Design and Analysis of Cooling System of FSAE Car

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ABSTRACT

The purpose of this project is to design and implement an effective cooling system for the Formula SAE Combustion Vehicle. The main components of the drivetrain of the combustion vehicle are the engine and the engine components. The cooling system is designed to cool the engine and engine components to ensure that they operate in an optimal temperature range thus increasing drivetrain efficiency and ultimately improving vehicle performance. During the design process, an extensive heat transfer analysis of the water side and air side of a potential radiator is to be performed. Additionally, system resistance curves and performance curves have to calculate, plot, and utilize in the component selection process. A suitable fan will be selected and a radiator will designe. After determining the critical cooling components, it is necessary to place the components in effective locations within the vehicle. In addition to placing the components, attachment tabs should be designed to fix the cooling system to the frame of the vehicle and to fix the fan to the radiator. A shrouding for the radiator should also be create to direct air to the radiator and improve the performance of the system.

General Terms

FSAE Combustion Vehicle, Cooling System, Radiator, Overheating of Engine, Cooling Effectiveness, Shrouding, Radiator Positioning, Overall Heat Transfer Coefficient, Fan Selection.

Keywords

Designing, Analysis, Effectiveness, Shrouding, Positioning, Manufacturing, Testing, Validation.

1.INTRODUCTION

Radiators are heat exchangers used for cooling of internal combustion engines, not only in automobiles but also in piston-engined aircraft, railway, generators, compressors, locomotives, motorcycles, stationary generating plant or any similar use of such an engine. Internal combustion engines are also cooled by circulating a liquid called *engine coolant* throughout the engine block, where it is heated, then through a radiator where it dissipates heat to the atmosphere,

and then came back to the engine. Engine coolant is usually water-based, but also may be oil. It is common to employ a water pump to force the engine coolant to circulate, and also for an axial fan to force air throughout the radiator. The theory of a cooling system consists of the analysis of the water flow with the analysis of the air, and also the analysis of the radiator.

In motorcycles and automobiles with a liquid-cooled internal combustion engine, a radiator is connected to channels running through the engine and cylinder head, through which a liquid coolant is pumped. This liquid might be water in climates where water is almost to freeze but it is more commonly a mixture of water and antifreeze in proportions appropriate to the climate. Antifreezeitself is usually ethylene glycol or propylene glycol with very small amount of corrosion inhibitor.

2.MOTIVATION

Cooling system is one of the most important engine auxiliarysystem, and it is crucial to maintain the engine in its working temperature. The working temperature of KTM RC 390 is about 96 degree and sometimes this temperature is stretched further with our standalone ECU, so proper withdrawing of heat is very important to maintain working temperature of engine.

The cooling here is due to forced convection and convection increases as we increase the flow velocity therefore the optimum fan is used here. The experiment is also performed as shown to calculate the mass flow of fan.

3.LITERATURE SURVEY

1. "Transient operation of plate fin and tube". Dawid Taler , *Anna Korzen* proposed an approach for Effect of Reynolds number of water and volume flow rate.

2. "Study regarding air flow along the channels." Angela Plesa , Oana Giurgiu, proposed research for Intensity of heat transfer by forced convection of air through the fins.

3. "Cooling due to natural convection" .Yu Zhang , Xiaohua Liua. proposed that The aluminum radiator cools down quicker, because it has lower heat capacity and higher heat transfer coefficient.

4. "Efficiency measurement for temperature range." Alisher Mukashev , Alexey Pugovkin , Stepan Kuprekov , Nadezhd Petrova , Stanislav Abramchuk , proposed the dependence of the heat transfer coefficient on the temperature drop contains both a constant and a variable component.

5. "Study of heat exchange due to radiation." Wenxian Zheng, Ying Chen, Nan Hu , Tianming Zhong , Yulie Gong , searched variable components which are responsible for the convective heat transfer and infrared radiation.

Designing Process

In an combustion vehicle's cooling system, heat is transferred between the drivetrain (engine) and the single flow radiator. In order for the cooling system to work properly, the rate of heat transferred by the drivetrain must be equal to the rate of heat transferred by the airflow and the water flow. This is shown below:

$$\dot{Q}_{DT} = \dot{Q}_{AIR} = \dot{Q}_{W} \qquad ...(1)$$

where the subscripts DT, AIR, and W, represent drivetrain, airflow, and water flow, respectively. Note that the rate of heat transfer is lost by the water in the tubes and gained by the air passing through the radiator. If this equation is expanded, the following is obtained:

$$\dot{Q}_{DT} = \dot{m}_{AIR} c_{pAIR}(T_{AIRO} - T_{AIRI}) = \dot{m}_W c_{pW}(T_{WO} - T_{WI}) \quad \ldots(2)$$

where $\dot{m}$ is the respective substance's mass flow rate, *cp* is the specific heat capacity of the respective substance, *TO* is the temperature of the respective substance's outlet temperature, and *TI* is the temperature of the respective substance's inlet temperature.

The rate of heat transfer of the cross-flow radiator can be calculated using Equation 3, where *UO* represents the overall heat transfer coefficient of the radiator, *AO* represents the heat transfer surface area of the radiator, *F*, represents the radiator's correction factor, and *LMTDCF* represents the log mean temperature difference for a cross-flow heat exchanger. The overall heat transfer coefficient of the radiator and the heat transfer surface area of the radiator are both dependent on the core characteristics of the radiator as well as the characteristics of the airflow and water flow.

$$\dot{Q}_{HX} = U_O\, A_O\, F\, LMTD_{CF} = U_O A_O F \frac{[T_{WI} - T_{AIRO}] - [T_{WO} - T_{AIRI}]}{\ln\left[\frac{T_{WI} - T_{AIRO}}{T_{WO} - T_{AIRI}}\right]} \quad \ldots(3)$$

The overall heat transfer coefficient can be calculated using the following equation:

$$U_O = \frac{1}{R_o + R_{wall} + R_i} = \frac{1}{\frac{1}{h_o} + \frac{A_o}{A_i}\frac{t_{wall}}{k_{wall}} + \frac{A_o}{A_i h_i}} \quad \ldots(4)$$

where *RO*, *Rwall*, and *Ri* represent the heat transfer resistance outside of the water tubes, in the wall of the water tubes, and inside of the water tubes, respectively. Additionally, *Ao* and *Ai* are the outside and inside surface areas of the water tubes that are in contact with the water, *twall* is the thickness of the tube wall, *kwall* is the thermal conductivity of the tube material, *ho* is the outside (air) convective heat transfer coefficient, and *hi* is the internal (water) convective heat transfer coefficient. By analyzing

Equation 4 it can be seen that the heat transfer resistivities can be evaluated as follows.

$$R_o = \frac{1}{h_o}$$

$$R_{wall} = \frac{A_o}{A_i}\frac{t_{wall}}{k_{wall}}$$

$$R_i = \frac{A_o}{A_i h_i} \quad \ldots(5,6,7)$$

Furthermore, the outside convective heat transfer coefficient can be represented by the following equation:

$$h_o = \frac{k_{AIR}\overline{NU}_{AIR}}{D_{hAIR}} \quad \ldots(8)$$

where *kAIR* is the thermal conductivity of air, Nuair is the Nusselt number for air flowing through the air channels, and *DhAIR* is the hydraulic diameter of the air channel between the water tubes and fins. The hydraulic diameter and the Nusselt number of the air channels can be calculated using Equation 9 and Equation 10, respectively.

$$D_{hAIR} = \frac{4(\text{Air Flow Area})}{\text{Air Flow Perimeter}} = \frac{4(0.5\ \text{Fin Height})(\text{Fin Spacing})}{(\text{Fin Spacing}) + 2(\text{Fin Height})}$$

$$\overline{NU}_{AIR} = 1.86\left(\frac{Re_{air}Pr_{air}}{\frac{L_{air}}{D_{hAIR}}}\right)^{\frac{1}{3}} \quad \ldots(9,10)$$

Note that *Reair* is the Reynolds number of the airflow, *Prair* is the Prandtl number of the airflow, and *Lair* is the fin length. The Reynolds number of the airflow can be evaluated as the following:

$$Re_{air} = \frac{V_2 D_{hAIR}}{\nu_{air}} \quad \ldots(11)$$

where Vair is the kinematic viscosity of the air, and the increase in air velocity through the channel, *V2*, can be evaluated as

$$V_2 = V_1\frac{A_{air1}}{A_{air2}} = V_1\frac{\text{Surface Area of Radiator Face}}{A_{air1} - (\text{Frontal Area of Tubes}) - (\text{Frontal Area of Fins})} \quad \ldots(12)$$

where *V1* is the approach air velocity. After determining these variables, one is able to use Equation 3 and Equation 4 to determine the necessary overall heat transfer coefficient of the radiator for the required rate of heat transfer. Quite a few conclusions can be reached by analyzing the airflow rate of the cooling system. Realizing that the a radiator consists of three different resistances to the heat transfer from water to air, it can be observed that the thermal resistance of air is greater than the thermal resistance of the water and the thermal resistance of the tube wall and fins. Thus, it is necessary to determine the required airflow through the radiator and select a combination of radiator and cooling fan which is capable of producing this airflow. Figure 4 depicts the profile view of the radiator and fan orientation. Note that the airflow reaches the radiator before the fan meaning the fan is in a pulling configuration.

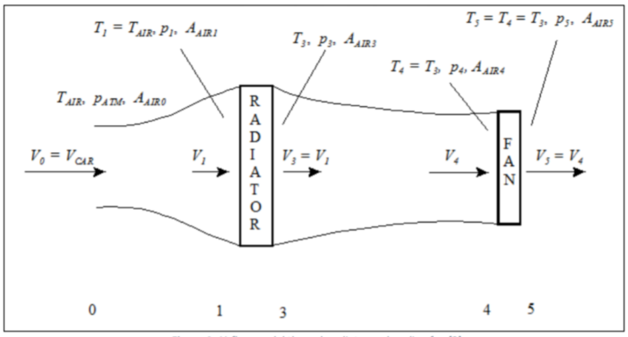


Figure 4: Airflow model through radiator and cooling fan [2]

If Bernoulli's equation is written for point 0 to point 1 in Figure 4, the following is obtained.

$$\frac{P_{ATM}}{\rho_{AIR}} + \frac{V_{car}^2}{2} = \frac{P_1}{\rho_{AIR}} + \frac{V_1^2}{2} \quad \ldots(13)$$

If the mechanical energy equation is used to analyze the flow through the radiator (point 1 to point 3), the following is obtained:

$$P_1 - P_3 = K_R \rho_{AIR}\frac{V_1^2}{2} \quad \ldots(14)$$

where *KR* is the loss coefficient due to pressure loss across the radiator. Continuing with this approach,

Bernoulli's equation from point 3 to point 4 yields Equation 15.

$$\frac{P_3}{\rho_{AIR}} + \frac{V_3^2}{2} = \frac{P_4}{\rho_{AIR}} + \frac{V_4^2}{2} \quad \ldots(15)$$

The static pressure rise of the cooling fan can be represented as a function of the airflow rate as follows:

$$P_5 - P_4 = C_o - C_1 Q_F - C_2 Q_F^2 \quad \ldots(16)$$

where *QF* is the volumetric flow rate of air passing through the fan and *Co*, *C1*, and *C2* are constants for a quadratic representation of the fan static pressure rise. If this relationship is assumed to be linear, *C2* is equal to zero, and Equation 17 is obtained.

$$P_5 - P_4 = C_o - C_1 Q_F \quad \ldots(17)$$

where *Co* is the intercept of the linear regression and *C1* is the slope of the linear regression. The pressure difference between point 0 and point 4 can be represented as follows:

$$P_0 - P_4 = (P_0 - P_1) + (P_1 - P_3) + (P_3 - P_4) + (P_4 - P_5) = 0 \quad \ldots(18)$$

Realizing that *Po* and *P4* are both equal to atmospheric pressure and substituting Equation 13, 14, 15, and 16 into Equation 17 yields the following.

$$\frac{\rho_{AIR}}{2}\left[(V_1^2 - V_{car}^2) + K_R V_1^2 + (V_4^2 - V_3^2)\right] - (C_o - C_1 Q_F) = 0 \quad \ldots(19)$$

The velocity of air at point 1, point 3, and point 4 can be written as Equations 20, 21, and 22.

$$V_1 = \frac{Q_F}{A_{air1}} \qquad V_3 = \frac{Q_F}{A_{air3}} \qquad V_4 = \frac{Q_F}{A_{air4}}$$

…(20,21,22)

By analyzing Figure 4, it can be seen that the area at point 1 is equal to the area at point 3. Additionally, since the volumetric flow is constant and the density of air is assumed to be constant, Equation 19 can be rewritten as Equation 23.

$$\left[\frac{\rho_{AIR}}{2}\left(\frac{K_R}{{A_{air1}}^2} + \frac{1}{{A_{air4}}^2}\right)\right] {Q_F}^2 + C_1 Q_F - \left(C_o + \frac{\rho_{AIR}}{2} {V_{car}}^2\right) = 0$$

…(23)

This equation can be used to solve for *QF* based on the area of the radiator, the area of the fan, the car velocity, and the performance characteristics of a specific cooling fan. Equation 24 shows the equation in this form.

$$Q_F = \frac{-C_1 \pm \sqrt{(C_1)^2 - 4\left[\frac{\rho_{AIR}}{2}\left(\frac{K_R}{{A_{air1}}^2} + \frac{1}{{A_{air4}}^2}\right)\right]\left[-\left(C_o + \frac{\rho_{AIR}}{2} {V_{car}}^2\right)\right]}}{\left[\frac{\rho_{AIR}}{2}\left(\frac{K_R}{{A_{air1}}^2} + \frac{1}{{A_{air4}}^2}\right)\right]}$$

(24)

The volumetric flow rate obtained from this equation can be compared with the volumetric flow rate required by the system. An iterative process can then be used to determine the proper values of the variables within the equation.

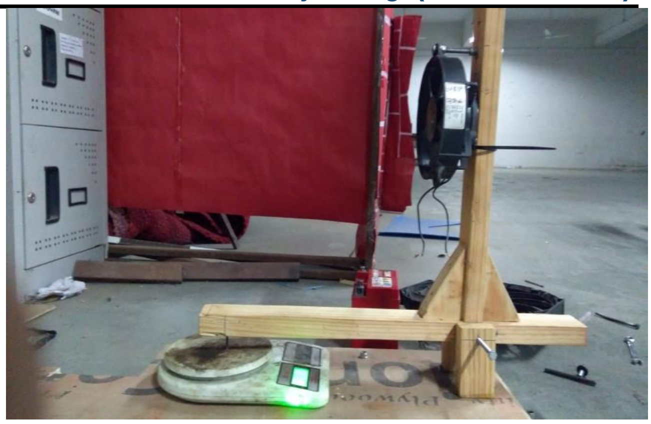
Positioning:-

The radiator is placed in rear compartment of the vehicle below rear wings so that air in dynamic condition will support cooling along with the fan.

The Aluminum sheet is used as main mounting of thickness 3mm and bent according to radiator mounting points. The mounting sheet is bolted on chassis which is a rigid mount for the radi at

Selection of Fan:-

We had compared two small fans and a single big fan of 12 volts.We read some myths that, two small fans are better than a single big fan but for proper validationwe conducted an experiment as shown!



EXPERIMENT FOR SMALLER FAN

The fan placed on vertical wooden fitment and another wooden block placed horizontally having nail attached to it, to get point load in weighing machine.

So basically the fan's thrust will move vertical wood and as reaction the nail will apply load on the weighing machine. So more is the thrust more will be load on weighing machine.

When the same experiment was carried for bigger fan the output rating was higher on weighting display.

So we decided to choose bigger fan than two smaller fan on this experimental basis.

Also a shroud was convenient and effective for a single fan.

Conclusion:

The purpose of this design process was to research, design, and create an effective cooling system for an comustion FSAE vehicle. The hope for this design is to not only be an effective and efficient system that guarantees the performance of the drivetrain components, but to serve as a guide for the combustion vehicle's cooling system design for years to come.

Although the real world performance of the cooling system will not be known until testing is complete, it is believed that this system will have no issues providing ample cooling for the drivetrain components of the vehicle.

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