International Engineering Research Journal
Development Of Improved Cooling System for Tracked Vehicle

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Abstract

This research paper focuses on a development of radiator of tracked Vehicle in which heat transfer enhancement is carried out by designing a new radiator with different configuration of fins like Rectangular Offset serrated plate fins on Hot Side and Wavy Fins On Cold Side to improve its thermal performance .Detailed thermal analysis, design,(by Effectiveness- No of transfer Units (ε-NTU) method) experimental investigation and comparison of heat transfer enhancement is done of both the old and new radiator. The designed radiator is going to be used for 300 HP engine of Tracked Vehicle (BMP2) which has been used by Vehicle Research and Development Establishment (VRDE), Ahmednagar, Government of India.

Keywords: *Thermal Analysis, Effectiveness, Heat Dissipation, Heat Reception, Pressure Drop, Ejector cooling.*

1. Introduction

Compact heat exchangers are extensively used in aerospace, vehicle and cryogenic manufacturing because of their compactness for necessary thermal performance, compact space, weight, energy requirement and less cost.

Radiator is the vital important component of automotive cooling system. Upwards of 33% of the energy produced by the engine through combustion is lost in heat (Frank et al, 1996). Insufficient heat dissipation results in overheating of the engine, which can turns in breakdown of lubricating oil, weakening, wear of engine parts leads in less productivity. To reduce the stresses of engine as a result of high heat generation, radiators must be more compact so as to maintain required levels of thermal performance. (Amrutkar et al, 2013).

Coolant surrounding engine passes through radiator. In radiator coolant flows through it, gets cooled down and it is re-circulated into system again and again. Radiator sizing is very important while designing cooling system. Radiator size depends on mainly heat load and space availability. Heat load depends on heat rejection requirement for keeping engine surface at optimum temperature (Yadav et al, 2011). Compactness, low pressure drop, low cost and new material should be considered in the radiator design. The radiator size will be increased so that more heat can be brought away from the engine (Bengt Sunden, (2010).

Design of fin plays an important role in heat transfer. There is a scope of improvement in heat transfer of air cooled engine cylinder fin if mounted fin's shape varied from conventional one. The fin geometry and cross sectional area affects the heat transfer co efficient. In High speed vehicles thicker fins provide better efficiency. Increased fin thickness resulted in swirls being created which helped in increasing the heat transfer. Large number of fins with less thickness can be preferred in high speed vehicles than thick fins with less numbers as it helps inducing greater turbulence and hence higher heat transfer takes place (Durai Raju et al, 2015).Generally Logarithmic mean temperature difference (LMTD) or Effectiveness-No of Transfer Units (ε-NTU) methods are useful for calculations of thermal performance heat exchanger. Both methods have its own merits and preferred according to availability of data. When radiator inlet and outlet temperatures are known, LMTD gives quick solution. When any of the temperature is unknown, LMTD method requires more iterations to find exact solution (Shah et al, 2003). In this project Effectiveness-NTU (ε-NTU) classical method is used for thermal analysis because of its accuracy (Kays and London, 1998). The heat sink design of the radiator must be analyzed using the Effectiveness-NTU method to find the theoretical effectiveness, overall heat transfer rate of the radiator, and outlet temperatures of both air and water. Experimental analysis was conducted on the radiator to compare and confirm the analytical results. Matthew Carl et al, (2012).

The surfaces with wavy patterns are one of the popular surfaces in Plate-fin heat exchanger due to sinusoidal curve. Friction factor has an effect on mass flow rate of air.The suction side of the wavy fin punched with Rectangular Winglet Pairs(RWPs) can increase Nusselt number by 1.2%–4.1%, and decrease friction factor by 2.7%–9.6% (Balanna et al, 2015). In Heat Exchanger for air-side heat transfer applications, special surfaces are often employed to obtain high rates of heat transfer within the imposed size constraints. One geometry that can be used to enhance heat exchanger performance is a sinusoid ally curved wavy passage. Wavy channels are easy to fabricate and can provide significant heat transfer enhancement if carried out in an appropriate (transitional) Reynolds number regime. Calculating total volume of the heat exchanger is possible just at the end of the designing process and naturally after doing all calculations of related to pressure drops, heat transfer coefficients, heat exchanger efficiency and outlet temperature talking about total heat transfer area is possible (Masoud et al, 2013).

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, (Mounika et al, (2016). Ejector cooling system is used In Military Vehicles by using compact heat exchangers,(Engineering Design handbook Power Plant Cooling, headquarters United States army Materiel Command, 1975).

Ejector Cooling System- The cooling system is a high temperature, liquid, closed and forced-circulation cooling system. (Compact Heat Exchanger -Radiator.)

Principal Of Cooling System-With high velocity of exhaust gaseous coming out of nozzle creates low pressure zone in the ejector tray, which causes suction of atmospheric air Inside the ejector tray passing over radiator and oil cooler. (Venturi effect) and hence the radiator is cooled.

2. Project Overview

Fig. 1 BMP2 Tracked Vehicle.

This project is sponsored by (DRDO-VRDE) Vehicle Research and Development Establishment, Ahmednagar, Government of India, there was requirement to design and development of radiator for 300 HP engine of BMP2 Tracked Vehicle.

To reduce the Overheating of BMP2 Vehicle engine was the main objective of the project. In this project work, based on size of radiator, the theoretical calculations have been made by using ε-NTU method. The experimentation made on experimental set up available at VRDE which is with proper arrangement of coolant and air supply, temperature measurement sensors for coolant and air. And then after thermal performance has been validated by experimental testing. Objectives of this project includes, design and development of new radiator, its thermal analysis, and to carry out the experiment to check the required effectiveness based on the availability of hardware and finally to reduce the temperature of cooling system from 120 degree Celsius to 105 to 110 degree Celsius.

3. Experimental set up layout

The heat dissipation performance is investigated by using experimental setup. The efficiency of cooling system of an Internal Combustion engine when fitted with radiator is judged by its heat transfer performance. Comparison between theoretical and experimental heat balance is done for heat transfer performance.

The thermal performance of radiator is experimentally investigated in laboratory at VRDE Ahmednagar. The test section is mainly divided into waterside circuits and airside circuits. The test section is shown in Fig.2.

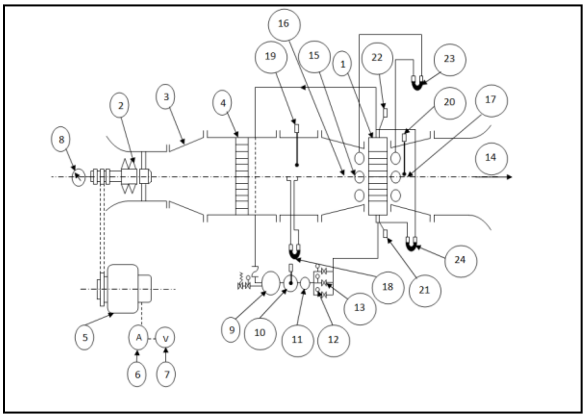

Fig.2 Experimental Setup

Experimental layout includes following components: 1)Test Radiator 2)Fan 3)Tunnel body 4)Rectifying Lattice 5)Shunt motor 6)Ampere Meter 7)Voltmeter 8)Speed Counter for Fan 9)Hot Coolant Tank 10) Additional Hot Coolant Tank 11)Coolant Pump And Motor 12)Coolant Flow meter 13)Coolant Flow Valve 14)Wind Direction 15)Connecting Tube 16)Upstream End 17)Downstream End 18) Liquid Column Gauge (Water) For Air Flow meter 19)Thermometer For Inlet Air Temp 20)Thermometer For Outlet Air Temp 21)Thermometer For Coolant inlet Temp. 22) Thermometer For Coolant outlet Temp. 23) Liquid Column Gauge (Water) for Air Side Pressure Loss 24) Liquid Column Gauge (Mercury) for Water Side Pressure Loss.

Measuring Equipment's used are

i. Water Flow Meter: The water flow meter used with an accuracy of +2% of maximum scale.

ii. Air flow Meter: The minimum scale for liquid column is 1 mm on 30° inclined type manometer.

iii. Pressure Gauges: For waterside the liquid mercury column gauge have minimum 1mm accuracy. For the airside to measure pressure loss, the liquid column has 1mm accuracy.

iv. Thermometers: For measuring temperatures the thermometers used have +/- 0.1°C accuracy for waterside and 1°C accuracy for the airside.

4. Heat Transfer Calculations

Thermal analysis is determined by classical method first theoretically and then by experimental method which consists of heat rejection requirement, heat transfer requirement is decided as per engine specifications, engine operating conditions and vehicle operating conditions. Cooling system designed to fulfill all above requirements.

Table 1 Radiator dimensions

Parameter	Unit	Value
Total Heat Transfer	KW	105
Height	mm	733
Length	mm	1080
Depth	mm	140

Following parameters are considered for analytical approach.

Table 2 Inputs for Radiator thermal calculations.

Parameters	Hot Side	Cold Side
Fluid	Water	Air
Inlet temp (^oC)	120 (Th_1)	73 (Tc_1)
Outlet temp (^oC)	110.66 (Th_2)	114.70 (Tc_2)
Mean temp (^oC)	115.33	93.85
Mass flow rate (m) Kg/s	3.086	2.5
Density (ρ) Kg/m^3	1028.55	0.950
Specific heat (Cp) KJ/Kg-K	3.644	1.007
Dynamic viscosity (μ) N-s/m^2	0.00077	$19.8x10^{-6}$
Thermal Conductivity (k) W/m-K	0.37974	$28x10^{-3}$
Prandtl no. (P_r)	1.23	0.7214

5. Thermal Analysis

Thermal analysis of heat exchanger is to determine by doing the performance calculations to find out heat transfer rate (Rating Method). It is necessary to find out amount of heat transfer, outlet temperatures of both fluids. E-NTU method is based on concept of heat exchanger effectiveness.

Thermal analysis of Heat Exchanger -

A) Calculations for finding out required effectiveness

i. Coolant outlet temperature (hot)

$Th2 = Th1 - (Q/Ch)$ (1)

ii. Air outlet temperature (cold)

$Tc2 = Tc1 + (Q/Cc)$ (2)

iii. Coolant side heat capacity rate (hot)

$Ch = mh * Cph$ (3)

iv. Airside heat capacity rate (cold)

$Cc = mc * Cpc$ (4)

v. Heat capacity rate ratio:

$Cr = Cmin/Cmax$ (5)

vi. Required effectiveness

$\varepsilon reqd = [Ch * (Th1 - Th2)]/[Cmin * (Th1 - Tc1)]$ (6)

B) Selection of fins-calculations of free flow area (Aff), frontal area (A), heat transfer area per fin (As), Fin area (Af), Equivalent Diameter Dh, Heat Transfer area.

C) Heat Transfer coefficients and surface effectiveness of fins.

i. Core mass velocity, Gh = m / Affh (7)

ii. The Reynolds no. Re. = G Dhh/μ (8)

iii. The Colburn factor j given by correlation proposed by Joshi and Webb is

$j = 0.53 \, Re^{-0.5} \times (1/Dhh)^{-0.15} \times \alpha^{-0.14}$ (9)

Iv. The Convective Heat Transfer Coefficient,

$hh = (jh \times cph \times Gh)/(Pr)^{0.667}$ (10)

v .The Fin Parameter is given by, M-

$M = \sqrt{2x\,hh / (kf \times t)}$ (11)

vi. Fin effectiveness is given by$\eta f = \tanh(Mlh)/(Mlh)$(12)

Overall surface effectiveness is given by

$\eta oh = 1 - (af / as) \times (1 - \eta f)$ (13)

D) Pressure Drop Calculations-

i. Friction Factor f is given by correlation -

$f = 8.12 \, Re^{-0.74} \times (1/Dh)^{-0.41} \times \alpha^{-0.02}$ (14)

ii. Pressure Drop $\Delta p = (4x\, f \times L \times G^2) / (2x\, Dh \times \varrho)$ (15)

Above calculations are done for both hot and cold sides.

E) Overall Heat Transfer coefficients and Number of Transfer Units (NTU)-

i. $1/UA = 1/(\eta overall \times hh \times A)\, hot + t/(Kw \times Aw) + 1/(\eta overall \times hc \times A)\, cold$ (16)

ii. Hot Side, Uoh = (UoAo) h / Aoh (17)

iii. Cold Side, Uoc = (UoAo) c / Aoc (18)

iv. Number of Transfer Units, Ntu = UoAo/Cmin (19)

F) Radiator effectiveness is calculated by

$$\varepsilon_{cal} = 1 - e\left((e(-NTU^{0.78} \times Cr) - 1) \times \frac{NTU^{0.22}}{Cr}\right) (20)$$

As the Cold Side (Air) is Critical, Compare this Pressure Drop with the Pressure Drop Of Old Radiator at Cold Side (Air)

Pressure Drop = 176.61 mm of Water Column with Old Heat Exchanger at cold side (Air).

=37 mm of Water Column with New Heat Exchanger at Cold Side (Air).

Hence From Above Comparison, it is proved that Design is Completely Safe.

From the results obtained, the heat dissipated from waterside (hot) has been calculated and this value is judged by heat received on airside (cold) simultaneously.

Mathematical expressions used for calculations;

i. Heat dissipated on coolant (hot):

$Qh = mh * Cph * (Th1 - Th2)$ (21)

ii. Heat received on airside (cold):

$Qc = mc * Cpc * (Tc2 - Tc1)$(22)

6. Results and Discussion

Comparison of analytical and experimental results at 180 lpm coolant flow rate and 35 m/s air velocity,

Table 3 Analytical Results

Parameter		Unit	Value
Heat dissipated by coolant	Qh	KW	105
Heat received by air	Qc	KW	105
Coolant inlet temperature	Th1	°C	120
Coolant outlet temperature	Th2	°C	110.66
Air inlet temperature	Tc1	°C	73
Air outlet temperature	Tc2	°C	114.70

Table 4 Experimental Results

Parameter		Unit	Value
Heat dissipated by coolant	Qh	KW	118.23
Heat received by air	Qc	KW	105.99
Coolant inlet temperature	Th1	°C	90
Coolant outlet temperature	Th2	°C	79.5
Air inlet temperature	Tc1	°C	36.8
Air outlet temperature	Tc2	°C	78.9

The above results it seems that both analytical and experimental results for heat dissipation from coolant are nearby matched with each other. Thus theoretical thermal analysis of radiator using ε-NTU method is validated using experimental method.

But from above experimental results it is shown that the heat dissipated by coolant is not received by air totally. The main reason behind this is, there are some radiation heat losses in the range of 9% to 11.3% and remaining heat losses are unaccounted heat losses.

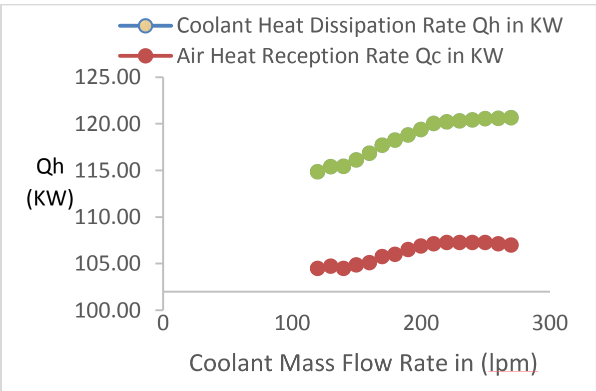

Fig. 3 Coolant Mass Flow Rate Vs Heat Transfer

From the above graph it is shown that the heat dissipated by coolant as well as heat received by air are simultaneously increasing with coolant mass flow rate.

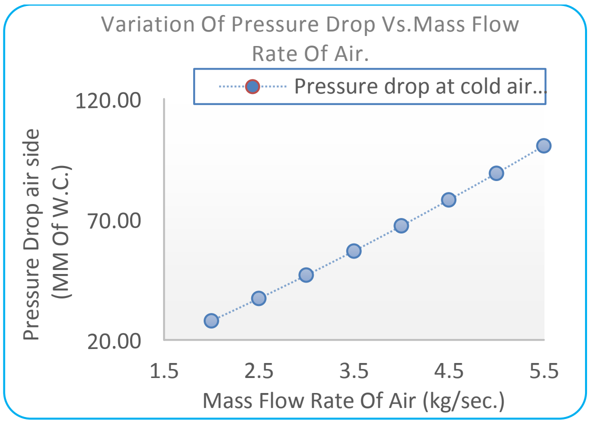

Fig. 4 Mass Flow Rate vs Pressure Drop

From the above graph it is found that as mass flow rate of air increases, pressure drop across heat exchanger also increases.

Motivation-The performance of new radiator can be understood by characteristics curve.

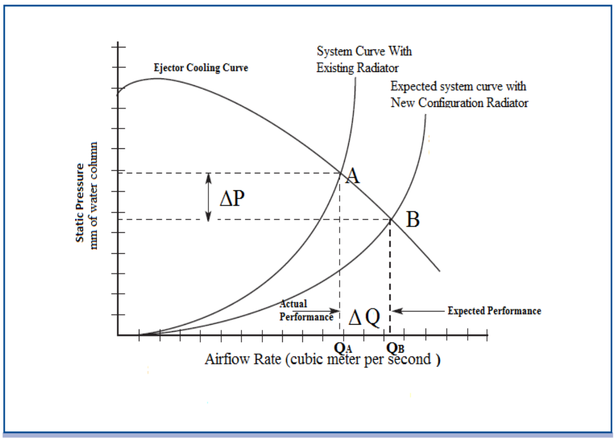

Fig. 5 Characteristic Curve for the Performance of Radiator.

Conclusions:

In this project work testing have been made with variation in mass flow rate of coolant. After completing all the tests the following conclusion can be made;

1) From the experimental analysis, it is found that the heat dissipated by coolant is not received by air totally. Some of the heats dissipated by coolant get lost while transferring from coolant to air.
2) The heat transfer losses are varied from 9 % to 11.3% over entire range of coolant inlet temperature change.
3) Out of total heat transfer losses radiative heat transfer has more contribution and the remaining heat losses are unpredictable heat losses.
4) It is found that due to reduction in pressure drop, heat transfer rate increases and the effective (working) temperature of coolant decreases and radiator gets cooled.
5) From the Characteristics curve (Motivation), it is also concluded that Mass flow rate of air Increased from Q_A to Q_B. Hence due to increase in mass flow rate heat transfer rate is increased by Equation,
 Q= m.Cp. ΔT.

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