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Heat transfer augmentation of cylinder block by using permeable fin over solid fin by using CFD Analysis

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ABSTRACT
Engines of two wheeler four stroke vehicle cannot be cooled by water cooling system due to lack of space. In this case efficient air cooling system should be applied for high performance of engine. Permeable fins can be used in engine cylinder to enhance the heat transfer rate. This paper is concerned about an experiment in which a solid annular fin was mounted on a cylinder. The cylinder was filled with water. At a constant temperature (100°C) of water the base & tip temperature of fin was measured and the temperature difference was calculated at different time. A graph of time vs. temperature difference was plotted. In simulation analysis temperature difference of same dimensions solid fin was found & a temp difference vs. time graph was plotted for these results. Both results obtained by experimental & simulation slightly deviated which showed the validity of the simulation work. Now in case of solid fin cylinder temperature difference between base & tip temperature was determined by simulation analysis. Same work was done for permeable fin cylinder. Temperature difference vs. time graph was plotted for both solid & permeable fin cylinder. From this paper it is found that permeable fin is about 10-15% efficient over solid fin. This paper also states that about 3-5% cost will be reduced by using permeable fin instead of solid fin.

Keywords: Permeable fin, heat transfer rate, CFD analysis, cooling system.

1. Introduction

During combustion of the air fuel mixture in the engine cylinder, temperature reaches as high as 6000°F (3316°C) [1]. A part of this heat is absorbed by cylinder wall, head and piston. They, in turn, must be cooled so that their temperature are not excessive. Cylinder wall temp must not increase beyond about 400 or 500°F. That's why engine cooling is necessary. In general, two types of cooling system are used, air cooling and liquid cooling. Air cooling system is mostly used in light vehicle like motor cycle due to lack of space. Air cooled engines have metal fins on the head and cylinder to help radiate the heat from the engine. Fin is an extended surface which is mounted on cylinder block to increase the rate of heat transfer to or from the environment by convection. The heat transfer enhancement can be achieved through some techniques: (1) extending the surface area to volume ratio, (2) enhancing the thermal conductivity of fin by different high conductive material and (3) enhancing the convective heat transfer coefficient between the surface of the fin and the surrounding fluid.
Bassam A/K Abu-Hijleh [2] numerically analyzed heat transfer of solid and permeable fins. They showed that permeable fins offered much higher nusselt number than the solid fins under same operating conditions. They assumed that the fins are made of highly conductive material. Ashok Tukaram Pise [3] investigated the heat transfer of permeable and solid fins by experimental analysis. They modified solid rectangular fins to permeable fins by drilling three holes in line at one half lengths of the fins of two wheeler cylinder block. They tested cylinder blocks having solid and permeable fin for different input. They showed that the heat transfer rate is more in permeable fins as compared to the solid fins. J.

Ajay Paul [4] showed in their paper that the difference of heat transfer between 4mm thickness fins and 6mm thickness fins are negligible at zero velocity. They showed that the heat transfer from 6mm thickness fins is higher at high velocities. Mishra A.K. [5] investigated numerical analysis of heat transfer from air cooled engine cylinder fins. They showed that by using copper as fin material greatest effective cooling can be found.
This paper represents a numerical analysis of solid and permeable annular fins. The analysis was done by "Autodesk Simulation CFD 2014". Design and modelling was done by "SolidWorks 2013". The purpose of this analysis is to performance test of permeable fins over solid fins. The parameter of this analysis are heat transfer rate, temperature difference.

2. Experimental setup

2.1 Experimental Setup for Validation Process
The experimental setup consisted a cylinder, a solid annular fin, a 500W heater, a temperature meter and thermocouples. Here inside the cylinder water was used. The cylinder was made of aluminium. The height, outer radius and inner radius of cylinder were 254mm, 38mm, and 35mm respectively. The fin was made of aluminium. The thickness, outer radius and inner radius of fin were 1mm, 139.7mm and 38mm respectively. The fin was mounted on the cylinder by gas welding. The thermocouple wires were attached at tip and base of the fin to measure the fin temperature. Then the thermocouple wires were connected to the temperature meter. The cylinder was filled with water. A 500W heater was inserted into the cylinder to heat the water. A thermometer was inserted inside the cylinder to take the water temperature. Then the heater and temperature

meter were connected to power. The fin temp was taken when the temperature inside the cylinder reached at 100°C temperature. After every 10 seconds the fin base and tip temperature were recorded. The experiment were continued for 300 seconds (5 minutes). The experimental setup is shown below in Fig 1.

Fig.1 Photographic view of experimental setup.

For validation of simulation analysis same dimension of cylinder and fin were used and simulation was run at same operating conditions.

2.2 Proposed numerical model
The material used for cylinder was cast iron. The height, outer and inner radius of the cylinder were 254mm, 38mm and 32mm respectively. The material used for solid and permeable fin was aluminium. The radius and thickness of the solid fin was 139.7mm and 6mm respectively. The thickness of permeable fin was 6mm. The dimensions of permeable fin are shown in Fig.2.
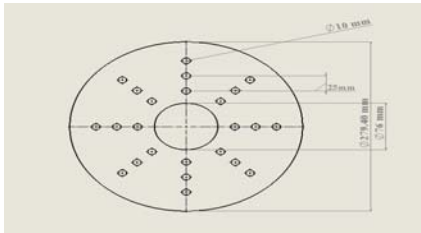

Fig.2 Dimensions of permeable fin.

An external volume was created for these models which was filled with air. The dimensions of external volume are given in Table 1

Table 1 Dimensions of external volume.

Direction/Angle	Value
X-length	0.7395m
Y-length	0.8414m
Z-length	2.2141m
X-offset	0.097m
Y-offset	0.1216m
Z-offset	0.2038m
Pitch angle	0
Yaw angle	0
Roll angle	0

The entire geometry was divided into four regions, (a) water, (b) cylinder, (c) solid or permeable fin and (d) surrounding air. The assemble geometry with external volume is given in Fig.3.
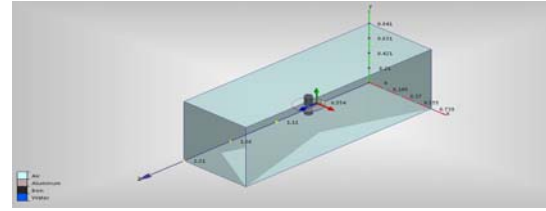

Fig.3 Assemble geometry with external volume.

3. Assumptions
The following assumptions are made for numerical simulation of fin:
  a) Steady state heat transfer through the fin.
  b) Constant temperature of water inside the cylinder.
  c) Incompressible fluid.
  d) The radiation heat transfer is neglected.
  e) The properties of solid and fluid are constant.
  f) The temperature does not vary along the fin thickness.
  g) The ambient temperature is considered as 33°C uniformly.

4. Governing equations
The three dimensional heat flow was passed through cylinder and fin. It was simulated by solving the necessary governing equation viz. conservation of mass, momentum equation and energy equation using Autodesk® Simulation CFD 2014 code which is worked by finite element method.

5. Boundary conditions
The ambient temp and pressure were assumed as 33°C and 101325 Pa respectively. Density, specific heat, thermal conductivity and material properties were considered as constant. The temperature of water domain was fixed at 100°C. The inlet velocity of air was 0 km/h. The base and tip temperature of fin were taken after every 10 seconds. The analysis was done for 5 minutes.

6. Meshing and solving the model
For meshing and solving the model Autodesk® Simulation CFD 2014 was used. The meshing parameters used for the final simulation are given in Table 2

Table 2 Parameters for meshing the model.

Meshing Parameter	Setting/Value
Model mesh setting	Automatic
Surface refinement	Enabled
Volume growth rate	1.35
Surface growth rate	1.2
Enhancement growth rate	1.1

Gap refinement	Enabled
Fluid gap element	1
Thin solid elements	0.2
Mesh enhancement	Enabled
Number of layers	3
Layer factor	0.45

The solver settings are given in Table 3

Table 3 Solver settings

Parameter	Setting/Value	
Solution mode	Transient	
Time step size	10	
Inner iteration	5	
Time step to run	30	
Solution control	Intelligent solution control enabled	
Under relaxation factor	Velocity	0.5
	Pressure	0.5
	Temperature	1
	Turbulence	0.5
	Density	0.5
	Eddy viscosity	0.10
Flow	On	
Compressibility	Incompressible	
Heat transfer	On	
Gravity method	Earth	
Gravity direction	0,-1,0	

7. Validation
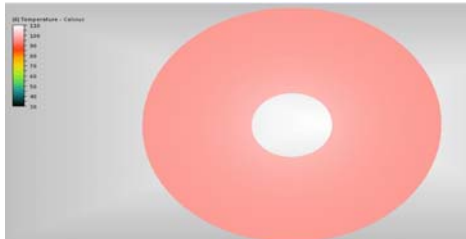
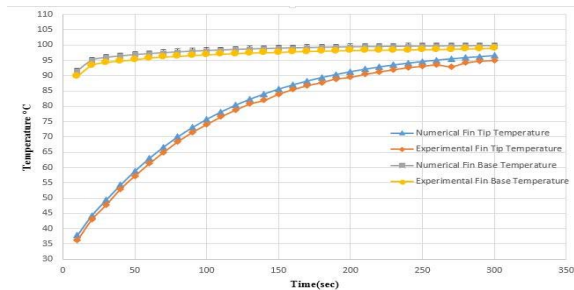**Fig.4** Temperature contour of solid fin at 300 seconds.

Fig.5 Comparison between experimental and CFD value.

Fig.5 shows the numerical and experimental value of solid fin temperature at tip and base. The deviation of

numerical value from experimental value is maximum 5%.
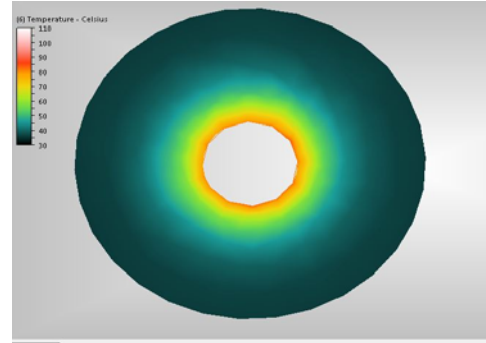
8. Results and Discussions

Fig.6 Temperature contour of solid fin at 10 seconds.

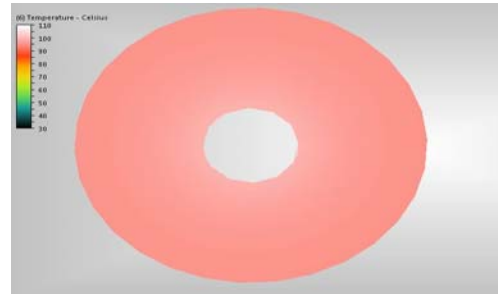**Fig.7** Temperature contour of solid fin at 150 seconds.

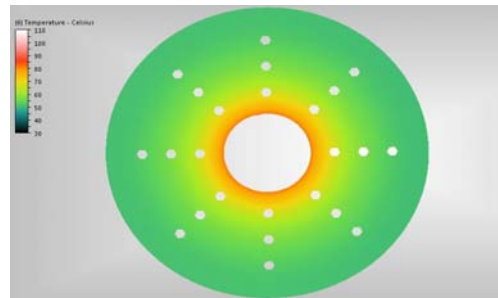**Fig.8** Temperature contour of solid fin at 300 seconds.

Fig.9 Temperature contour of permeable fin at 10 seconds.
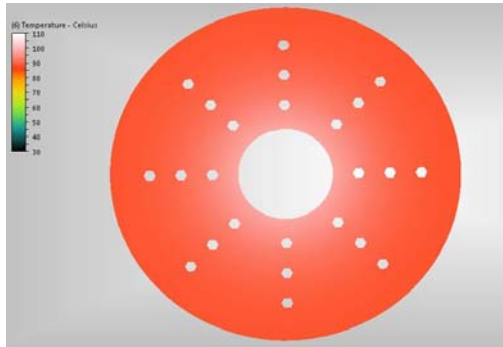
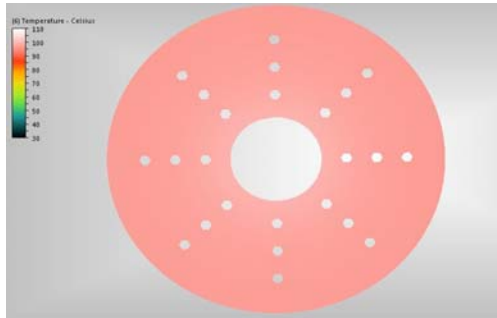**Fig.10** Temperature contour of permeable fin at 150 seconds.

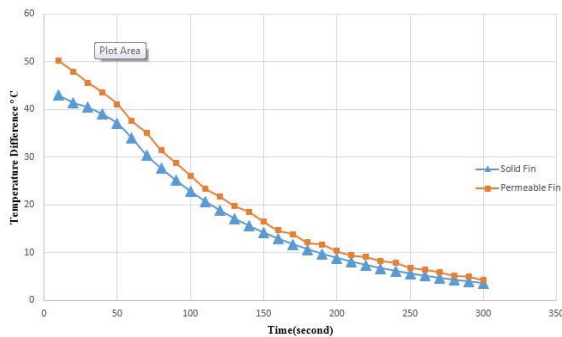**Fig.11** Temperature contour of permeable fin at 300 seconds.

Fig.12 Temperature difference vs. Time for solid and permeable fin.

The temperature contours of solid fin and permeable fin at different time are shown in figures 6, 7, 8, 9, 10, 11. From figures 6, 7, 8 it can be noted that the temperature of solid fin is increasing with respect to time. From figures 9, 10, 11 it can be appeared that the temperature of permeable fin is increasing faster than solid fin temperature with respect to time.

In Fig.12 a graph of temperature difference (°C) vs. time (sec) is plotted. This graph shows the change of temperature difference between fin tip and fin base with respect to time for solid and permeable fin. It is evident from this graph that in case of permeable fin the temperature difference is higher than solid fin. So it can

be easily said from above discussion that the heat transfer rate of permeable fin is higher than solid fin.

8. Conclusion

Thus heat transfer rate of permeable fin is higher than solid fin, it can increase the efficiency of cooling system about 10-15%. There is a reduction of material. By this proposed method about 3-5% material can be eliminated. So there will be a reduction of cost.

One can extend this experiment by changing the geometry of permeable fin, by using different air velocity or by using different high conductive fin material.

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