



NATURAL CONVECTIVE HEAT TRANSFER FROM INCLINED NARROW 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 modeled 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 (00,300,450&600) of the vertical narrow plates. Thermal analysis done for the vertical narrow plates by steel, aluminum & 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 modeled in parametric software Pro-Engineer and analysis done in ANSYS.

Keywords— Types of convection, Natural convection, inclined plates, copper material.

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. The temperature of the air adjacent to the hot object is higher, thus its density is lower. As a result, 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.

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 Coriolis 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 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.

$$\text{Num} = 0.478(\text{Gr}^{0.25})$$

Mean Nusselt Number = $\text{Num} = \text{hmL}/k$ Where

hm = mean coefficient applicable between the lower edge of the plate and any point in a distance L ($\text{W}/\text{m}^2 \cdot \text{K}$)

L = height of the vertical surface (m) k = thermal conductivity ($\text{W}/\text{m} \cdot \text{K}$) Grashoff Number = $\text{Gr} =$

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)

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

T = absolute temperature (K)

II. LITERATURE REVIEW

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' experimental ones [7]. They ascribed the discrepancies to the assumption of a flat velocity profile at the channel inlet.

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 asymmetrically heated vertical channel. They worked on isoflux heating with a modified Rayleigh number (see eq. 13) changing from 500 to 107. Their temperature measurements performed in horizontal direction on the heated wall showed variations of $\pm 1.5\%$, 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 C_1 and C_2 were strongly dependent on modified Rayleigh numbers below $\text{Ra}_b \approx 105$ 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].

III. PROCEDURE:

Air flow through vertical narrow plates is modeled using CREOdesign software. The thesis will focus on thermal and CFD analysis with different Reynolds number (2×10^6 & 4×10^6) and different angles ($0^\circ, 30^\circ, 45^\circ$ & 60°) of the vertical narrow plates.

Thermal analysis done for the vertical narrow plates by steel, aluminum & copper at different heat transfer coefficient values.

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

INTRODUCTION TO CAD

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 modeling 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

INTRODUCTION TO CREO

PTC CREO, formerly known as

Pro/ENGINEER, is 3D modeling software used in mechanical engineering, design, manufacturing, and in CAD drafting service firms. It was one of the first 3D CAD modeling applications that used a rule-based parametric system. Using parameters, dimensions and features to capture the behavior of the product, it can optimize the development product as well as the design itself.

ADVANTAGES OF CREO 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

CREO parametric modules:

- Sketcher
- Part modeling
- Assembly
- Drafting

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

- 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.

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. 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-linearities 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:

Pre-Processing (Defining the Problem): The major steps in pre-processing are given below

- Define key points/lines/ areas/volumes.
- Define element type and material/geometric properties
- Mesh lines/ areas/volumes as required.

The amount of detail required will depend on the dimensionality of the analysis (i.e., 1D, 2D,

axi-symmetric, 3D).

Solution (Assigning Loads, Constraints, And Solving): Here the loads (point or pressure), constraints (translational and rotational) are specified and finally solve the resulting set of equations.

Post Processing: In this stage, further processing and viewing of the results can be done such as:

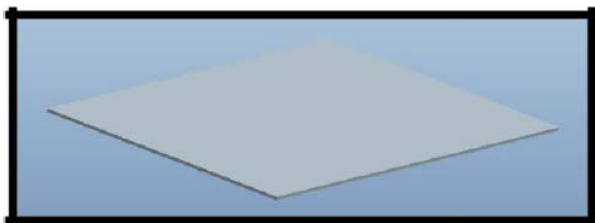
- Lists of nodal displacements
- Element forces and moments
- Deflection plots
- Stress contour diagrams

Advanced Post-Processing:

ANSYS provides a comprehensive set of post-processing tools to display results on the models as contours or vector plots, provide summaries of the results (like min/max values and locations). Powerful and intuitive slicing techniques allow getting more detailed results over given parts of your geometries. All the results can also be exported as text data or to a spreadsheet for further calculations. Animations are provided for static cases as well as for nonlinear or transient histories. Any result or boundary condition can be used to create customized charts.

IV . MODELLING AND ANALYSIS

Vertical narrow plate 3D model



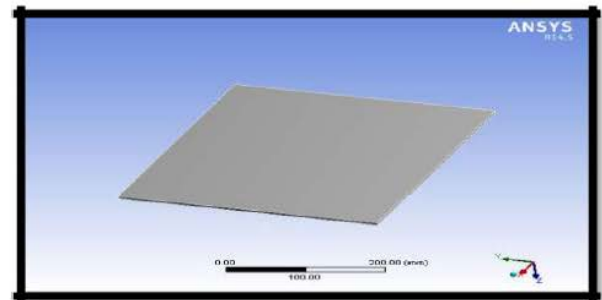
MATERIAL PROPERTIES OF AIR

Thermal conductivity = 0.024 w/m-k

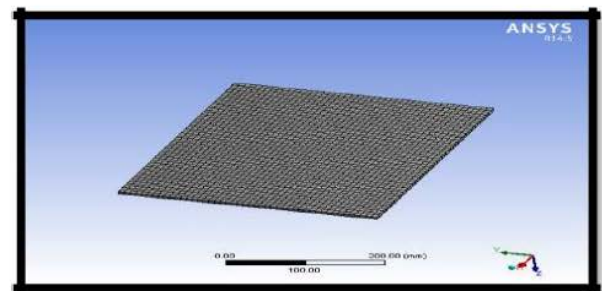
Density = 1.225 kg/m³

Viscosity = 1.98 × 10⁻⁵ kg/m-s

IMPORTED MODEL

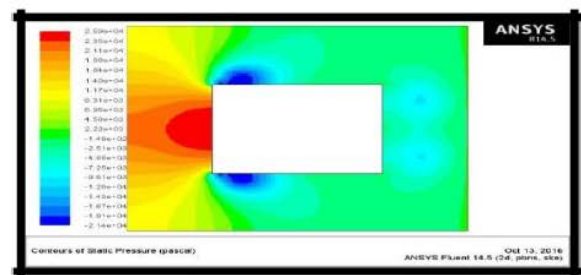


MESHED MODEL



VERTICAL NARROW PLATE AT

0° REYNOLDS NUMBER - 2 × 10⁶



Mass flow rate

Mass Flow Rate	(kg/s)
inlet	79.311481
interior-trn_srf	196.93365
outlet	-79.3256
wall-trn_srf	0
Net	-0.014198383

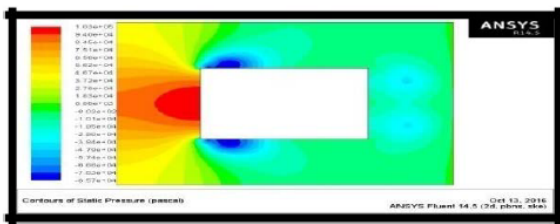
Heat transfer rate

Total Heat Transfer Rate		(w)
inlet	5974630.5	
outlet	-6031706	
wall_trn_srf	0	
Net	-57075.5	

Mass flow rate

Mass Flow Rate		(kg/s)
inlet	99.139221	
interior_trn_srf	-54.444607	
outlet	-99.00412	
wall_trn_srf	0	
Net	0.13510132	

REYNOLDS NUMBER - 4×10^6



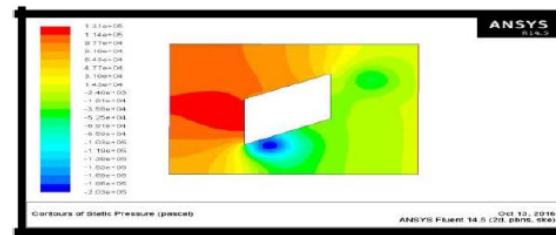
Heat transfer rate

Total Heat Transfer Rate		(w)
inlet	1481683.6	
outlet	-1479661.3	
wall_trn_srf	0	
Net	2022.375	

MASS FLOW RATE

Mass Flow Rate		(kg/s)
inlet	158.63991	
interior_trn_srf	393.53253	
outlet	-158.66556	
wall_trn_srf	0	
Net	-0.025650024	

REYNOLDS NUMBER - 4×10^6



HEAT TRANSFER RATE

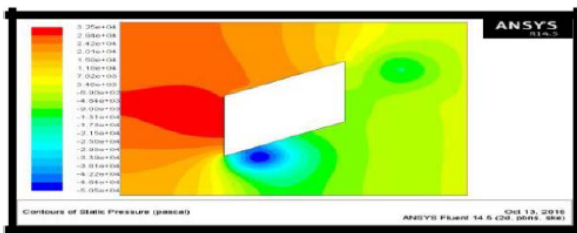
Total Heat Transfer Rate		(w)
inlet	11950556	
outlet	-12070637	
wall_trn_srf	0	
Net	-120081	

Mass flow rate

Mass Flow Rate		(kg/s)
inlet	198.29097	
interior_trn_srf	-105.51104	
outlet	-197.43877	
wall_trn_srf	0	
Net	0.86120605	

VERTICAL NARROW PLATE AT

30^0 REYNOLDS NUMBER - 2×10^6

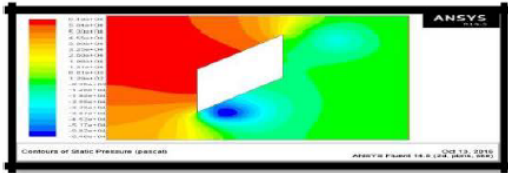


Heat transferrate

Total Heat Transfer Rate		(w)
inlet	2963688.3	
outlet	-2950814	
wall_trn_srf	0	
Net	12874.25	

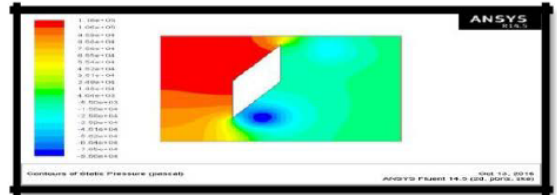
VERTICAL NARROW PLATE AT 45^0

REYNOLDS NUMBER - 2×10^6



Mass flow rate

Mass Flow Rate	(kg/s)
inlet	99.139221
interior_trn_srf	1081.3646
outlet	-98.893143
wall_trn_srf	0
Net	0.24607849



Mass flow rate

Mass Flow Rate	(kg/s)
inlet	99.139221
interior_trn_srf	1325.8466
outlet	-99.647263
wall_trn_srf	0
Net	-0.50804138

Heat transfer rate

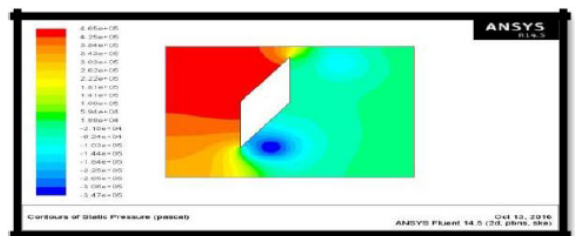
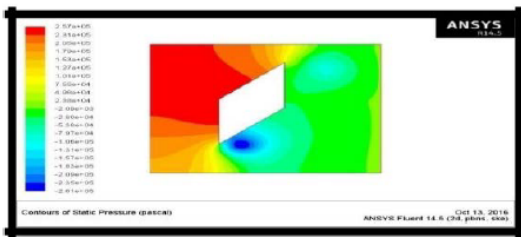
Total Heat Transfer Rate	(w)
inlet	1481683.6
outlet	-1478005.8
wall_trn_srf	0
Net	3677.875

Heat transfer rate

Total Heat Transfer Rate	(w)
inlet	1481683.6
outlet	-1491557.3
wall_trn_srf	0
Net	-9873.625

REYNOLDS NUMBER - 4×10^6

REYNOLDS NUMBER - 4×10^6



Mass flow rate

Mass Flow Rate	(kg/s)
inlet	198.29997
interior_trn_srf	2164.0718
outlet	-197.68851
wall_trn_srf	0
Net	0.61146545

Mass flow rate

Mass Flow Rate	(kg/s)
inlet	198.29997
interior_trn_srf	2652.6765
outlet	-199.35345
wall_trn_srf	0
Net	-1.0534821

Heat transfer rate

Total Heat Transfer Rate	(w)
inlet	2963688.3
outlet	-2954559.3
wall_trn_srf	0
Net	9129

Heat transfer rate

Total Heat Transfer Rate	(w)
inlet	2963688.3
outlet	-2983982.5
wall_trn_srf	0
Net	-20294.25

VERTICAL NARROW PLATE AT 60°

REYNOLDS NUMBER - 2×10^6

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

Models	Materials	Temperature (°C)		Heat flux (w/mm ²)
		Max.	Min.	
0°	Steel	343	333.99	0.14103
	Aluminum	343	339.2	0.15159
	Copper	343	341.76	0.15657

30°	Steel	343	331.7	0.17153
	Aluminum	343	338.22	0.18744
	Copper	343	341.41	1.1951
45°	Steel	343	329.74	0.20385
	Aluminum	343	341.08	0.23701
	Copper	343	337.26	0.22608
60°	Steel	343	325.73	0.3144
	Aluminum	343	335.2	0.35993
	Copper	343	340.34	0.38359

5.00E+05
 4.50E+05
 4.00E+05
 3.50E+05
 3.00E+05
 2.50E+05
 2.00E+05
 1.50E+05
 1.00E+05
 5.00E+04
 0.00E+00

angles (°)

re
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 e6

THERMAL ANALYSIS

HEAT FLUX

1.4

1.2

1

0.8

0.6

0.4

0.2

0

steel aluminum copper

0 degree

30 degree

45 degree

60 degree

CONCLUSION

In this thesis the air flow through vertical narrow plates is modeled 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, 30, 45 & 60) of the vertical narrow plates. Thermal analysis done for the vertical narrow plates by steel, aluminum & 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 degrees.

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 & aluminum.

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

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