PERFORMANCE TESTING OF RADIATOR OF HIGH ALTITUDE VEHICLE ENGINE

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Abstract-Till now there are many interventions have been made in the area of thermal performance enhancement of radiator which is cross flow type of heat exchanger. It is only because the radiator is key component of engine cooling system. These interventions include changes in material, changes in shape, various types of coolants, variations in air velocity and so on. And these interventions have been made improvement in efficiency of automotive cooling system. Radiator thermal analysis consist sizing and rating of heat exchanger. The radiator size mainly depends on heat rejection requirement. Heat transfer calculations are important fundamentals to optimize radiator size. This paper focuses on thermal analysis of radiator theoretically using Effectiveness- No of transfer Units (ε-NTU) method and its validation by experimental testing. The theoretical analysis can be validated furthermore with CFD based analysis. The designed radiator is going to be used for 65 HP rotary engine of Unmanned Air Vehicle (UAV) which has been newly invented by Vehicle Research and Development Establishment (VRDE), Ahmednagar, Government of India.

Keywords-Thermal Analysis, Effectiveness, Heat Dissipation, Heat Reception, Air Velocity.

I. Introduction

Radiator is the key component of automotive cooling system. 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 (Frank P. Incropera et al, 1996). Insufficient heat dissipation can result in overheating of the engine, which leads to the breakdown of lubricating oil, metal weakening of engine parts, and sufficient wear between engine parts. To minimize the stress on engine as a result of heat generation, automotive radiators must be redesign to be more compact while still maintaining high levels of heat transfer performance (P. S. Amrutkar, 2013).

Coolant surrounding engine passes through radiator. In radiator coolant flown through it gets cooled down and re-circulated into system again and again. Radiator sizing is the important factor while designing cooling system. The radiator size depends on mainly heat load as well packaging space availability. Heat load depends on heat rejection required to keep engine surface at optimum temperature (JP Yadav et al, 2011). Generally Log Mean temperature Difference (LMTD) or Effectiveness-No of Transfer Units (ε-NTU) methods are used to do heat transfer calculations of heat exchanger. Both methods have its own advantages and preferred according to data availability. When radiator inlet and outlet temperatures are known, LMTD gives faster solution. When any of the temperature is unknown, LMTD method undergoes more iteration to find solution (Ramesh K. Shah et al, 2003). In this case ε-NTU method is described to do heat transfer calculations because it give more accurate solution in this type of case.

II. Project Overview

As this project is sponsored by Vehicle Research and Development Establishment (VRDE), Ahmednagar, Government of India, there was requirement to design radiator for 65 HP rotary engine of Unmanned Air Vehicle (UAV). For that we have specifications of engine that are required for radiator and the space available to place the radiator. In this project work, approximate size of radiator has been assumed according to space availability. Based on this size the theoretical calculations have been made by using ε-NTU method. Radiator size and heat transfer rate have been finalized accordingly. The experimentation has been made on experimental set up available at VRDE which is with proper provision for appropriate coolant and air supply, temperature measurement sensors for both coolant and air. And then thermal performance has been validated by experimental testing.

III. Objectives

1) To Design radiator for 65 HP rotary engine of Unmanned Air Vehicle (UAV) with given specifications of engine and for expected requirements.
2) To provide radiator that will be more efficient and compact.
3) To assess heat dissipation performance of designed radiator by experimental testing.
4) To compare heat dissipation rate by theoretical data and that of by experimental data.

IV. Experimetal Setup Layout

A. Terminology

1. Heat Dissipation Rate on Waterside: The heat dissipation rate under test conditions, expressed as the quantity of heat which water losses under, and is expressed by the unit of Kilograms per second (Kg/s).
2. Heat Reception Rate on Airside: The heat rate which the cooling air receives under test conditions and is expressed by the unit of Kilograms per second (Kg/s).
3. Inlet temperature difference (ITD): The difference between inlet temperatures of water and air expressed by the unit of degree Celsius (˚C).
4. Water Flow Rate: The flow rate of water which is passes through the radiator expressed in meter cube per second (m3/s).
5. Air Velocity at Frontal Area: The flow rate of air passing through the radiator divided by the frontal area and is expressed in meter per second (m/s).

6. Pressure Loss of Waterside: The difference of static pressure between the waterside inlet and outlet of the radiator which is measured at the test state and is expressed by the unit of mercury column height of millimeter (mm Hg).
7. Pressure Loss of Airside: The difference of static pressure between the airside inlet and outlet of the radiator which is measured at the test state and is expressed by the unit of water column height of millimeter (mm Aq).
8. Upstream End: Area before the radiator which permits entry of air into the radiator
9. Downstream End: Area after the radiator which permits exit of air away from the radiator.

B. Test Requirements

1. The radiator should comply with IS 7611: 1993.
2. The test room conditions should be steady and at normal ambient temperature and humidity. The air flow shall be steady without large fluctuations.
3. Unless otherwise specified the water used for test purposes should be clear without suspended impurities and the radiator inlet water temperature maintained at +/- 5˚C to the exhaust temperature of coolant from engine at the dissipation state. The temperature should be recorded at the steady state conditions and a variation of +/- 2˚C in the coolant inlet temperature is permissible between successive readings.
4. The measuring equipment should be calibrated before start of test.
5. The test should be maintained at steady atmospheric conditions.

C. Testing and Measuring Arrangement

The typical testing arrangement is shown in Fig.1.

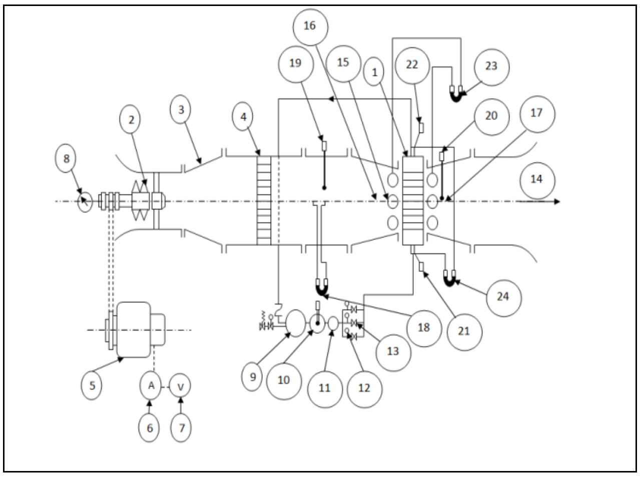


Fig.1 Experimental Setup

V. Tests

The airside circuit has been completed by connecting the radiator and blower with the connecting tube. The waterside circuit of the test apparatus has been connected to the inlet and outlet pipes of the radiator. When radiator has reached the stable conditions with specified rate of air and water flow, the required tests have been conducted. The following have been measured:

i. Atmospheric pressure and humidity
ii. Inlet and outlet coolant temperatures
iii. Inlet and outlet air temperatures
iv. Rate of air and coolant flow
v. Air velocity

All tests mentioned above have been conducted at atmospheric conditions i.e. at atmospheric temperature of 36.8°C, atmospheric pressure of 94Kpa and 30% Relative humidity.

VI. Heat Transfer Calculations

Actual thermal analysis is performed first theoretically and then by experimental approach for following requirements. It includes heat rejection requirement, space available under hood to mount radiator. Heat transfer requirement is decided as per engine specifications, engine operating conditions and vehicle operating conditions. Cooling system design should fulfill all these requirements.

Table 1 Requirement of Engine Cooling System

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

Following parameters have been considered for analytical approach.

Table 2 Inputs for Theoretical calculations

Description	Parameter	Unit	Value
Coolant	Density	Kg/m^3	1028.55
	Specific Heat	KJ/Kg-K	3.644
	Dynamic Viscosity	$N\text{-}s/m^2$	0.00077
	Thermal conductivity	W/m-K	0.37974
	Prandtl no.		7.163
Air	Density	Kg/m^3	1.11
	Specific Heat	KJ/Kg-K	1.007
	Dynamic Viscosity	$N\text{-}s/m^2$	$19.8*10^{-6}$
	Thermal conductivity	W/m-K	$28*10^{-3}$
	Prandtl no.		0.7214
Tube	Width	mm	1.5
	Thickness	mm	0.06
	Height	mm	25
	Length	mm	225
	Numbers		29
Fin	Height	mm	6.17
	Thickness	mm	0.18
	No of spacing		28
	Flow Length	mm	25
	Fin area/total area		0.882

Purpose of thermal analysis of heat exchanger is to determine the heat transfer surface area (sizing) and performance calculations to determine heat transfer rate (rating). 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. Here approximate size is assumed according to space availability. Based on this size heat transfer rate is calculated which should fulfill the requirement. Radiator size and heat transfer rate finalized accordingly.

Calculations to find out required effectiveness

i. Coolant outlet temperature
$Th2 = Th1 - (Q/Ch)$

ii. Air outlet temperature
$Tc2 = Tc1 + (Q/Cc)$

iii. Coolant side heat capacity rate
$Ch = mh * Cph$

iv. Airside heat capacity rate
$Cc = mc * Cpc$

v. Heat capacity rate ratio
$Cr = Cmin/Cmax$

vi. Required effectiveness
$\varepsilon reqd = [Ch * (Th1 - Th2)]/[Cmin * (Th1 - Tc1)]$

Coolant side heat transfer coefficient calculations:

i. Hydraulic diameter
$D_h h = (4 * Aoh)/Ph$

ii. Mass flow rate per unit area
$Gh = mh/Aoh$

iii. Reynolds no.
$Reh = (Gh * D_{hh})/\mu h$

iv. Nusselt no. for 2
$Nuh = 0.0265 * Re^{0.8} * Pr^{0.3}$

v. Heat transfer coefficient
$h_h = (Nuh * k)/D_h h$

Airside heat transfer coefficient calculations

i. Hydraulic diameter
$D_h c = (4 * Aoc)/Pc$

ii. Mass flow rate per unit area
$Gc = mc/Aoc$

iii. Reynolds no.
$Rec = (Gc * D_h c)/\mu c$

Radiator effectiveness calculations

i. Number of transfer units
$NTU = (Uo * Ac)/Cmin$

ii. Required Constants
$A = Cr * NTU^{0.78}$

iii. Calculated radiator effectiveness
$\varepsilon cal = 1 - e^{D}$

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

Mathematical expressions used for calculations;

i. Heat dissipated on waterside:
$Qh = mh * Cph * (Th1 - Th2)$

ii. Heat received on airside:
$Qc = mc * Cpc * (Tc2 - Tc1)$

VII. Results and Discussion

Comparison of analytical and experimental results at 70 lpm coolant flow rate and 35 m/s air velocity,

Table 3 Analytical Results

Parameter		Unit	Value
Heat dissipated by coolant	Qh	KW	29
Heat received by air	Qc	KW	29
Coolant inlet temperature	Th1	°C	105
Coolant outlet temperature	Th2	°C	98.37
Air inlet temperature	Tc1	°C	45
Air outlet temperature	Tc2	°C	55.98

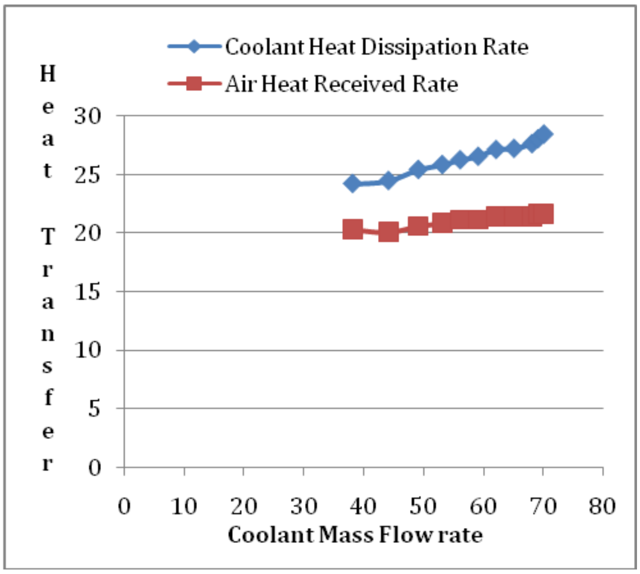
Table 4 Experimental Results

Parameter		Unit	Value
Heat dissipated by coolant	Qh	KW	28.4226
Heat received by air	Qc	KW	23.8832
Coolant inlet temperature	Th1	°C	101.3
Coolant outlet temperature	Th2	°C	94.8
Air inlet temperature	Tc1	°C	36.8
Air outlet temperature	Tc2	°C	45

The above comparison shows that both analytical and experimental results for heat dissipation from coolant are closely matched with each other. Thus theoretical thermal analysis of radiator using ε-NTU method is validated using experimental approach. Size of radiator is fixed from these results and to be used while designing radiator.

But from experimental results it is shown that the heat dissipated by coolant is not received by air totally. The main reason behind this is that there some radiation heat losses in the range of 10% to 15% and the remaining heat losses are unpredictable heat losses.

From the graph 1 it is shown that the heat dissipated by coolant as well as heat received by air are simultaneously increasing with coolant mass flow rate.



Graph 1 Heat Transfer vs. Coolant Mass Flow Rate

VIII. CONCLUSION

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

1) The heat transfer rate increases with coolant mass flow rate.
2) There are 16% to 24% heat transfer losses while transferring heat from coolant to air; out of these losses 10% to 15% heat transfer losses are due to radiative heat transfer to atmosphere and remaining heat transfer losses are unpredictable heat transfer losses.
3) As the coolant inlet temperature increases the wall temperature also increases. The radiative heat transfer proportional to wall temperature. Hence the radiative heat transfer losses increases with increase in coolant inlet temperature.

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