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Thermal Analysis of Natural Convection in A Pipe

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Abstract— The aim of this work is to make a thorough study of natural convection from a heated pipe having fins of various configurations using ANSYS WORKBENCH. The material under consideration is aluminum and the free stream fluid is air. The heat transfer rate from the fins, outer wall and the overall heat transfer rate has been calculated and compared for various fin configurations. The surface Nusselt number and surface overall heat transfer co-efficient has been found out. Temperature contours for various fin configuration has been plotted showing the convection loops formed around the heated pipe surface. Velocity contours for various fin configurations has been plotted and the motion of heated fluid is shown. Path lines were also drawn indicating the path of the heated air molecules along their flow .The Nusselt number and heat transfer co-efficient plots are also shown. The assumptions during the analysis have been taken considering the manufacturing and practical applications and working conditions. Hence the results obtained can be referred to while solving any such kind of problems in the practical field where only natural convection is under consideration. After comparing it is shown that we can find that the best configuration for this type of convective heat transfer of a heated pipe is a TRAPEZOIDAL fin as they have the highest total heat transfer rate.

Key words: Natural Convection , Heated Pipe , ANSYS WORKBENCH , Fins , Nusselt Number , Overall Heat Transfer Coefficient , Temperature & Velocity Contours

I. INTRODUCTION

Heat exchangers are widely used in various, transportation, industrial, or domestic applications such as thermal power plants, means of heating, transporting and air conditioning systems, electronic equipment and space vehicles. In all these applications improvement in the efficiency of the heat exchangers can lead to substantial cost, space and material savings. The referred investigation includes the selection of fluid with high effective heat transfer surfaces made out of high conductivity materials, high thermal conductivity and selection of their flow arrangements. In the present work only single phase steady state natural convection technique has been considered.

The heat transfer enhancement methods reported in publications be summarized in many forms but primarily they may be grouped as active enhancement methods. The most effective heat transfer enhancement can be achieved by using fins as elements for the heat transfer surface area extension. Plate fin rotary regenerators and tube fin are widely encountered compact heat exchangers across the industry. Here the area of interest is the tube fin configuration. These are built as a combination of tubes with various cross sections with fins present both outside and inside the tubes. The common form of the tube cross-section is round or rectangular, but elliptical cross-sections are also encountered. Fins are generally attached by means of tight mechanical fit, adhesive bonding, soldering, brazing, and welding or by extrusion. Depending upon the form and direction of the fins, the tubes may be classified as individual tube with normal fins, individual tubes with longitudinal fins or tube arrays with plain, wavy or interrupted external of internal fins. The Heat Transfer through these fins is done by natural Convection.

Convection is a process which involves mass movement of fluids. Natural convection occurs due to temperature difference which produces the density difference which results in mass movement, this process is called natural or free convection.

Convective heat transfer is the transfer of heat from one place to another place by the fluid movement. Convection is usually occurred in liquids and gases. The causes of convection can be described as either natural (free) or forced convection. The difference between natural and forced convection is important for heat transfer through convection. The main cause of Natural convection or free convection is due to temperature differences which affect the density and the relative buoyancy of the fluid. Heavier components move down while the lighter components rise which leads to fluid movement. Hence gravitational field plays an important role in natural convection. The examples of natural convection is the rise of smoke from a fire, boiling water in the pot in which the hot and less dense water from the bottom layer moves downward and the cool and high dense water moves upward to the top of the pot. Natural convection will occur due to variation in density between the two fluids, the acceleration due to gravity that drives the convection to a larger distance through the convection medium. The convection can be determined by the Nusselt Number(Nu).

A. Nusselt Number (Nu):

In heat transfer at a boundary (surface) within a fluid, the Nusselt number is the ratio of convective to conductive heat transfer across (normal to) the boundary. In this context, convection includes both advection and conduction. It is a dimensionless number. The conductive component is measured under the same conditions as the heat convection but with a (hypothetically) stagnant (or motionless) fluid.

The Nusselt number represents the enhancement of heat transfer through a fluid layer as a result of convection relative to conduction across the same fluid layer. The larger the Nusselt number, the more effective the convection. A Nusselt number of Nu=1 for a fluid layer represents heat transfer across the layer by pure conduction.

B. Extended Surfaces:

Convective heat transfer is governed by the relation

$$Q = h A (T w – T00)$$

To increase the heat transfer rate the following ways can be adopted

- Increasing heat transfer co-efficient (h). However increasing the value of h does not significantly influence the value of Q.
- Surrounding fluid temperature (T00) can be decreased. But it is often impractical as in most cases the surrounding is atmosphere.
- Hence the only way is by increasing the surface area across which convection occurs

The increase in cross sectional convection area can be achieved by using fins that extend from the wall of the convection shell. The thermal conductivity of the fin material has a very strong effect on the temperature distribution across the wall of the convection shell and thus the degree to which the heat transfer rate is enhanced.

Various types of fins are usually used:

- Straight fins of uniform cross section
- Straight fins of non-uniform cross section
- Annular fins
- Cylindrical fins
- Pin fins

C. Design Calculations:

The design of fins is based on different parameters like minimum weight maximum surface area etc. The fin with minimum weight is chosen among the different possible cases.

D. Boussinesq Equation:

Equations governing natural convection:

CONTINUITY EQUATION : $\delta u/\delta x + \delta v/\delta x = 0$

MOMENTUM EQUATION : $\rho CP(u \delta u/\delta x + v \delta u/\delta y) = -\rho g – \delta p/\delta x + \mu \delta^2 u/\delta y^2$

ENERGY EQUATION : $\rho CP (u \delta T/\delta x + v \delta T/\delta y) = K \delta^2 T/\delta y^2$

In natural convection the term – ρg on the right hand side of the momentum equation represents the body force exerted on the fluid element in negative x direction. For the small temperature differences the density ρ in the buoyancy term is considered to vary with temperature whereas ρ appearing elsewhere is constant. This is called Boussinesq approximation.

E. Ansys:

ANSYS is a general purpose software, used to simulate interactions of all Disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic for engineers. So ANSYS, which enables you to simulate tests or working conditions, in the virtual environment enables you to test products before manufacturing of prototypes. Furthermore, Determining and improving weak points, computing problems are probable life and foreseeing possible by 3D simulations in virtual environment.

ANSYS engineering software can work with other integrated CAD and FEA connection on desktop by adding modules .ANSYS can import CAD data and also enables you to build a geometry with its "pre-processing" abilities. Similarly in the same pre-processor, finite element model (aka mesh) which is required for computation is generated. After defining and carrying out ANALYSES loadings, can be viewed as the numerical and graphical results.

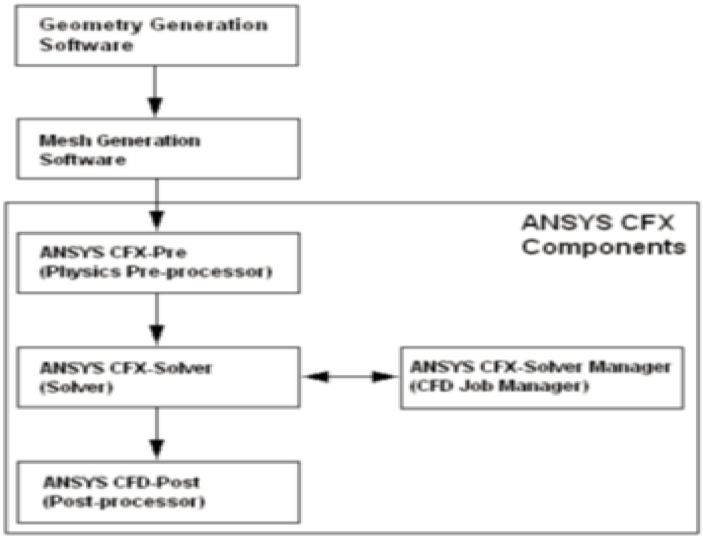

Fig. 1: Block Diagram of ANSYS simulation

II. MODELING AND SIMULATION

A. Modelling:

ANSYS Design Modeller has been used for the creation of Geometries Required.

- Launch ANSYS, by going to the start-up menu and double clicking on workbench file in the ANSYS folder.
- Once the program is launched, go to Analysis Systems Fluid Flow (FLUENT) and double click
- Next Double click on the Geometry. Then Design the required pipe, by seeing along X-Axis
- The cross sectional element of the required figure is drawn, and it is revolved along the symmetrical (Z-Axis) through 3600 making it a closed pipe.
- The required design of the pipe is produced as a result of the Revolution of the cross sectional element
- Various pipe (with fin) configurations have been given below.

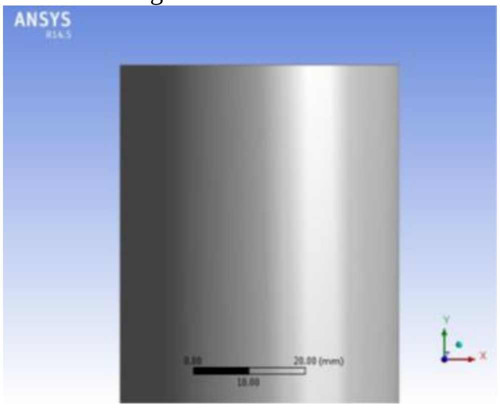

Fig. 2: Vertical Pipe Without Fin

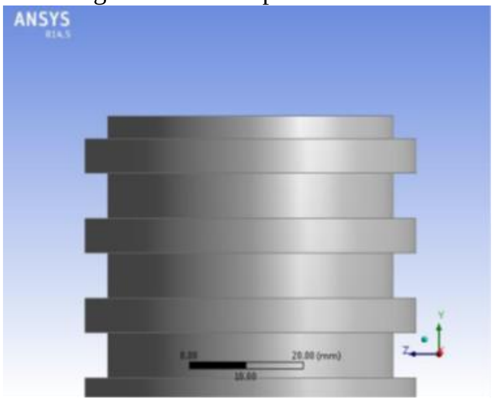

Fig. 3: Vertical Pipe with Rectangular Fin

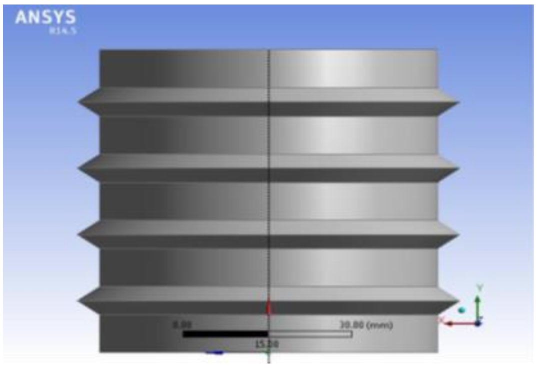

Fig. 4: Vertical Pipe with Triangular Fin

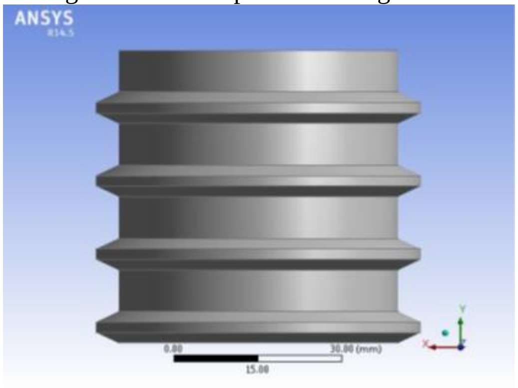

Fig. 5: Vertical Pipe Without Fin

B. Meshing:

The Design Obtained can be meshed using Meshing tool. It is updated so that it can be accessible at any point of time. It is then imported to MESHING system.

Meshing is done in the following manner:

– On Double clicking the meshing window, a new Meshing Opens attaching the designed geometric file.
– Now create the named selections as per the requirement of the model
– Select the MESH option from the outline and make necessary changes.
– In the Mesh Control Option, select Method. Then select the geometry and now change the method to TETRAHEDRONS
– Select UPDATE from the toolbar options. It generates the required Tetrahedral Mesh for further analysis of the designed model.

The Necessary Changes to be made in the outline window are as follows

Solver Preference	Fluent
Relevance Center	Fine
Smoothing	Medium
Initial Size Seed	Active Assembly
Transition	Slow
Span Angle Center	Fine
Use Automatic Inflation	Program Controlled
Inflation Option	Smooth Transition
Active Meshing Method	Tetrahedrons
Mesh Control Method	Tetrahedrons

Fig. 6: Meshing Parameters

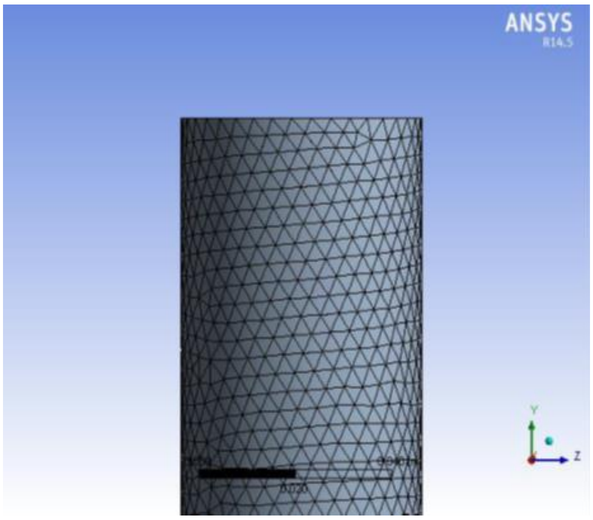

Fig. 7: vertical pipe with meshing

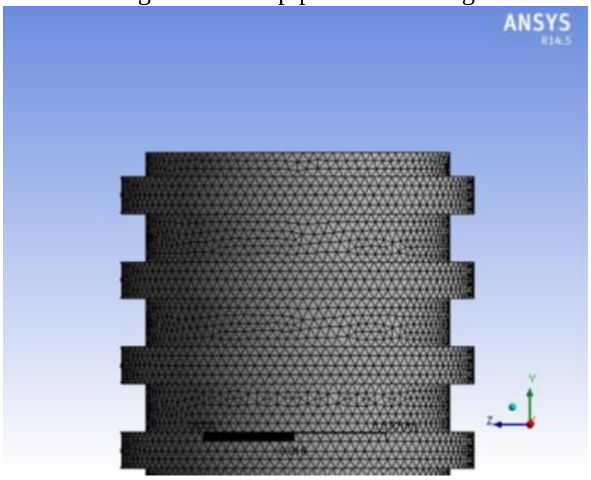

Fig. 8: vertical pipe with rectangular fins after meshing

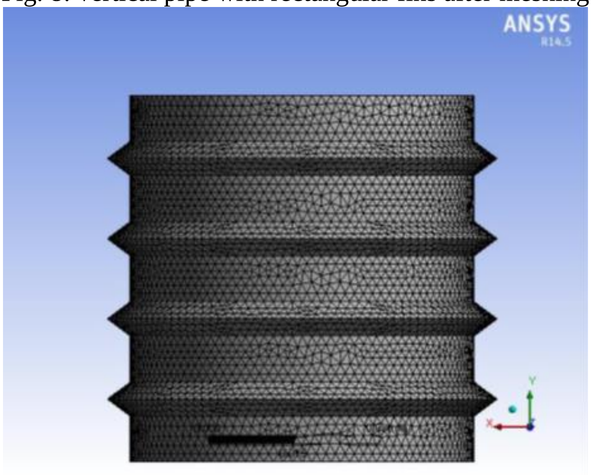

Fig. 8: vertical pipe with triangular fins after meshing

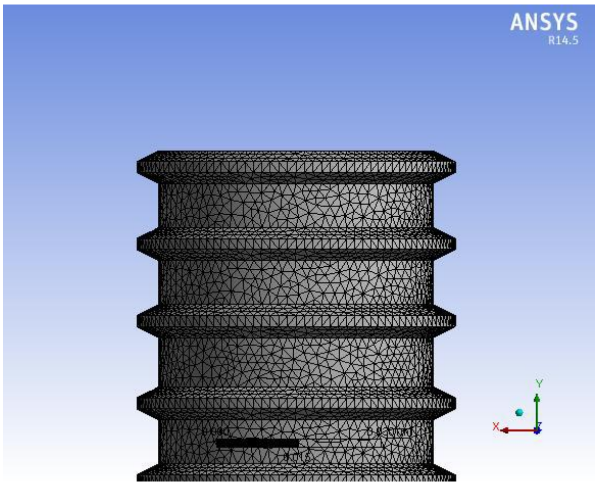

Fig. 9: vertical pipe with trapezoidal fins after meshing

C. Simulation:

- Import the design model, by selecting the update option, once the meshing is finished.
- Now Open the ANSYS FLUID FLOW (FLUENT) solver and select Solution set up in the outline.
- In GENERAL Scale the dimensions, if the required units and the units used to design are not the same.
- In Solver, Select Pressure based solver, set the Velocity formulation to Absolute, and the let the time be steady.
- From the Models Option set the ENERGY EQUATION to ON, and let the model be a Laminar flow model.
- Select the materials used for design. The pipe material is ALUMINIUM and the fluid flowing is free stream Air.
- Let the Cell Conditions be same, without making any changes to the cell zone conditions.
- Now Select the Boundary conditions. Set the conditions by editing all the predefined zones.
- Set the Solution Method as given below, then Initialize the solution to make all the Conditions for analysis ready. After running Calculations for about 100-200 Iterations the solution converges.
- Select the Results Schematic and Plot the difference plots like Temperature Contours, Velocity Contours etc.

Solution methods Used for analysis in Fluent

SOLUTION SCHEME	SIMPLE
GRADIENT	LEAST SQUARE CELL BASED
PRESSURE	PRESTO
MOMENTUM GRADIENT	SECOND ORDER UPWIND
ENERGY	FIRST ORDER UPWIND

Table 1: Solution control

D. Boussinesq Method:

PARAMETERS	VALUES
DENSITY	1.225 Kg/M 3
SPECIFIC HEAT	1006.43 J/Kg K
THERMAL CONDUCTIVITY	0.0242 W/m- K
VISCOSITY	1.7894 e -05 kg/ m-S
THERMAL EXPANSION	0.003334 K-1

III. RESULTS AND DISCUSSIONS

A. Analysis for Tube Without Fins:

Mess statistics and parameters during analysis;	
Physical Parameters	Characteristic
Type of fin	Without fins
Cross section of fin	Circular
External diameter of the pipe	50mm
Length of the pipe	120mm
Free stream fluid	Air
Material for tube and fins	Aluminum
Model for convection	Bousinessq
Tube wall temperature	380K

Free stream air temperature	300K
Mesh Parameters	Values
Messing method	Trapezoid
Relevance sizing centre	Medium
Element size	0.001m
Initial size seed	Active assembly
Smoothing	High
Transition	Slow
Span angle centre	Fine

Mesh parameters of pipe without fins

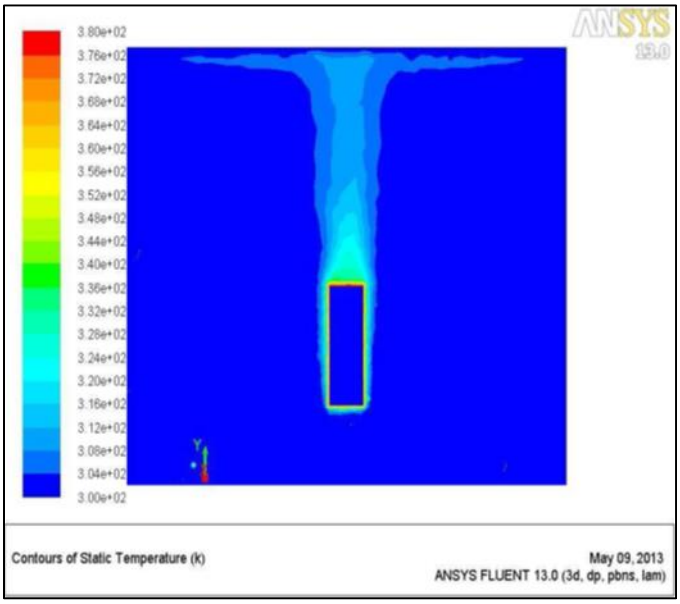

Fig. 10: Temperature contours of the circular pipe without fins

The above fig. shows the temperature contours of the circular pipe without fins, subjected to natural convection. Air flows with a velocity of 2m/s and at a temperature of 300K, and the heated pipe which is at a higher temperature of 380K cools down gradually.

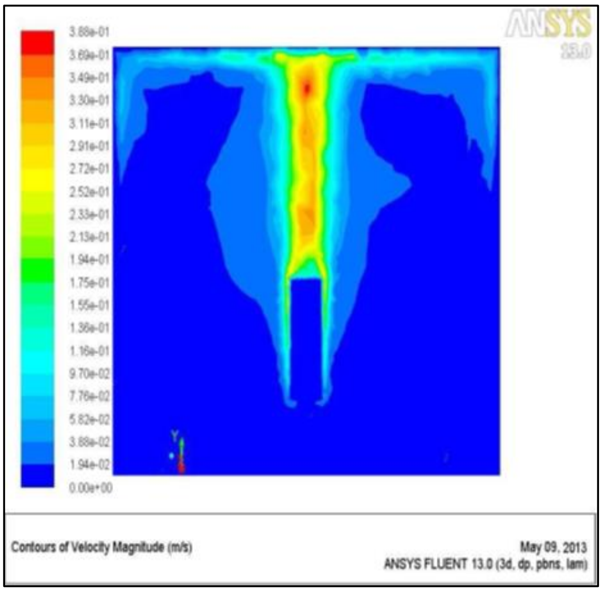

Fig. 11: Velocity Counters Of Circular Pipe without Fins

Fig.11 Indicates the variation of velocity of air due to natural convection heat transfer taking place between the surface of pipe and the ambient air flowing along the surface of the pipe

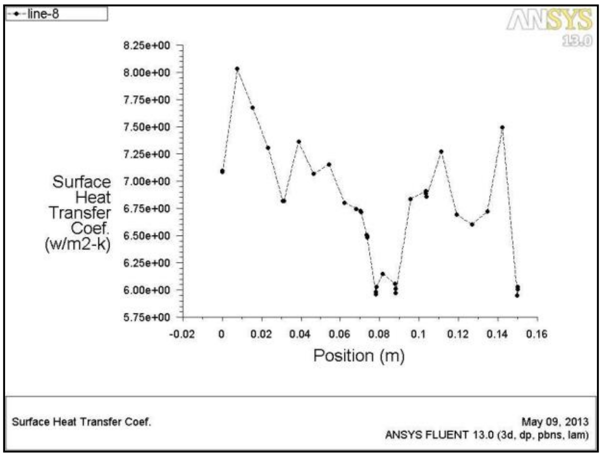

Fig. 12: Variation of Surface heat transfer coefficient along the length of the pipe

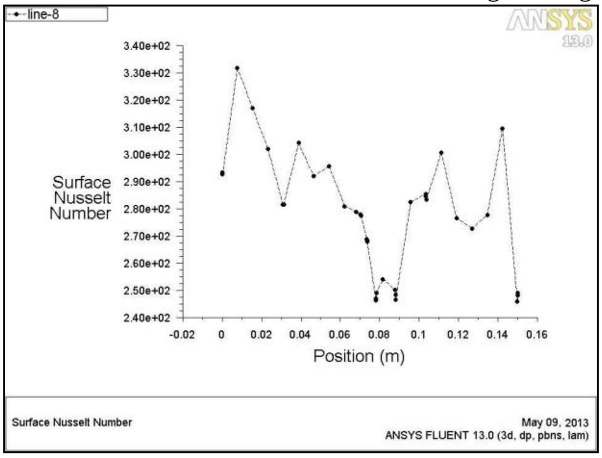

Fig. 13: The variation of Surface Nusselt number along the length of the pipe

B. Analysis for Tube With Rectangular Fins:

Mess statistics and parameters during analysis;	
Physical parameters	Characteristic
Type of fin	Rectangular Base-6mm, Width-5mm
Cross section of fin	Circular
External diameter of the pipe	50mm
Length of the pipe	120mm
Free stream fluid	Air
Material for tube and fins	Aluminum
Model for convection	Bousinessq
Tube wall temperature	380K
Free stream air temperature	300K
Mesh Parameters	Values
Messing method	Trapezoid
Relevance sizing centre	Medium
Element size	0.001m
Initial size seed	Active assembly
Smoothing	High
Transition	Slow
Span angle centre	Fine

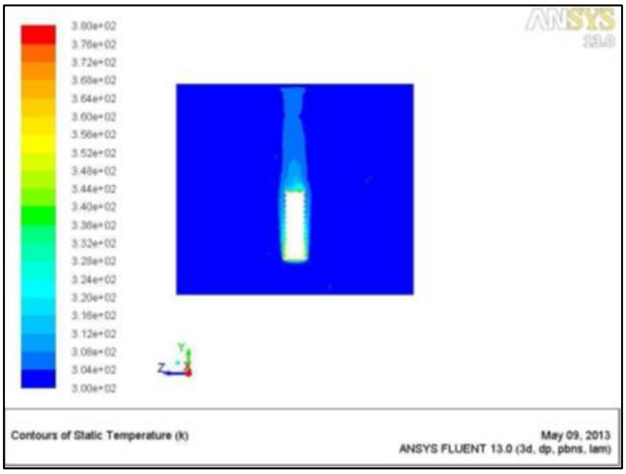

Fig. 14: The temperature contours of the circular pipe with rectangular fins

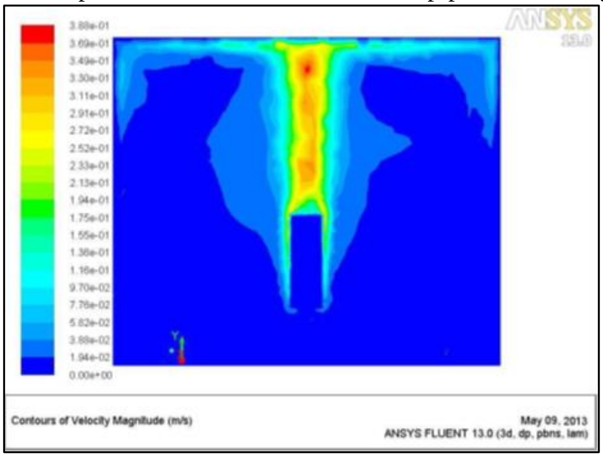

Fig. 15: Velocity Counters Of Circular Pipe without Fins

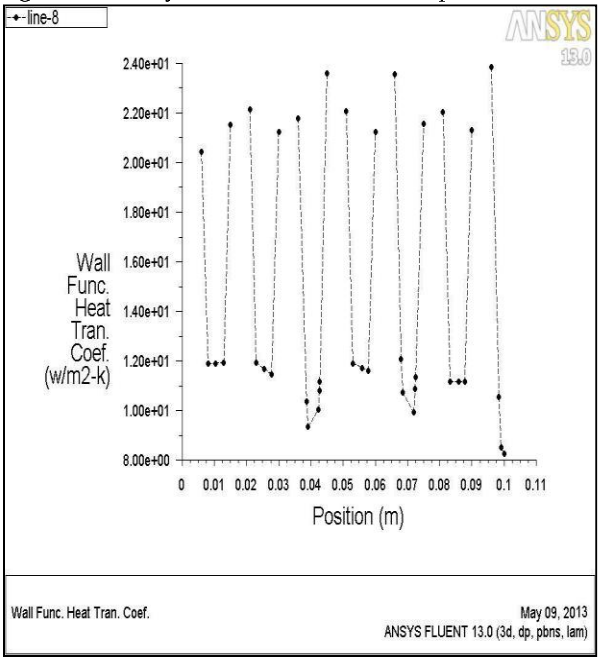

Fig. 16: Variation of Surface heat transfer coefficient along the length of the pipe

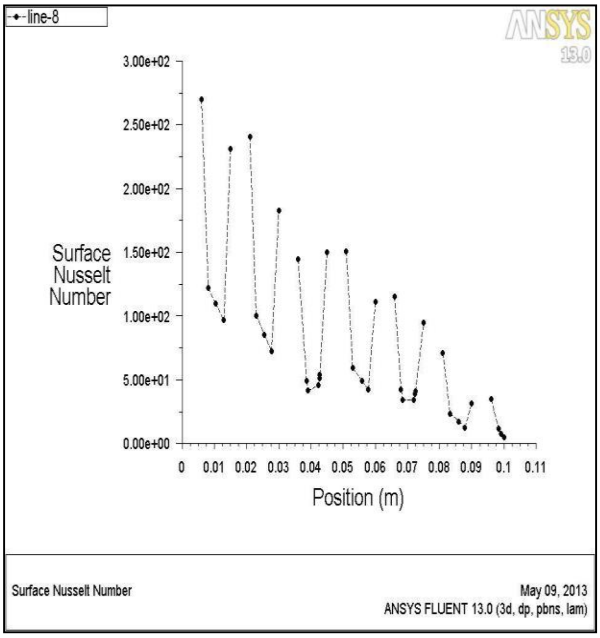

Fig. 17: The variation of Surface Nusselt number along the length of the pipe

C. Analysis for Tube With Triangular Fins:

Mess statistics and parameters during analysis:	
Physical parameters	Characteristic
Type of fin	Triangular Base –6mm, Height-5mm
Cross section of fin	Circular
External diameter of the pipe	50mm
Length of the pipe	120mm
Free stream fluid	Air
Material for tube and fins	Aluminum
Model for convection	Bousinessq
Tube wall temperature	380K
Free stream air temperature	300K
Mesh Parameters	Values
Messing method	Trapezoid
Relevance sizing centre	Medium
Element size	0.001m
Initial size seed	Active assembly
Smoothing	High
Transition	Slow
Span angle centre	Fine

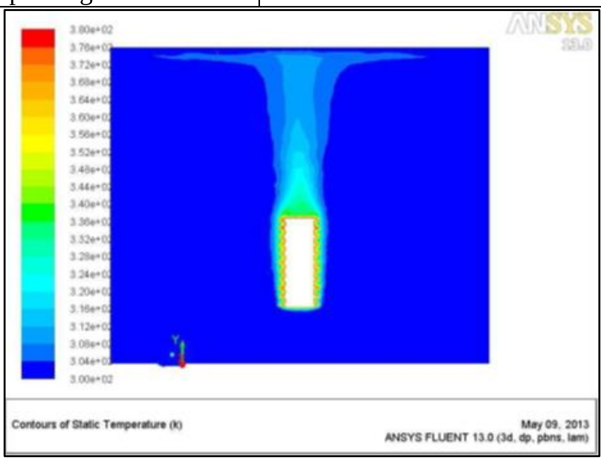

Fig. 18: The temperature contours of the circular pipe in case of triangular fins

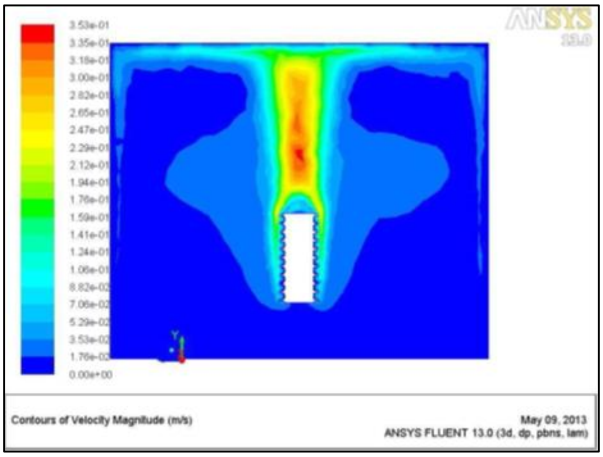

Fig. 19: Velocity counters of circular pipe with triangular fins

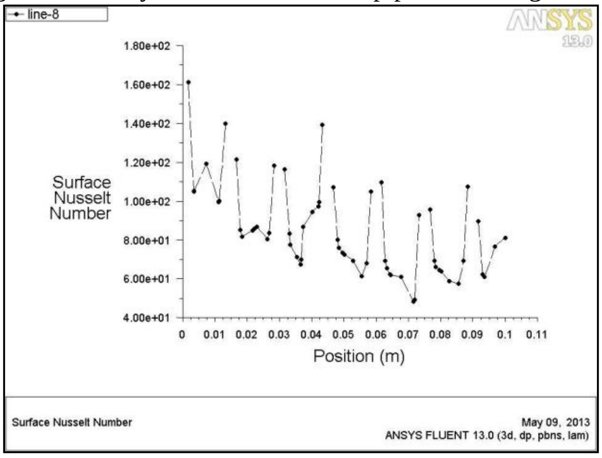

Fig. 20: variation of Surface Nusselt number along the pipe with triangular fins

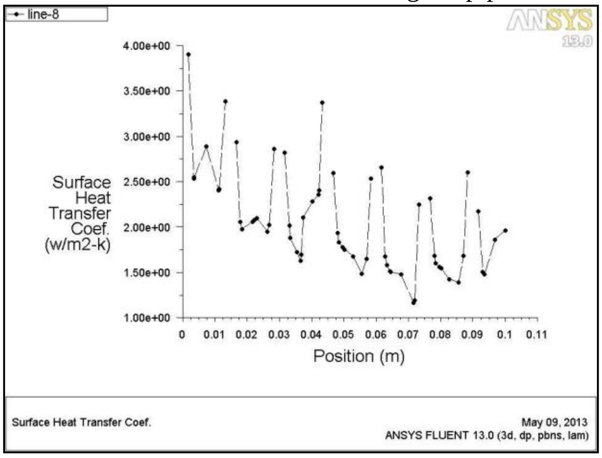

Fig. 21: variation of Surface heat transfer coefficient along the pipe with triangular fins

D. Analysis for Tube With Trapezoidal Fins:

Mess statistics and parameters during analysis	
Physical parameters	Values
Type of fin	Trapezoidal Base-6mm, Width-5mm
Cross section of fin	Circular
External diameter of the pipe	50mm
Length of the pipe	120mm
Free stream fluid	Air
Material for tube and fins	Aluminum
Model for convection	Bousinessq
Tube wall temperature	380K
Free stream air temperature	300K

Mesh Parameters	Values
Messing method	Trapezoid
Relevance sizing centre	Medium
Element size	0.001m

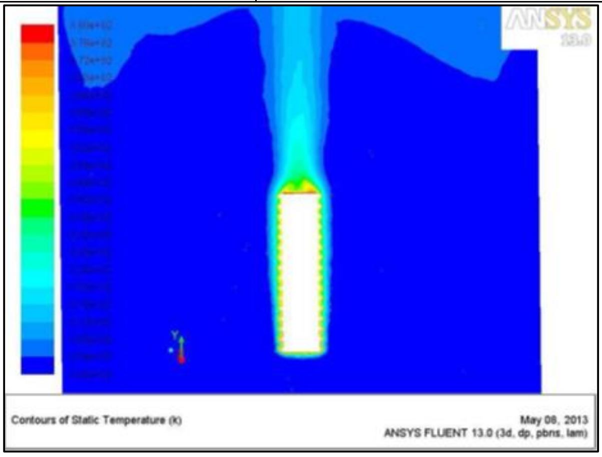

Fig. 22: The temperature contours of the circular pipe with Trapezoidal fins

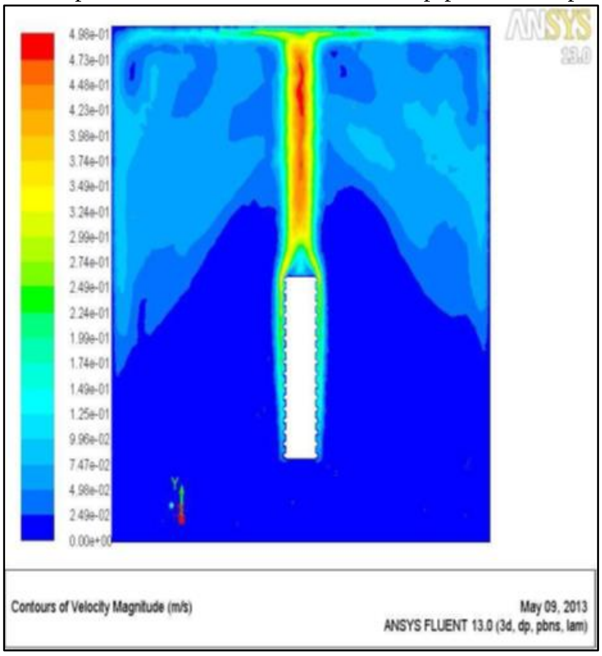

Fig. 23: Velocity counters of circular pipe with trapezoidal fins

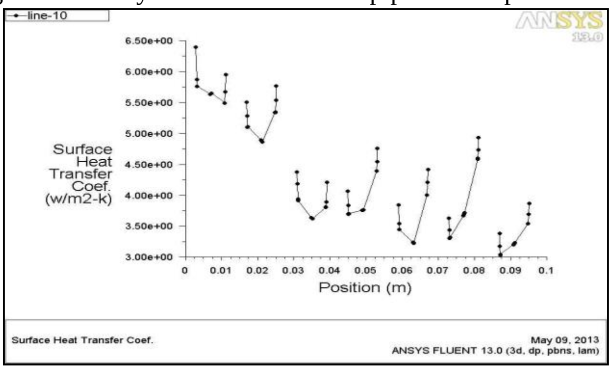

Fig. 24: The variation of Surface heat transfer coefficient along pipe with Trapezoidal fins

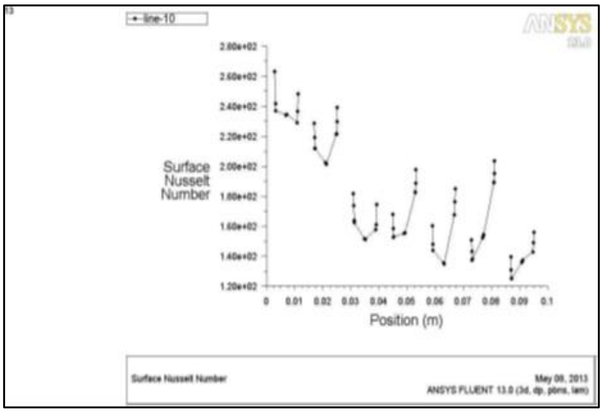

Fig. 25: Variation of Surface Nusselt number along the pipe with Trapezoidal fins

IV. CONCLUSIONS

A. Temperature Contours:

The temperature contours are obtained for the various analyses with various fin configurations. These figures show the variation between the maximum and minimum temperature values across the entire length of the pipe section taken into consideration. Also these contours shows the convection loops formed around the pipe cross section.
MAXIMUM TEMPERATURE = 380 K
MINIMUM TEMPERATURE = 300 K

B. Velocity Contours and Velocity Vectors:

The figures of velocity contours are for the various analyses with various fin configurations. These figures show the variation between the maximum and minimum velocity values across the entire length of the pipe section and around the enclosure surrounding the pipe area taken into consideration. Also these contours show the convection loops formed around the pipe cross section.

Type of Fin	Maximum Velocity m/sec	Minimum Velocity m/sec
Pipe without fin	3.8e-01	1.9e-02
Pipe with Rectangular fin	2.9e-01	1.4e-02
Pipe with Triangular fin	3.5e-01	1.7e-02
Pipe with Trapezoidal fin	4.9e-01	2.4e-02

C. Surface Nusselt Number and Heat Transfer Coefficient:

These plots show the variation of Nusselt number across the length of the pipe. The values of the surface Nusselt number show the extent of convective heat loss from the fin surfaces and the outer wall of the heated pipe. Similarly, the plot for surface heat transfer coefficient vs the length of the pipe shows the values of surface heat transfer coefficient at various points near the outer wall of the pipe and the fin surfaces.

Type of Fin	Nusselt Number	Heat Transfer Coefficient (W/m2-K)
Pipe without fin	3.4e+02	4.25
Pipe with Rectangular fin	3e+02	4.8
Pipe with Triangular fin	3.4e+02	4.25
Pipe with Trapezoidal fin	4.6e+02	6.5

D. Heat Transfer Rate

Type of Fin	Heat Transfer rate at the tube walls	Heat Transfer rate through fins	Total heat transfer Rate
Pipe without fin	14.01	---	14.01
Pipe with Rectangular fin	4.1	11.4	15.6
Pipe with Triangular fin	3.5	11.9	15.4
Pipe with Trapezoidal fin	6.2	14.4	20.6

The best fin configuration for this type of convective heat transfer of a heated pipe is a TRAPEZOIDAL fin, as they have the highest total heat transfer rate, and the best surface Nusselt number along with highest surface heat transfer coefficient. There is a considerable increase in the heat transfer with the use of Trapezoidal fins (from the above mentioned values). If fins of minimum weight are considered as a criteria for the selection of fins, then trapezoidal fins are the best configuration

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