DESIGN AND ANALYSIS OF NATURAL CONVECTIVE OF HEAT TRANSFER OF NARROW INCLINED PLATES

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***Abstract**: Natural Convection flow in a vertical channel with internal objects is encountered in several technological applications of particular interest of heat dissipation from electronic circuits, refrigerators, heat exchangers, nuclear reactors fuel elements, dry cooling towers, and home ventilation etc.*

In this thesis the air flow through vertical narrow plates is modelled using CATIA design software. The thesis will focus on thermal and CFD analysis with different Reynolds number (2×10^{6}& 4×10^{6}) and different angles (0^{0},30^{0},45^{0}&60^{0}) of the vertical narrow plates. Thermal analysis done for the vertical narrow plates by steel, aluminium & copper at different heat transfer coefficient values. These values are taken from CFD analysis at different Reynolds numbers.

In this thesis the CFD analysis to determine the heat transfer coefficient, heat transfer rate, mass flow rate, pressure drop and thermal analysis to determine the temperature distribution, heat flux with different materials.

3D modelled in parametric software CATIA and analysis done in ANSYS.

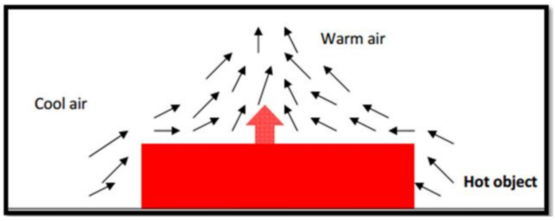
I. INTRODUCTION

Natural Convection

In natural convection, the fluid motion occurs by natural means such as buoyancy. Since the fluid velocity associated with natural convection is relatively low, the heat transfer coefficient encountered in natural convection is also low.

Mechanisms of Natural Convection

Consider a hot object exposed to cold air. The temperature of the outside of the object will drop (as a result of heat transfer with cold air), and the temperature of adjacent air to the object will rise. Consequently, the object is surrounded with a thin layer of warmer air and heat will be transferred from this layer to the outer layers of air.



Natural convection heat transfer from a hot body

The temperature of the air adjacent to the hot object is higher, thus its density is lower. As a resut, the heated air rises. This movement is called the natural convection current. Note that in the absence of this movement, heat transfer would be by conduction only and its rate would be much lower.

In a gravitational field, there is a net force that pushes a light fluid placed in a heavier fluid upwards. This force is called the buoyancy force.

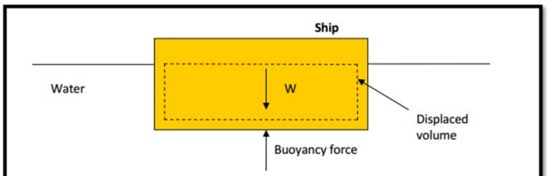


Fig. 2: Buoyancy force keeps the ship float in water.
The magnitude of the buoyancy force is the weight of the fluid displaced by the body.

Natural convection is a mechanism, or type of heat transport, in which the fluid motion is not generated by any external source (like a pump, fan, suction device, etc.) but only by density differences in the fluid occurring due to temperature gradients. In natural convection, fluid surrounding a heat source receives heat, becomes less dense and rises. The surrounding, cooler fluid then moves to replace it. This cooler fluid is then heated and the process continues, forming convection current; this process transfers heat energy from the bottom of the convection cell to top. The driving force for natural convection is buoyancy, a result of differences in fluid density. Because of this, the presence of a proper acceleration such as arises from resistance to gravity, or an equivalent force (arising from acceleration, centrifugal force or Carioles effect), is essential for natural convection. For example, natural convection essentially does not operate in free-fall (inertial) environments, such as that of the orbiting International Space Station, where other heat transfer mechanisms are required to prevent electronic components from overheating.

Natural convection has attracted a great deal of attention from researchers because of its presence both in nature and engineering applications. In nature, convection cells formed from air rising above sunlight-warmed land or water are a major feature of all weather systems. Convection is also seen in the rising plume of hot air from fire, oceanic currents, and sea-wind formation (where upward convection is also modified by Carioles forces). In engineering applications, convection is commonly visualized in the formation of microstructures during the cooling of molten metals, and fluid flows around shrouded heat-dissipation fins, and solar ponds. A very common industrial application of natural convection is free air cooling without the aid of fans: this can happen on small scales (computer chips) to large scale process equipment.

Advantages and disadvantages of natural convection

- No bulk flow- no power consumption.
- No noise- quiet operation.
- Hardly any vibration.
- Heat transfer coefficients are low.
- Larger area requirement.
- Orientation dependence.
- Difficult to control.

First, there is no bulk flow in natural convection so we don’t have to consume any power to drive a pump or rotate a compressor or blower. Perhaps, because there is no power consumption required the natural convection may perhaps be called as free convection. Because there is no fluid flow equipment involved, associated with natural convection, there is no noise process of natural convection - almost invariably proceeds in a quiet fashion. Because there is no bulk flow, there is hardly any vibration associated with flow phenomenon or with equipment nearby.

The disadvantages compared to forced convection are - heat transfer coefficients in natural convection are low typically by an order of magnitude. If you look up the problems we have solved with the forced convectio0,n forced convection with air gave us heat transfer coefficient of the order of maybe 7500 Watt per meter squared Kelvin. With natural convection, the order of heat transfer coefficients with air would typically be10-12 Watt per meter squared Kelvin. With water, forced convection would easily provide heat transfer coefficients of the order of a 1000 Watt per meter squared Kelvin or even higher. Water during the process of natural convection will lead to heat transfer coefficient of the order of a few tens of Watts per meter squared Kelvin - maybe 20, 30, 40 of that order perhaps 10000 and 50 that is about it.

Because the heat transfer coefficients are low, the area required for a given amount of transfer of heat is large. Because natural convection depends on density differences and gravity, the direction of gravity and the orientation of the surface plays a role and because there is no fluid flow, no blower to switch on or off, no velocity to adjust, natural convection is difficult to control.

Now let us look at some dimensionless numbers associated with the phenomenon of natural convection.

Natural Convection from a Vertical Plate

In this system heat is transferred from a vertical plate to a fluid moving parallel to it by natural convection. This will occur in any system wherein the density of the moving fluid varies with position. These phenomena will only be of significance when the moving fluid is minimally affected by forced convection.

When considering the flow of fluid is a result of heating, the following correlations can be used, assuming the fluid is an ideal diatomic, has adjacent to a vertical plate at constant temperature and the flow of the fluid is completely laminar.

$Nu_m = 0.478(Gr^{0.25})$

Mean Nusselt Number = $Nu_m = h_m L/k$

Where

h_m = mean coefficient applicable between the lower edge of the plate and any point in a distance L (W/m^2. K)

L = height of the vertical surface (m)

k = thermal conductivity (W/m. K)

Grash of Number = Gr = $[gL^3(t_s - t_\infty)]/v^2 T$

Where

g = gravitational acceleration (m/s^2)

L = distance above the lower edge (m)

t_s = temperature of the wall (K)

t_∞ = fluid temperature outside the thermal boundary layer (K)

v = kinematic viscosity of the fluid (m^2/s)

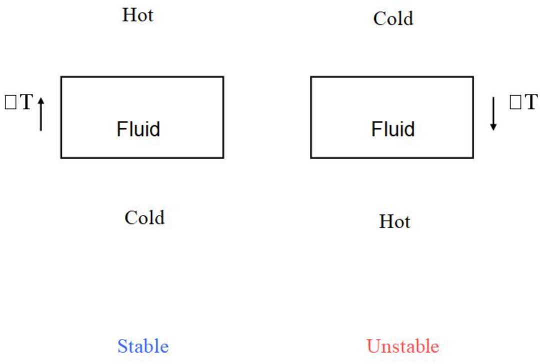
T = absolute temperature (K)

When the flow is turbulent different correlations involving the Rayleigh Number (a function of both the Grashof Number and the Prandtl Number) must be used.

Note that the above equation differs from the usual expression for Grashoff number because the value has been replaced by its approximation, which applies for ideal gases only (a reasonable approximation for air at ambient pressure).

Natural or “Buoyant” or “Free” convection is a very important mechanism that is operative in a varietyofenvironmentsfromcoolingelectroniccircuitboardsincomputerstocausinglarge scale circulation in the atmosphere as well as in lakes and oceans that influences the weather. It iscausedbytheactionofdensitygradientsinconjunctionwithagravitationalfield.Thisisa brief introduction that will help you understand the qualitative features of a variety of situations you might encounter.

There are two basic scenarios in the context of natural convection. In one, a density gradient exists in a fluid in a direction that is parallel to the gravity vector or opposite to it. Such situations can lead to “stable” or “unstable” density stratification of the fluid. In a stable stratification, less dense fluid is at the top and denser fluid at the bottom. In the absence of other effects, convection will be absent, and we canter at the heat transfer problem as one of conduction. In an unstable stratification, in which less dense fluid is at the bottom, and more dense fluid at the top, provided the density gradient is sufficiently large, convection will start spontaneously and significant mixing of the fluid will occur.



II. LITERATURE SURVEY

In 1972, Aung et al. [12] presented a coupled numerical experimental study. Under isothermal conditions at high Rayleigh numbers their experimental results were 10% lower than the numerical ones. This difference has also been observed between Bodoia’s and Osterle’s numerical results [8] and Elenbaas’experimentalones [7]. They ascribed the discrepancies to the assumption of a flat velocity profile at the channel inlet.

However, the difference could also be attributed to the 2D hypothesis for the numerical simulations. In their 2D simulations in 1981, Dalbert et al. [13] introduced a pressure loss at the channel inlet in order to satisfy the Bernoulli equation between the hydrostatic conditions far from the channel and the channel inlet. Their results agreed better with the vertical flat plate regime than those of previous studies.

In 2004, Olsson [17] presented a similar study. He worked on the different existing correlations, including those of Bar-Cohen and Rohsenow, and compared them with experimental results. Finally he proposed some corrected correlations that are valid for a wide range of Rayleigh numbers. In 1989, Webb and Hill [18] studied the laminar convective flow in an experimental symmetrically heated vertical channel. They worked on is of lux heating with a modified Rayleigh number (see eq. 13) changing from 500 to 107. Their temperature measurement performed in horizontal direction on the heated wall showed variations of ± 1.5%, and the flow was assumed to be 2D. They studied correlations for local, average and higher channel Nusselt numbers and compared them to previous works ([9], [10] and [11]). Their correlations were calculated for pure convective

Flow and the radiation losses were estimated and subtracted from the heat input. They found that constants C1and C2 were strongly dependent on modified Rayleigh numbers below Ra_b _ 105 but that they were independent for higher Rayleigh numbers. Good agreement was seen between their results for high Rayleigh numbers and the flat plate solution of Sparrow and Gregg [10]. However, in the log-log diagram the slope of their correlation was found to be 11% higher than the analytical one. They explained this difference by the uncertainty on correction for radiation and conduction losses and the variation of the physical properties with temperature. The papers listed above dealt with laminar free convection, but in BIPV applications flows are mainly turbulent. The first authors to study turbulent free convective flow in a vertical channel were Borgers and Akbari in 1984 [19]. They simulated an isothermally heated 2D channel and used former studies on turbulent vertical flat plate flows to develop a code capable of modelling the transition from laminar to turbulent flow. They gave correlations to predict flow rate and heat transfer in turbulent was developed by Miyamoto et al. in 1986 [20]. They work done a 5 m high and 50 - 200 mm wide channel asymmetrically heated under is of lux conditions. They focused on the transition from laminar to turbulent regime via velocity and temperature profiles. The flow was seen to be fully turbulent up to 4 min all the experiments. In 1997, Fedorov ET Viskanta [21] presented numerical simulation based on Miyamoto's results. In their simulations radioactive heat transfers between surfaces were

III METHODOLOGY

Air flow through vertical narrow plates is modelled using CREO design software. The thesis will focus on thermal and CFD analysis with different Reynolds number (2×10^6& 4×10^6) and different angles ($0^0,30^0,45^0$&60^0) of the vertical narrow plates. Thermal analysis done for the vertical narrow plates by steel, aluminium & copper at different heat transfer coefficient values.

Reynolds numbers	Angle of plate	material
2×10^6	$0^0,30^0,45^0$&60^0	Copper
4×10^6		aluminum
		steel

INTRODUCTION TO CAD

Throughout the history of our industrial society, many inventions have been patented and whole new technologies have evolved. Perhaps the single development that has impacted manufacturing more quickly and significantly than any previous technology is the digital computer. Computers are being used increasingly for both design and detailing of engineering components in the drawing office. Computer-aided design (CAD) is defined as the application of computers and graphics software to aid or enhance the product design from conceptualization to documentation. CAD is most commonly associated with the use of an interactive computer graphics system, referred to as a CAD system. Computer-aided design systems are powerful tools and in the mechanical design and geometric modelling of products and components.

There are several good reasons for using a CAD system to support the engineering design

Function:

- To increase the productivity
- To improve the quality of the design
- To uniform design standards
- To create a manufacturing data base
- To eliminate inaccuracies caused by hand-copying of drawings and inconsistency between
- Drawings

CAD/CAM Software

Software allows the human user to turn a hardware configuration into a powerful design and manufacturing system. CAD/CAM software falls into two broad categories, 2-D and 3-D,based on the number of dimensions are called 2-D representations of 3-D objects is inherently confusing. Equally problem has been the inability of manufacturing personnel to properly read and interpret complicated 2-D representations of objects. 3-D software permits the parts to be viewed with the 3-D planes-height, width, and depth-visible. The trend in CAD/CAM is toward3-D representation of graphic images. Such representation approximates the actual shape and appearance of the object to be produced; therefore, they are easier to read and understand.

APPLICATIONS OF CAD/CAM

The emergence of CAD/CAM has had a major impact on manufacturing, by standardizing product development and by reducing design effort, tryout, and prototype work; it has made possible significantly reduced costs and improved productivity.

Some typical applications of CAD/CAM are as follows:

Programming for NC, CNC, and industrial robots;

Design of dies and melds for casting, in which, for example, shrinkage

Allowances are pre-programmed;

Design of tools and fixtures and EDM electrodes;

Quality control and inspection----for instance, coordinate-measuring

Machines programmed on a CAD/CAM workstation;

Process planning and scheduling.

ADVANTAGES OF CATIA PARAMETRIC SOFTWARE

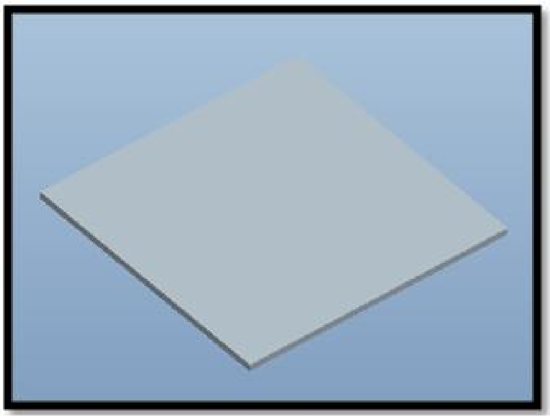
1. Optimized for model-based enterprises
2. Increased engineer productivity
3. Better enabled concept design
4. Increased engineering capabilities
5. Increased manufacturing capabilities
6. Better simulation
7. Design capabilities for additive manufacturing

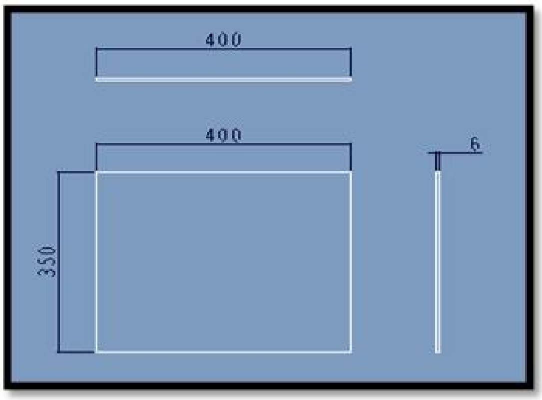
IV MODELLING AND ANALYSIS

Models of narrow plate using CREO wild fire 5.0

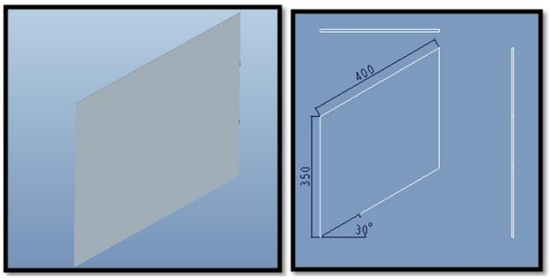
The vertical narrow plate is modelled using the given specifications and design formula from data book. The isometric view of vertical narrow plate is shown in below figure. The vertical narrow plate profile is sketched in sketcher and then it is extruded vertical narrow plate using extrude option.

Vertical narrow plate at $0^0$3D model vertical narrow plates at 0^0 2D models





Vertical narrow plate at $30^0$3D model vertical narrow plates at 30^0 2D models



V ANALYSIS PROCEDURE

INTRODUCTION TO FINITE ELEMENT ANALYSIS

Finite Element Method (FEM) is also called as Finite Element Analysis (FEA). Finite Element Method is a basic analysis technique for resolving and substituting complicated problems by simpler ones, obtaining approximate solutions Finite element method being a flexible tool is used in various industries to solve several practical engineering problems. In finite element method it is feasible to generate the relative results.

In the present day, finite element method is one of the most effective and widely used tools. By doing more computational analysis the approximate solution can be improved or refined in Finite element method. In Finite element method, matrices play an important role in handling large number of equations. The procedure for FEM is a Variation approach where this concept has contributed substantially in formulating the method.

FEM/FEA helps in evaluating complicated structures in a system during the planning stage. The strength and design of the model can be improved with the help of computers and FEA which justifies the cost of the analysis. FEA has prominently increased the design of the structures that were built many years ago.

General Description of FEM:

To acquire a solution for a continuum problem by FEM, the procedure follows an orderly step by step process. The step- by step procedure is as follows:

1. Discretization of the Structure: The first step involves dividing the structure into elements. Therefore suitable finite element should be used to model the structure.

2. Selection of a proper interpolation or displacement model: Since the displacement solution is not known exactly for a complex structure under any given load, we assume an approximate solution. The assumed solution must be simple and should satisfy the convergence requirements. In general, interpolation or displacement model should be in polynomial form.

3. Derivation of element stiffness matrices and load vector: From the second step, stiffness matrix [k^ (e)] and load vector P^ (e) of element e is solved from either equilibrium conditions or variation principle.

4. Assemblage of element equations to obtain the overall equilibrium equation: Since the structure is divided into several finite elements, load vector and individual element stiffness matrices are arranged in a suitable manner. From this, the overall equilibrium equation is formulated as

[K]φ = P

Where [k] = assembled stiffness matrix.

φ = vector of nodal displacement.

P = vector of nodal forces for the complete structure.

Computation of element strains and stresses:

Since φ is known, element strain and stress are computed using necessary equations.

Engineering Applications of Finite Element Method:

Initially FEM method was used for only structural mechanics problems but over the years researchers have successfully applied it to various engineering problems. It has been validated that this method can be used for other numerical solution of ordinary and partial differential equations.

The finite element method is applicable to three categories of boundary value problems:

- Equilibrium or Steady State or Time-Independent problems
- Eigen value problems
- Propagation or transient problems

Various applications of FEM:

- Civil Engineering Structures
- Aircraft Structures
- Heat Conduction
- Geo-mechanics
- Hydraulic and Water Resource Engineering
- Nuclear engineering
- Bio-Medical Engineering
- Mechanical Engineering
- Electrical Machines and Electromagnetic

Advantages of FEA/FEM:

- Non-linear problems are easily solved.
- Several types of problems can be solved with easy formulation.

- Reduces the costs in the development of new products.
- Improves the quality of the end product.
- Life of the product is increased.
- Rapid development of new products
- High product reliability.
- Product fabrication process is enhanced.

Disadvantages of FEA/FEM:

1. Extreme aspect ratios can cause problems.
2. Not well suited for open region problems.

ANSYS Software:

ANSYS is an Engineering Simulation Software (computer aided Engineering). Its tools cover Thermal, Static, Dynamic, and Fatigue finite element analysis along with other tools all designed to help with the development of the product. The company was founded in 1970 by Dr. John A. Swanson as Swanson Analysis Systems, Inc. SASI. Its primary purpose was to develop and market finite element analysis software for structural physics that could simulate static (stationary), dynamic (moving) and heat transfer (thermal) problems. SASI developed its business in parallel with the growth in computer technology and engineering needs. The company grew by 10 percent to 20 percent each year, and in 1994 it was sold. The new owners took SASI’s leading software, called ANSYS®, as their flagship product and designated ANSYS, Inc. as the new company name.

Benefits of ANSYS:

- The ANSYS advantage and benefits of using a modular simulation system in the design process are well documented. According to studies performed by the Aberdeen Group, best-in-class companies perform more simulations earlier. As a leader in virtual prototyping, ANSYS is unmatched in terms of functionality and power necessary to optimize components and systems.
- The ANSYS advantage is well-documented.
- ANSYS is a virtual prototyping and modular simulation system that is easy to use and extends to meet customer needs; making it a low-risk investment that can expand as value is demonstrated within a company. It is scalable to all levels of the organization, degrees of analysis complexity, and stages of product development.

Structural Analysis:

Structural analysis is probably the most common application of the finite element method. The term structural (or structure) implies not only civil engineering structures such as ship hulls, aircraft bodies, and machine housings, as well as mechanical components such as pistons, machine parts, and tools.

Types of Structural Analysis:

Different types of structural analysis are**:**

- Static analysis
- Modal analysis
- Harmonic analysis
- Transient dynamic analysis
- Spectrum analysis
- Bucking analysis
- Explicit dynamic analysis

Static Analysis:

Static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads. A static analysis can, however, include steady inertia loads (such as gravity and rotational velocity), and time-varying loads that can be approximated as static equivalent loads (such as the static equivalent wind arid seismic loads commonly defined in many building codes).

Static analysis is used to determine the displacements, stresses, strains, and forces in structural components caused by loads that do not induce significant inertia and damping effects. Steady loading and response are assumed to vary slowly with respect to time.

The kinds of loading that can be applied in a static analysis include**:**

- Externally applied forces and pressures
- Steady-state inertial forces (such as gravity or rotational velocity)
- Imposed (non-zero) displacements
- Temperatures (for thermal stain)

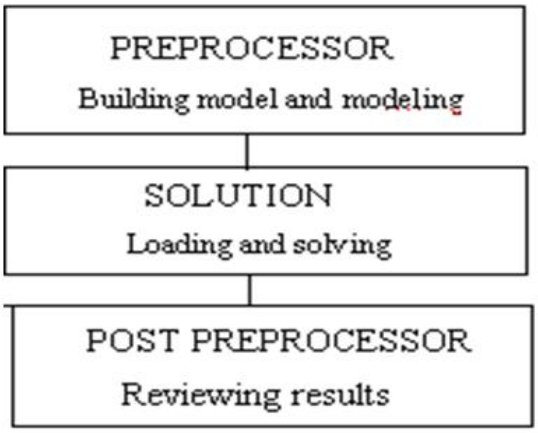
A static analysis can be either linear or non-linear. All types of non-linearity are allowed-large deformations, plasticity, creep, stress, stiffening, contact (gap) elements, hyper elastic elements, and so on.

Over-view of steps in a static analysis:

The procedure for a modal analysis consists of three main steps:

1. Build the model.
2. Apply loads and obtain the solution.
3. Review the results.

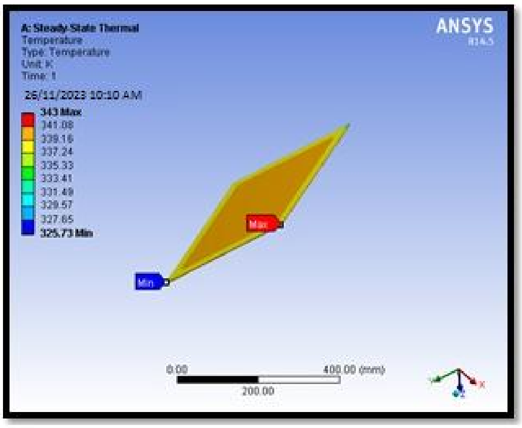
Basic Steps in ANSYS:



IV RESULTS

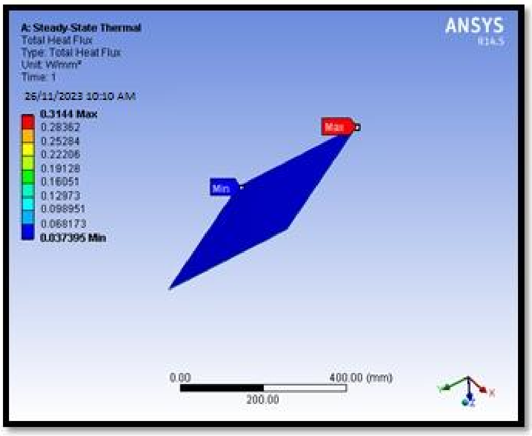
MATERIAL – STEEL

TEMPERATURE



According to the contour plot, the temperature distribution maximum temperature at bottom of the narrow plate because the temperature passing from the bottom of the plate. So we are applying the temperature bottom of the plate and applying the convection except bottom of the plate.

HEAT FLUX



According to the contour plot, the maximum heat flux at corner portion of the narrow plates. Minimum heat flux except corners of the narrow plates.

According to the above contour plot, the maximum heat flux is 0.3144w/mm^2 and minimum heat flux is 0.037395w/mm^2.

CFD ANALYSIS RESULT TABLE

Reynolds number	Models	Pressure (Pa)	Velocity (m/s)	Heat transfer co-efficient (w/m^2-k)	Mass flow rate (kg/s)	Heat transfer rate (W)
2×10^6	0^0	2.59e+04	2.22e+02	3.14e+02	0.0141983	57075.5
	30^0	3.25e+04	2.80e+02	3.39e+02	0.13510132	2022.375
	45^0	6.49e+04	3.40e+02	4.06e+02	0.246078	3677.875
	60^0	1.16e+05	5.01e+02	4.93e+02	0.50804138	9873.625
4×10^6	0^0	1.03e+05	4.44e+02	5.52e+02	0.02565	120081
	30^0	1.31e+05	5.60e+02	5.96e+02	0.86120605	12874.25
	45^0	2.57e+05	6.80e+02	7.09e+02	0.611465	9129
	60^0	4.65e+05	1.00e+03	8.55e+02	1.05348	20294.25

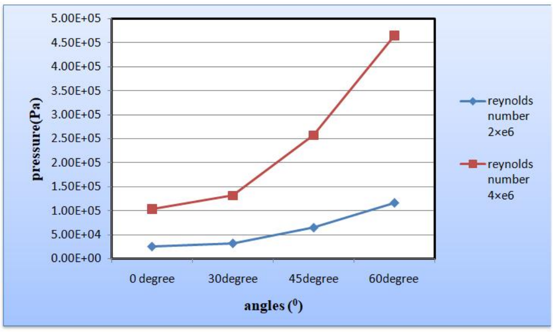
THERMAL ANALYSIS RESULT TABLE

Models	Materials	Temperature (^0C)		Heat flux (w/mm^2)
		Max.	Min.	
0^0	Steel	343	333.99	0.14103
	Aluminum	343	339.2	0.15159
	Copper	343	341.76	0.15657
30^0	Steel	343	331.7	0.17153
	Aluminum	343	338.22	0.18744
	Copper	343	341.41	1.1951
45^0	Steel	343	329.74	0.20385
	Aluminum	343	341.08	0.23701
	Copper	343	337.26	0.22608
60^0	Steel	343	325.73	0.3144
	Aluminum	343	335.2	0.35993
	Copper	343	340.34	0.38359

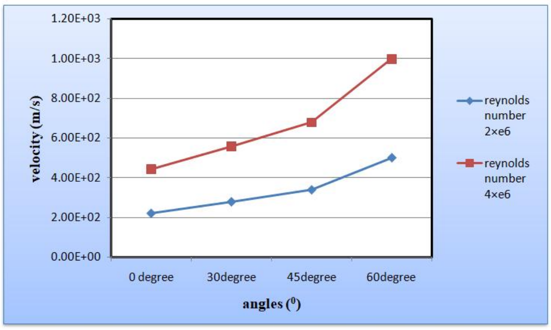
GRAPHS

CFD ANALYSIS GRAPHS

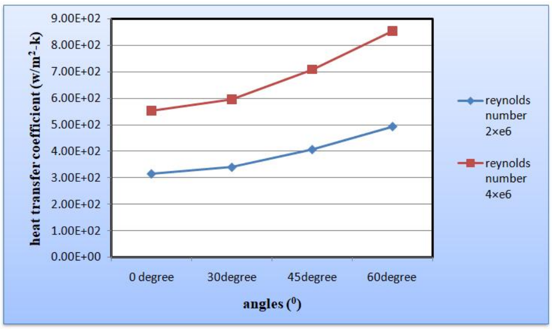
PRESSURE PLOT



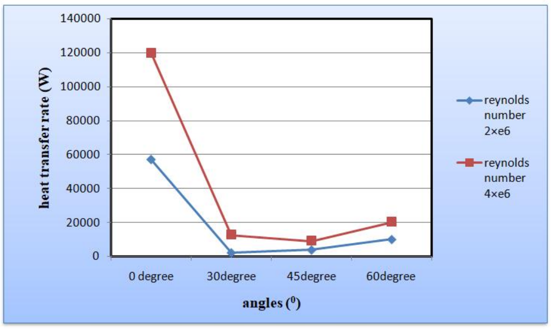
VELOCITY PLOT



HEAT TRANSFER COEFFICIENT PLOT



MASS FLOW RATE PLOT



THERMAL ANALYSIS

VII CONCLUSION

In this thesis the air flow through vertical narrow plates is modelled using CREO design software. The thesis will focus on thermal and CFD analysis with different Reynolds number (2×10^6& 4×10^6) and different angles (0^0,30^0,45^0&60^0) of the vertical narrow plates. Thermal analysis done for the vertical narrow plates by steel, aluminium & copper at different heat transfer coefficient values. These values are taken from CFD analysis at different Reynolds numbers.

By observing the CFD analysis the pressure drop &velocity increases by increasing the inlet Reynolds numbers and increasing the plate angles. The heat transfer rate increasing the inlet Reynolds numbers, more heat transfer rate at 0^0 angles.

By observing the thermal analysis, the taken different heat transfer coefficient values are from CFD analysis. Heat flux value is more for copper material than steel & aluminium.

So we can conclude the copper material is better for vertical narrow plates.

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