Effects of Altitude on Performance of Automotive Radiator and Hence on Engine

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Abstract— **While designing the engine, the engine of vehicles are generally tuned at sea level. However, in many of the countries the engine operation is performed at higher altitudes than that of the sea level. The air densities at different altitude have significant effects on the fuel consumption and other engine parameters. Theoretically in case of gasoline engines, the higher altitude causes to lower fuel consumption. It is because of lower throttle frictions results from wider throttle opening. From other side, because of lower density at higher altitudes, the vehicle aerodynamic gets changed and this also leads to lower fuel consumption.**

In case of air vehicles, as the altitude increases there is considerable reduction in ambient temperature, and accordingly the thermo physical properties of air as well as coolant changes. It affects the thermal performance of radiator and hence the engine. The respective work studies the effects of high altitude on thermal performance of radiator of air vehicle engine. The impact of altitude is studied by calculating the required and calculated effectiveness of radiator of 65 HP rotary engine by considering analytical as well as experimental evaluation.

Keywords— **Thermal performance, required effectiveness, calculated effectiveness, cooling capacity, heat load.**

I. INTRODUCTION

The today's demand for more powerful engines in smaller spaces causes the problem of insufficient heat dissipation rates in vehicle radiators. Much of the energy generated by vehicle engine through fuel consumption is lost in form of heat. This leads the overheating of engine and hence causes the improper functioning of lubricating oil, weakening of engine parts and wears between engines parts can also be resulted from insufficient heat dissipation. Hence, in order to minimize the stress results from heat generation, automotive radiators must be redesigned to be more compact without affecting the thermal performance.

In India, the defence vehicles operate at high altitudes up to 6000 m. The reason is our international frontiers fall within Himalayan ranges. The problems comes during engine operation at high altitude are different than that of the problems faced under mean sea level conditions. The major factors that contribute to operational problems are the rarefied atmospheric conditions and lower temperature prevailing at high altitudes.

The major problem in operation at high altitude is the loss of power causes from reduction in mass flow rate of air and poor combustion efficiency results from the change in injection characteristics. Other effects are poor thermal efficiency, higher smoke density and exhaust temperatures depending upon the altitude as compared to mean sea level. For every 100 m of altitude, the output power of diesel engine falls at the rate about 1 percent.

While designing the cooling system of automotives the sizing of radiator is the most important factor. Hot coolant surrounding the engine passes through radiator for cooling. Coolant flown through the radiator gets cooled down and re-circulated into system again and again. The radiator size is mainly depending on space availability for mounting and the heat load. The head load depends on the required heat rejection in order to keep engine surfaces at optimum temperature.

General methods for heat transfer calculations of heat exchanger i. e. Radiator are Log Mean Temperature Difference (LMTD) method or Effectiveness-Number of Transfer Units (ε-NTU) method. Both methods have their own advantages and they can be preferred according to availability of data. When radiator inlet and outlet temperatures are known, faster solution can be meeting from LMTD method. When any of the temperature is unknown, more iterations are required for finding out the solution while using LMTD method. Because of more accuracy in solution, in this case ε-NTU method is described for heat transfer calculations.

II. METHODOLOGY ADOPTED

For starting every work we should find out a problem, the topic was selected by counting effects on various parameters at higher altitudes. When we go to higher altitudes vehicle output power is found to be decreasing which increases driving difficulties. Technically speaking as we go to higher altitudes the volumetric efficiency of the engine is found to be decreasing. The radiator plays an important role for power influence. Because heat dissipated by engine is absorbs by radiator and it cools the coolant which is recirculated to the engine. So our first step towards this project is to verify the problem. We discussed in team, guide and heavy vehicle drivers. Our next step was to find key factor that cause these problems. Then we noticed that as altitude increases the atmospheric pressure and air density is found to be decreasing. Then we learnt about the effects of decrease in atmospheric pressure and air density in the performance of the engine. We chose the different altitudes 0m, 1000m, 2000m, 3000m, 3600m, 4000m to make analysis simpler. The next step was finding out the atmospheric pressures and air densities at above mentioned altitudes. And finally applying these values at different altitudes we found the changes in output power and effectiveness of radiator. The experimentation has been made on experimental set up available in VRDE(Vehicle Research and Development Establishment, Government of India, Ahmednagar) with proper provision for appropriate coolant and air supply, temperature measurement sensors for both coolant and air.

A. Experimental Setup for testing

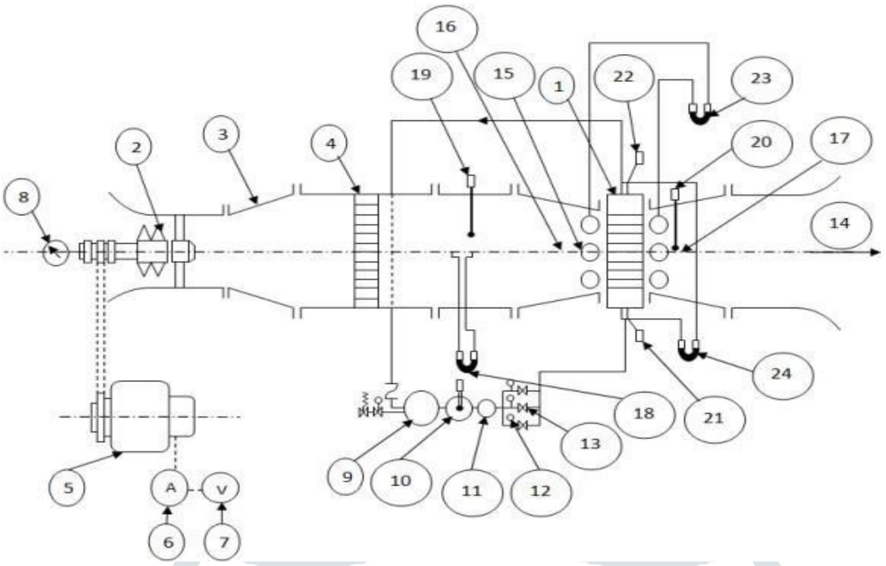


Fig. 1: Line Diagram of Experimental Testing Setup

Fig.1 shows the typical experimental setup. It contains 1)Test Radiator; 2)Fan; 3)Wind Tunnel Body; 4)Rectifying Lattice; 5)Ampere Meter; 6)Shunt Motor; 7)Voltmeter; 8)Speed Counter For Fan; 9)Hot Coolant Tank; 10)Supplementary Hot Coolant Tank; 11)Coolant Pump And Motor; 12)Coolant Flow meter; 13)Coolant Flow Adjusting Valve; 14)Wind Direction; 15)Connecting Tube; 16)Downstream End; 17)Upstream End; 18)Liquid Column Gauge (Water) For Air Flow meter; 19)Thermometer For Inlet Air Temperature; 20)Thermometer For Outlet Air Temperature; 21)Thermometer For Inlet Coolant Temperature; 22)Thermometer For Outlet Coolant Temperature; 23)Liquid Column Gauge (Mercury) For Coolant Side Pressure Loss; 24)Liquid Column Gauge (Water) For Air Side Pressure Loss.

By connecting the radiator and blower with the connecting tube, the air side circuit has been completed. The coolant side circuit of the test apparatus has been connected to the outlet and inlet pipes of the radiator. When radiator has reached the stable conditions with specified air mass flow rate and coolant mass flow rate, the required tests have been conducted.

During experimental testing the following parameters have been measured and the analysis is completed by comparing the analytical values with experimental values.

i. Pressure and humidity at ambient conditions;
ii. ii. Mass flow rate of air and coolant;
iii. iii. Inlet and outlet coolant temperatures;
iv. iv. Inlet and outlet air temperatures;
v. v. Air velocity

III. HEAT TRANSFER CALCULATIONS

Purpose behind thermal analysis of radiator is sizing i. e. to determine the heat transfer surface area and rating i. e. performance calculations to determine rate of heat transfer. The method used for radiator design i. e. ε-NTU method is based on the concept of effectiveness of heat exchanger. Heat transfer requirement is decided depending upon the engine specifications, operating conditions of engine and the respective vehicle.

TABLE I
REQUIREMENTS FOR ENGINE COOLING SYSTEM

Parameter	Value	Unit
Total Heat Transfer	29	KW
Height	225	Mm
Length	350	Mm
Depth	25	Mm

The size of radiator as per space available for radiator mounting is given in table 1.

And the input data required for theoretical calculations of radiator are given in table 2.

TABLE III
INPUT DATA FOR THEORETICAL CALCULATIONS

Description	Parameter	Value	Unit
Coolant	Density	1028.55	Kg/m3
	Specific Heat	3.644	KJ/Kg-K
	Dynamic Viscosity	0.00077	N-s/m2
	Thermal conductivity	0.37974	W/m-K
	Prandtl no.	7.163	-
Air	Density	1.11	Kg/m3
	Specific Heat	1.007	KJ/Kg-K
	Dynamic Viscosity	19.8*10-6	N-s/m2
	Thermal conductivity	28*10-3	W/m-K
	Prandtl no.	0.7214	-
Tube	Width	1.5	mm
	Thickness	0.06	mm
	Height	25	mm
	Length	225	mm
	Numbers	29	-

A. *Calculations to find out required effectiveness:*

i. Heat transfer rate

$Q = m * Cp * \Delta T$ (1)

ii. Heat capacity rate

$Ch = m * Cp$ (2)

iii. Heat capacity rate ratio

$Cr = Cmin / Cmax$ (3)

iv. Required effectiveness

$\varepsilon_{reqd} = [Ch * (Th1 - Th2)] / [Cmin * (Th1 - Tc1)]$ (4)

Heat transfer coefficient calculations [8]:

i. Hydraulic diameter

$Dh = (4 * Ao) / P$ (5)

ii. Mass flow rate per unit area

$G = m / Ao$ (6)

iii. Reynolds no.

$Re = (G * Dh) / \mu$ (7)

iv. Nusselt no. for 2300 < Re < 1000

$Nu = 0.0265 * Re0.8 * P\ 0.3$ (8)

v. Heat transfer coefficient

$h = (Nu * k) / Dh$ (9)

Radiator effectiveness calculations [8]:

i. Number of transfer units

$NTU = (Uo * Ac) / Cmin$ (10)

ii. Required Constants

$A = Cr * NTU0.78$ (11)

$B = Cr * NTU-0.22$ (12)

$D = (e-A - 1) / B$ (13)

iii. Calculated radiator effectiveness

$\varepsilon_{cal} = 1- eD$ (14)

If the calculated effectiveness for selected radiator size is greater than that of required effectiveness the design is said to be safe in thermal design point of view.

B. *Comparison between analytical and experimental results*

After calculations all analytical and experimental results are listed in Table 3 and Table 4 respectively.

TABLE IIIII

ANALYTICAL RESULTS

Parameter		Value	Unit
Coolant inlet temperature	Th1	105	°C
Coolant outlet temperature	Th2	98.37	°C
Air inlet temperature	Tc1	45	°C
Air outlet temperature	Tc2	55.98	°C
Heat dissipated by coolant	Qh	29	KW
Heat received by air	Qc	29	KW
Required Effectiveness	ε_{reqd}	0.1831	-
Calculated Effectiveness	ε_{cal}	0.2347	-

TABLE IV

EXPERIMENTAL RESULTS

Parameter		Value	Unit
Coolant inlet temperature	Th1	101.3	°C
Coolant outlet temperature	Th2	94.8	°C
Air inlet temperature	Tc1	36.8	°C
Air outlet temperature	Tc2	45	°C
Heat dissipated by coolant	Qh	28.42	KW
Heat received by air	Qc	21.63	KW
Required Effectiveness	ε_{reqd}	0.1623	-
Calculated Effectiveness	ε_{cal}	0.2305	-

The above comparison (for reading no 11) shows that both analytical and experimental results for heat dissipation from coolant are closely matched with each other. Thus, theoretical thermal analysis of radiator by using ε-NTU method is validated using experimental approach. Size of radiator is fixed from these results and to be used while designing radiator.

C. *All Experimental Results*

The readings have been taken for eleven coolant inlet temperatures and the variation of heat transfer and effectiveness with increasing coolant inlet temperature is shown in Fig 2. From Fig. 2 it is observed that the heat dissipation rate as well as effectiveness increases with increasing coolant inlet temperature. But the heat dissipated by coolant is not received by air totally.

Some of the heat is lost while transferring from coolant to air. Out of these heat losses near about 10% to 15% heat losses are due to radiation heat transfer to atmosphere and the remaining are unpredictable heat losses. These losses are increasing with increase in coolant inlet temperature because radiative heat transfer is proportional to wall surface temperature and as the coolant inlet temperature increases wall surface temperature also increases.

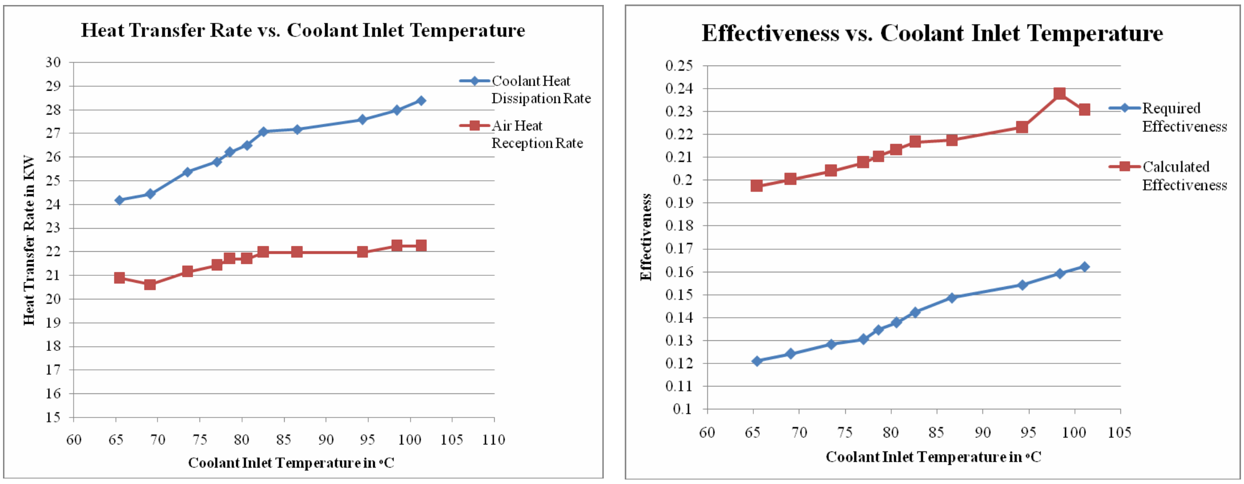


Fig. 2: Experimental Results (a. Heat Transfer Rate vs. Coolant Inlet Temperature, b. Effectiveness vs. Coolant Inlet Temperature)

D. Effect of coolant inlet temperature on radiator performance parameters

It is found from these results that all radiator performance parameters increase with increasing coolant inlet temperature. But it satisfies the basic requirement i.e. the calculated effectiveness is greater than that of required effectiveness which proves that the design is safe.

TABLE V

Variation of Radiator Effectiveness and Cooling Capacity with Coolant Inlet Temperature

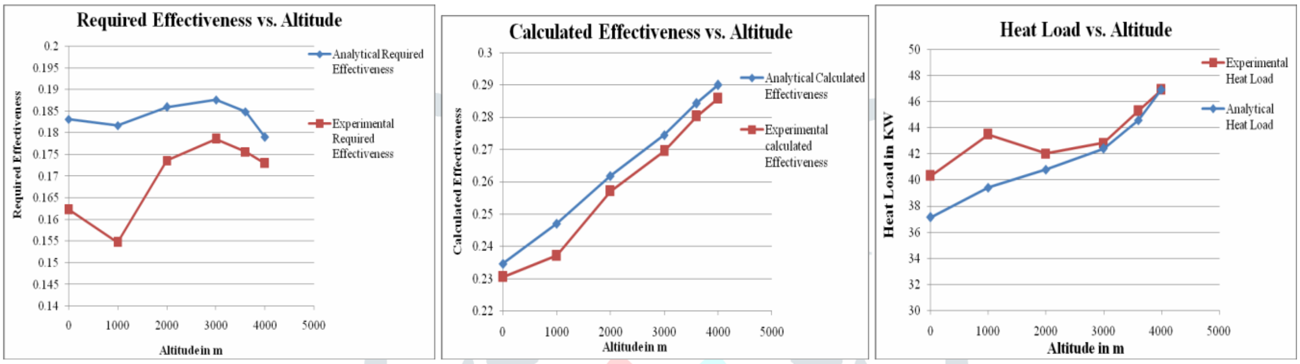
Sr. No	Coolant Inlet Temperature in °C	Required Effectiveness (εreqd)	Calculated Effectiveness (εcal)	Cooling Capacity in KW
1	65.4	0.1211	0.1973	24.212
2	69.1	0.1243	0.2003	24.462
3	73.5	0.1284	0.2039	25.405
4	77	0.1306	0.2077	25.824
5	78.6	0.1348	0.2104	26.236
6	80.6	0.1379	0.2134	26.536
7	82.6	0.1423	0.2166	27.111
8	86.6	0.1487	0.2175	27.205
9	94.3	0.1544	0.2230	27.611
10	98.4	0.1593	0.2300	28.017
11	101.3	0.1623	0.2305	28.391

IV. High Altitude Analysis

It is necessary know the performance of the designed radiator at high altitude, the ambient temperature decreases with increase in altitude. Accordingly the thermo physical properties of coolant and air will change considerably. Here, the cooling capacity of the heat exchanger is estimated by up to 4000 meters altitude as ceiling altitude of the UAV is 3600 meters. The variation of radiator performance parameters with altitude is shown in Table 6 and Fig. 3 (for reading no 11).

TABLE VI
VARIATION OF RADIATOR PERFORMANCE PARAMETER WITH ALTITUDE

Sr. No.	Altitude (m)	Required Effectiveness (εreqd)		Calculated Effectiveness (εcal)		Heat Load (KW)	
		Analytical	Experimental	Analytical	Experimental	Analytical	Experimental
1	0	0.1832	0.1623	0.2347	0.2305	37.1471	40.3174
2	1000	0.1817	0.1548	0.2471	0.2371	39.4178	43.4953
3	2000	0.1860	0.1736	0.2618	0.2571	40.8138	42.0398
4	3000	0.1876	0.1786	0.2745	0.2696	42.4112	42.8428
5	3600	0.1849	0.1757	0.2843	0.2803	44.5834	45.2997
6	4000	0.1790	0.1729	0.2899	0.2858	46.9582	46.9193



a. b. c.

Fig. 3: Variation of Radiator Performance Parameters with Altitude (**a.** Required Effectiveness vs. Altitude, **b.** Calculated Effectiveness vs. Altitude, **c.** Heat Load vs. Altitude)

From Fig. 3, it is observed that as the altitude increases the radiator performance parameters also increases but it still shows that the calculated effectiveness is greater than that of required effectiveness. That means the designed radiator will work at high altitude without creating any problem.

V. CONCLUSIONS

After completing the study, the following conclusion can be made:

1. The heat transfer rate increases with coolant mass flow rate.
2. There are 16% to 24% heat transfers losses while transferring heat from coolant to air; out of these losses some heat transfer losses are due to radiative heat transfer to atmosphere and remaining heat transfer losses are unpredictable heat transfer losses.
3. The radiative heat transfer losses increases with increase in coolant inlet temperature i.e. wall surface temperature.
4. As the air density decreases with increase in altitude the heat load increases.

REFERENCES

[1] Bureau of Indian Standards, “Internal Combustion Engines-Radiators-Heat Dissipation Performance-Method of Test”, UDC 621.43:629.113, 1993.
[2] D. K. Chavan and, G. S. Tasgaonkar, “Study, Analysis and Design of Automobile Radiator (Heat Exchanger) Proposed with CAD Drawings and Geometrical Model of the Fan”, TJPRC Pvt. Ltd., ISSN2249-6890, Vol. 3, Issue 2, 2013.
[3] Frank P. Incropera and David P. Dewitt, “Fundamentals of Heat and Mass Transfer”, 4th Edition, pp. no 581-603.
[4] JP Yadav and, Bharat Raj Singh, “Study on Performance Evaluation of Automotive Radiator”, S-JPSET: ISSN: 2229-7111, Vol. 2, Issue 2, 2011.
[5] Matthew Carl, Dana Guy, Brett Leyendecker, Austin Miller and, Xuejun Fan, “The Theoretical and Experimental Investigation of the Heat Transfer Process of an Automobile Radiator”, ASEE-GSAC, 2012.
[6] Pawan S. Amrutkar, Sangram R. Patil and, S. C. Shilwant, “Automotive Radiator-Design and Experimental Validation”, IJAUERD, ISSN: 2277-4785, 2013.
[7] Ramesh K Shah and, Dusan P. Sekulic, “Fundamentals of Heat Exchanger Design”, John Wiley & Sons, Inc., pp. no 1-209, 378-418, 2003.
[8] W. M. Kays and A. L. London, “Compact Heat Exchangers”, Third Edition, McGraw-Hill Book Company.
[9] W. S. James and, S. R. Parsons, “Effect of Altitude on Radiator Performance”, National Advisory Committee for Aeronautics.
[10] G. A. Sivasankaran and S. K. Jain, “Performance of diesel engines at high altitudes”, *Indian Institute of Petroleum, Dehra dun.*
[11] Sherin George^1, Sreelal M^2, Saran S^3, Shaiju Joseph^4, Arun K Varghese^5, “high altitude air flow regulation for automobiles”, IJARSE, Vol. No.4, Special Issue (01), March 2015
[12] Efthimios Zervas, “Impact of altitude on the fuel consumption of a gasoline passenger car”