

Thermal Analysis Of Hollow Pipe Using Altair Hyperworks

Pramod Bhatt

(M.Tech Scholar)

Associate Proff. Anirudh Gupta

(BTKIT, Dwarahat)

ABSTRACT

In this paper thermal analysis of hollow duct is done computationally using Altair Hyperworks Software. Simple Analytical results were obtained for conduction and convection through cylindrical hollow duct which can be used to build up thermal circuit. The inner surface of duct is maintained at constant temperature and ambient air is at certain temperature that is less than inner surface temperature of pipe. Due to temperature difference heat will flow from higher temperature to lower temperature. The material of pipe provides conductive resistance and air provides convective resistance. Hence this is a mix mode of heat transfer. The heat transfer takes place in one dimension only and properties are considered to be isotropic. The cylindrical duct is assumed to be made of steel having known thermal conductivity and density. The surrounding of pipe has known convective heat transfer coefficient and temperature. The results obtain on hyper view are for heat flux, temperature gradient and grid temperature. The different characteristics can be obtained by varying the material of the duct and so conductivity varies.

Keywords: Cylindrical duct, Rectangular duct, Altair Hyper wor

1. INTRODUCTION

Heat transfer is the study of thermal energy transport within a medium or among neighbouring media by molecular interaction, fluid motion, and electromagnetic waves, resulting from a spatial variation in temperature. This variation in temperature is governed by

The principle of energy conservation, which when applied to a control volume or

a control-mass, states that the sum of the flow of energy and heat across the system, the work done on the system, and the energy stored and converted within the system, is zero. Heat transfer finds application in many important areas, namely design of thermal and nuclear power plants including heat engines, steam generators, condensers and other heat exchange equipments,

catalytic convertors, heat shields for space vehicles, furnaces, electronic equipments etc, internal combustion engines, refrigeration and air conditioning units, design of cooling systems for electric motors generators and transformers, heating and cooling of fluids etc. in chemical operations, construction of dams and structures, minimization of building heat losses using improved insulation techniques, thermal control of space vehicles, heat treatment of metals, dispersion of atmospheric pollutants.

A thermal system contains matter or substance and this substance may change by transformation or by exchange of mass with the surroundings. To perform a thermal analysis of a system, we need to use thermodynamics, which allows for quantitative description of the substance. This is done by defining the boundaries of the system, applying the conservation principles, and examining how the system participates in thermal energy exchange and conversion.

2. MODES OF HEAT TRANSFER

Heat transfer generally takes place by three modes such as conduction, convection and radiation. Heat transmission, in majority of real situations, occurs as a result of combinations of these modes of heat transfer. Conduction is the transfer of thermal energy between neighbouring

molecules in a substance due to a temperature gradient. It always takes place from a region of higher temperature to a region of lower temperature, and acts to equalize temperature differences. Conduction needs matter and does not require any bulk motion of matter.

Conduction takes place in all forms of matter such as solids, liquids, gases and plasmas. In solids, it is due to the combination of vibrations of the molecules in a lattice and the energy transport by free electrons. In gases and liquids, conduction is due to the collisions and diffusion of the molecules during their random motion.

Convection occurs when a system becomes unstable and begins to mix by the movement of mass. A common observation of convection is of thermal convection in a pot of boiling water, in which the hot and less-dense water on the bottom layer moves upwards in plumes, and the cool and denser water near the top of the pot likewise sinks. Convection more likely occurs with a greater variation in density between the two fluids, a larger acceleration due to gravity that drives the convection through the convecting medium.

Radiation describes any process in which energy emitted by one body travels through a medium or through space absorbed by another body. Radiation occurs in nuclear weapons, nuclear

reactors, radioactive radio waves, infrared light, visible light, ultraviolet light, and X-rays substances.

Usually, when both conduction and convection are possible, convection will play a stronger role than conduction. The relative importance of the two heat transfer modes is described by the Nusselt number. Conduction will only dominate at low Nu, which is far from being a realistic scenario in the majority of engineering applications you will face. The most straightforward way of approaching conductive heat transfer in isolation is to consider solid bodies, inside which there can be no fluid motion, and hence no convective heat transfer.

3. LITERATURE REVIEW

Heat conduction is increasingly important in various areas, namely in the earth sciences, and in many other evolving areas of thermal analysis. A common example of heat conduction is heating an object in an oven or furnace. The material remains stationary throughout, neglecting thermal expansion, as the heat diffuses inward to increase its temperature. The importance of such conditions leads to analyze the temperature field by employing sophisticated mathematical and advanced numerical tools, *Schneider (1957)*.

The section considers the various solution methodologies used to obtain the temperature field. The objective of conduction analysis is to determine the temperature field in a body and how the temperature within the portion of the body. The temperature field usually depends on boundary conditions, initial condition, material properties and geometry of the body, *Teixeira and Rincon (2009)*.

Why one need to know temperature field. To compute the heat flux at any location, compute thermal stress, expansion, deflection, design insulation thickness, heat treatment method, these all analysis leads to know the temperature field, *Fried,(1957)*.

The solution of conduction problems involves the functional dependence of temperature on space and time coordinate. Obtaining a solution means determining a temperature distribution which is consistent with the conditions on the boundaries and also consistent with any specified constraints internal to the region. *Keshavarz and Taheri (2007)* have obtained this type of solution.

The problem is known and analytical solution is obtained but the on Altair software and making thermal analysis on it is a new challenge. The conduction of heat on material is by Fourier law and in the fluid around pipe the heat transfer is due to

convection. The heat transfer in cylindrical case is of logarithmic variation in contrast to the linear variation in plane wall, *Gnielinski, (1973)*. In steady one-dimensional conduction in cylinder requires that temperature is a function of only the radial co-ordinates r . The analysis of steady heat flow across a plane wall is simple because the flow area A did not change in the flow direction. In the case of cylinder the area for heat flow changes in the direction of heat flow, *Incropera and Dewitt, (2009)*.

The convective heat transfer coefficient term is used to describe heat transfer from surface to a moving fluid. The flow may be forced using some external means or free caused by buoyancy forces arising from density difference, *Churchill and Chu, (1974)*. The flow may be laminar and turbulent which depends upon the Reynold's number. Heat transfer rate tends to be much higher in turbulent flow than in laminar flow. The rate of heat transfer by convection is usually function of surface area, geometry and thermo physical properties *Mills and Ganesan, Second Edition (2009)*. In an external flow heat transfer is directly proportional to the temperature difference. When convective heat transfer coefficient is known than that can be find by correlation given in hand book for external and internal flow. Knowing the value of h we can find the

rate of heat transfer rate. Here, in the given case we know the value of convective heat transfer coefficient, *Kadambi and Drake (1981)*.

4. OBJECTIVE OF THE PRESENT WORK:

1. An effort has been made to predict the temperature field in solid by Hyperworks and analytically.
2. Effort has been made analyze more practical case of cross sectional duct.
3. Effort has been made to obtain grid temperature in heat transfer process.

The present work on the project mainly deals with the use of Altair Hyper works Software on the mechanical engineering problems. Here, we are modelling a component and doing thermal analysis on it using the Altair software. There are various problems on heat analysis that may be conduction, convection or radiation and any two modes simultaneously act on the component. Our work is on hollow pipe in which we are assuming steam is flowing at certain temperature due to which inner surface of the pipe is maintain at the steam temperature. The atmospheric temperature is less than steam temperature due to which heat flow takes place from inner surface to ambient air. This is done by conduction and convection both.

5. MATHEMATICAL MODELING OF HOLLOW DUCT

Derivation of heat conduction through cylindrical duct:

The general heat conduction equation is given by

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial T}{\partial r} + \frac{1}{r^2} \cdot \frac{\partial^2}{\partial \theta^2} + \frac{\partial^2 T}{\partial z^2} + \frac{q_g}{k} = \frac{1}{\alpha} \cdot \frac{\partial T}{\partial \tau}$$

For steady state, unidirectional and without heat generation the equation becomes

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial T}{\partial r} = 0$$

$$\frac{1}{r} \cdot \frac{\partial}{\partial r} \left(r \cdot \frac{\partial T}{\partial r} \right) = 0$$

Since, $\frac{1}{r} \neq 0$

Therefore equation 3 becomes,

$$\frac{\partial}{\partial r} \left(r \cdot \frac{\partial T}{\partial r} \right) = 0$$

$$r \cdot \frac{\partial T}{\partial r} = \text{constant}$$

Integrating above equation we get,

$$T = C \ln(r) + C_1 \quad \text{Eq. 4}$$

Applying boundary condition

At $r = r_1$ $T = T_1$ and $r = r_2$

$T = T_2$ we get,

$$T_1 = C \ln(r_1) + C_1$$

$$T_2 = C \ln(r_2) + C_2$$

Putting value in equation 4 we get

$$\frac{(T - T_1)}{T_2 - T_1} = \frac{\ln \frac{r}{r_1}}{\ln \frac{r_2}{r_1}}$$

The heat conduction rate Q is given by

$$Q = -kA \frac{dT}{dr}$$

Putting value of T and differentiating w.r.t. r we get

$$Q = \frac{(T_1 - T_2)}{\frac{\ln(r_2/r_1)}{2\pi kL}}$$

In the given case we have a hollow tube having internal radius, r and outer radius, R. The tube is assumed to be made of steel material having isotropic property i.e.; the thermo physical properties are directional independent and the properties are constant in all direction.

The material having thermal conductivity within the material and there is convective heat transfer coefficient outside tube due to air is fluid around tube. The air and material provide thermal resistance to the heat flow. Due to which there is a drop in temperature in each successive stage.

The temperature distribution at any radius is given by the given formula:

$$\frac{T_1 - T}{T_1 - T_2} = \frac{\ln \frac{r_i}{r}}{\ln \frac{R}{r}}$$

Where,

T_1 = inner surface temperature

T_2 = outer surface temperature

r_i = element at any radius on hollow pipe

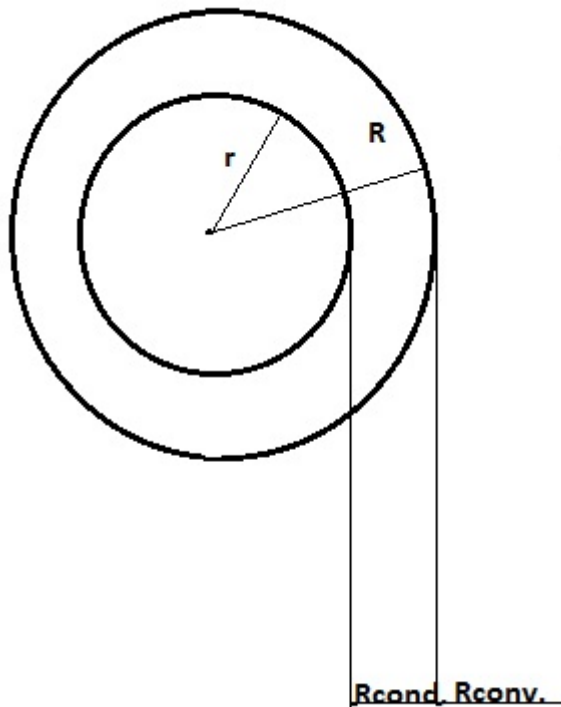
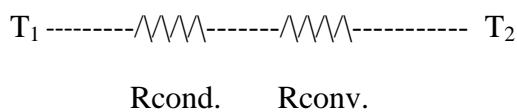


Figure Hollow pipe with conductive and convective resistance

6. PROBLEM FORMULATION:

The thermal resistance can be express as electrical analogy as given:



The overall heat transfer is given by:

$$Q = \frac{\Delta T_{overall}}{\Sigma R_{th}}$$

Where R_{th} is total thermal resistance and is sum of conductive and convective resistance

$$\Sigma R_{th} = R_{cond} + R_{conv}$$

Where,

$$R_{cond} = \frac{\ln (R/r)}{2\pi kL}$$

$$R_{conv} = \frac{1}{2\pi RLh}$$

Rate of heat transfer is given by:

$$Q = \frac{2\pi L(T_1 - T_2)}{\frac{\ln (R/r)}{k} + \frac{1}{hR}}$$

7. ANALYSIS SOFTWARE - Altair® Hyperworks®

Finite element analysis (FEA) involves solution of engineering problems using computers. Engineering structures that have complex geometry and loads, are either very difficult to analyze or have no theoretical solution. However, in FEA, a structure of this type can be easily analyzed. Commercial FEA programs, written so that a user can solve a complex engineering problems without knowing the governing equations or the mathematics; the user is required only to know the geometry of the structure and its boundary

conditions. FEA software provides a complete solution including deflections, stresses, reactions, etc.

In order to become a skilful FEA user, a thorough understanding of techniques for modelling a structure, the boundary conditions and, the limitations of the procedure, are very crucial. Engineering structures, e.g., bridge, aircraft wing, high-rise buildings, etc., are examples of complex structures that are extremely difficult to analyze by classical theory. But FEA technique facilitates an easier and a more accurate analysis. In this technique the structure is divided into very small but finite size elements (hence the name finite element analysis). Individual behaviour of these elements is known and, based on this knowledge; behaviour of the entire structure is determined.

FEA solution of engineering problems, such as finding deflections and stresses in a structure, requires three steps:

- Pre-process or modelling the structure
- Analysis
- Post processing

A brief description of each of these steps follows.

Step1: Pre-process or modeling the structure

Using a CAD program that either comes with the FEA software or provided by

another software vendor, the structure is modelled. The final FEA model consists of several elements that collectively represent the entire structure. The elements not only represent segments of the structure, they also simulate it's mechanical behaviour and properties.

Regions where geometry is complex (curves, notches, holes, etc.) require increased number of elements to accurately represent the shape; whereas, the regions with simple geometry can be represented by coarser mesh (or fewer elements). The selection of proper elements requires prior experience with FEA, knowledge of structure's behaviour, available elements in the software and their characteristics, etc. The elements are joined at the nodes, or common points.

In the pre-processor phase, along with the geometry of the structure, the constraints, loads and mechanical properties of the structure are defined. Thus, in pre-processing, the entire structure is completely defined by the geometric model. The structure represented by nodes and elements is called "mesh".

Step 2: Analysis

In this step, the geometry, constraints, mechanical properties and loads are applied to generate matrix equations for each element, which are then assembled to generate a global matrix equation of the structure.

Step 3: Post processing

This is the last step in a finite element analysis. Results obtained in step 2 are usually in the form of raw data and difficult to interpret. In post analysis, a

CAD program is utilized to manipulate the data for generating deflected shape of the structure, creating stress plots, animation, etc. A graphical representation of the results is very useful in understanding behaviour of the structure

Altair® Hyperworks®, A Platform for Innovation™, is built on a foundation of design optimization, performance data management, and process automation. Hyperworks is an enterprise simulation solution for rapid design exploration and decision-making. As one of the most comprehensive CAE solutions in the industry, Hyperworks provides a tightly integrated suite of best-in-class tools for modelling, analysis, optimization, visualization, reporting, and performance data management. Leveraging a revolutionary "pay-for-use" token-based business model, Hyperworks delivers increased value and flexibility over other software licensing models. Firmly committed to an open-systems philosophy, Altair Hyperworks continues to lead the industry with the broadest interoperability to commercial CAD and CAE solutions.

Altair Hyper works 11.0 is the new version of Altair's CAE software suite. It includes many new features and several new applications. Hyper works 11.0 highlights are

Altair RADIOSS is finite element software using an explicit or implicit time integration scheme with a Lagrangian, Eulerian, or an arbitrary Euler-Lagrange formulation. It allows mechanical, structure, fluid, or fluid-structure interaction problems resolution, under dynamic or static solicitations. The structures can be subjected to large strains, large displacements, and large rotations by using the materials non-linear behaviours.

Solver: RADIOSS is well suited to the simulation of rapid dynamic phenomena, such as the study of hyper-velocity impacts in space, and is also used for simulating shocks and crash in the automobile, aeronautics, rail, and marine industries. The latest version is enhanced with an implicit formulation capable of dealing with static, dynamic, and linear or non-linear problems. A collision simulation's initial equilibrium conditions can now be efficiently integrated using a single solver.

Benefits:

A state-of-the-art finite element solver that:

1. Enables users to solve both static and dynamic calculations with its completely parallelized implicit solution algorithms (i.e. initial

equilibrium and elastic recover after crash)

2. Allows you to analyze accidents and safety related problems (i.e. occupant safety and pedestrian safety) thanks to a wide database of safety tools (i.e. dummies, head forms, and leg forms)

3. Enhances risk prediction for studying the behaviour of high strength steel parts with the development of new rupture models

STEPS IN GIVEN PROBLEM :

The following exercises are included:

- Create the thermal material and property
- Create and apply the thermal boundary conditions on the model
- Submit the job to RADIOSS
- Post-process the results in HyperView

Step1: Load the RADIOSS (Bulk Data) User Profile and draw the model

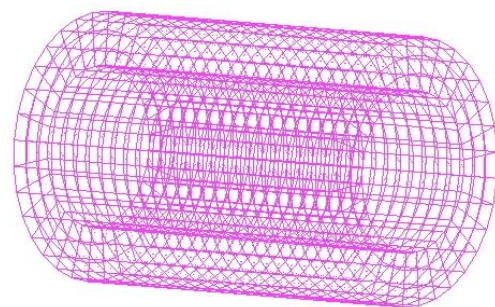


Figure 3.2 Wireframe model of meshed hollow pipe

Step 2: Create the thermal material properties. Create the material and property collectors before creating the component collectors.

Step 3: Link the material and property to the existing structure. Once the material and property are defined, they need to be linked to the structure.

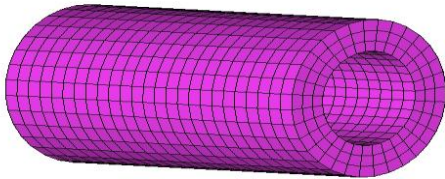


Figure 3.3 Solid model of meshed hollow pipe with material and property

Step 4: Create temperatures on the inner surface of the pipe.

Step 5: Create ambient temperature.

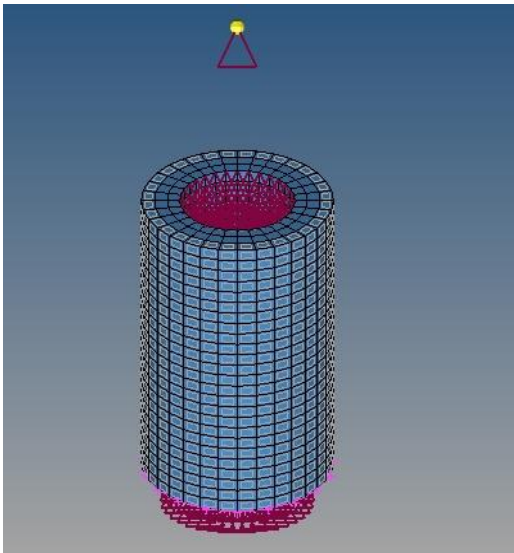


Figure 3.4 Ambient load collector

Step 6: Create CHBDYE surface elements for heat convection. Surface elements are to be created to simulate the heat exchange

between the solid pipe and the surrounding air.

A predefined element set `elem_convect`, which contains the solid elements on the outer surface of the pipe, is used to define the surface elements.

Step 7: Define the convection boundary condition to surface elements

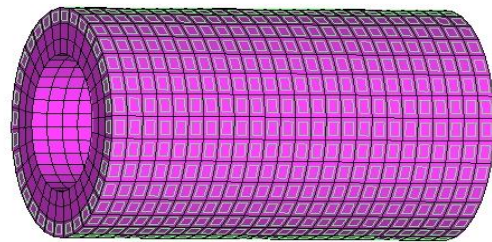


Figure 3.5 Convective surface of hollow pipe

Step 8: Create a heat transfer load step. A RADIOSS steady state heat convection load step will be created which references the thermal boundary conditions in the load collector `spc_temp`. The gradient, flux, and temperature output for the heat transfer analysis will also be requested in the load steps panel.

Step 9: Launch RADIOSS

View and Post process the Results. Gradient temperatures and flux contour results for the steady state heat conduction analysis and the stress and displacement results for the structural analysis are computed from RADIOSS. Hyper View will be used to post process the results.

Step 10: View the results for heat transfer analysis

8. RESULT

The analytical result as well as contour results of Hyper works software that grid temperature drops along radius and have temperature 100°C on surface and have 46.67°C on outer surface this is due to thermal resistance provided by material and surrounding temperature is 20°C which is due to convective resistance. All the results are shown in contour results of Hyper works. The graph in figure is plotted between temperature and radius which is logarithmic in nature.

4.3 CONTOUR PLOTS:

The contour plots obtain in hyper view circular and rectangular cross section duct are given below:

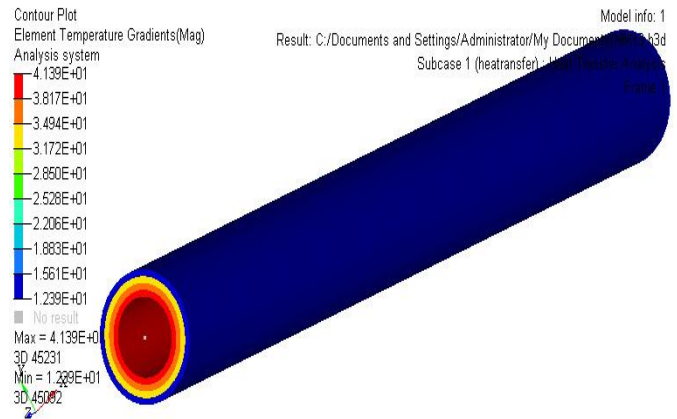


Figure Contour plot of element temperature gradient

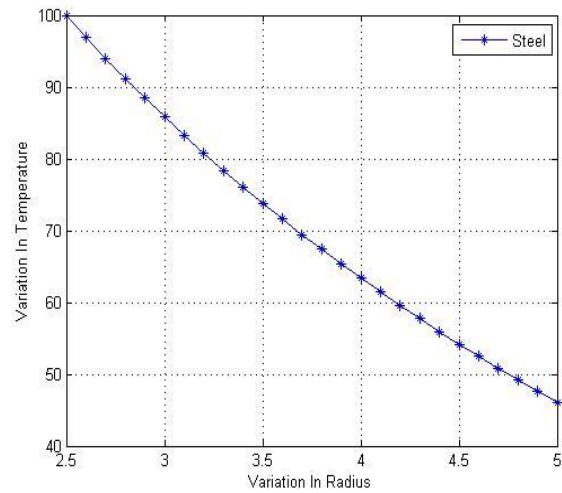


Figure Temperature variation along radius for steel pipe

Above Figure shows that the temperature distribution is logarithmic curves for cylindrical body. The temperature drop along the radius of pipe logarithmically.

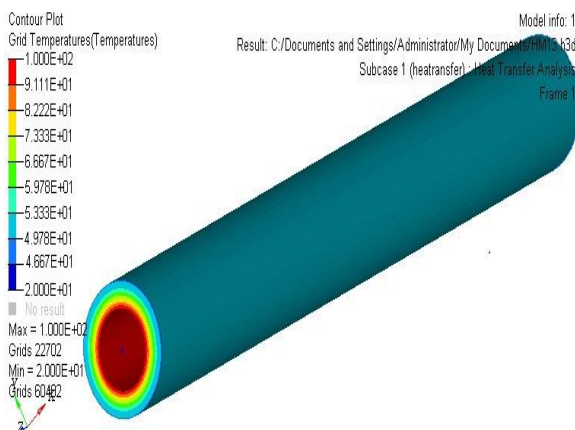


Figure Contour of grid temperature

9. FUTURE SCOPE:

If Future scope is concern then we can use a fluid inside the tube and knowing the inlet parameters we can find velocity, temperature, mass flow rate at outlet

section by CFD software tool of hyper works. We can also take a pipe of composite material in which fluid is flowing and optimizing the result. The different insulating material can be added to the cylindrical hollow pipe to obtain critical thickness of insulation. The measurement of velocity inside tube can be obtained by CFD and by this pressure drop and amount of pumping power required to lift the fluid can be obtained. If practical approach is concerned then it is used in pipe flow like in thermal power plant where steam is passed through pipes. We can find the minimum thickness of insulation so that steam is not condensed. As well as the behaviour of material of duct can be analysed.

10. REFERENCES

- [1] Brekovsky , B.M. Polyvikov, V.K., (1987) “*Numerical study of problem on high intensive free convection*”
- [2] Churchill S. W, and Chu, (1974) “*Correlating equation for laminar and turbulent free convection from horizontal cylinder*”
- [3] Frank P. Incropera and David P. Dewitt ,(2009) “*Fundamental of heat and mass transfer* “by Wiley Publication, Fifth Edition
- [4] Fried, E; (1970) “*Thermal conduction contribution to heat transfer at contacts*” 24-33
- [5] Gnielinski V; (1973) ”*New equations for heat and mass transfer in pipe and chanel flow*” Heat Transfer Soviet Research,
- [6] Jakob, M; (1949) *Heat transfer, John Wiley and sons, New York*
- [7] Jian Su, (2001)“*Improved lumped models for asymmetric cooling of a long slab by heat convection*”, Int. Comm. Heat Mass Transfer, 28, 973-983
- [8] Kadambi. V; and Drake, M; (1981) “*Free convection heat transfer from horizontal surface and mass flow through surface*”
- [9] Keshavarz P and Taheri M, (2007), “*An improved lumped analysis for transient heat conduction by using the polynomial approximation method*”, Heat Mass Transfer, 43, 1151–1156
- [10] Ligrani P.M, Oliveira M.M, Blaskovich, T. (2003) “*Comparison of heat transfer augmentation Techniques*” AIAA journal, Volume41
- [11] Milles A.F and Ganesan V, (2009) “*Heat and Mass Transfer*”, Pearson Education, Second Edition
- [12] Schneider P.J,(1957), “*Conduction Heat transfer*”, Addison Wesley,

- [13] Teixeira M.G, Rincon b M.A. and I.-S. Liu, (2009), “*Numerical analysis of quenching – Heat conduction in metallic materials*”, Applied Mathematical Modelling, 33, 2464–2473
- [14] Wheeler R.F, (1984),”*Thermal conduction of fuel element material*”
- [15] Giedt W.H,(1972)”*Investigation of variation of point unit heat transfer coefficient around a cylinder normal to air stream*” McGraw-Hill, New York
- [16] Kays W.M and Crawford, (2005) “*Convective heat and mass transfer*” 4th edition McGraw-Hill Higher Education
- [17] Yovanovich M.M, (1964),”*Recent Developments in Thermal contact Gap and joint conduction theoriesand experiment*” in C.L.Tien, V.P. Carey and J.K.Farrel,