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Thermal Analysis of I C Engine cylinder fins array using CFD

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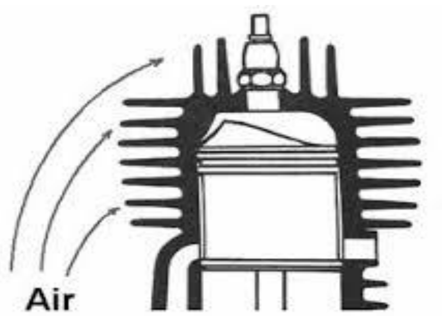
Abstract: The Engine cylinder is one of the major I C Engine components, which is subjected to high temperature variations and thermal stresses. To cool the cylinder, fins are provided on the surface of the cylinder to increase the rate of heat transfer. By doing thermal analysis on the engine cylinder fins, it is helpful to know the heat dissipation inside the cylinder.The principle implemented in the project is to increase the heat dissipation rate by using the invisible working fluid of air. We know that, by increasing the surface area we can increase the heat dissipation rate, so designing such a large complex engine is very difficult. The main purpose of using these cooling fins is to cool the engine cylinder by air.

The main aim is the project is to analysis thermal properties by varying geometry, material and thickness of cylinder fins.Transient thermal analysis determines temperatures and other thermal quantities that vary over time. The variation of temperature distribution over time is of interest in many applications such as in cooling. The accurate thermal simulation could permit critical design parameters to be identified for improved life.

Keyword : Thermal analysis, fins geometry, CFD

1. INTRODUCTION

An IC engine is one in which the heat transfer to the working fluid occurs within the engine itself, usually by the combustion of fuel with the oxygen of air. Internal combustion engines use heat to convert the energy of fuel to power. In IC engine all of the fuel energy is converted to power. And after converting the heat to power Excess heat must be removed cycle. The heat is moved to the atmosphere by means of fluids water and air. In engines, heat is moved to the atmosphere by fluids low temperature. Due to combustion process Engine temperature is not consistent throughout the power. If excess heat is not removed, engine components fail due to excessive temperature. Heat moves from areas of high temperature to areas of low temperature as shown in below area. In Engine When fuel is oxidized (burned) heat is produced. Additional heat is also generated by friction between the moving parts. Only approximately 30% of the energy released is converted into useful work. The remaining (70%) must be removed from the engine to prevent the parts from melting.



I C ENGINE CROSS SECTION

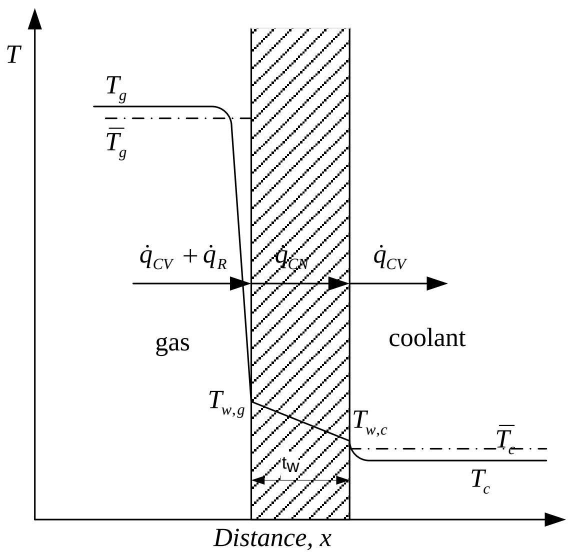
Peak burned gas temperature in engine is near about 2500 K and during Combustion period heat fluxes may reach to 10 MW/m2, during other part of the cycle it is essentially zero. The maximum metal temperature for the inside of the combustion chamber is much lower values due to Cracking on materials (cast iron 400°C, aluminum alloys 400°C)Prevent deterioration of lubrication oil (keep below 180°C) also Spark plugs and valves must be kept cool to avoid knock and pre ignition problems.

Basically we should maintain the combustion temperature to achieve high heat transfer reduce the engine efficiency.

Extended fins are well known for enhancing the heat transfer in I C engine. However liquid-cooled system is better than air cooled system but in S I engine air cooled system is better than liquid cooled and simpler also. Therefore it I very important for air cooling system to utilize extended surface fins effectively to obtain uniform temperature in cylinder periphery.[12]

OVERALL HEAT TRANSFER FROM S I ENGINE

An air cooled motorbike engine dissipates waste heat from the cylinder through the cooling fins to the cooling air flow created by the relative motion of moving motorbikes. The cooling system is an important engine subsystem. The air cooling mechanism of the engine is mostly dependent on the fin design of the cylinder head and block. It also depends on the velocity of the vehicle and the ambient temperature. Following section shows basic heat transfer mechanism and relative equations of same.[14]



Gas side heat transferred$Q_{\text{Convection}} = h_{c,g}\left(T_g - T_{w,g}\right)$

Wall side heat transfer $Q_{\text{Convection}} = k\,\frac{\left(T_{w,g} - T_{w,c}\right)}{T_w}$

Coolant side heat transfer $Q_{\text{Convection}} = h_{c,c}\left(T_{w,c} - T_c\right)$

For force convection, convective heat transfer coefficient can be calculated by Nusselt theory

N_U= C*Re^m*$Pr^n$$\frac{hL}{k}$= $C\left(\frac{\rho u L}{\mu}\right)^m\left(\frac{cp\mu}{k}\right)^n$

2. LITRATURE REVIEW

1. "Masao YOSHIDA, Soichi ISHIHARA, Kohei NAKASHIMA: Air-Cooling Effects of Fins on a Motorcycle Engine"[1] The author had developed the experimental cylinder for an air-cooled engine and the effects of the number of fins, fin pitch and wind velocities on cylinder cooling were investigated. The major results obtained are

To increase the cylinder cooling, the cylinder should have a greater number of fins. But not more

At a lower speed the air flow separated on the fin surface at the leeward side and the temperature on the fin surface increased there. The higher temperature on the local fin surface makes cylinder bore a greater deformation, as a result, scuffing and increased lubricating oil consumption may occur.[1]

2. "Pratima S. Patil, S.N. Belsare, Dr. S. L. Borse Analysis of internal combustion engine heat transfer rate to improve engine efficiency, specific power & combustion performance prediction" [2]This paper focuses on substantial difference of heat flux exists for various places in the cylinder of an engine.A substantial difference of heat flux exists for various places in the cylinder of an engine. Maximum heat flux in each part occurs when pressure in the cylinder is maximum. Heat flux on the intake valves is higher than other place of the cylinder. Heat flux on the cylinder head is more than piston and it has the lowest value on the cylinder liner.[2]

3. G.Raju, Dr. Bhramara Panitapu, S. C. V. Ramana Murty Naidu. "Optimal Design of an I C engine cylinder fin array using a binary coded genetic algorithm".[3]This study also includes the effect of spacing between fins on various parameters like total surface area, heat transfer coefficient and total heat transfer .The aspect rations of a single fin and their corresponding array of these two profiles were also determined. Finally the heat transfer through both arrays was compared on their weight basis. Results show theadvantage of triangular profile finarray.

Heat transfer through triangular fin array per unit mass is more than that of heat transfer through rectangular fin array. Therefore the triangular fins are preferred than the rectangular fins for automobiles, central processing units, aero-planes, space vehicles etc… where weight is the main criteria. At wider spacing, shorter fins are more preferred than longer fins. The aspect ratio for an optimized fin array is more than that of a single fin for both rectangular and triangular profiles.[3]

4. Magarajan U. , Thundil karrupa Raj R. , Elango T. " Numerical study on heat transfer I C Engine cooling by extended fins using CFD" [4]In this study, heat release of an IC engine cylinder cooling fins with six numbers of fins having pitch of 10 mm and 20 mm are calculated numerically using commercially available CFD tool Ansys Fluent. The IC engine is initially at 150 and the heat release from the cylinder is analyzed at a wind velocity of 0 km/h.

It is observed from the CFD result that it takes 174.08 seconds (pitch=10mm) and 163.17 secs (pitch =20mm) for ethylene glycol domain to reach temperature of 423 K to 393 K for initially. The experiment results shows that the value of heat release by the ethylene glycol through cylinder fins of pitch 10mm and 20mm are about 28.5W and 33.90 W.[4]

5. Mr. N. Phani Raja Rao, Mr. T. Vishnu Vardhan. "Thermal Analysis Of Engine Cylinder Fins By Varying Its Geometry And Material."[5]

The principle implemented in the project to increase the heat dissipation rate by using the invisible working fluid nothing but air. The main aim of the project is to varying geometry, material. In present study, Aluminium alloy 6061 and magnesium alloy are used and compared with Aluminium Alloy A204. - The various parameters (i.e., shape and geometry of the fin) are considered in the study, shape (Rectangular and Circular), thickness (3 mm and 2.5 mm). By reducing the thickness and also by changing the shape of the fin to circular shaped, the weight of the fin body reduces thereby increasing the heat transfer rate and efficiency of the fin. The weight of the fin body is also reduced when Magnesium alloy is used. The results shows, by using circular fin with material Aluminium Alloy 6061 is better since heat transfer rate, Efficiency and Effectiveness of the fin is more. By using circular fins the weight of the fin body reduces compare to existing engine cylinder fins.

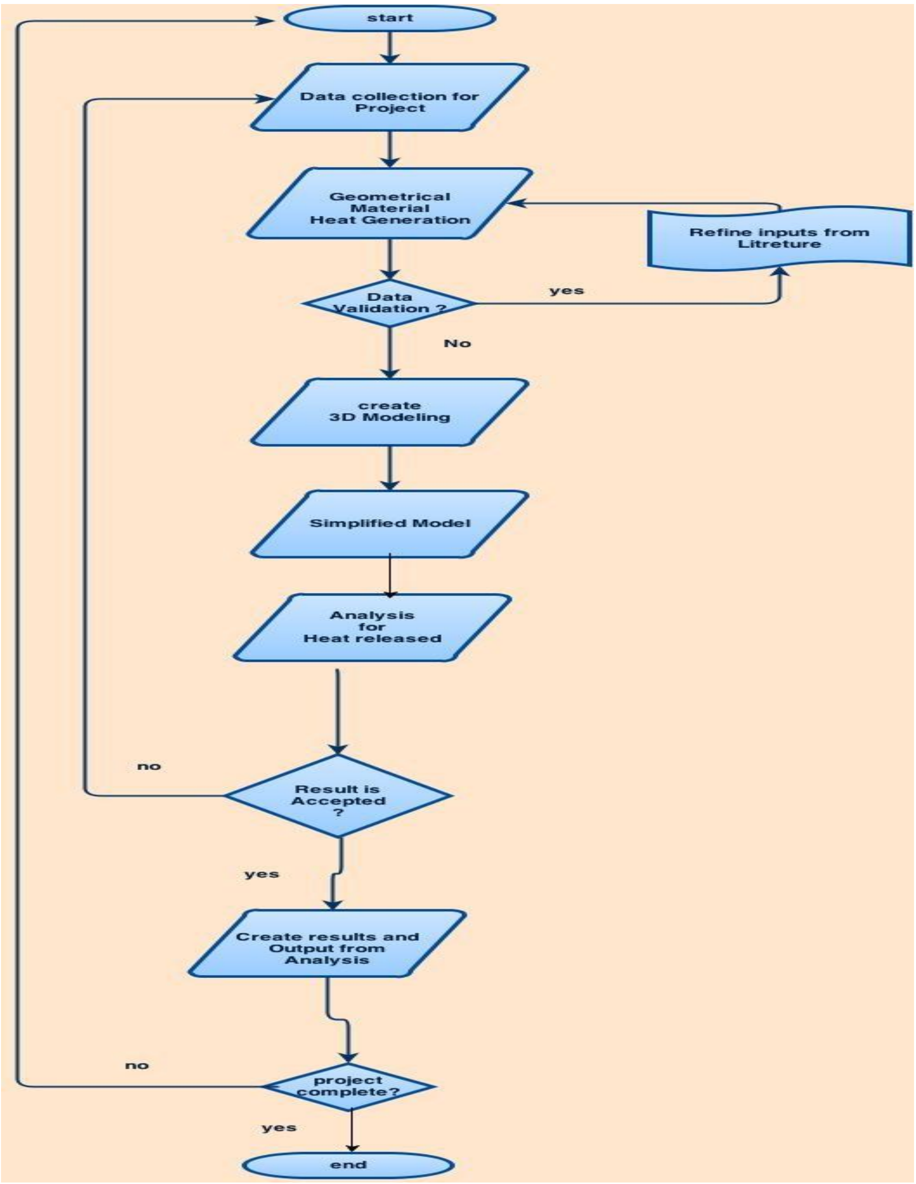
6. Heat Transfer Augmentation of Air Cooled 4 stroke SI Engine through Fins- A Review Pape.[8]

The author had study number of research paper and conclude that the phenomenon by which heat transfer takes place through engine fins must frequently be improved for these reasons. Fins are extended surface which are used to cool various structures via the process of convection. Generally heat transfer by fins is basically limited by the design of the system. But still it may be enhanced by modifying certain design parameters of the fins. Hence the aim of this paper is to study from different literature surveys that how heat transfer through extended surfaces (fins) and the heat transfer co- efficient affected by changing cross-section, climatic conditions, materials etc.

It is to be noted that heat transfer of the fin can be augmented by modifying fin pitches, geometry, shape, and material and wind velocity. As per available literature surveyed there is a little work available on the wavy fins geometry pertaining to current research area to till date. So there is a scope of research in the field of heat transfer study on wavy fins on cylinder head –block assembly of 4 stroke SI engine.

7. N.Nagarani and K. Mayilsamy, Experimental heat transfer analysis on annular circular and elliptical fins."[9]This other had analyzed the heat transfer rate and efficiency for circular and elliptical annular fins for different environmental conditions. Elliptical fin efficiency is more than circular fin. If space restriction is there along one particular direction while the perpendicular direction is relatively unrestricted elliptical fins could be a good choice. Normally heat transfer co-efficient depends upon the space, time, flow conditions and fluid properties. If there are changes in environmental conditions, there is a change in heat transfer co-efficient and efficiency also.[9]

3. FLOW CHART OF METHODOLOGY



EXISTING MODEL SPECIFICATION

Engine model : Hero- Honda

Engine type : Four-stroke, air cooled,

Bore X stroke : 52.0 X 58.6 mm

Fuel system : Carburetor

Number of valves : 2

Displacement volumes : 100 c.c.

Compression ratios : 10.2

Spark advance : 5 °/1500 rpm, 26 °/ 4500 rpm

Cylinder head material : Aluminum alloy

(Thermalconductivity110-150 w/m k)Combustion chamber : Hemisphere shaped

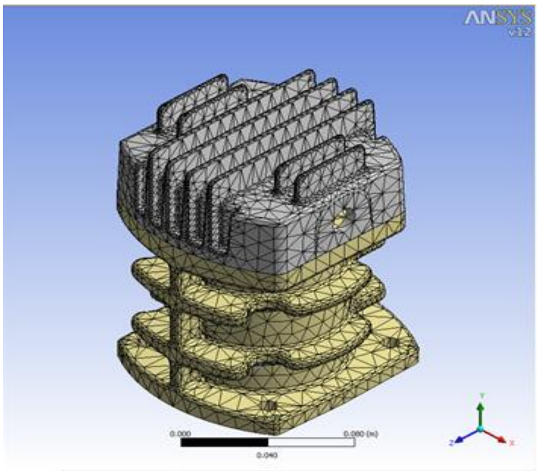
Fin shape : Rectangular with curves at corner

Curve radius : R18

Fin thickness' : 3.048

Tapper angle : 5*

Pitch of fin : Uneven



EXISTING MESH MODEL

3.HEAT TRANSFER CALCULATIONS

Heat release, Q = m CΔT

Where,

Q = Heat Released by Cylinder in Watts.

m = mass of the heat storage liquid, in Kg,

C = specific heat capacity J/kg K

ΔT = change in temperature at inlet and outlet, in K

The governing equations are continuity, momentum and energy equations, which are derived from fundamental principles of heat and fluid flow. The equations are posed to implement assumptions are made

The compressibility, the gravitational force and the dissipating heat caused by viscosity are neglected, the continuity, momentum ad energy equations for a fully developed 3D flow heat transfer are: Continuity Equation, Momentum Equation (Navier-stokes Equation), and Energy Equation.

The Continuity Equation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{dw}{dz} = 0$$

$$\nabla\left(\rho \underset{V}{\rightarrow}\right) = 0$$

Simplified Momentum Equation (Navier-stokes Equation),

X-momentum: $\nabla\left(\rho \underset{V}{\rightarrow}\right) = - \frac{\partial p}{\partial x} + \frac{\partial \tau xx}{\partial x} + \frac{\partial \tau yx}{\partial y} + \frac{\partial \tau zx}{\partial z}$

Y-momentum: $\nabla\left(\rho \underset{V}{\rightarrow}\right) = - \frac{\partial p}{\partial x} + \frac{\partial \tau xy}{\partial x} + \frac{\partial \tau yy}{\partial y} + \frac{\partial \tau zy}{\partial z} + \rho g$

Z-momentum: $\nabla\left(\rho \underset{V}{\rightarrow}\right) = - \frac{\partial p}{\partial x} + \frac{\partial \tau xz}{\partial x} + \frac{\partial \tau yz}{\partial y} + \frac{\partial \tau xx}{\partial z} + \rho g$

Energy Equation

$\nabla\left(\rho \underset{V}{\rightarrow}\right) = -p\nabla \underset{V}{\rightarrow} + \nabla\,(k\nabla T) + q + \psi$

Turbulence is taken care by Shear Stress Transport (SST) k-ώ model

$\frac{\partial(pk)}{\partial t} + \frac{\partial(kui)}{\partial xi} = \frac{\partial}{\partial xj}\left[\frac{\partial k}{\partial xj}\right] + Gk - Yk + Sk$

According to LANGHAAR EQUATION the length required to fully developed laminar flow entrance length = 0.057Re DH < L fin for fully Laminar Flow.

Where

Re = Reynolds Number

L fin = Effective length of Fin

DH = the hydraulic diameter of Fin

BOUNDARY CONDITION SETUP

For a steady, fully developed laminar flow $\frac{\partial p}{\partial x} = 0$.

The boundary conditions are applied to all the boundaries of the solid region except the cylinder bottom surface wall, where a constant heat flux is applied.

$$- Ks \frac{\partial T}{\partial y} = \ddot{q}$$

For 0 < z < L; 0 < x < W and y = 0

At inlet, the temperature is equal to a given constant inlet temperature.

T = Tin For Z = 0, t < x < t + w and The flow is assumed to be thermally fully developed at the fin.

$\frac{\partial^2 T}{\partial Z^2} = 0$ for Z = L

BOUNDARY CONDITIONS ARE MENTIONED IN THE TABLE BELOW

The below table shows list of input parameter used for analysis.

1	Engine Linear Speed (KM / Hr)	50 / 60/ 70
2	Temperature of surrounding (Ambient)	45 ˚ C with 45 % RH 50 ˚ C with 40 % RH 25 ˚ C with 60 % RH
3	Geometrical Altitude	1000 Meter Above mean sea Level
4	Heat transfer coefficient w / m² K	10
5	Thermal conductivity w / m K	400
6	Nominal Wind Speed (m / Sec)	10.45/ 11.12/ 12.30

4.RESULT AND DISCUSSION

TABLE- 1 EXISTING CYLINDER FIN(Engine Linear Speed (50 KM / Hr.)

THICKNESS	3.048 MM THICKNESS CASE 01			4.0 MM THICKNESS CASE 02		
Ambient temp ˚ c	25	40	50	25	40	50
Heat loss (w)	141.05	142.21	144.36	142.1	144.5	145.46
Effectiveness	60.29	60.56	61.35	60.23	61.13	62.79
Efficiency	12.29	12.59	12.78	12.34	12.63	**12.94**
Thermal flux (w/mm2)	4.122	4.159	4.200	4.166	4.179	4.220

Thermal Gradient (K/mm)	0.5725	0.5730	0.5733	0.5813	0.5699	0.590 2

TABLE – 2 ALUMINUM ALLOY 6061 SQUARE FIN
Engine Linear Speed (50 KM / Hr.)

THICKNESS	3.5 MM THICKNESS CASE 03			4.0 MM THICKNESS CASE 04		
Ambient temp ˚ c	25	40	50	25	40	50
Heat loss (w)	142	144	145	143.1	145.2	146.02
Effectiveness	61.23	61.49	63.30	63.21	62.12	66.38
Efficiency	13.22	13.51	13.62	13.12	13.61	13.69
Thermal flux (w/mm2)	4.234	4.244	4.251	4.341	4.350	4.412
Thermal Gradient (K/mm)	0.5812	0.5813	0.5835	0.5912	0.5714	0.5918

TABLE- 3 CAST IRON SQUARE FIN (Engine Linear Speed (50 KM / Hr.)

THICKNESS	3.5 MM THICKNESS CASE 05			4.0 MM THICKNESS CASE 06		
Ambient temp ˚ c	25	40	50	25	40	50
Heat loss (w)	115.44	116.64	118.13	117.342	117.412	115.3558
Effectiveness	50.8086	49.729	49.27	53.4722	52.96	51.31604
Efficiency	11.8404	10.82151	10.898	11.03232	11.4241	10.8151
Thermal flux (w/mm2)	3.97188	3.45276	3.35829	3.45962	3.9235	3.48548
Thermal Gradient (K/mm)	0.496584	0.470853	0.479	0.484784	0.479034	0.467364

TABLE - 4 ALUMINUM ALLOY 6061 CIRCULAR FIN
(Engine Linear Speed (50 KM / Hr.)

THICKNESS	3.5 MM THICKNESS CASE 07			4.0 MM THICKNESS CASE 08		
Ambient temp ˚ c	25	40	50	25	40	50
Heat loss (w)	136	136.8	138.2	137.2	138.01	139.21

Effectiveness	61.23	61.39	62.3	65.21	66.12	66.38
Efficiency	12.09	12.21	12.31	12.41	12.45	12.53
Thermal flux (w/mm2)	3.912	3.941	3.958	3.943	3.951	3.976
Thermal Gradient (K/mm)	0.5912	0.5929	0.5948	0.59.12	0.5967	0.5983

TABLE – 5 CI CIRCULAR FIN WITH CURVE
(Engine Linear Speed (50 KM / Hr.)

THICKNESS	3.5 MM THICKNESS CASE 09			4.0 MM THICKNESS CASE 10		
Ambient temp ˚ c	25	40	50	25	40	50
Heat loss (w)	129.32	130.21	131.16	132.31	132.11	132.34
Effectiveness	58.43	58.431	58.582	58.12	58.52	58.73
Efficiency	10.09	10.62	10.71	10.89	10.91	10.92
Thermal flux (w/mm2)	3.8971	3.9123	3.959	3.923	3.934	3.978
Thermal Gradient (K/mm)	0.5730	0.5812	0.5836	0.5722	0.5732	0.5740

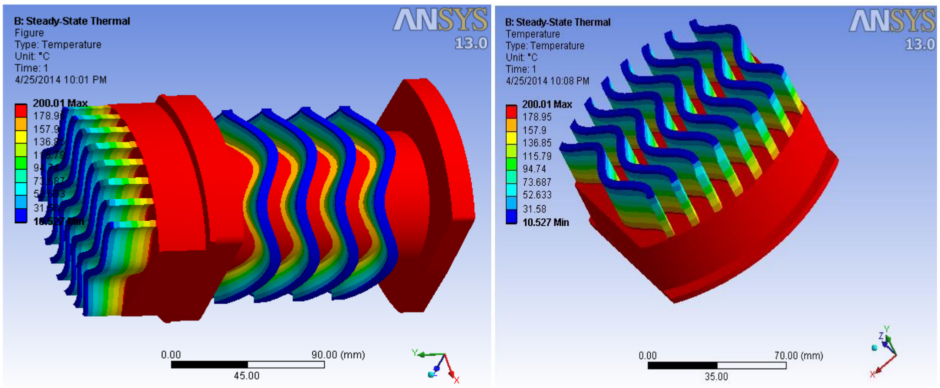
TABLE - 6 AI6061 WAVY FINS WITH CURVE
(Engine Linear Speed (50 KM / Hr.)

THICKNESS	3.5 MM THICKNESS CASE 11			4.0 MM THICKNESS CASE 12		
Ambient temp ˚ c	25	40	50	25	40	50
Heat loss (w)	149.78	149.23	149.56	148.34	148.81	148.92
Effectiveness	67.12	67.23	67.98	66.23	66.89	67.03
Efficiency	13.92	13.98	14.05	13.22	13.28	13.6
Thermal flux (w/mm2)	3.8012	3.8351	3.9321	3.8219	3.857	3.971
Thermal Gradient (K/mm)	0.5923	0.5935	0.5950	0.5938	0.5943	0.5952

TABLE-7 COMPARISON OF ALL CASES.

	CASE2	CASE 4	CASE6	CASE 8	CASE 10	CASE 12

Ambient temp ˚ c	50	50	40	50	50	50
Heat loss (w)	145.46	146.02	117.412	139.21	132.34	149.56
Effectiveness	62.79	66.38	52.96	66.38	58.73	67.98
Efficiency	12.94	13.69	11.4241	12.53	10.92	14.05



WAVY FIN CFD ANALYSIS

4.CONCLUTION

We have done analysis of total 12 variety of cases in major two group of thickness 3.5 and 4.0 mm. The variable in each cases were ambient temperature like 25, 40 and 50 Degree C. The safe operating speed of bike is 50 Km / Hr but to know the performance of same at lower ambient temperature like 40 and 25 degree C were also studied. Each case was evaluated basically on 50 C temp the case where we were having good results but amb temp are 25 and 40 were not considered for final comparison and to conclude the design.

Based selection criteria we can see the heat rejection rate from fin varies from 132.32 watt to 149.56 watt which is having variation of 17.24 Watts which is an important indicator of huge scope of improvement in fin design and selection to have better performance. Also the effectiveness was observed in the range of 52.96 to 67.98 which is having margin of 15.02. also the important parameter like fin efficiency is having extreme limits like 10.92 on lower side and 14.05 on upper side total margin is 3. 13 %

Based in selection criteria decided as per literature review we can conclude that the case no 12 i.e. wavy fins with AL 6061 Material is superior among all the cases we studies which is having a heat loss of 149.56 Watts and effectiveness is 67.98 % and efficiency of 14.05 %. If we compare this final out put with an existing design then we can conclude that by moving from existing fin shape to wavy fin we may get an improvement in heat loss 4.1 Watts which is equal to 2.81864 % and in terms of effectiveness and efficiency it is near about 8.265 and 8.57805 respectively. The manufacturing aspects were also study with help of M/s. Karan techno cast to check the possibility of such shape and they did confirmation on possibility of this shape via die casting process.

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