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Performance and Heat Analysis for a FSAE Water Cooled Radiator

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ABSTRACT*:* Internal Combustions engine have been proven to be one of most used technology for decades to power the vehicles. But this contraption comes with some drawback and major one of them is overheating. IC Engines produce the power at the cost of mechanical friction, noise, vibration and heating. It is seen that an IC Engine is only 40-50% efficient as other part is wasted in the form of friction and heating in order to prevent the overheating of the engine oil, cylinder walls, pistons, valves, and other components by these extreme temperatures, it is necessary to effectively dispose of the heat. Hence, a cooling system is necessary for this job. Radiator is a heat exchanger and it makes sure that the engine operated within the optimum temperature limits. Radiators are used to transfer thermal energy from one medium to another for the cause of cooling. A radiator transfers the heat from the fluid inside to the air out of doors, thereby cooling the fluid, which in flip cools the engine. Research is being carried out for several many years now, in improving the performance of the heat exchangers.

KEYWORDS*:* Cooling, Heat Exchanger, IC Engine, Overheating, Radiator

I. INTRODUCTION

Modern automotive internal combustion engines generate a huge amount of heat. In order to prevent the overheating of the engine oil, cylinder walls, pistons, valves, and other components by these extreme temperatures, it is necessary to effectively dispose of the heat. Temperatures in the combustion chamber of the engine can reach 250°C, so cooling the area around the cylinders is critical.

Radiators are warmness exchangers used to transfer thermal energy from one medium to any other for the motive of cooling and heating. The majority of radiators are constructed to characteristic in motors, homes, and electronics. Despite the name, the radiators transfer the bulk in their heat vis convection. Hence, mounted in a position where they get hold of airflow from the forward movement of the automobile.

The cooling system is made up of the passages inside the engine block and heads, a water pump to circulate the coolant, a thermostat to control the temperature of the coolant, a radiator to cool the coolant, a radiator cap to control the pressure in the system, and some plumbing consisting of interconnecting hoses to transfer the coolant from the engine to radiator. The improvement in the automobile industry had led to increase in thermal load. As a result, it is necessary to increase the cooling rate onboard. Cooling of engine is one of the biggest challenges because the excessive heating of the system can destroy it and to maintain a higher cooling rate weight of radiator increases leading to increase in fuel consumption. The radiator is an important accessory of vehicle engine.

II. DESIGN OBJECTIVES

In order to optimize the system, the design parameters must be defined. It is important to remember that the design parameters are similar to that of a production car, however their order of importance is different, given the context of its racing application. The design parameters listed in descending order of importance are as follows:

- Maintain an optimal engine operating temperature over a wide range of ambient conditions.
- Maximize the overall system reliability.
- Meet all of the design criterions while minimizing the system mass.
- Minimize mechanical power requirements.
- Minimize electrical power requirements.
- Meet the packaging constraints of chassis design.
- Make sure the design does not have a negative impact on the rest of the sub- system.

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- Keep the mass as central and as close to the ground as possible.
- Minimize the cost of the system.

III. RULES FOR THE COOLING SYSTEM

In order to participate in the dynamic events at Formula Student competition, every team has to comply with the rules mentioned in the FSAE Rule book. Few rules pertaining to the cooling system are:

- Any cooling or lubrication system must be sealed to prevent leakage.
- Water-cooled engines must only use plain water. Electric motors, accumulators or HV electronics can use plain water or oil as the coolant. Glycol-based antifreeze, “water wetter”, water pump lubricants of any kind, or any other additives is strictly prohibited

IV. HEATING ISSUE WITH KTM DUKE 390

- The heating problem may be attributed to mainly two reasons:
    - **a.** The first one is the use of DUKE 390 engine in the SAE Supra vehicle. DUKE 390 engine is generally cooled by a coolant called ethyl glycol which gives the sufficient cooling to the engine. However, according to FSAE rules the coolant must not contain any chemical and therefore it has been mandated that only air and water can be used for cooling of the engine.
    - **b.** The second one is improper position of radiator

V. FACTORS THAT ARE TO BE CONSIDERED FOR THE RADIATOR DESIGN

- **Modified & Performance Engines**
- To upgrade to an aftermarket radiator, it’s important to understand your options.
- Increased power and high rpm require more cooling capacity.

- **Core Size**
- In the world of radiators, bigger is better. A larger surface area can dissipate more heat.
- You will need to measure your vehicle. For more cooling capacity, get the biggest radiator that will fit.

- **Material**
- Copper/Brass Radiators have been used for a long time. If you are going for a classic look, these radiators are a good choice.
- However, if you are going for performance, an Aluminium Radiator is what you want.

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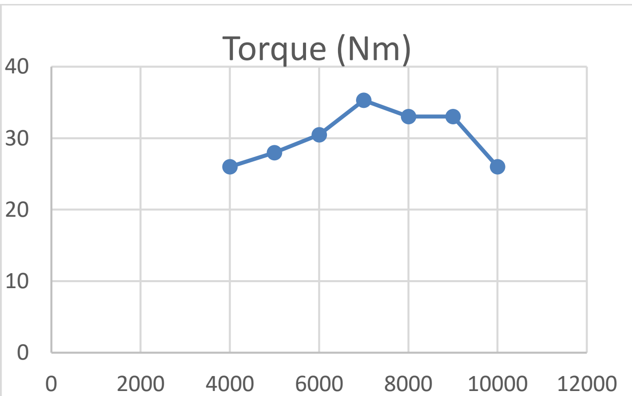
- Aluminium is stronger and lighter. This allows for larger tubes and less airflow restriction.

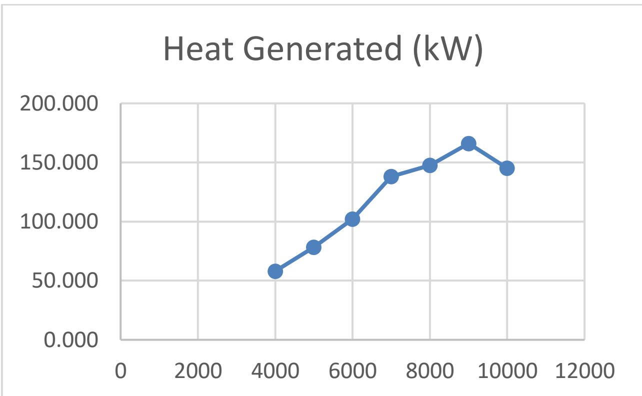
- **Row Quantity & Tube Size**
- The radiator transfers heat from the coolant to the air. It does this through tube-to-fin contact. More contact area means higher cooling capacity.
- To increase the contact area, you can use more tubes and/or bigger tubes.
- The cooling of the coolant depends upon the number of passes.

VI. HEAT GENERATION ANALYSIS

- To estimate the heat generation through combustion chamber and its distribution through different auxiliary's system we must first obtain the Brake Power vs Engine RPM from the available literature.
- Various assumptions are to be taken for the calculation of heat flow through the combustion chamber and amount of heat being taken by the water from the water jacket.
- These assumptions are as follows-
  a. Brake power taken as 75 percent of the indicated power.
  b. Indicated power is taken as 25 percent of the heat generated due to combustion in combustion chamber.
  c. 35 percent of the heat generated is carried by cooling water.
  d. Ambient temperature taken as 25 °C or 298 K.
  e. Brake Power BP = $(2\pi NT)/60x1000$ (kW)

RPM	Torque (Nm)	Brake Power (kW)	Indicated Power (kW)	Heat Generated (kW)	Heat Transferred to Coolant(water) (kW)
4000	26	10.891	14.521	58.085	20.330
5000	28	14.661	19.548	78.191	27.367
6000	30.5	19.164	25.552	102.206	35.772
7000	35.3	25.876	34.502	138.007	48.302
8000	33.02	27.663	36.884	147.535	51.637
9000	33.04	31.139	41.519	166.077	58.127
10000	26	27.227	36.303	145.211	50.824





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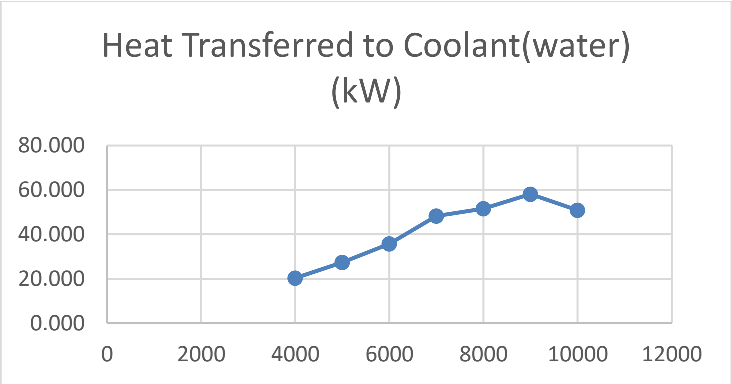
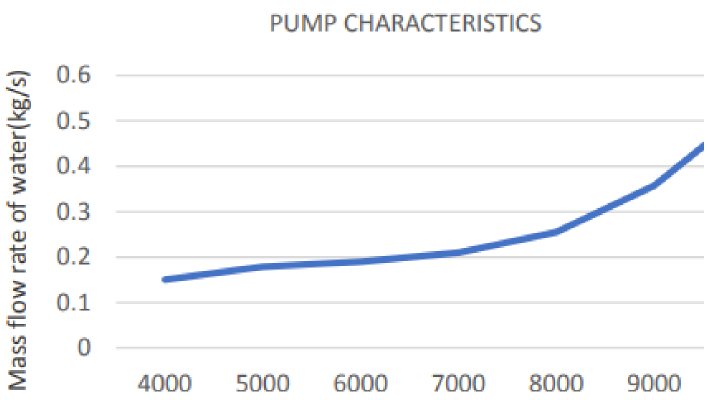


VII. WATER PUMP CHARACTERICTICS

- Theoretically the mass flow rate of water from the pump is calculated and then later on it will be compared with the experimental value.

Engine Sped (RPM)	Mass flow rate of water (kg/s)
4000	0.1600
5000	0.1792
6000	0.1897
7000	0.2100
8000	0.2552
9000	0.3571
10000	0.5300



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VIII. THERMAL CALCULATIONS

1) Equation of heat transfer to cooling water

Q = mwCwaterΔT

where, Q- Heat transferred to cooling water mw- mass flow rate of water from single tube of the radiator ma- mass flow raete of air through radiator Cwater- specific heat of water

2) ΔT= T2-30

The water temperature (T1) at radiator outlet is taken as 30 $°C$. The corresponding value of water temperature from engine outlet will carry. T1 be the temperature of water coming out of the radiator. T2 be the inlet temperature of water. T3 be the ambient temperature = 25$°C$. T4 be the temperature of air after passing through the tube of radiator.

- Convective heat transfer coefficient, h
- Nusselt number empirical relation is used – Nu = z(Re)a (Pr)b
- Re (Reynolds number) = $\rho VL/\mu$
- Pr (Prandtl Number) = μCp/k
- Z, a, b are empirical coefficients - z= 0.664, a= 0.5, b= 0.33(assuming air flowing over flat plat with length = tube width of the radiator, 2.5cm)
- V- mean velocity of air at radiator core
- L- characteristic length, here 2.5 cm

- Properties of air-

a. ρ- Density of fluid
b. μ- Dynamic viscosity
c. Cp= specific heat capacity of air
d. k= thermal heat conductivity of air

- T4 can be calculated using following relation

  Q= hA(LMTD) Where LMTD =((T2-T4) – (T3-T1)) / ln ((T2-T4) – (T3-T1))

  Q= mairCairΔt Here,

  Δt = T4-T3

  Also, It is to be noted heat transferred by water to the cooling air will be same, therefore:

  Q = mwCwaterΔT= mairCairΔt= hA(LMTD)

RPM	LMTD	Mass Flow rate Of Water (Pump Characteristics) Kg/sec	Specific Heat Capacity of Water (Cw) J/Kg°C	ΔTw= T2-T1 °C
4000	10.211	0.16	4182	30.38
5000	13.745	0.1792	4182	36.52
6000	17.967	0.1897	4182	45.09
7000	24.260	0.21	4182	55.00
8000	25.935	0.2552	4182	48.38
9000	29.195	0.3571	4182	38.92
10000	25.527	0.53	4182	22.93

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RPM	Temp. of water coming out of the radiator (T1 °C)	Inlet temp. of water at radiator (T2°C)
4000	69.62	100
5000	63.48	100
6000	54.91	100
7000	45.00	100
8000	51.62	100
9000	61.08	100
10000	77.07	100

Prandtl Number	Renoyld's Number	Nusselts Number	Convective Heat Transfer Coefficient (h)	Core Area of Radiator (A)
0.7255	6855.23	49.400	26.300	0.075702

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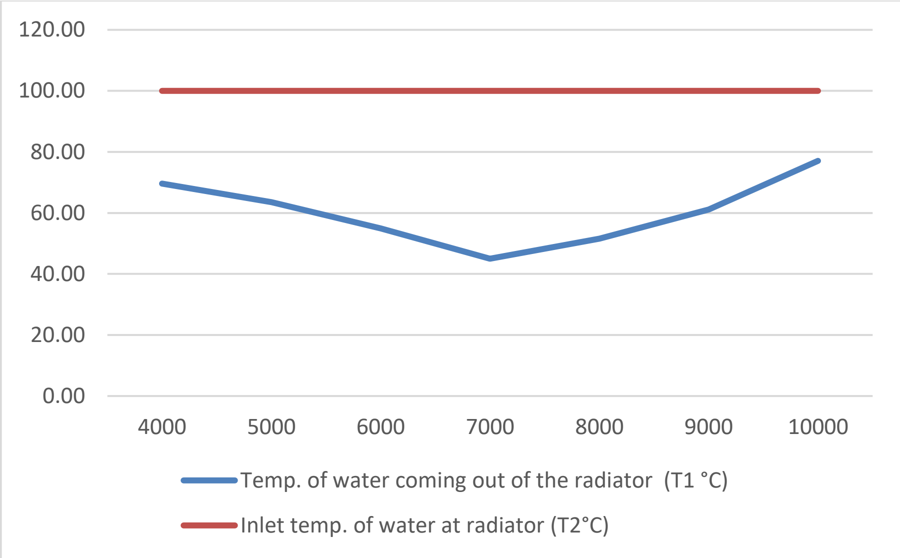

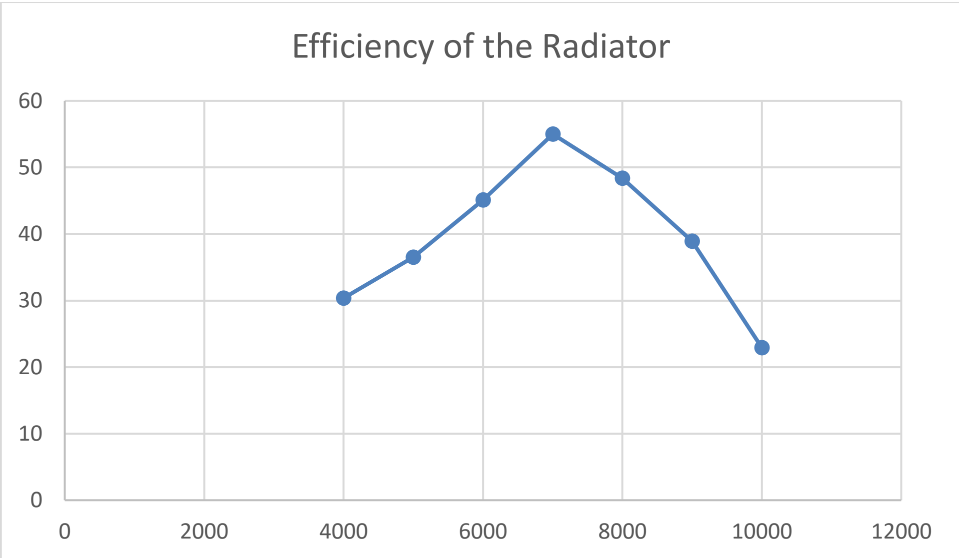

IX. EXPERIMENTAL VALIDATIONS

The radiator installed on the vehicle must be able to cool down the engine and maintain its temperature in the optimum range for the best performance. To verify it, it was necessary to test the performance of the radiator when the vehicle was stationary as for the thermal calculations were completed assuming that the vehicle is stationary. In order to do so, we decided to install temperature sensors at the inlet and at the outlet of the radiator.

- **Calibrations of the sensors**

Sensors needed to be calibrated before the installation. They were calibrated by using a scientific thermometer.

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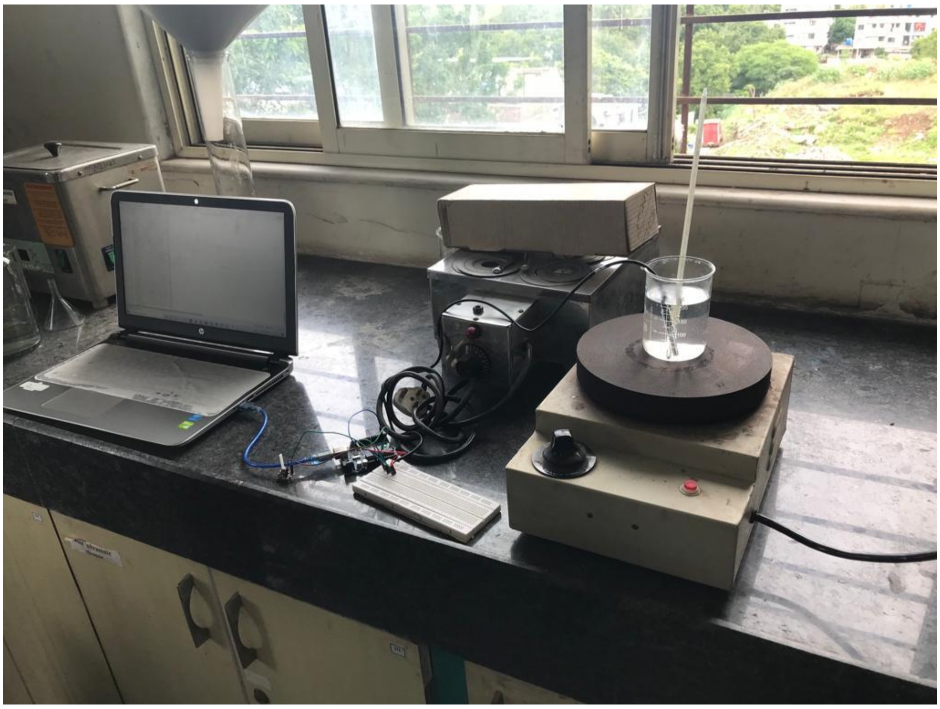

- **Installation of the sensors**

In order to install the two sensors, we needed to design new mounts for the cooling system. These mounts would be installed for data seeking and then will be removed.

Mount at Outlet of the Radiator

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Mount at Inlet of the Radiator

X. TEMPERATURE SENSORS DATA

https://docs.google.com/spreadsheets/d/1q1dYLOK3vJjbdmZzp_GTQlZofyVbJP9NEeIlRuihIA0/edit#gid=0

XI. CONCLUSION

Radiator being an important part of the cooling system it is necessary to make sure the selected one is sufficient to keep the engine at an optimum temperature. The theoretical calculation and the experimental data given in the sheets show that the radiator is able to cool the system very efficiently even when the vehicle is stationary.

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Atharva is currently is pursuing Bachelor of technology Degree in Mechanical Engineering from Vishwakarma Institute of Information Technology, Pune. Along with his academics he is working for the Formula Student Team for VIIT College- Team Vishwaracers in Powertrain Department and as Cost Report Head for the team. Besides these, he is an author of many research papers and is also working Research Intern under college faculty on different projects.