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Design, development and improvement in thermal performance of radiator of BMP2 tracked vehicle

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Abstract
This research focuses on the detail design, development, manufacturing and testing of cooling system of tracked Vehicle in which thermal performance is improved by designing a typical radiator with different mixture shapes of fins like Rectangular plain Offset serrated plate fins on Hot Side and Wavy Fins on Cold Side. The designed radiator is going to be used for 300 HP engine of Tracked Vehicle (BMP2 Vehicle used in NBC Attack) which has been used by DRDO, Vehicle Research and Development Establishment (VRDE), Ahmednagar, Government of India.

Keywords: radiator, thermal performance, efficiency, heat dissipation, heat reception, pressure drop, ejector cooling

Introduction
Compact heat exchangers are used fields like automobiles, aerospace, cryogenics because of their compactness for required thermal performance, compact space, weight, energy requirement with moderate cost. Radiator is important component of any automotive cooling system. Upwards of 35% of the energy produced by the engine through combustion is lost in heat (Frank *et al*, 1996) [2] as per the heat balance sheet. Incomplete heat dissipation results in overheating of the engine, breakdown of lubricating oil, weakening, wear and rear of engine parts resulting in less thermal efficiency. To increase the productivity, radiators must be more compact so as to maintain required thermal performance. (Amrutkar *et al*., 2013) [9].

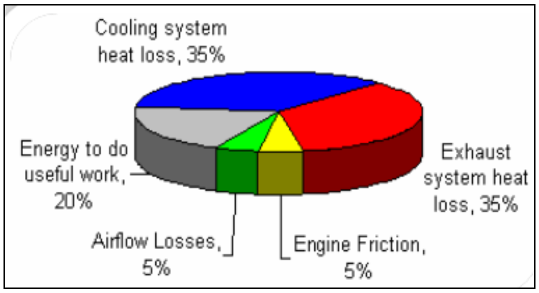

Fig 1: Energy distribution in vehicle

Coolant surrounding engine passes through radiator. In radiator fluid flows through it, gets cooled down and it is re-circulated into system again and again. Radiator size is important criteria considered in designing vehicle cooling system. Radiator size is proportional to heat load and space. Heat load is depends on heat rejection requirement for keeping engine surface at optimal temperature (Yadav *et al*., 2011) [6]. Compactness, low pressure drop, low cost, weight and new optimum materials-alloy 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) [5]. Fins configuration plays vital role in enhancement of heat transfer. There can be scope of improvement in heat transfer of air cooled engine cylinder fin if mounted fin's shapes modified from conventional one. The fins geometry, shape and effective free flow area affects the heat transfer coefficient. In High speed vehicles thicker fins provides better efficiency. Increased fin thickness resulted in swirl being created which helped in enhancement in 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) [11]. Generally Logarithmic mean temperature difference (LMTD) or Effectiveness-No of Transfer Units (ε-NTU) methods are useful for calculations of thermal performance heat exchanger enhancement. 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 iteration to find exact solution (Shah *et al*, 2003) [4]. In this research, Effectiveness-NTU (ε-NTU) classical method is used for enhancement in thermal performance because of its accurate results. (Kays and London, 1998) [3]. 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 exit 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) [7, 13].
The surfaces with wavy patterns surfaces in Plate-fin type heat exchanger due to sinusoidal curve gives better thermal performance compared to others. 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) [14]. 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 sinusoidal curved wavy passage. Wavy channels are easy to manufacture with Punch and Die Assembly, Press machines 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) [16].

When engines run at high rpm to increase the Speed of the vehicle, the heat generated in the parts of the engine also increases. Hence, at higher speed, cooling process should must be effective in order to dissipate the heat. It is concluded with this analysis that, even at higher speed the designed radiator with moderate number of fins attached to it works properly with slight compromise with decrease in efficiency of the fins used in the radiator, (Mounika *et al*., (2016) [17]. Ejector cooling system is used In Military Vehicles by using compact heat exchangers for high thermal efficiency, (Engineering Design handbook Power Plant Cooling, headquarters United States army Materiel Command, 1975) [12].

Ejector Cooling System- The cooling system is a high temperature, liquid, closed and forced-circulation cooling system. (Compact Heat Exchangers are nothing but Radiator, Intercoolers, Oil Coolers). Principal of Ejector Cooling System-With high velocity of exhaust gaseous coming out of nozzle creates low pressure zone (Negative Pressure zone) in the ejector tray, (just like in vacuum cleaner) which causes for suction of fresh atmospheric air inside the ejector tray passing over radiator and oil cooler. (Venturi effect) and hence the radiator is cooled and temperature drops down.

2. Project Overview

Fig 2: BMP2 Tracked Vehicle

This project is sponsored by (DRDO-VRDE) Vehicle Research and Development Establishment, Ahmednagar, Government of India, there was requirement of design and development of radiator for 300 HP engine of BMP2 Tracked Vehicle. To reduce the Overheating of BMP2 Vehicle engine was the main motive of the project. In this project work, based on available 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 theoretical calculated thermal performance is validated by experimental testing. Objectives of this project was, design and development of new radiator, to do 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**.**

Most Research in automotive cooling systems has done with radiator Position is vertical, where as in BMP2 Tracked vehicle Radiator position is horizontal. Special efforts are to be taken for air intake. Also In all automotive Cooling Systems are equipped with cooling fan for heat transfer for cooling /reducing the temperature of hot fluid, but in BMP2 vehicle cooling systems is such that there is no cooling fan. Hence it is a challenging task for development of improved cooling system with existing space and to improve the effectiveness of radiator in peak summer condition at place like Rajasthan.

New Radiator is a compact heat exchanger which is designed with different combination of fins. Fins selected are at hot fluid side-Serrated or offset strip fins (d) and at cold fluid side wavy fins (c) as shown in figure 3. Offset serrated fins- This type of fins has heat transfer coefficient 1.5 to 4 times more those of plain fins. Here flow is thus periodically interrupted, leading to creation of fresh boundary layers and consequent heat transfer enhancement.

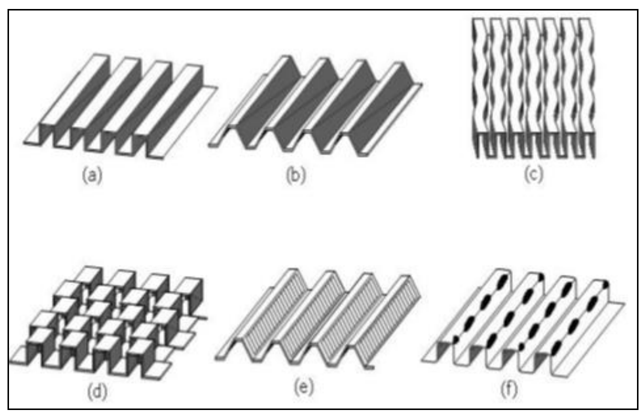

Fig 3: Types of plate fin surfaces: (a) Plain rectangular (b) Plain trapezoidal (c) Wavy (d) Serrated or offset strip fin (e) Louvered (f) Perforated.

Wavy Fins-Heat transfer enhancement in wavy fin heat exchangers is achieved by extension of the flow passage and breaking of the boundary layer periodically which causes change in flow direction. Hence it results in better heat transfer.

Core Data –for Offset serrated fins,

a. fin thickness (t)=0.2 mm
b. fin frequency (f)=500 fin per meter (Fin Pitch = 2 mm)
c. fin length (l) = 5 mm
d. fin height (h)= 3 mm

Core Data –for Wavy fins

a. fin thickness (t)=0.2 mm
b. fin frequency(f)=500 fins per meter (Fin Pitch=2 mm)
c. fin length (l)=5 mm
d. fin height (h)= 9.5 mm

No. of Passages=39

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 air side circuits. The test section is shown in Fig.4.

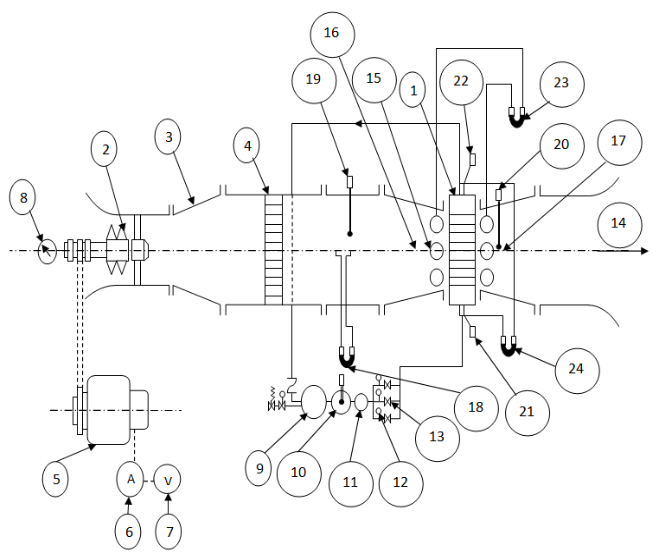

Fig 4: Experimental Setup

Experimental set up layout consist of 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,

1. Water Flow Meter: The water flow meter used with an accuracy of +/-2% of maximum scale.
2. Air flow Meter: The minimum scale for liquid column is 1 mm on 30˚ inclined type manometer.
3. 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.
4. Thermometers: resistance temperature detectors (RTD) used 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 and compared with heat balance equation. Cooling system designed to fulfil all above requirements.

Table 1: Overall 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 taken for Radiator thermal analysis.

Parameters	Hot Side	Cold Side
Fluid	Water	Air
Inlet temp (ºC)	120 (Th_1)	73 (Th_1)
Outlet temp (ºC)	111 (Th_2)	115 (Th_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 Performance and 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

1. Coolant outlet temperature (hot side)
   $$Th2 = Th1 - (Q/Ch) \quad (1)$$
2. Air outlet temperature (cold side)
   $$Tc2 = Tc1 + (Q/Cc) \quad (2)$$
3. Coolant side heat capacity rate (hot side)
   $$Ch = mh * Cph \quad (3)$$
4. Airside heat capacity rate (cold side)
   $$Cc = mc * Cpc \quad (4)$$
5. Heat capacity rate ratio:
   $$Cr = Cmin/Cmax \quad (5)$$
6. Required effectiveness
   $$\varepsilon reqd = [Ch * (Th1 - Th2)]/[Cmin * (Th1 - Tc1)] \quad (6)$$

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

1. Core mass velocity, Gh = m / Affh (7)
2. The Reynolds no. Re. = G Dhh/μ (8)
3. 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)
4. The Convective Heat Transfer Coefficient, $hh = (jh \times cph \times Gh)/(Pr)^{0.667}$ (10)
5. The Fin Parameter is given by, M-
   $M = \sqrt{2x\ hh / (kf \times t)}$ (11)
6. Fin effectiveness is given by Ƞf=tanh(Mlh)/(Mlh)(12)
   Overall surface effectiveness is given by
   Ƞoh = 1 − (af / as) x (1 − ηf) (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)-

1. 1/UA = 1/ (Ƞoverall x hh x A) hot + t/ (Kw x Aw) + 1/ (Ƞoverall x hc x A) cold (16)
2. Hot Side, Uoh = (UoAo) h / Aoh (17)
3. Cold Side, Uoc = (UoAo) c / Aoc (18)
4. Number of Transfer Units, Ntu = UoAo/Cmin (19)

F) Radiator effectiveness is calculated by

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

As the Cold Side (Air) is most important, 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).and Pressure Drop
= 32 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 /rejected on coolant (hot):

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

ii. Heat received on airside (cold):

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

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	ºC	120
Coolant outlet temperature	Th2	ºC	111
Air inlet temperature	Tc1	ºC	73
Air outlet temperature	Tc2	ºC	115

Table 4: Experimental Results

Parameter		Unit	Value
Heat dissipated by coolant	Qh	KW	119.4
Heat received by air	Qc	KW	106.9
Coolant inlet temperature	Th1	ºC	98
Coolant outlet temperature	Th2	ºC	88.4
Air inlet temperature	Tc1	ºC	36.8
Air outlet temperature	Tc2	ºC	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.

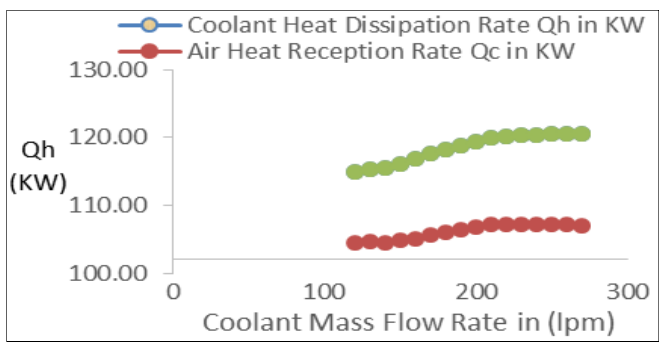

Fig 5: Coolant Mass Flow Rate Vs Heat Transfer

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.

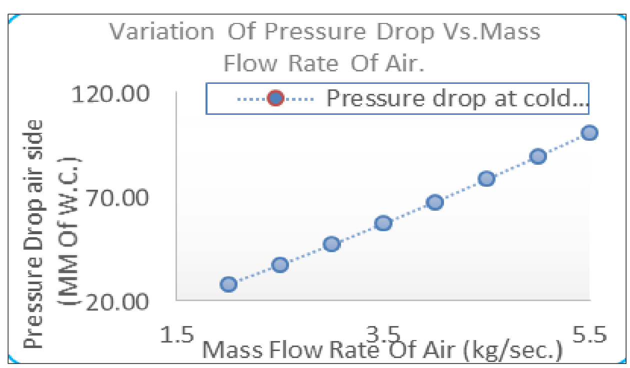

Fig 6: Mass Flow Rate vs Pressure Drop

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

7. Comparison of Old and New Radiator

Table 5: Comparison of Old and New Radiator in Terms of heat transfer.

Coolant Flow Rate		Heat Transfer Rate of New radiator	Heat Transfer Rate of old radiator	Percentage increase in heat transfer (%)
LPM	Kg/s			
120	2.06	104.48	90.08	15.98
130	2.23	104.73	91.01	15.07
140	2.4	104.48	90.08	15.98
150	2.57	104.85	90.84	15.43
160	2.74	105.11	90.86	15.68
170	2.91	105.74	91.19	15.94
180	3.09	105.99	91.21	16.21
190	3.26	106.49	92.66	14.93
200	3.43	106.87	92.49	15.54
210	3.6	107.12	93.14	15.01
220	3.77	107.25	93.42	14.80
230	3.94	107.25	93.32	14.92
240	4.11	107.25	92.86	15.50
250	4.29	107.25	92.23	16.28
260	4.46	107.12	92.64	15.63
270	4.63	106.99	92.79	15.30

Motivation

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

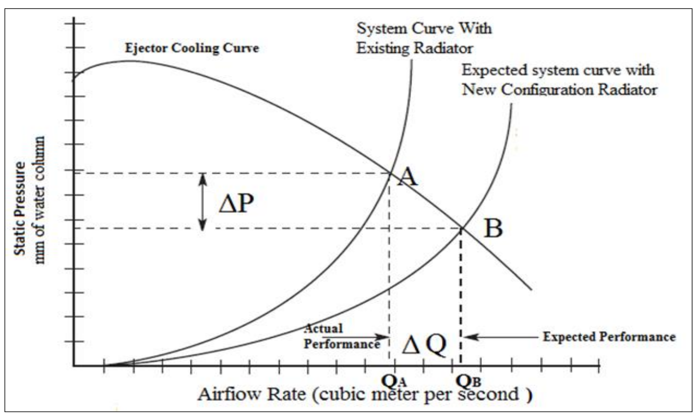

Fig 6: Characteristic Curve for the Performance of Radiator.

8. 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 QA to QB. Hence due to increase in mass flow rate heat transfer rate is increased by Equation, Q= m. Cp. ΔT.
6. It is again proved that heat transfer rate is function of mass flow rate of fluid and temperature difference. As the Temperature difference varies heat transfer Rate also varies. In this project by changing the fins configuration, mass flow rate is increased and temperature varied by creating the turbulence and heat transfer rate increased by around 15 % and radiator gets cooled and new radiator is proved more thermal efficient than older one.
7. Pressure drop is very important criteria for designing heat exchanger because it is associated with pumping power. Increase in pumping power is not beneficial because it increases cost with reduction in productivity.

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