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Thermal Analysis of Vertical Heated Cylindrical Surface Employing V - Shape Fin Surfaces

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Abstract

Natural convection is an important and economical mode of heat transfer .It is used in many of the engineering applications such as cooling of electronic components, cooling of Printed circuit boards, HVAC & R, I.C. engines fins, radiators of automobiles etc. Some of these heat sinks are cylindrical in shape. The heat that is produced in such system that conducts through the walls surfaces is need to be continuously dissipated to the surrounding atmosphere to keep the system in steady state condition. More quantities of heat have to be dissipated from small area as heat transfer by convection between a surface and the fluid surroundings. It can be improved by attaching fins or by use of some form of extended surfaces. V shape fin geometries have been selected for cooling such cylindrical surfaces or heat sinks. Initially the dimensions for the vertical cylinder with array of v shape fins have been obtained. Computational analysis of array of v shape fins over vertical heated cylinder have been studied by using Ansys software. The results reveal that the 60-degree V-shaped fins exhibit the highest natural convection heat transfer coefficient, owing to their streamlined flow-promoting characteristics. These V-shaped fins act as flow turbulators, causing minimal air obstruction and, consequently, enhancing heat dissipation. The computational findings are further validated by comparing them with analytical results, affirming the effectiveness of this approach in improving heat transfer from cylindrical surfaces. This research contributes to the understanding and optimization of natural convection heat transfer in cylindrical systems utilizing V-shaped fins, demonstrating its potential for enhancing thermal performance in various engineering applications.

Keywords: Finite element analysis, vertical heated cylinder, computational fluid dynamics (CFD) analysis, thermal analysis,v-shape fin.

1. Introduction

Heat is a form of energy. Natural convection, an intrinsic mode of heat transfer driven by density variations in a fluid, holds significant importance in various engineering applications. Its cost-effectiveness and efficiency make it a vital component in the realm of thermal management, particularly in scenarios where heat dissipation is critical. Heat sink are widely used in electronics, automobile, mechanical, chemical, nuclear, solar, friction industry. Fins are the extended surfaces used to remove heat from heat generating devices, different shape of fins are used in practical applications such as pin fins, trapezoidal profile, rectangular, annular fins. Shape of fins plays important role in heat transfer, so analysis is done on V-shape. Many researchers studied parallel & radial fins for better heat transfer results. Sujan et al. [1] experimented on C & V shape fins and compare results, Shah et al. [2] experimented on split fin pattern and V fin pattern they obverse that V fins pattern has best effectiveness value, Senapati et al. [3] conducted experiment on heat transfer with vertical cylinder with annular fins by varying the Rayleigh number (Ra), Shah et al. [4] did analysis on CFD transient thermal by using different materials and compare their results and they found that aluminium 6061 has better heat dissipation properties, Jang et al. [5] analyzed LED bulb as a heat sink with fins and they observed that as the angle of inclination increased, the plate fins blocked the upward air flow; thus, stagnation points and flow separation appeared. Roy et al. [6] have completed experiment of CFD analysis on inclined plate fins and they observed that, the values of induced velocity tend to increase with the increase in inclination due to chimney effect, as the inclination increases from 30° to

60°, overall Nusselt number increases by 40–60%. Lee et al. [7] did experiment on cooling of electronics equipments. In this experiment they analyzed fins at various inclination angle and observed that the optimal thermal resistance of the cylinder with inclined fins is 30% lower than that of the cylinder with radial plate fins. Zhang et al. [8] conducted experiment on W type fins and observed that the cooling effect of the W-type finned heat sink is much better than the optimized parallel plate finned heat sink. Sun et al. [9] did experiment on vertical cylinder heat sinks with longitudinal fins. They observed that, Nu number are almost independent of fin height. Edlabadkar et al. [10] conducted study on single v-type partition plate and they observed that the computational analysis done so far confirms the experimental analysis done earlier well within the 10% variation and concluded that V-fin performs better than vertical fin and horizontal fin of the equal dimensions. Sable et al. [11] did experimentation on vertical cylinder with multiple V fin array and they observed that 60^0 shape of V fin array gives better performance over vertical plate. As per the Literature review, it is observed that during the heat flow on horizontal as well as on vertical surfaces through fins, development of thermal boundary layer around the fin takes place. Due to this boundary layer, less heat transfer occurs which is ineffective. Obstruction's to the air flow takes place. To improve heat transfer and air circulation around the surfaces and fin, it was planned to use V- Shape fins on vertical heated cylinder. Already V shape fins found very effective on various other surfaces. The V fin acts as a flow tarbulators so it gives better cooling and effective heat transfer.

2. Development of CAD model for V shape fins over cylindrical surface

2.1 Equations Used for Developing CAD Model and analytical analysis.

(i) Mean film Temperature : -

$$Tf = \frac{Ts + Ta}{2} \quad (1)$$

(ii) Rayleigh Number [12]: -

$$\mathrm{Ra} = \frac{\mathrm{g} \times \beta \times (\mathrm{Ts} - \mathrm{Ta}) \times \mathrm{L}^3 \times \mathrm{Pr}}{\vartheta^2} \quad (2)$$

Where,

g= Acceleration due to gravity (m/s^2)

β= Volume expansion coefficient (1/k)

L= Characteristic length (m)

P_r= Prandtl number

(iii) Nusselt Number : -

$$Nu = \frac{0.67 \times Ra^{0.25}}{\left[1 + \left[\frac{0.492}{Pr}\right]^{\left(\frac{9}{16}\right)}\right]^{\left(\frac{4}{9}\right)}} \quad (3)$$

Where,

Ra = Rayleigh number

Pr = Prandtl Number

(iv) Nusselt Number [12]: -

$$Nu = \frac{h.L}{k} \quad (4)$$

Where,

h = Heat transfer coefficient

k = Thermal conductivity

L = Characteristic length

2.2 Geometry of CAD Model.

CAD model was being developed as shown in fig. 2.1 in SOLIDEDGE 2019 version. It gives basic idea of shape of cylinder and fins. Calculation of optimum fin spacing was also carried out.

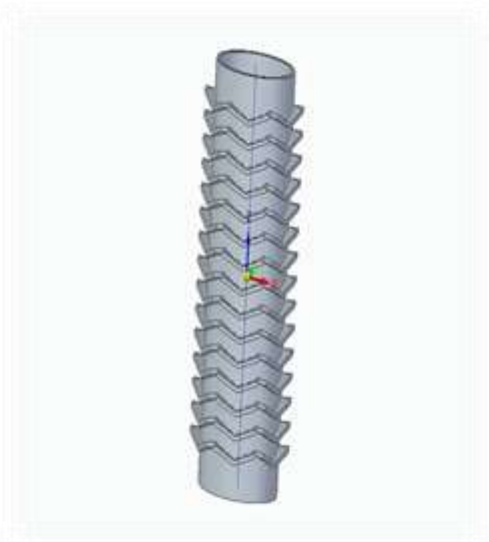

Fig: 2.1. Demo Shape of CAD Model in Solid Edge Software

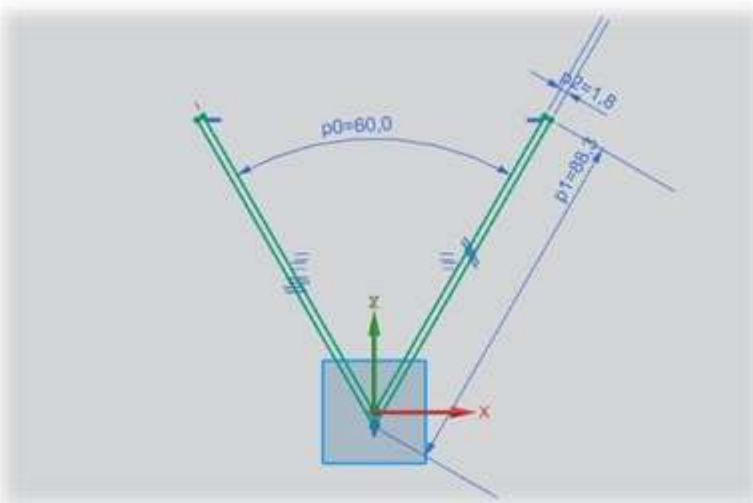

Fig. 2.2 CAD model development in the initial stage

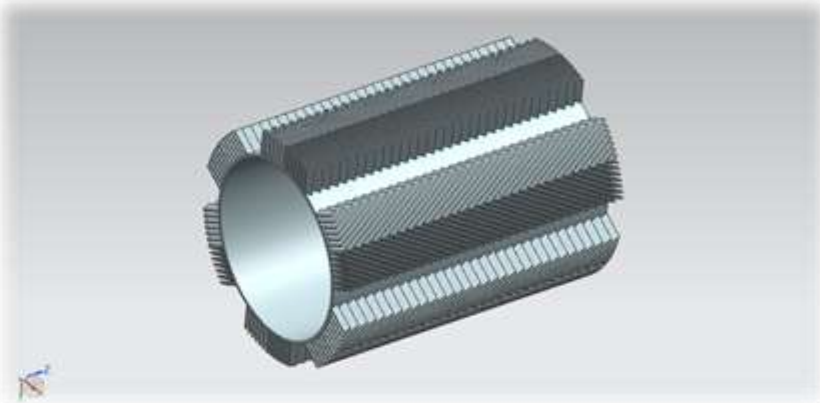

Fig.2.3. Vertical Cylinder with V-Shape Fins 3D View

The above model of heat sink is developed in NX 12.0 software and heat source is applied at inlet hollow portion of cylinder and fins are extended outside of cylinder .The angle of V-shape fin was 60^0, gap between to fins array were 18.6 mm, surface area of cylinder exposed to fluid domain were 2116237.22 mm^2. Following were the dimensions of V-shape heat sink model.

Table 2.1 Dimensions table of V-shape fins

Dimension	Values
External Cylinder Diameter	208 mm
Internal Cylinder Diameter	205 mm
Cylinder Length	353 mm
Fin Height	55 mm
Fin Thickness	1.8 mm
Fin Length	176.5 mm
Pitch Angle	60 degree

3. CFD ANALYSIS OF CYLINDERICAL SURFACE WITH V FIN.

The generated CAD model imported to Ansys geometry in ".igs" format for next process like making fluid domain, meshing, boundary conditions, Pre-processing, post-processing etc. as shown in fig 3.1.

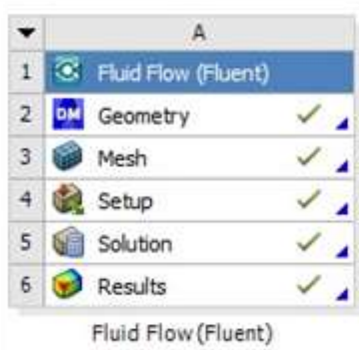

Fig. 3.1 Steps of CFD analysis in Ansys Fluent

3.1 Meshing.

Initially geometry is imported to Ansys software for meshing. We used very fine mesh for better accuracy of results. We took fine mesh with resolution of 6 and adaptive mesh option is selected. Smoothing is selected as medium and skewness was in between 0 to 1. The quality of mesh was selected. This fluid domain was discretized in finite no. of parts. Generated mesh for fluid domain same as for cylinder. The quality of the mesh could be checked by selecting mesh quality and kept the default parameters. For this model minimum of quality is 0.66 and maximum is 1. On the given number of nodes and element ,the solver solves the equations which is shown. in fig. 3.2

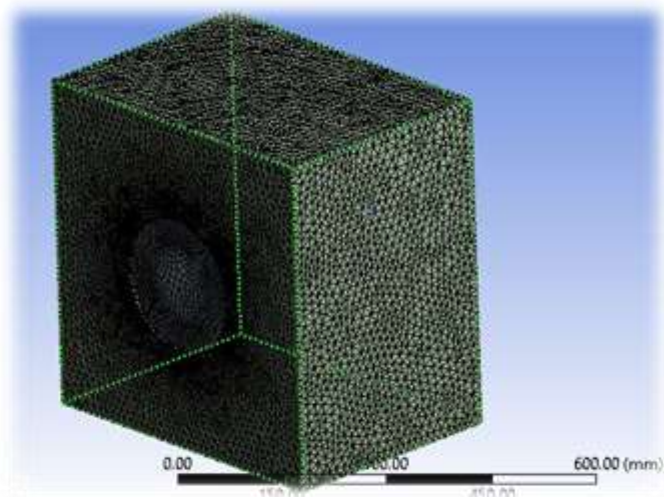

Fig. 3.2 Meshing of fluid domain

3.2 Pre – processing.

The model was imported in ansys where the different domains are created such as solid domain of cylinder with fins, fluid domain where the fluid is flowing over the cylinder. The precautions was taken for fluid must be covering all sides of model. After generation of this domain we set boundary conditions such as fluid flow inlet, fluid flow outlet, no sleep walls, sleep walls and contact regions between both domains of fluid and solid where the solver will solve heat transfer equations.

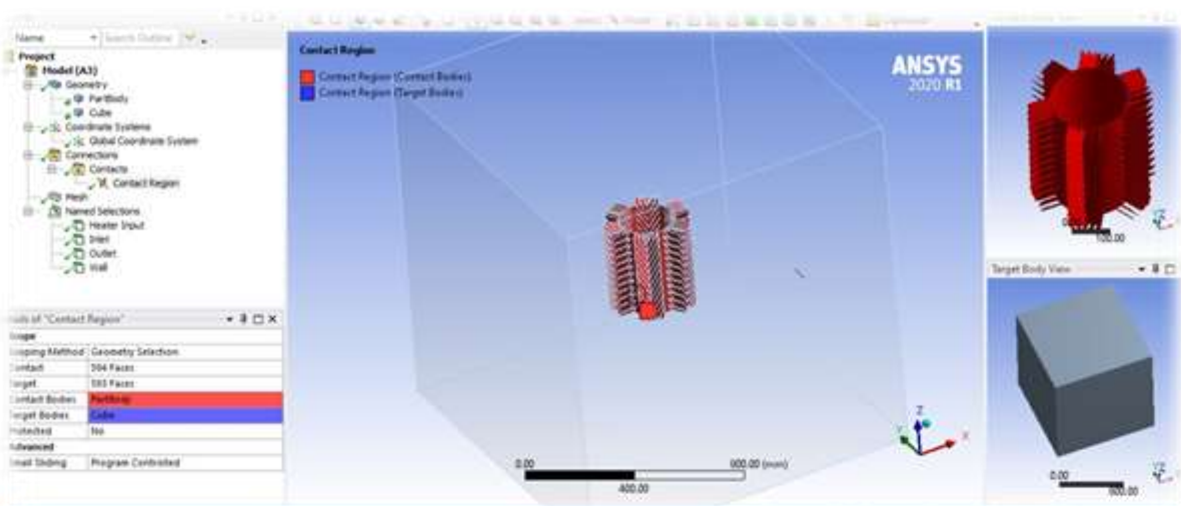

Fig. 3.3 Boundary conditions and contact region

As shown in fig. 3.3 the names were given to the various regions, heater input, inlet, outlet, and walls. Selected type of solver is pressure based, then selected velocity formulation type is absolute. Choose steady state analysis in which the time is constant.

Gravity in Z direction which is -9.81.Turned on the energy option which initiates energy equation. Specified model is viscous model for better heat transfer result. To initiate momentum equation by K-omega model. In K- omega model SST model is selected which shows better results of heat transfer. We selected aluminium 6061 as a metal with density 2719 kg/m^3, specific heat 871 j/kg-k, thermal conductivity 202.4 w/m-k. For fluid domain air as fluid with density 1.225kg/m^3,specific heat 1006.43 j/kg-k, thermal conductivity 0.0242 w/m-k, viscosity 1.7894×10^{-05} kg/m-s have been selected. Velocity of air at inlet set as 1 m/s and temperature is 300 k. At outlet pressure outlet is selected, which shows that incoming mass is equal to outgoing mass and temperature at outlet is 300 k. Heat flux of 1000 w/m^{2}k were provided. Wall thickness was 0.1.We set this temperature at inner side of cylinder so that heat will be flowing from inside of cylinder to outside fluid. In solution methods simple method and is solution controls all default condition are set for better accuracy. We did hybrid initialization of solution. Scaled residual results are shown in fig. 3.4.

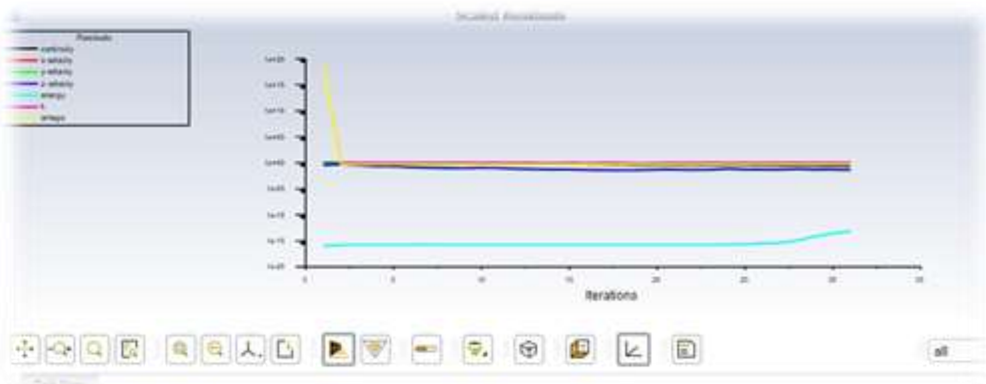

Fig. 3.4 Scaled residuals

3.3 Post processing.

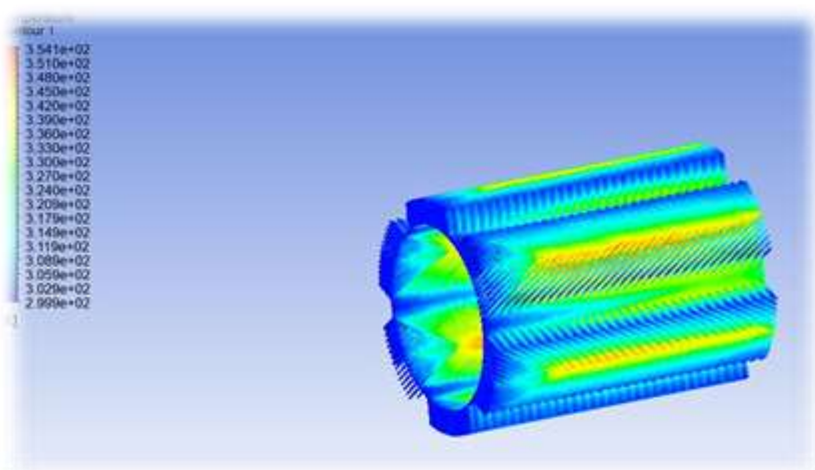

Fig. 3.5 Temp. contour of cylinder with V fins

As shown in fig. 3.5, It was observed that maximum temp. of 354 K (81 degree cel.) and minimum temp is 300 K which is ambient temp. of fluid. From this contour it was also observed that at middle portion of fin temperature is maximum and at the corners temp. is low, it also indicates that V- shape fins has better surface to air contact and it help to increase heat transfer by convection. The natural convection heat transfer coefficient obtained from the temperature contour and by newton's law of cooling is 7.94 $W/m^{2o}c$. It shows that this value is closely approximated with analytical results.

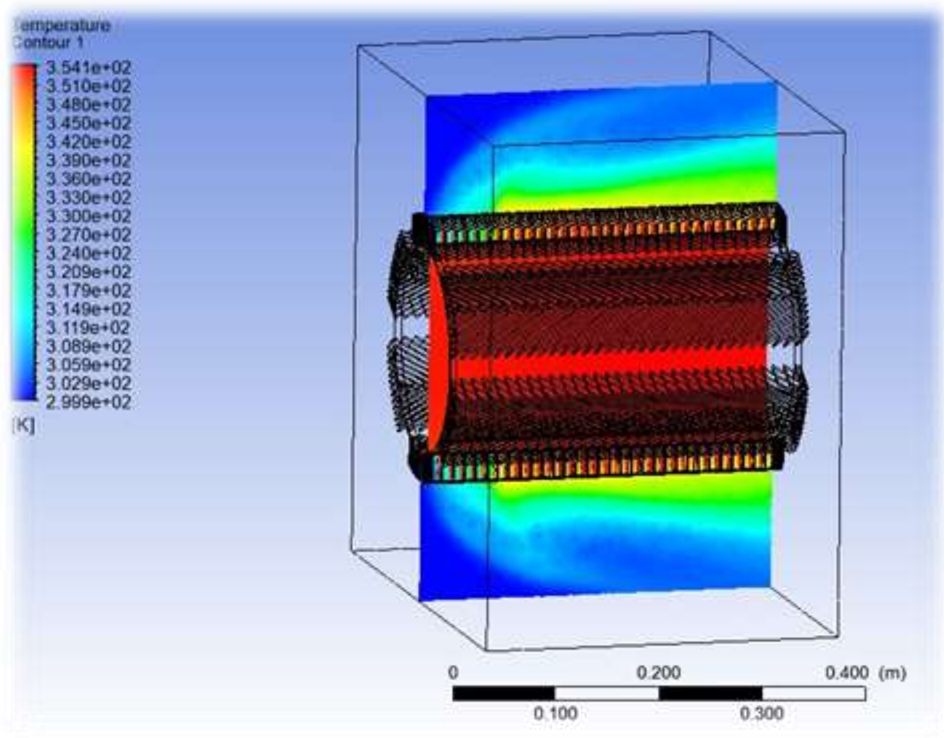

Fig. 3.6 Temperature contour of fluid domain

Fig. 3.6 shows the fluid enters from left side where the heat transfer is maximum. Air enters at 1 m/s velocity and at 300 K temp. and comes in contact with fins and cylinder. The results were obtained of natural convection heat transfer like at the outlet of cylinder observed maximum temp. of air of 340 K. At the centre of cylinder maximum temp.is seen. Its due to the applied heat source at cylinder and we restricted fluid flow from inside of cylinder. Fluid only comes in contact with cylinder at outer surface. At all sides of fluid domain we set slip wall boundary condition it shows that at all sides of fluid domain there is free stream velocity which gives a better temp. distribution than no sleep wall. Hot air goes in upward direction as the temp of fluid increases its density decreases so it goes in upward direction. The velocity contour where air enters at a velocity of 1 m/s and leaves the domain at right side. It is observed that at the inlet velocity is disturbed and it suddenly goes away from cylinder. From this contour it is observed that there is no back flow of air, air is well circulated on cylinder and it also seen that there is better air and surface contact. V- shape fins gives better circulation of air on object. At contour scale one can see the velocity values at different locations. The fluid flow is laminar but only at middle portion of cylinder some turbulence effects is observed. Heat losses are also considered.

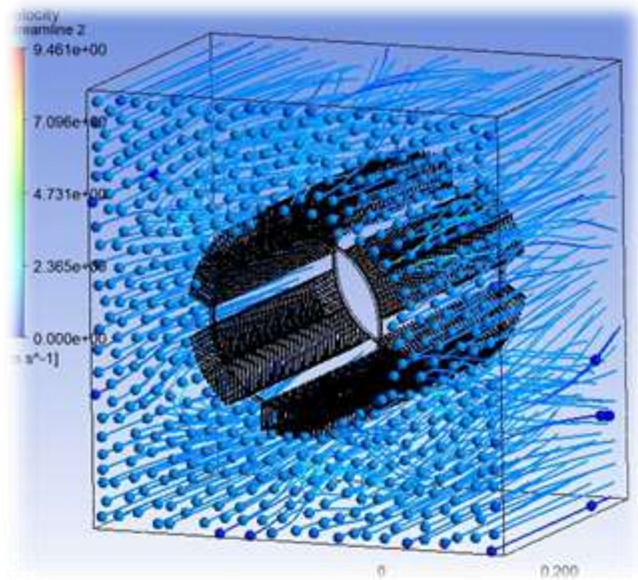

Fig. 3.7 Stream lines of fluid flow

Fig 3.7 shows fluid flow is uniformly distributed throughout the domain. At some point eddies are formed at middle portion of cylinder. It shows V-shape fins gives better circulation of air.

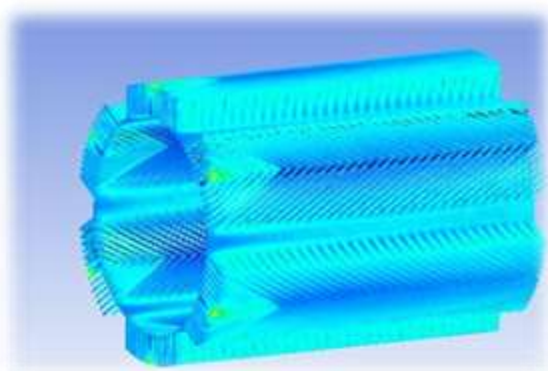

Fig. 3.8 Heat transfer coefficient contour

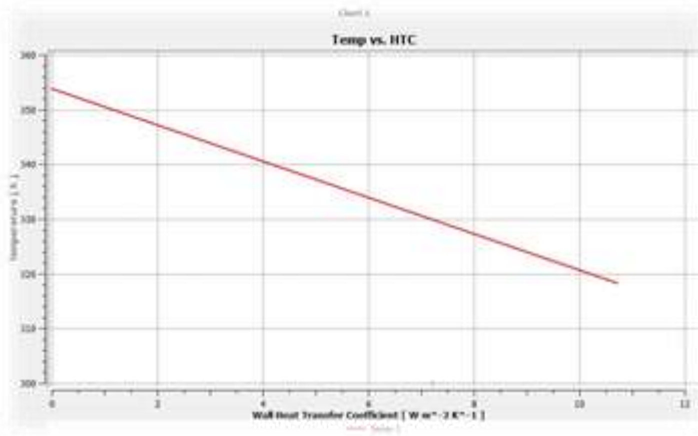

Fig. 3.9 Heat Transfer Coefficient

From the figure 3.8 it is observed that the heat transfer coefficient on cylinder is constant throughout the cylinder surface. We also studied the heat transfer coefficient & temperature relations. The temp.vs heat transfer coefficient graph shows the maximum heat transfer coefficient (HTC) of 11 w.m^2/k was obtained. As the temp. increases heat transfer coefficient decreases which is shown in fig. 3.9. From the literature similar results were obtained.

4. CONCLUSION & FUTURE SCOPE.

From the present simulation following conclusions are drawn and also mentioned few some points about future scope for heat sink by using V- shape fins:

4.1 Conclusion

Because of the use of V- shape of fins over the heated vertical cylinder, better heat dissipation is obtained. V shape of fin over the cylindrical base acts like flow turbulator or flow separator. Heat transfer coefficient is increased. It is observed that at the middle portion of V fin minimum heat transfer coefficient and at outer side maximum heat transfer coefficient. From the temp. Contour it is found that at the middle portion of V- shape fin maximum temp. was observed. From inlet to oulet of domain fluid temperature was uniformly distributed throughout the domain. From the velocity stream lines, the maximum velocity obtained over the present model is 9.41 m/s. For validation, the computational results are compared with analytical results and found similar trends. Eddy's are formed in middle portion of fluid domain. It is also observed that air and solid body contact is better than annular or pin fin.

4.2 Future scope

Experimentation can be done for the present computational model. In the present computational analysis aluminum material is used but for further improvement in heat transfer coefficient copper material may be used. This V-shape fin configuration can be used over LED bulbs, electronic components, I.C. engine cylinders as a further work. The same computational model may be tested for different boundary conditions and turbulence model.

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