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OPTIMIZING DESIGN OF INCLINED HEAT PIPE BY NATURAL CONVECTION ANALYSIS OF FLOW USING CFD SIMULATION

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ABSTRACT

Free convection heat transfer for an inclined steel pipe of 55 ^{0} was carried out for different heat inputs .The experiments were carried on specially developed facility to perform constant heat flux and the temperatures were measured by thermocouples. The electrical input to the heater was controlled by dimmer stat and is measured by wattmeter. The experiments are carried for Gr number; the effects of inclination and Gr number on the temperature distribution were investigated. The average Nusselt numbers (Nu) were estimated along the tube length. The experimental heat transfer co-efficient was calculated from Nu number. The aim of project was concentrated on optimizing the Design (D/L RATIO) of inclined heated steel pipe for different heat input.

Further by using the boundary condition of different heat input flow of steel pipe, analysis for copper pipe is carried out through CFD and L/D ratio of inclined heated copper pipe for different heat input was finalized.

Key Words: Inclined Heat Pipe, Natural Convection, Nusselt Number, Heat Transfer, CFD Simulatio.

I. INTRODUCTION

Free convection is one such process, it functions because heated fluids, due to their lower density, rise and cooled fluids fall. A heated fluid will rise to the top of a column, radiate heat away and then fall to be reheated, rise and so on. Gasses, like our atmosphere, are fluids, too. A packet of fluid can become trapped in this cycle. When it does, it becomes part of a convection cell. Convection cells can form at all scales. They can be millimetres across or larger than Earth. They all work the same way. The convection that you are most likely to have observed is in cumulonimbus clouds or "thunderheads." These towering vertical clouds can be seen to evolve over a few minutes. The moisture in the cloud condenses as it cools. The air gives up some of its heat to the cold high altitude air and begins to fall.

Heat transfer continues to be a major field of interest to engineering and scientific researchers, as well as designers, developers, and manufacturers. The wealth of applications includes a wide variety of components and systems for energy devices, including general power systems, heat exchangers, high performance gas turbines and other power conversion devices. Other areas of interest include chemical processing, general manufacturing, bio-heat transfer, electronic cooling, comfort heating and cooling, and a number of natural phenomena from upwelling currents in the oceans to heat transport in stellar atmospheres

Natural convection heat transfer from vertical plate and cylinders are different than heat transfer from horizontal cylinders. When the fluid flows over a surface, boundary layer is formed. Boundary layer of natural convection flow has extensively been studied for long years. Many experimental and theoretical investigations have been carried out to study the behaviour of the development of boundary layer flow on plates and cylinder.

II. LITERATURE SURVEY

Jarall and Campo [1]

Natural convection from vertical slender circular cylinders has been studied for many years. Typical of the experimental studies of natural convective heat transfer from vertical circular cylinders are those of Jarall and Campo, Welling et al. and Fukusawa and Iguchi.Cylinders with exposed top inclined at an angle to the vertical have received attention by Oosthuizen.

Natural convection heat transfer from a single vertical tube is different from to a bundle of vertical tubes. Due to the development of the boundary layer, the heat transfer from the tubes varies for different center to center spacing, aspect ratio and inclination of tube array.

S.A.Nada , M.Mowad[2]

S.A.Nada, M.Mowad performed an experimental study on free convection from a vertical and inclined semi-circular cylinder at different orientations at constant heat flux. The experiments were carried at four inclination angles (0º, 30º, 45º and 60º) of the semi-circular cylinder. The results showed that the average Nusselt number increases as the inclination angle of the semi-circular cylinder increases.

Eckert & Soehngen [3]

Natural convection heat transfer from cylinders and array of horizontal cylinders was done by Eckert & Soehngen and M.Sadegh Sadeghipour, M. Ashegfhi. The study included heat transfer from horizontal cylinders of small diameter with rectangular grid. Lieberman and Gebhart experimentally investigated the heat transfer from heated wires with uniform flux. Heat transfer from vertical array of horizontal elliptic cylinders was studied by Annunziata O'Orazo& Lucia Fontana and Yousefi & Ashjaee.

T. Fujii et al. [4]

T. Fujii et al. performed experimental study on natural-convection heat transfer from a plate with arbitrary inclination. The heat is transferred from one side surface of two plates of 30 cm height,15 cm width and 5 cm height, 10 cm width for a two dimensional flow. In the laminar region the expression for the vertical plate is applicable to the inclined plate if only the gravitational term in the 'Ra' number is altered to the component parallel to the inclined surface. For the horizontal heated plate and the slightly inclined heated plate with the horizontal surface both facing downward, 'Nu' number is proportional to one fifth power of 'Ra' number. For the horizontal heated plate facing upwards the flow in the boundary layer is turbulent and the 'Nu' expression agrees with that in the turbulent region for the vertical plate. The 'Nu' number for the smaller plate is somewhat larger than that for larger (Lengthwise) plate. The Nusselt number value of 5 cm plate is 23 % larger than 30 cm Plate. For the plate facing downwards the applicable range of angle of inclination in this expression is extended almost to the horizontal, and for the plate facing upwards it is limited by the occurrence of flow separation in the boundary layer. The fluid flows into the boundary layer not perpendicularly to the plate, but almost horizontally.

A. S. Lavine [5]

A. S. Lavine investigated the linear stability of mixed and free convection between inclined parallel plates with fixed heat flux boundary conditions. His results may have significance in low Rayleigh number natural and mixed convection applications, such as solar collectors, solar cells, cooling of electronic components and chemical vapour deposition systems. The fixed flux boundary conditions tend to promote instability more than do fixed temperature boundary conditions. Therefore the natural convection heat loss across the air layers bounded by two parallel plates is of special interest to the designers of solar collectors.

Naga .S Sarada et al carried out CFD analysis to investigate the enhancement of heat transfer by incorporating different wire coil inserts in a tube of length 610 mm with an inside diameter of 27 mm. The analysis was performed with air as working fluid for the plain tube and the heat transfer coefficient obtained is compared with the experimental results for validation. It is observed that the heat transfer coefficient obtained analytically is 10.7% more than that obtained experimentally.

Taylor (1984) [6]

A large number of research analyses have been carried out on the internal flows during the recent years. **Taylor (1984)** mathematically modeled the airflow through sampling pipes. Taylor (1984) begins by stating that for a steady incompressible fluid flow through a smooth pipe, the energy conservation equation can be used. He quoted Darcy's formula forehead loss in pipes caused by friction. He also commented that this equation is applicable to either laminar or turbulent flow. **Cole (1999)** investigated the disturbances to pipe flow regimes by jet induction to improve the available techniques to mathematically model the performance of aspirated smoke detection systems. He stated that there is a significant area of uncertainty in determining the friction factor and it has not been established that the friction factor is unaffected by upstream disturbances to the flow regime whether that regime is turbulent, laminar or transitional.

III. PHYSICAL MODEL AND MATHEMATICAL FORMULATION

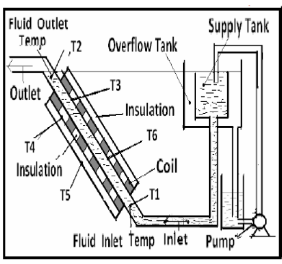
Free convection heat transfer for an inclined steel pipe of 55^0 was carried out for different heat inputs .The experiments were carried on specially developed facility to perform constant heat flux and the temperatures were measured by thermocouples. The electrical input to the heater was controlled by dimmer stat and is measured by wattmeter. The experiments are carried for Gr number; the effects of inclination and Gr number on the temperature distribution were investigated. The average Nusselt numbers (Nu) were estimated along the tube length. The experimental heat transfer co-efficient was calculated from Nu number. The aim of project was concentrated on optimizing the Design (D/L RATIO) of inclined heated steel pipe for different heat input.

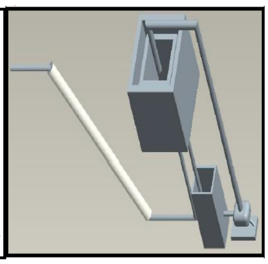
Further by using the boundary condition of different heat input flow of steel pipe, analysis for copper pipe is carried out through CFD and L/D ratio of inclined heated copper pipe for different heat input was finalized.

3.1 Cfd Simulation in Cfx-13

The second method is the CFD simulation. All the work is done in ICEM CFD andCFX-13. These are very powerful tools with many advanced features. The geometry is created and mesh in ICEMCFD and CFX-13. In meshing, unstructured meshing technique with high mesh concentration is used where the gradients are large. The boundaries are also specified in the CFX-13. The boundary conditions are specified in CFX-13 Segregated solver with axi-symmetric space and k-epsilon model will be used.

IV. EXPERIMENTAL SET UP



4.1 Experimental Calculations

4.1.1 Dimensions of model

Tube diameter: 0.015m

Tube length: 1.1m

Heat Flux is the product of voltage and current. Here a voltage input of 130V is given for 1st model. Heat transfer coefficient and L/D ratio is calculated as shown below.

$Q = V \times I$ [With reference to Methodology]

$Q = 130 \times 0.59$ [V and I values from experiment conduction]

Q = 76.88 watts

$\frac{Q}{A} = \frac{76.88}{\pi \times 0.015 \times 1.1} = 1483\ w/m^2$ [A is surface area of test section]

4.1.2 Experimental Reading

$T_{in} = 29^0C$

$T_{out} = 31^0C$

$T_s = \frac{49+52+47+50}{4} = 49.5^0C$

Pressure at inlet = 1.65 bar

Discharge = 1ltr/28sec [Discharge value obtained from experiment conduction]

4.1.3 For Internal Flow

$T_{film} = \frac{T_{in} + T_{out}}{2} = \frac{29+31}{2} = 30^0C$

Properties of water from table at 30^0C

Pr = 5.68

K = 0.6129

$\upsilon = 0.8315 \times 10^{-6}$

$Gr = \frac{g\beta D^3 \Delta T}{v^2}$

$Gr = \frac{9.81 \times \left(\frac{1}{273+30}\right) \times 0.015^3 \times (31-29)}{(0.8315 \times 10^{-6})^2}$

Gr = 316071.1703

GrPr = 316071.1703x 5.68 = 1795284.247

Nu from Data Hand Book (Page number 136 Heat transfer data hand book by Kothandaraman)

$Nu = 0.59\ (GrPr)^{0.25}$

For inclined Pipe GrPr is multiplied by $\cos\theta$

$\theta = 55^0$

$Nu = 0.59(1795284.247x \cos 55)^{0.25}$

Nu = 18.79

$Nu = \frac{hD}{k}$

$h = \frac{18.79 \times 0.6129}{0.015} = 767\ w/m^2k$

To find dia of the pipe

Q = hAΔT

76.88 = 767 x π x D x 1.1 x (31 - 29)

D = 0.0145mt = 14.5mm

$\frac{D}{L}$Ratio for 55^0 at Q = 76.88 watts

Is$\frac{0.0145}{1.1}$ = 0.013

$\frac{D}{L}$ = 0.013 for steel pipe at Q = 76.88 watts

Therefore, according to $\frac{D}{L}$ ratio

We can design length or diameter of steel pipe at 55^0

4.2 CFD SIMULATION

There are four basic steps involved in the CFD analysis of pipe. They are given as below

1. **Creating geometry and meshing** [Done in ICEM CFD for required dimensions]
2. **Pre-processing** [Includes applying Boundary conditions done in CFX-13]
3. **Solver** [Solved in CFX-13 for Heat Flux and Heat Transfer Coefficient]
4. **Post processing**. [Results obtained from CFD-Post]

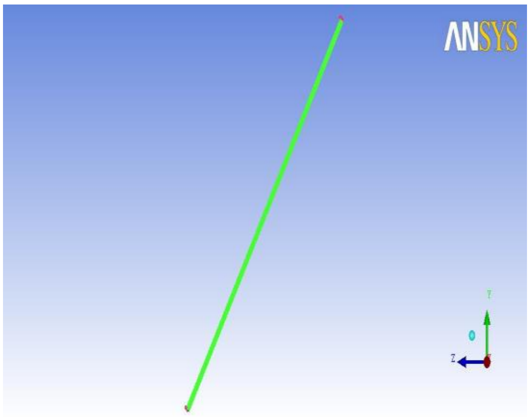


Fig 4.1 Model of Pipe in ICEM CFD

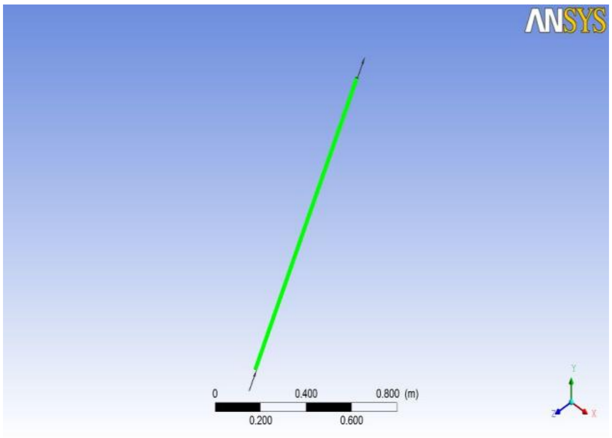


Fig 4.2 Model Imported to CFX-13

V. RESULTS AND DISCUSSION

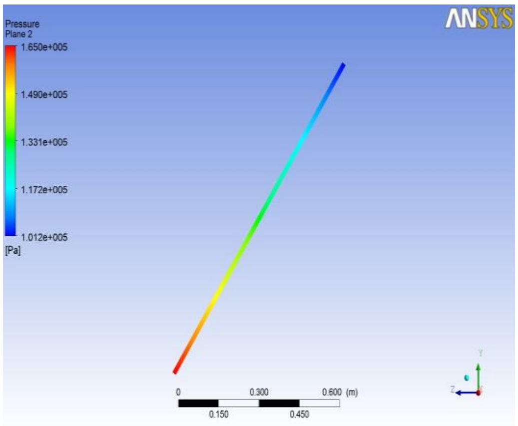


Fig 5.1 Pressure Contour.

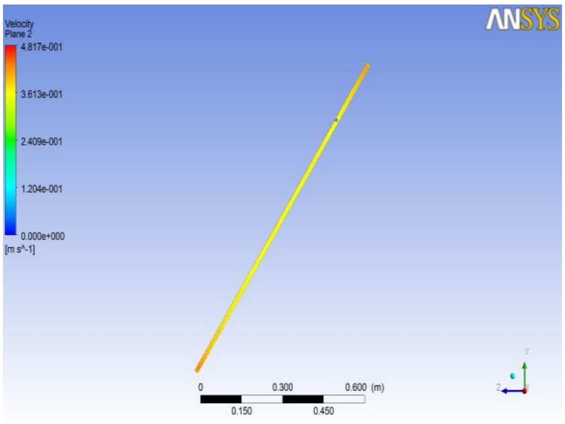


Fig 5.2 Velocity Plane.

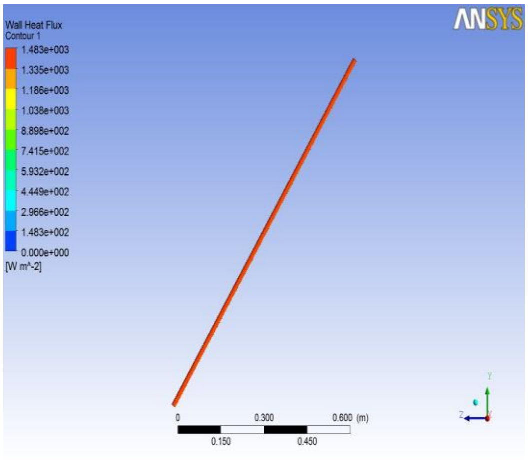


Fig 5.3 Wall Heat Flux.

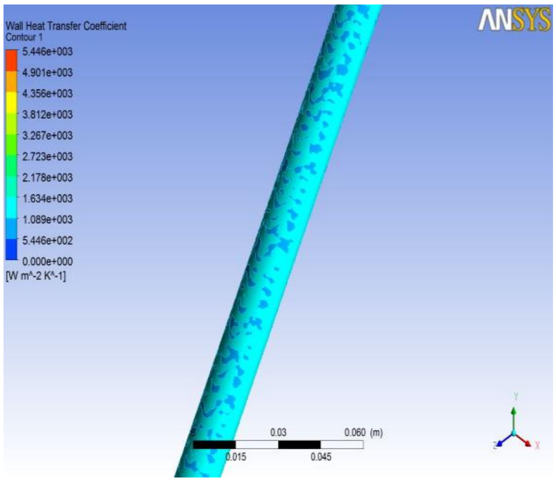


Fig 5.4 Wall Heat Transfer Coefficient

5.1 Comparison of Experiment and Cfd Result for Steel Pipe

From the Experimental result calculations, the below values are tabulated.

Sl No	Heat Input Watts	Experimental h(w/m^{2}k)	CFD h(w/m^{2}k)	% of error
1	76	767	790	2.91
2	189	880	960	8.33
3	315	973	1080	9.9

SL NO	MATERIAL	HEAT INPUT watts	LENGTH Mt	DIA Mt	D/L RATIO
1	copper	76	1.1	0.0116	0.0106
2	copper	76	1.2	0.0106	0.0088
3	copper	76	1.5	0.0159	0.0084
4	copper	189	1.1	0.0124	0.0113
5	copper	189	1.2	0.0115	0.0095
6	copper	189	1.5	0.0092	0.0061
7	copper	315	1.1	0.0122	0.0111
8	copper	315	1.2	0.0113	0.0094
9	copper	315	1.5	0.0166	0.0090

5.2 Optimization of Design for Different Heat Input –Steel Pipe and Copper Pipe

Sl No	Material	Heat Input Watts	Length Mt	Dia Mt	D/L Ratio
1	Steel	76	1.1	0.0145	0.013
2	Steel	76	1.2	0.0133	0.011
3	Steel	76	1.5	0.0106	0.007
4	Steel	189	1.1	0.0155	0.014
5	Steel	189	1.2	0.0142	0.0118
6	Steel	189	1.5	0.0113	0.0075
7	Steel	315	1.1	0.0156	0.01418
8	Steel	315	1.2	0.0143	0.0119
9	Steel	315	1.5	0.0114	0.0076

VI. CONCLUSION

- The time required for discharge of waterdecreaseshas heat input is increased.
- Better the thermal conductivity better heat transfer coefficient has been observed.
- comparision of heat transfer coeeficient between copper and steel shows that less time is required for copper pipe to collect same quantity for same input.
- As observed from velocity plot velocity of fluid increases for copper pipecompared to that of steel pipe.
- It has been observed that percentage of error for both experimentally conducted and CFD simulation is within the agreed value (up to 10%).
- As velocity is increased the heat transfer between the flowing fluid and the surface increases, clearly these results can be observed from the above results.
- As heat flux is increased the heat transfer between the flowing fluid and the surface increases, clearly these results can be observed from the above results.
- From the above result clearly we can observe boundary layer formation is taking place at wall where velocity is decreasing, pressure and temperature is increasing.
- The maximum velocity will be occurring at the center line of the test specimen where profile obtained is parabolic, which indicates fully developed flow.
- From the velocity plane clearly we can observe an increase in velocity at outward, this is due to density decrease of the fluid medium.
- More turbulence kinetic energy has been observed at wall.
- It has been observed that better thermal conductivity material gives better heat transfer coefficient.
- The diameter to length ratio for copper is less compared to that of steel pipe for same heat input.

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