C

Exit temperature of cold fluid from radiator is 37.53°C.
Net Heat Transfer
Heat Exchanged, (Q) = $C_{min}(T_1 - t_1)$
Q = 0.128× 4656 × (90 – 30)
Q = 35758.08 W

Net Heat Transfer is 35.758 KW.
Heat Transfer occurs due to Nozzle Effect & Ambient Air
Temperature drop = Temperature drop due to nozzle + Temperature drop due to fins
= 5.1 + 6.7
= 11.8 ˚c

Final Temperature

Final Temperature = Inlet temp. – Difference in Temp.
Final Temperature = 90 – 11.8

Final Temperature = 78.2 ˚c
Efficiency of Modified Radiator
Efficiency, $\eta = T_1 - T_2 / T_1$
η = 90 – 78.2 / 90
η = 13.1 %

4. Results and Discussion

The calculated values of the inlet-outlet temperature, heat transfer, effectiveness and efficiency of the existing as well as proposed radiator are tabulated in Table 1.

Table 1. Inlet-outlet temperature, heat transfer, effectiveness and efficiency of the existing as well as proposed radiator

Description	Existing Radiator	Proposed Radiator
Inlet Temp. T_1	90 ˚C	90 ˚C
Outlet Temp. T_2	83.04 ˚C	78.2 ˚C
Heat Transfer , Q	32.4 KW	35.7 KW
Air Inlet Temp., t_1	30 ˚C	30 ˚C
Air Outlet Temp., t_2	36.8 ˚C	37.53 ˚C
Effectiveness ,	0.116	0.128
Efficiency , η	7.73%	13.1%

From the obtained results the Heat transfer rate and efficiency of the proposed radiator are high. The life time of Engine is also increases. In this proposed radiator two flat plates inside the tube which act as the nozzle. Hence nozzle velocity increases, pressure decreases. Pressure is directly proportional to temperature. Thereby pressure decreases, temperature decreases. As a result efficiency of the proposed radiator is increased 5.37% when comparing with existing method.

5. Conclusion

Generally, contribution of radiator to an engine is considered when the efficiency of a radiator is good and constant. Currently, the temperature factor is dependent on the tubes used in the radiator. So modification of tubes in the radiator contributes to the engine cooling through efficient radiator action.

The nozzle effect provided by us provides additional cooling to the engine because its decreases the pressure and increases the velocity thereby decreasing the temperature which is directly proportional to the pressure according to ideal gas equation. Therefore, engine cooling and radiator efficiency is increased. Thus the life time of engine is also increased.

As a result efficiency of the proposed radiator is increased 5.37% when comparing with existing method.

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