Research Journal of Recent Sciences ISSN 2277-2502
Vol. **1(6),** 32-37, June **(2012)** *Res.J.Recent Sci.*

Numerical Study on Heat Transfer of Internal Combustion Engine Cooling by Extended Fins Using CFD

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Available online at: www.isca.in
(Received 23rd March 2012, revised 31st March 2012, accepted 5th April 2012)

Abstract

It is important for an air-cooled engine to utilize fins for effective engine cooling to maintain uniform temperature in the cylinder periphery. Many experimental works has been done to improve the heat release of the cylinder and fin efficiency. 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. The heat release from the cylinder which is calculated numerically is validated with the experimental results. With the help of the available numerically results, the design of the I.C engine cooling fins can be modified for improving the heat release and efficiency.

Key words: Heat release, Fins, CFD.

Introduction

Extended fins are well known for enhancing the heat transfer in IC engines. However, liquid-cooling system enhances better heat transfer than air-cooling system, the construction of air-cooling system is very simpler. Therefore it is important for an air-cooled engine to utilize the fins effectively to obtain uniform temperature in the cylinder periphery[1].

There have been a number of studies on air-cooling of air-cooled engine fins. Table 1 shows the experimental cylinders and air velocity investigated by other researchers. They acquired data on cylinder cooling at relatively high air velocity. Some researchers tested at air velocity from 7.2 to 72 km/h to enable the fin design of motorcycle engines but did not investigate temperature distribution in the fin circumference in detail. An experimental equation of the fin surface heat transfer coefficient using a copper cylinder at air velocity from 32 to 97 km/h was derived by the researchers as follows[2],

$$\alpha = 241.7\left\{0.0247 - 0.00148\left(h^{0.8}/p^{0.4}\right)\right\}u^{0.73} \qquad (1)$$

where,
α = Fin surface heat transfer coefficient, W/m^2k, h = Fin length, mm, p = Fin pitch, mm, u = Air velocity, km/h

However it is not clear whether the equation (1) is applied with an aluminum cylinder at the air velocity of less than 32 km/h. The experimental equation of the fin surface heat transfer coefficient using an aluminum cylinder at the air velocity from 7.2 to 72 km/h was derived by another researcher is as follows[3],

$$\alpha = 2.11u^{0.71} \times S^{0.44} \times h^{-0.14} \qquad (2)$$

where, s = Fin separation at middle fin length, mm

Equation (2) has less deviation with lower value of $u^{0.71} \times S^{0.44} \times h^{-0.14}$ but greater deviation with higher $u^{0.71} \times S^{0.44} \times h^{-0.14}$ [4, 5].

Another researcher came up with an expression from the experiment of an aluminium cylinder by varying fin pitch, number of fins and air velocity. Equation (3) shows the expression for heat transfer co-efficient determined[6].

$$\alpha_{avg} = \left(2.47 - \left(2.55/p^{0.4}\right)\right)u^{0.9} + 0.0872p + 4.31 \qquad (3)$$

The comparisons of the experiments done are given in the coming tabular column which shows the different variation of pitch and no. of cylinders using for the fins[7].

Table-1
Experimental cylinders, fins and air velocities investigated by researchers

00	Reference 2	Reference 3	Reference 4		Reference 1
Cylinder diameter	32-95	118.364	86	100	78
Fin pitch	4-19	1.448-15.240	7-14	8-14	7-20
Fin length	16-41	9.398-37.338	25-65	10-50	35
Material	Copper, Steel , Aluminium	Steel	Aluminium alloy		Aluminium
Wind velocity	32-97	46.8-241.2	43.2-172.8	7.2-72	0-60

Material and Methods

In the above studies, experiments are carried out on an IC engine cylinder with fins using wind tunnel setup. The IC engine is initially heated to 150°c and cooing rate of cylinder and fin is analyzed by varying the air velocity from 0 to 20 km/h using wind tunnel[8]. This study is numerically extended for analysis of fin parameters using commercially available CFD code Ansys Fluent. The numerically predicted results are validated with the experiments carried out in the laboratory. Hence the numerical study can also be extended to study the effect of fin pitch, fin thickness, normal and tapered fins, effect of holes and slits in fins etc[9, 10].

Computational modeling: Figure 1 and 2 shows the modeled cylinder with six numbers of fins which was used for CFD analysis. The dimensions of cylinder and fins are similar to the model in literature. The outer diameter of the cylinder is Ø148 mm, inner diameter Ø78 mm and the thickness of 6 mm. The outer and inner diameters of the cylinder are Ø78 mm and Ø62 mm. The cylinder is of a length of 120 mm[11]. The hollow cylinder, six fins along with the outer air domain is created separately in Pro-E wildfire 4.0 and is then assembled. The output assembly design is created in parasolid format file for grid generation in ANSYS-ICEM CFD meshing tool.

Grid generation: The 3-D model is then discretized in ICEM CFD meshing tool. In order to capture both the thermal and velocity boundary layers the entire model is discretized using hexahedral mesh elements which are accurate and involve less computation effort. Fine control on the hexahedral mesh near the wall surface allows capturing the boundary layer gradient accurately. The entire geometry is divided into four domains FLUID_ETHYLENE_GLYCOL, FLUID_ AIR_ SOLID_FINS SORROUNDING, and SOLID_CYLINDER. The discretized model is checked to have a minimum angle of 27°and min determinant quality of 65 %.Once the meshes are checked for free of errors and minimum required quality it is exported to Ansys Fluent pre-processor. Figure 3-7 shows the mesh of air domain, fins, aluminium cylinder, ethylene glycol and assembly.

Governing equations: The 3-dimensional heat flow through the cylinder and fins were simulated by solving the appropriate governing equations viz. conservation of mass, momentum and energy using Ansys Fluent code which work by finite volume approach[12, 13]. Turbulence is taken care by Shear Stress Transport (SST) k-ω model.

Conservation of mass: $\nabla.\left(\rho\,\vec{V}\right) = 0$ (4)

x-momentum: $\nabla.\left(\rho u\,\vec{V}\right) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z}$ (5.1)

y-momentum: $\nabla.\left(\rho u\,\vec{V}\right) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + \rho g$ (5.2)

z-momentum: $\nabla.\left(\rho u\,\vec{V}\right) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + \rho g$ (5.3)

Energy: $\nabla.\left(\rho e\,\vec{V}\right) = -p\nabla.\vec{v} + \nabla.(k\nabla T) + q + \varphi$ (6)

SST omega turbulence equation:

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\Gamma_k \frac{\partial k}{\partial x_j}\right] + G_k - Y_k + S_k \quad (7)$$

Boundary Condition Setup: Both the fluids ethylene glycol and air are assumed to be incompressible fluids. Ambient temperature and pressure are assumed as 298 K and 101325 Pa respectively. The values of the boundary conditions like operating temperature, velocity of air are taken from the experimental work. Other boundary conditions like density, specific heat, thermal conductivity and other material properties are considered as constants throughout the analysis. The mesh is imported to Ansys-Fluent and then the domains are initialized. The boundary conditions and the interface cylinder, fins, ethylene glycol and air are set in the solver. The top and bottom of the cylinder surface are assumed to be adiabatic as it is insulated as per the experiment. The ethylene glycol domain is initialized at a temperature of 423 K as the initial temperature of the domain as per the experiment. The heat transfer takes place due to natural convection and conduction up to 393 K so that the fins and cylinder can be initialized with some higher temperature value than ambient temperature. After the temperature reaches 393K air at inlet velocity of 0 km/h is passed over the cylinder and fins. The heat release from ethylene glycol from 393K after a time period of ten minutes is calculated.

Results and Discussion

It is observed from the CFD result that it takes 174.08 seconds (pitch=10 mm) and 163.17 seconds (pitch=20 mm) for the ethylene glycol domain to reach the temperature of 423 K to 393 K for initially. After this initial heat transfer, the heat transfer is occurred up to a time period of 600 seconds. The experimental results shows that the value of heat release by the ethylene glycol through cylinder and fins of pitch 10 mm and 20 mm are about 28.5 W and 33.90. The heat release from the cylinder was obtained by multiplying the heat capacity of the heat storage liquid by the difference between 120°C and the temperature after 10 minutes.

Heat release, $Q = mc_p\Delta T$

Where, m = mass of the heat storage liquid, in Kg, c_p = specific heat capacity of ethylene glycol, in J/kg/K, ∇T = change in temperature after 10 minutes, in K.

Thus the numerical result by CFD analysis is calculated and the heat release from ethylene glycol is found to be 30.02 W for a fin pitch of 10 mm and 36.22 W for a fin pitch of 20 mm. It is seen that by increase in fin pitch there is an increase in heat release. The temperature distribution profile of whole assembly in the sectional front view is shown in figure 9 and 10. From the figure it is seen that the maximum temperature of the ethylene glycol is reduced from 423 K to 415 K after 774.08 seconds and the average temperature of ethylene glycol is 369.7236 K which is simulated from the CFD result. The temperature of air, cylinder and fins which are at ambient temperature is also increased from 298 K to 328 K which conforms the heat transfer physics.

Conclusion

From figure 9 it is seen the heat release by both experimental work and our CFD work is approximately the same. Therefore, in this present work, the heat transfer characteristics of the heat storage liquid by aluminium cylinder with six numbers of fins having a pitch of 10 mm and 20 mm are found. As our CFD results are mostly as same as that of the experimental results, it is possible to modify the fin geometry and predict those results. Changes like tapered fins, providing slits and holes in fins geometry can be made and the optimization of fins can be done with the help of CFD results.

Acknowledgement

I thank my professor Dr. R.Thundil karuppa raj for the support he gave for my research work. I also thank VIT university chancellor, my parents, sisters and friends.

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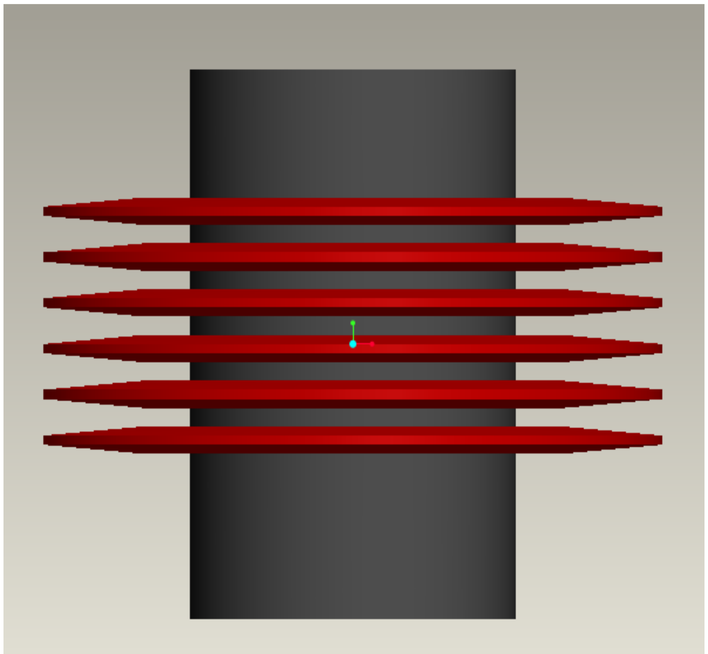

Figure-1
Assembly of the fins (6nos) with a pitch of 10mm along with the cylinder

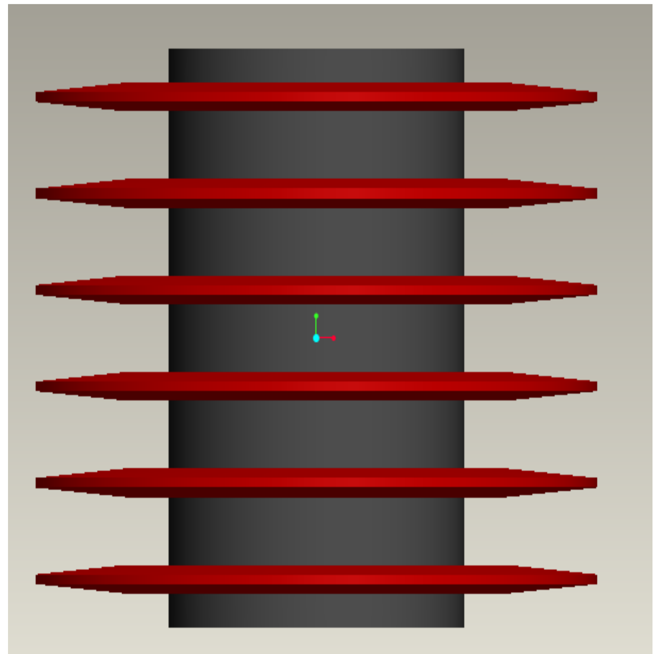

Figure-2
Assembly of the fins (6nos) with a pitch of 20mm along with the cylin

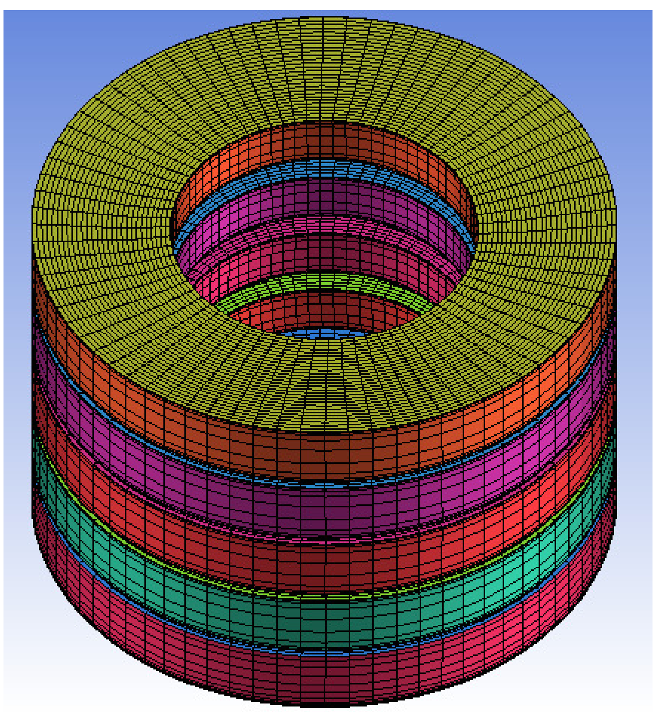

Figure-3
Mesh of air domain in between the fins

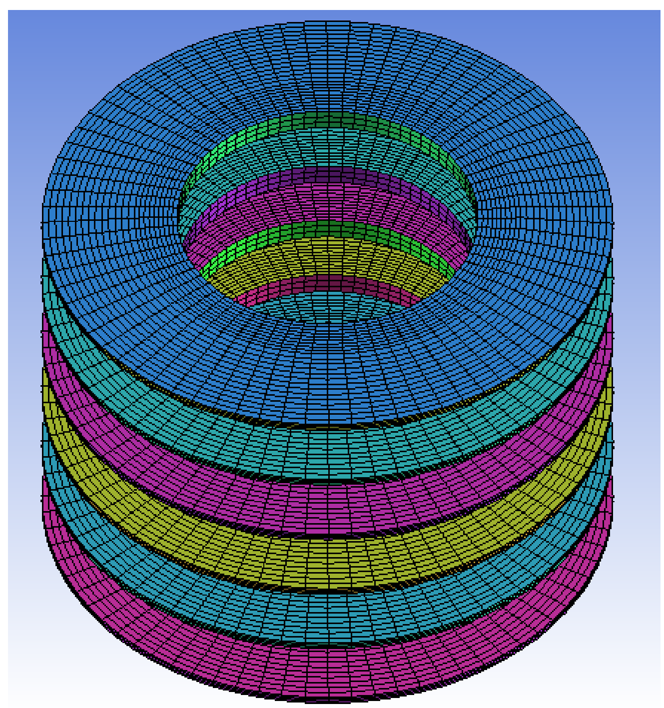

Figure-4
Mesh of fins (6-nos)

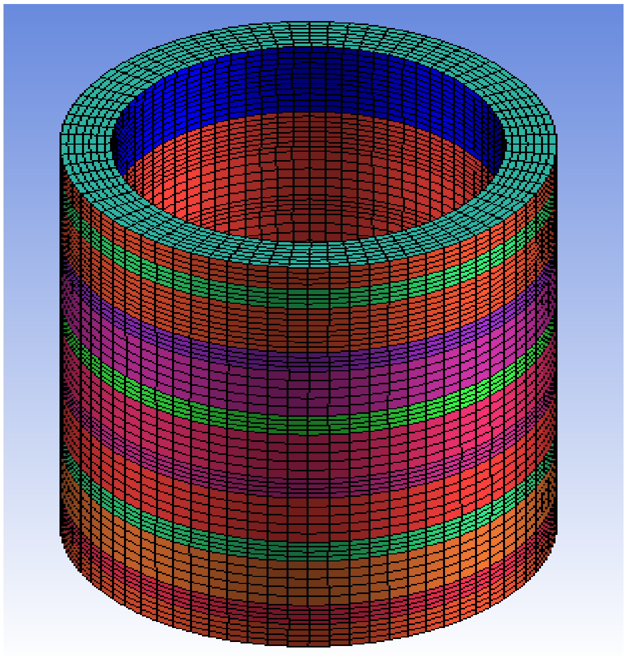

Figure-5
Mesh of Aluminium cylinder

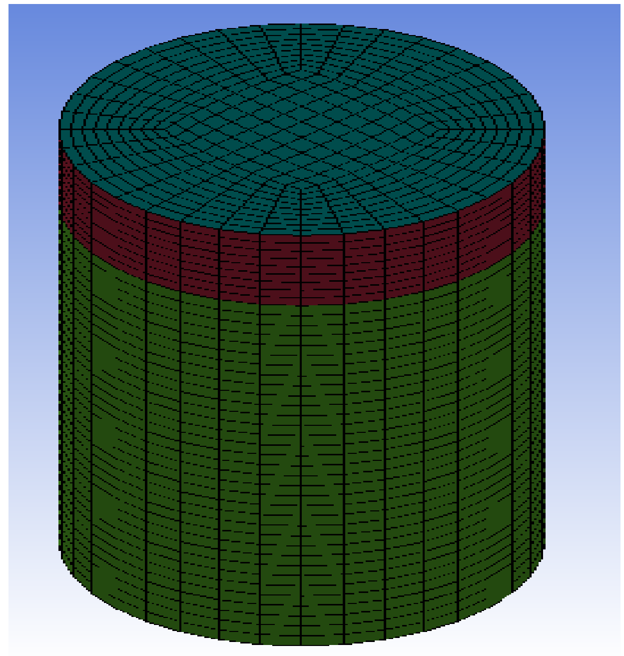

Figure-6
Mesh of Ethylene glycol domain

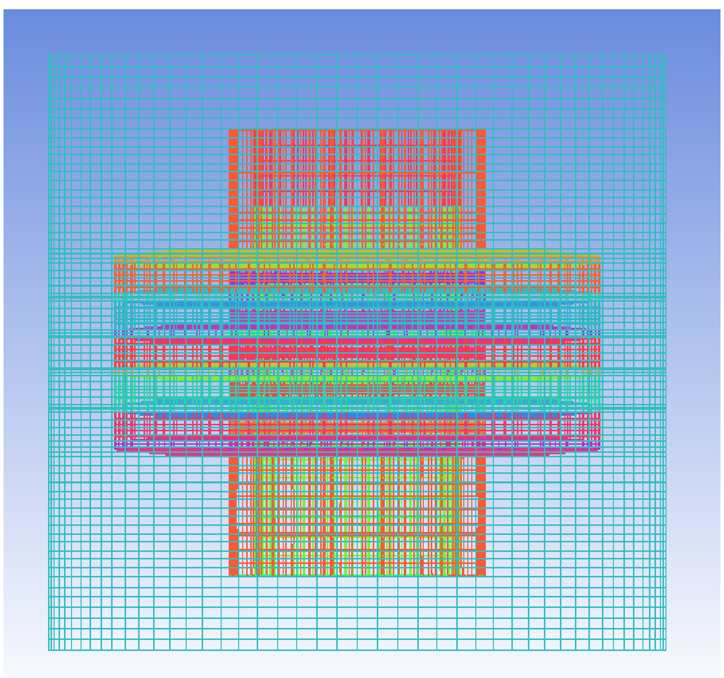

Figure-7
Wireframe front view of assembly mesh (cylinder, air domain, ethylene glycol and fins)

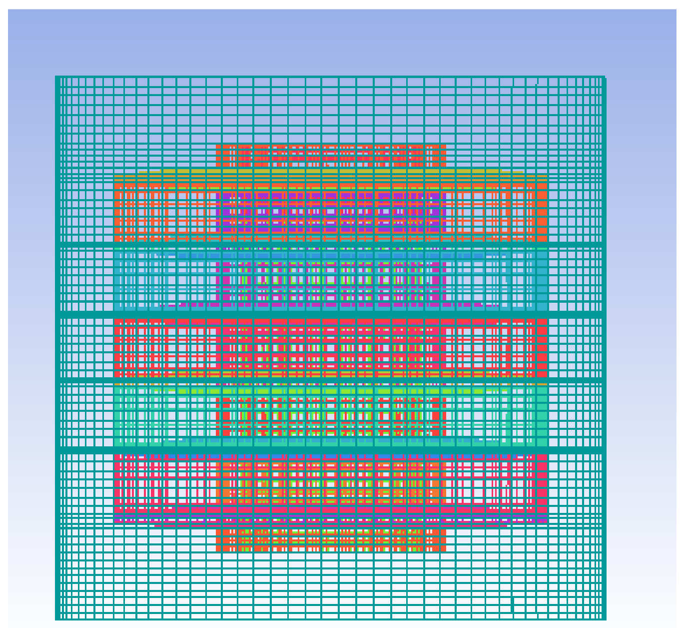

Figure-8
Wireframe front view of assembly mesh (cylinder, air domain, ethylene glycol and fins)

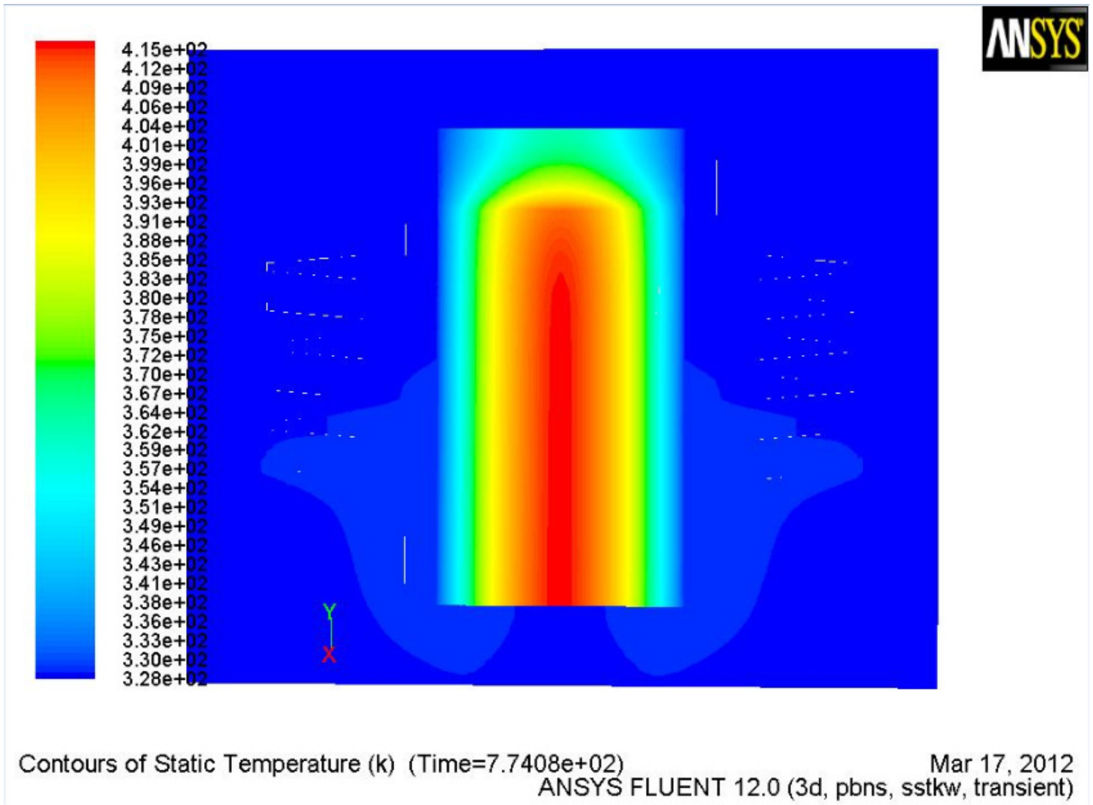

Figure-9
Temperature distribution of the sectional view of whole assembly (pitch=10 mm) simulated by ANSYS-FLUENT

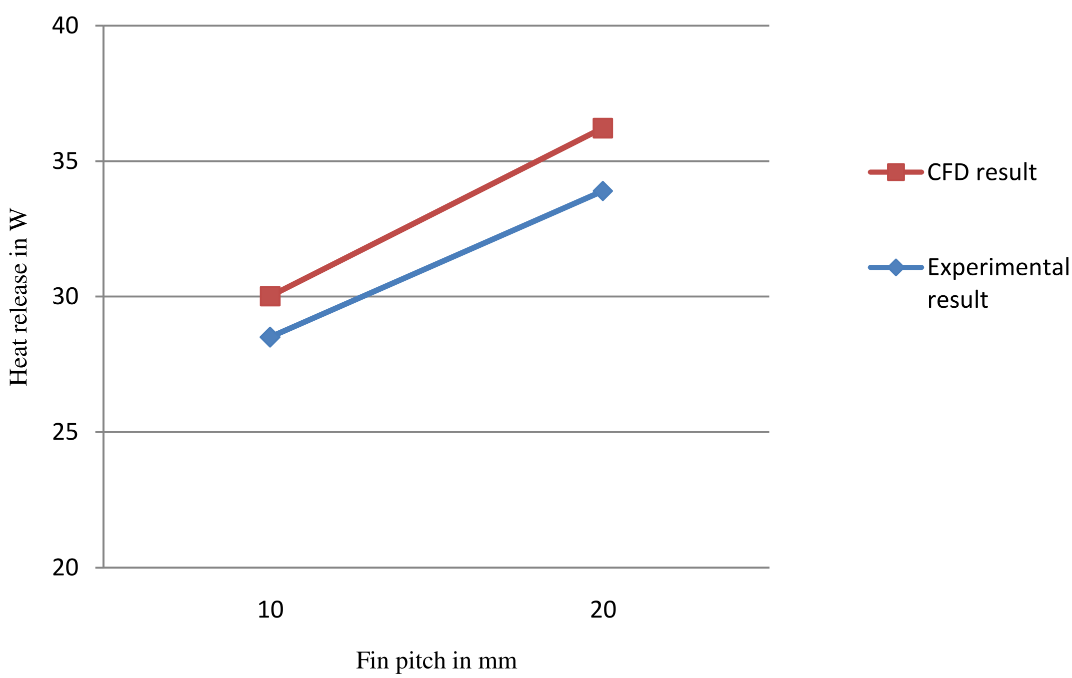

Chart-1
Comparison between experimental and CFD results