# DESIGN AND VALIDATION
of
# RADIATOR

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**Abstract:-***A vehicle radiator is a heart of a car cooling framework which assumes a significant part in moving the warmth from the motor parts to the climate through its unpredictable framework and working. It is only a sort of warmth exchanger which is intended to move the warmth from the hot coolant coming from the motor to the air passed up the fan. The warmth move measures happens from the coolant to the cylinders then from the cylinders to the air through the balances. Radiators are utilized for cooling interior burning motors, predominantly in vehicles and likewise in cylinder motor airplane, railroad trains, power producing plant or any comparable utilization of such an application.This venture on "Design and Validation of Radiator" predominantly centers around the warm plan and examination of radiator as warmth exchanger as it were. We have fostered this work as our final year project so as to get comfortable with the innovations just as use of hypotheses into commonsense work done by businesses. This undertaking contains the plan and examination of the radiator for various kind of vehicle too. For better effectiveness, improvement of warmth move rate is significant wonder. This is an attempt to improve this by utilizing KTM RC-390 bike details.The reason for this examination is to principally plan a cooling framework for a recipe styled race-vehicle which is completely planned, fabricated and tried by graduate understudies from universities across the world. The essential prerequisites of the vehicle are to have high speed increase, low loads and a capacity to persevere. Remembering the accompanying prerequisites and some administering rules made by the endorsing bodies, the understudies start their plan method. The motor utilized by us for the vehicle is a 4-stroke single chamber 390 cc one, picked its amazing ability to weight proportion. The methodology towards the plan of the cooling framework has not exclusively been a hypothetical one, yet in addition a down to earth one.This exploration starts with tentatively deciding some significant information of the motor. This information is utilized to decide the measured necessities of the framework during the different methods of vehicle activity. In light of the focused on qualities, the measuring of the radiator is finished utilizing fundamental warmth move ideas. Further enhancement is finished utilizing CFD investigation.*

***KeyWords:*** *Radiator, Heat transfer, CFD simulation.*

## 1. Introduction

The reason for this report is to perform broad testing and exploration to build up a bunch of rules for planning and upgrading a cooling framework for a Recipe SAE race vehicle. Making of a Recipe 1 vehicle (understudy form) is an immense task and requires a significant arrangement and cycle undertaking of different sub fragments. One of the fragments out of this was cooling structure which had various parts including radiator, water siphon, hose line and water storing chamber. On a very basic level, warmth of the engine is devoured by the water coat which is then cooled by radiator using water and the warmed water is then cooled through air, water is reused back to the radiator. In SAE vehicle the engine is set at the posterior, so the radiator compartment should be orchestrated near it. The proportion of air going through radiator and engine is comparatively outstandingly less when stood out from the radiator orchestrated before the vehicle. Along these lines, there is a need of preparation a fair air vent structure around the radiator for passing incredible proportion of air through radiator so suitable cooling of the engine can be gained .Equation Understudy is a SAE subsidiary understudy level plan rivalry, where understudies across the world plan and create a recipe styled race vehicle. The vehicle is needed to be light weight, speedy and persevering.

## 2. Methodology:

Different examinations were performed to decide the motor qualities. The acquired information was utilized for hypothetical estimations, CFD and approval. At first, the radiator was estimated considering the motor burden to cooling framework by hypothetical computations. These computations were likewise used to decide radiator execution at different air speeds going through radiator and mass stream pace of coolant. These qualities were cross confirmed utilizing CFD reenactments in SolidWorks. Correlation is made between the reenactment theoritical results and simulation outcomes to decide variety in real execution and planned execution.

## 3. Flowchart

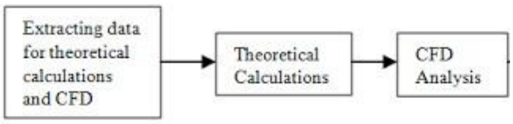


Figure 1 : Flowchart

## 3. Aim & Objective

**Aim**

The inspiration driving this assessment is to essentially design a cooling system for a condition styled race-vehicle which is completely arranged, manufactured and attempted by graduate understudies from colleges over the world. The fundamental essentials of the vehicle are to have high accelerating, low loads and an ability to endure. Recalling the going with essentials and some overseeing rules made by the approving bodies, the understudies start their arrangement method.

**Objective**

The objective is to design a side vent to extend the mass stream speed of air in an organized stream on the radiator place and to construct the mass stream speed of water so important proportion of warmth could be taken out from the water layer of the motor.To improve the system, the arrangement limits should be portrayed. Recollect that the arrangement limits resemble that of a creation vehicle, at any rate their solicitation for importance is special, given the setting of its hustling application.

## 4. Literature Review

The vehicle business is persistently expecting to improve the introduction of its vehicles. As vehicle engines become logically more noteworthy and insignificant, the solicitations put on the engine cooling module on how much warmth they should move away have moreover extended [1]. In like manner, vehicle makers are wanting to reduce the proportion of smoothed out drag of the vehicle which helps with mileage notwithstanding different things. In this way, vehicle producers have wanted to restrict cooling air confirmations and the proportion of air traveling through the radiator community [2]. This necessity for upgrade and refinement has put a more significant complement on accurately assessing and expecting the glow move execution of the cooling module. The School of Illinois' Condition SAE vehicle uses a water cooled engine. Taking everything into account, this hypothesis will not break down the cooling execution of air cooled engines. It is ordinarily understood that the introduction of a water engine cooling structure may be confined by more than one factor. Both the engine water stream to the radiator similarly as the breeze ebb and flow through the radiator need to satisfactorily have the choice to redirect the engine excused warmth [3]. On one side, the coolant/water traveling through the engine should have the choice to move the engine excused warmth to the radiator [3]. Different sources give the glow passing on constraint of the coolant to be: [3, 4]

$$\dot{E}\ RW = QW\ \rho W\ CW\ \Delta TW / 60$$

where

$\dot{E}$ RW = heat transport rate,
kW QW = coolant flow rate,
L/min ρW = coolant density = 1.0 kg/L
CW = specific heat of coolant, kJ/kg .°C
ΔTW = temperature drop as water moves through radiator, °C

Test estimations of these factors are genuinely standard as the coolant stream rate can be essentially estimated utilizing a stream meter, and the temperatures assembled with a thermometer.

Moreover, the warmth moved by the coolant moving through the motor must be diverted by the air coursing through the radiator. Once more, different sources give the warmth conveying limit of the air to be: [5,6]

$$\dot{E}Ra = Qa\ \rho a\ Cpa\ \Delta Ta$$

where

$\dot{E}$Ra = heat transport rate,
kW Qa = airflow rate, m3/s
ρa = density of air, kg/m3
Cpa = specific heat of air = 1.0 kJ/ kg .°C

$\Delta Ta$ = temperature rise as air moves through radiator, °C

The temperature distinction again can be handily estimated tentatively, in any case the wind stream rate is somewhat harder to precisely gauge and numerous techniques have been attempted to precisely get this information.

### 5. Material Selection

**Aluminium (6061)**

Aluminium 6000-series alloys (eg:- Al6061) have much better corrosion resistance and on further addition of a T6 heat treatment, the toughness and resistance to fatigue crack growth can be improved, hence increasing its strength by as much as 30%. [5]. Thermal conductivity for aluminium 6061 is 180 W/(m*K) and when the density is considered, the specific thermal conductivity of aluminium (thermal conductivity divided by specific gravity) is 62 W/(m*K). [6]

### 6. CADD Model

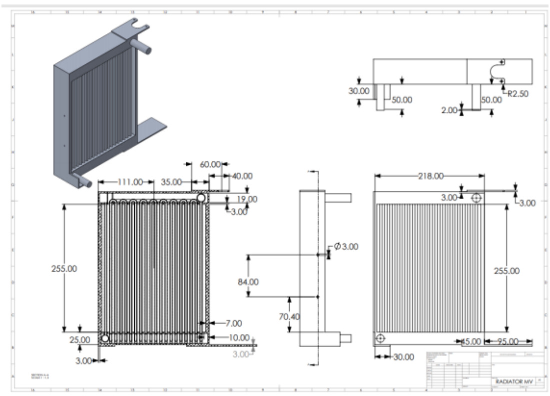

Figure 2 :CADD Drafting for Radiator Tube

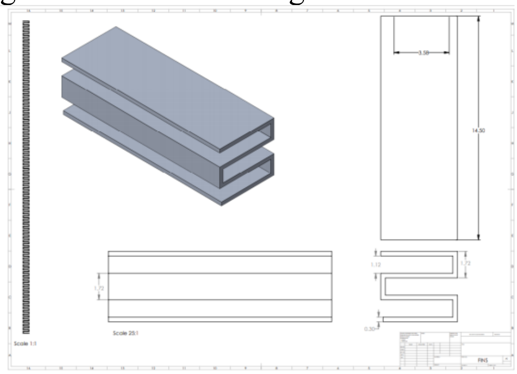

Figure 3 :CADD Drafting for Fins

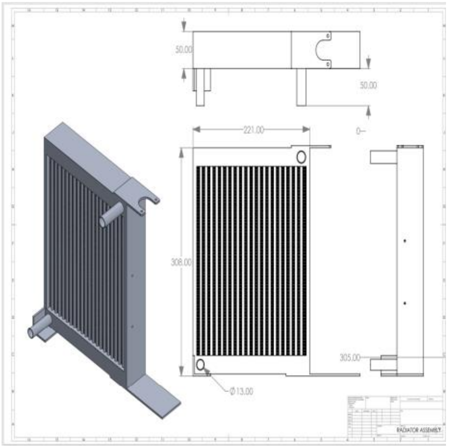

Figure 4 :CADD Drafting for Radiator Core

### 7. Calculations

**Radiator Tube Calculations**

The folllowing data is taken from the observations

D-d = 1mm

$T_{w1} = 82^0C$

$T_{w2} = 76.6^0C$

$m_w = 0.3995$ kg/s

$m_a = 2.3$ kg/s

$T_{a1} = 30^0C$
{Ambient Temperature}

$c_{pw} = 4.187$ kJ/kgK

$c_{pa} = 1.005$ kJ/kgK

$m_w * c_{pw} (T_{w1} - T_{w2}) = m_a * c_{pa} (T_{a1} - T_{a2})$.......................[7]

$T_{a2} = 36^0C$

Calulation for tube length

$\Delta T_m = (\Delta T_1 - \Delta T_2) / \ln(\Delta T_1 / \Delta T_2)$

$\Delta T_m = 6^0C$

$U_0 = (n_0 / n_1) * (1 / n_1) + (1 / n_0)$

$U_0 = 0.031$

$\theta = U_0 * A_0 * \Delta T_m$

$74.84 * 10^3 = 31.79 * (\pi * 0.01 * L) * 6$

L = 12.5 m

The size in which the radiator is to be manufactured is

Acoording to this size the tube of 12.5 m long can be turned 39 times and as per the available aea 39 turns will be sufficient.

**Fin Calculations**

Considering fin density in FPI (Fin Per Inch)

$N_f = 18/\text{inch}$

Reasons for selecting fin density as 18 FPI. [8]

- radiator is more effective the higher the FPI and the thicker it is, however the downside of this is that it requires stronger (i.e. louder) fans with high static pressure to get effective results. Optimum value considering the dimension of our radiator we have selected the following value as 18 FPI.
- The increase of FPI causes the increase of heat transfer over tubes.
- with the increase of FPI, pressure drop increases.
- 12, 14, and 16 FPI can run fine @800RPM fans, after that it is needed to run higher than 800RPM to achieve the same results if you are using a 35mm thick radiator.
- 17FPI+ is required to run @1200RPM. We could run those at 800RPM but by doing so, we will be splitting air pressure and it might not even have enough to push all the way through the radiator.
- Surely we can go with a higher fan RPM, that is, more than 1500 RPM, but it creates a lot of noise which is highly noticeable when the car is at idle condition.
- We can basically put it out more evenly, 12-16 is low, 17+ is medium, and at around 30 is high.

1 inch = 0.0254m

Fin Density per meter = 708.661

Calulating pitch of the fin

$N_f = 1 / p_f$

$p_f = 1.411 * 10^{-3}$ m

As there are no fixed and concrete method to determine the fin parameters, the method of itiration was decided to be carried out to further the equation. The method of itiration is done to decide which set of parameters will give the result close to the desired one.

Considering the following constants for calculations

$\alpha = 62$ W/m$^2$K (for Aluminium)

$\lambda = 0.6$ W/mk (for Water at 20$^0$C)

$T_0 = 355.15$ K

$T_\infty = 349.75$ k

Determining the fin parameters with the method of itiration

For the calculation consider the following data

$\delta_f = 0.4\text{mm} = 0.0004\text{m}$

$b = 5\text{mm} = 0.005\text{m}$

$s = p_f - \delta_f$

$s = 1.411 - 0.4 = 1.01\text{mm} = 0.00101\text{m}$

$h = 4.6\text{mm} = 0.0046\text{m}$

$l_f = 14.5\text{mm} = 0.0145\text{m}$

$A_{unfin} = 22585.01\ \text{mm}^2$

$A_{fin} = 32381.76\ \text{mm}^2$

To decide whether the set of parameters taken are correct; Fin Efficency, Overall Efficency, Total Surface Efficency are going to be calculated as these will help to decide which set of parameters are best suited to obtain the desired result.

Fin Efficency ($\eta_f$)........................[9,10,11]

$m = [(2\alpha / \lambda\delta_f) * (1 + (\delta_f / l_f))]^{1/2}$

$m = 728.64$ m

$l = (b / 2) - \delta_f$

$l = 2.1 * 10^{-3}$ m

$\eta_f = \tanh(ml) / (ml)$

$\eta_f = 0.5950$

$\eta_f = 59.50\%$

Overall Fin Effectiveness ($E_o$)...............[10]

$E_o = [\alpha * (A_{unfin} + \eta * A_{fin}) * (T_0 - T_\infty)] / [\alpha * A_{unfin} * (T_0 - T_\infty)]$

$E_o = 1.83$

Total Surface Efficiency ($\eta_o$).............[10]

$A = A_{unfin} + A_{fin}$

$A = 50584.46\ mm^2$

$\eta_o = 1- [A_{fin} * (1- \eta_f) / A]$

$\eta_o = 0.7614$

$\eta_o = 76.14\%$

After the third itiration it is observed that these parameters are the ones that give us result close to the desired one.

Theoretical Calculations to determine radiator sizing and performance

Water side calculations

$H_t = H_r$

$A_{cst} = 2 * \pi * r * l$

$A_{cst} = 785.39\ mm^2 = 0.00078539\ m^2$

$P_t = \pi * d$

$P_t = 3.14\ mm^2 = 3.14 * 10^{-6}\ m^2$

$A_{st} = P_t * H_t * n_t$

$A_{st} = 31227.3\ mm^2 = 0.0312273\ m^2$

$D_{hh} = 4 * (A_{cst}/P_t)$

$D_{hh} = 1000\ m$

$Q_w = m_h/\rho_h$

$Q_w = 4.089 * 10^{-4}\ m^3 / s$

$V_w = Q_h / (n_t * A_{cst})$

$V_w = 0.01334\ m / s$

$Re_w = (V_h * D_{hh} * \rho_h) / \mu_h$

$Re_w = 32920.74$

$N\mu_w = [(\alpha / 8) * (Re_h - 1000) * Pr_h] / [1 + (12.7 * (\alpha / 8)^{0.5} * (Pr_h^{(2/3)} - 1)]$

$N\mu_w = 33823.85$

$h_w = (N\mu_h * k_h) / D_{hh}$

$h_w = 22.5$

$A_t = (n_t * L_t * H_t) / n_c$

$A_t = 69062\ mm^2$

Air-side Calculations

$L_c = L_f + (H_f / 2)$

$L_c = 255\ mm$

$A_f = 2 * L_c * W_f$

$A_f = 2550\ mm^2$

$A_b = 2 * L_r * (W_r / n_c) + H_f * W_f * \rho_f$

$A_{base} = \rho_f * A_f + A_b$

$A_{sf} = A_{base} * n_f$

$A_{sf} = 50584.46\ mm^2$

$P_f = 2 * (W_f + H_f)$

$A_{csf} = W_f * H_f$

$Q_c = A_r * V_c$

$V_{ra} = Q_a / (A_r - A_t)$

$V_{ra} = 0.963\ m/s$

$Re_a = (V_a * W_f) / \nu_a$

$Re_a = 6826.10$

$Nu_a = 0.664 * Re_a^{0.5} * Pr_a^{(1/3)}$

$Nu_a = 6.0876$

$h_a = (Nu_a * W_f) / k_a$

$h_a = 1483.52\ W / m^2K$

$M_a = Q_a * S_a$

$m_f = \sqrt{[(h_a * P_a) / (A_a * k_{Al})]}$

$m_f = 728.64$

$\eta_f = (\tanh m_f * L_c) / (m_f * L_c)$

$\eta_f = 0.595$

$\eta_o = 1 - [(\rho_f * A_f * (1 - \eta_f)) / A_{base}]$

$\eta_o = 0.7614$

<u>NTU Method</u>

$(1 / U_A) = [1 / (\eta_f * h_w * A_{sf})] + [1 / (h_a * A_{sf})]$

$U_A = 11.235\ W / m^2K$

$C_w = m_w * c_{pw}$

$C_a = m_a * c_{pa}$

$C_{min} = C_w = 0.88$

$C_{max} = C_a = 1.162$

$C = C_{min} / C_{max}$

$C = 0.75$

$NTU = U_A / C_{min}$

$NTU = 14.98$

$\varepsilon = 1 - \exp[(1/C_t)(NTU)^{0.22} * \{\exp[-C * (NTU)^{6.78}]-1\}]$

$\varepsilon = 0.911$

$Q_{max} = C_{min} * (T_{h1} - T_{c1})$

$Q_{max} = 45.76$

$Q = \varepsilon * Q_{max}$

$Q = 41.68$

$T_{h2} = T_{h1} + (Q / C_h)$

$T_{h2} = 129.36$

$T_{c2} = T_{c1} + (Q / C_c)$

$T_{c2} = 65.86^0C$

**Abbreviation**

Height-H
Length-L
Width-W
Thickness-t
Cross-sectional area-$A_{cs}$
Surface Area-$A_s$
Perimeter-P
Hydraulic diameter-$D_h$
Mass flow rate-m
Discharge-$Q_d$
Velocity-V
Reynolds Number-Re
Factor for Nusselt number-α
Nusselt number-Nu
Convective Heat Transfer Coefficient-h
Frontal area-A
Fin constant-$m_f$
Corrected length-$L_c$
Fin density-$\rho_f$
Base surface area-$A_b$
Total base surface area-$A_{base}$
Conductive heat transfer co-efficient-k
Efficiency-η
Overall Efficiency-$\eta_o$
Overall heat transfer co-efficient-U
Number of transfer units-NTU
Capacity ratio-C Effectiveness-ε
Temperature-T
Density-ρ
Dynamic viscosity-μ
Kinematic viscosity-ν
Prantdl number-Pr
Specific heat at constant pressure-$C_p$
Number-n
Velocity Inside the radiator-$V_r$
Dynamic pressure drop-$P_d$
Inlet temperature of air-$T_{a1}$
Outlet temperature of air-$T_{a2}$
Inlet temperature of water-$T_{w1}$
Outlet temperature of water-$T_{w2}$
Fin density-$N_f$
Fin pitch-$p_f$
Distance between adjacent fins-s
Fluid thermal conductivity-λ
Fin efficiency-$\eta_f$
Fin thickness-$\delta_f$
Overall Fin Effectiveness-$E_o$
Heat transfer coefficient-α ,(W/m²K)
Fin thickness-$\delta_f$
Total surface efficiency-$\eta_o$
Fluid density-ρ

<u>Subscripts</u>:
t-tube
f-fin
h-hot fluid(water)
c-cold fluid(air)
R-radiator
C-core
w-water
a-air

**8. Analysis**

Step 1:

Generated CAD assembly.

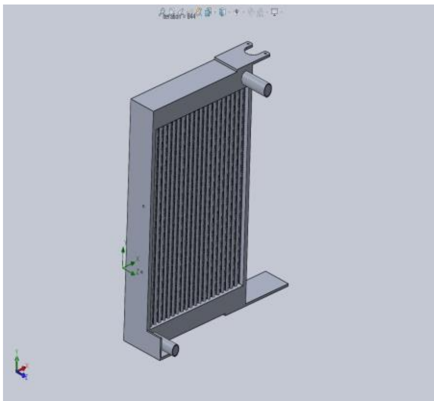

Figure 5 :Generated CAD assembly according to FSAE rules

Step 2:

Imported the assembly in flow simulations.

This step is necessary in order to generate simulations on CAD models. The CAD model is imported into flow simulation SolidWorks add-ins

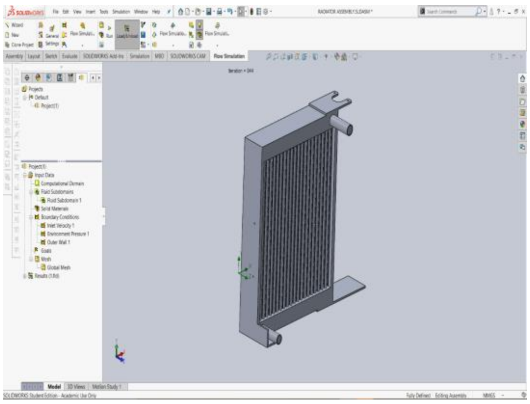

Figure 6 :Imported the assembly in flow simulations

Step 3:

Selected suitable boundary conditions.

Once CAD model is imported into simulation, we check if there are any failures or leaks in our model in order to input the boundary conditions.

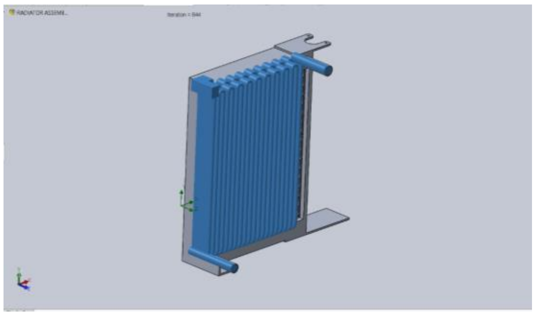

Figure 7: Flow Simulation

Step 7:

Obtained solutions for our fluid flow.

By applying Surface plot contours on the internal fluid, we obtained the thermal analysis of the fluid.

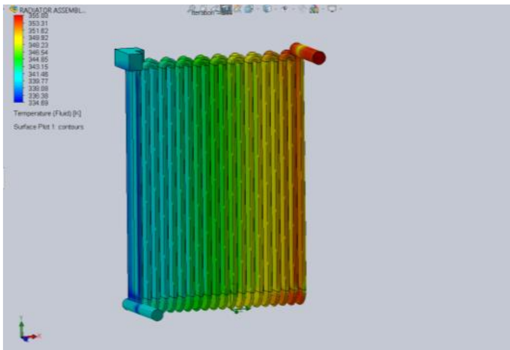


Figure 10 : Surface Plot of Fluid

Step8:

Obtained solution for fin convection.

By applying Body contours on the fins, we obtained thermal analysis for fin convection.

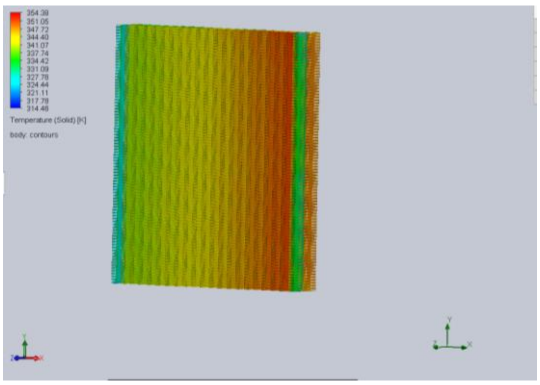


Figure 11: Body Plot of Fins

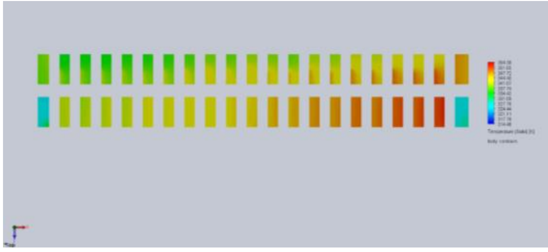

Figure 12 : top view

**Solidworks simulation results:**

Inlet Temperature of Water = 355.75 K

Inlet Temperature of Air = 303.15 K

Outlet Temperature of Water ($T_{c2}$) = 334.61 K

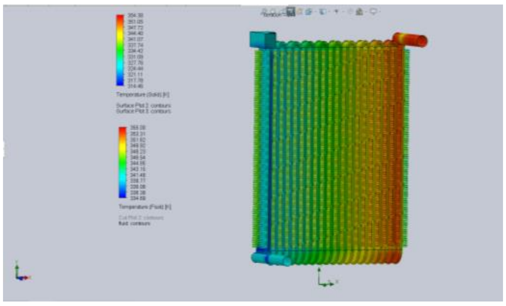

Figure 13 : radiator analysis

**Comparision**

| Sr. No. | Parameters | Proposed Model | |
|---|---|---|---|
| | | Theoretically | CFD |
| 1 | Outlet Temperature of Water | $65.86^0$C | $61.46^0$C |
| 2 | Effectiveness | 91.1 | 97 |

**9. Conclusion**

Mass stream pace of coolant and air speed through radiator, from the information gained, were contrasted with that reasoned by various hypothetical strategies. All the information was determined, reproduced and recorded at explicit motor RPM and vehicle speeds. It was seen that at a specific vehicle speed, the warmth dismissed by the radiator during down to earth try was practically like the determined worth of warmth dismissed furthermore, it was 6% lower when contrasted with the CFD results. Along these lines, the theoretical and CFD results were ready to precisely foresee the real warmth, the anticipated qualities were more than the genuine warmth dismissal. This was most likely because of the partition of stream in the sidepod.

**10. Refernces**


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