Experimental and Numerical Study of Natural Convection Heat Transfer in Heated horizontal Cylinder Located inside square Enclosure

This study
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Table of Contents

TABLE OF CONTENTS ................................................................................................................. 2
LIST OF FIGURES ....................................................................................................................... 4
LIST OF TABLES .......................................................................................................................... 5
ABSTRACT .................................................................................................................................. 6
NOMENCLATURE.......................................................................................................................... 8
Chapter 1 .................................................................................................................................... 10
  1. Introduction .......................................................................................................................... 10
    1.1. Background ....................................................................................................................... 10
    1.2. Objective of the research ............................................................................................... 10
Chapter 2 ................................................................................................................................... 11
  2. Literature Review .................................................................................................................. 11
Chapter 3 ................................................................................................................................... 14
  3. Basic Models of Natural convection over cylinder ................................................................. 14
    3.1. Convection ...................................................................................................................... 14
    3.2. Classifications of convection: ......................................................................................... 14
    3.3. Classifications of convection Based on driving mechanism: .......................................... 15
        3.3.1. Force convection: ..................................................................................................... 15
        3.3.2. Natural convection .................................................................................................. 16
    3.4. Natural convection over a horizontal cylinder: ............................................................... 17
    3.5. The model: ..................................................................................................................... 18
        3.5.1. Governing equations for natural convection: ......................................................... 18
        3.5.2. Empirical Equations of Nusselt number over horizontal hot cylinder: ................... 19
    3.6. Non-dimensional parameters ......................................................................................... 20
Chapter 4 ................................................................................................................................... 22
  4. COMSOL Multiphysics Software ......................................................................................... 22
    4.1. Introduction ..................................................................................................................... 22
    4.2. Modeling Instruction ....................................................................................................... 22
        4.2.1. Create a new file: .................................................................................................... 22
        4.2.2. Select Physics: ........................................................................................................ 23
        4.2.3. Global definition: .................................................................................................. 24
### Geometry

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.2.4.4</td>
<td>Geometry 1</td>
<td>25</td>
</tr>
<tr>
<td>.4.2.4.1</td>
<td>Square (sq1)</td>
<td>25</td>
</tr>
<tr>
<td>4.2.4.2</td>
<td>Circle1 (cl)</td>
<td>25</td>
</tr>
<tr>
<td>4.2.4.3</td>
<td>Difference</td>
<td>26</td>
</tr>
<tr>
<td>.4.2.5</td>
<td>Heat transfer in fluids</td>
<td>27</td>
</tr>
<tr>
<td>4.2.6</td>
<td>Thermal Insulation</td>
<td>27</td>
</tr>
<tr>
<td>.4.2.7</td>
<td>Hot temperature</td>
<td>28</td>
</tr>
<tr>
<td>4.2.8</td>
<td>Laminar flow</td>
<td>28</td>
</tr>
<tr>
<td>4.2.9</td>
<td>Initial valves</td>
<td>29</td>
</tr>
<tr>
<td>4.2.10</td>
<td>Volume force</td>
<td>29</td>
</tr>
<tr>
<td>.4.2.11</td>
<td>Wall</td>
<td>30</td>
</tr>
<tr>
<td>4.2.12</td>
<td>Mesh</td>
<td>30</td>
</tr>
</tbody>
</table>

### Chapter 5

5. The Experimental work

5.1. Introduction

5.2. The Components

### Chapter 6

6. Rustles, Conclusions and Future Studies

6.1. Results

6.2. Conclusions

6.3. Future studies

BIBLIOGRAPHY
List of Figures

14 .............................................................................. Figure 3-1 The convection model
15 .............................................................................. Figure 3-2 Forced convection types
16 .............................................................................. Figure 3-3 Velocity boundary layer
17 .............................................................................. Figure 3-4 Natural convection types
17 .............................................................................. Figure 3-5 Natural convection flow over a horizontal hot cylinder.
18 .............................................................................. Figure 3-6 Sketch of Cylinder inside Enclosure
23 .............................................................................. Figure 4-1 Select space dimension
23 .............................................................................. Figure 4-2 Select physics laminar flow
24 .............................................................................. Figure 4-3 Select physics heat transfer in fluid
24 .............................................................................. Figure 4-4 Definition of variables
25 .............................................................................. Figure 4-5 Geometry Draw square
26 .............................................................................. Figure 4-6 Draw circle
26 .............................................................................. Figure 4-7 Difference
27 .............................................................................. Figure 4-8 add heat transfer in fluids and initial values
27 .............................................................................. Figure 4-9 Thermal insulation
28 .............................................................................. Figure 4-10 Hot temperature
29 .............................................................................. Figure 4-11 Fluid properties
29 .............................................................................. Figure 4-12 Initial values
29 .............................................................................. Figure 4-13 Volume force
30 .............................................................................. Figure 4-14 Wall setting
30 .............................................................................. Figure 4-15 mesh
32 .............................................................................. Figure 5-1 The experimental model
List of Tables

19 ...................... Table 3-1 Empirical Equations of Nusselt number over horizontal hot cylinder
Abstract

The thermal transport of natural convection heat transfer in heated horizontal cylinder located inside square enclosure studied experimentally and numerically. Air assumed to use as a working fluid while an aluminum (14 mm diameter) used as heat sources. The horizontal cylinder located in 56 mm square and all the walls assumed to be insulated. COMSOL malty physics software have been used to validate the experimental work and present the results in streamline, isotherm, and the average Nusselt number. The results shown that, when the cylinder surface temperature increases, the wall heat transfer increases.
To my parents

To my wife and

إهداء

To my family and my friends
Nomenclature

\( cp \) specific heat at constant pressure

\( Da \) Darcy number, \( Da = K/L^2 \)

\( g \) magnitude of the gravitational acceleration, \( \text{ms}^{-2} \)

\( k \) thermal conductivity, \( \text{Wm}^{-1} \text{K}^{-1} \)

\( L \) length of the cavity, m

\( Nu_l \) local Nusselt number

\( Nu \) average Nusselt number

\( p \) pressure, \( \text{kg.m}^{-1}.\text{s}^{-2} \)

\( P \) non-dimensional pressure, \( P = pL^2/\rho\alpha^2 \)

\( Pr \) Prandtl number, \( Pr = \nu/\alpha \)

\( Ra \) Rayleigh number for porous medium, \( Ra = g \beta \Delta TL^3/\nu\alpha \)

\( Ra^* \) modified Rayleigh number for porous medium,

\( T \) non-dimensional temperature, \( T = (T^* - T_{c})/(T_{h} - T_{c}) \)

\( T^* \) dimensional temperature, K

\( u \) velocity vector, \( \text{ms}^{-1} \)

\( u \) velocity components in \( x \)-direction, \( \text{ms}^{-1} \)

\( U \) non-dimensional velocity components in \( X \)-direction, \( U = uL/\alpha \)

\( v \) velocity components in \( y \)-direction, \( \text{ms}^{-1} \)

\( V \) non-dimensional velocity components in \( Y \)-direction, \( V = vL/\alpha \)

\( x \) \( x \) coordinates, m

\( X \) non-dimensional \( X \)-coordinates, \( X = x/L \)

\( Y \) \( y \) coordinates, m

\( Y \) non-dimensional \( Y \)-coordinates, \( Y = y/L \)
Nomenclature

Greek symbols

\( \alpha \quad \text{effective thermal diffusivity} \), \( \alpha = k_{\text{eff}} / (\rho_c c_p) \), \( \text{m}^2 \text{s}^{-1} \)

\( \beta \quad \text{coefficient of thermal expansion} \), \( \text{K}^{-1} \)

\( \nu \quad \text{kinematic viscosity} \), \( \text{m}^2 \text{s}^{-1} \)

\( \rho \quad \text{density} \), \( \text{kgm}^{-3} \)

\( \sigma \quad \text{ratio of specific heats} \)

Subscripts

\( c \quad \text{cold} \)

\( f \quad \text{fluid} \)

\( h \quad \text{hot} \)

\( l \quad \text{local} \)

\( w \quad \text{wall} \)
Chapter 1

1. Introduction

1.1. Background

The necessary knowledge of fluid flow heat transfer from a heated horizontal cylinder is important in industrial applications such as heat exchanger, reactor safety device, chemical reactor and cooling of electronic equipment. According to Vincent Morgan [1] the overall convective heat transfer from smooth circular cylinder the aspect ratio L/D equal 10 for neglect axial conduction losses. Used a numerical simulation to study natural convection in a square cavity containing heated horizontal cylinder, when a temperature difference existed across the enclosure. The average Nusselt number at the hot and cold walls are presented and discussed. The COMSOL program is useful in the field of scientific research to understand a gas movement inside the cavity.

1.2. Objective of the research

In this project, a numerical and experimental analysis is performed for natural convection heat transfer from heated horizontal cylinder placed in a square cavity, which insulated from all sides. The COMSOL Multi physics Software chosen to solve a numerical problem. The device will be placed in one of the laboratories of the department of mechanical engineering, to take advantage of the device for students of the third year.
Chapter 2

2. Literature Review

Cesini [2] This research includes an experimental and theoretical study of natural convection heat transfer from a horizontal cylinder enclosed in a rectangular cavity. The cylinder is made of aluminum and its dimensions are \(L=0.42m\), \(H=57mm\) of cavity with width varied \((W=30, 40, \text{ and } 50 \text{ mm})\). The Rayleigh number as defined ranges between \((1.3*10^3 \text{ and } 3.4*10^3)\). The subject was discussed the overall convective heat transfer from smooth circular cylinders numerically. The \(L / D\) height should be less than 10 and that for neglect the axial conduction losses. Different kinds of working fluid have been used (air, gases and liquids). This search was submitted by Vincent T. Morgan [1]. Kitamura [3] studied the experimental analysis is performed for natural convection heat transfer from a large horizontal cylinders. The cylinders were heated with uniform heat flux and their diameters were varied from 60 to 800 mm to enable experiments over a wide range of modified Rayleigh numbers, \(Ra_D = (3.0*10^8 \text{ to } 3.6*10^{13})\). The local heat transfer coefficient were also measured. The results show that the coefficient are increased markedly in the transitional and turbulent regions.

Ahmed [4] studied natural convection heat transfer from a horizontal cylinder embedded in a porous media theoretically and experimentally. The experimental were carried out in cylinder the diameter is 20mm and the theoretical part of the work includes the derivation of the governing momentum and energy equation by using Darcy flow model. Both theoretical and experimental results revealed that the average heat transfer increased when Rayleigh increased. The relationship between \(Nu\) and \(Ra\) for both experimental and theoretical are given us \(Nu=4.311 \text{ in } Ra=11.1\), and \(Nu=2.155 Ln Ra-3.98\) Respect. Natural convection heat transfer around hot and cold micro tubes parallelized horizontally in cylindrical enclosure studied numerically by
Dai [5]. The hybrid Lattice-Boltzmann Finite-Difference Method (LBFDM) have been used in this simulation. The results shown for the effective heat transfer coefficient between the micro-tubes. When hot tube is placed directly over the cold one is the smallest, and the maximum can be achieved with the cold tube above the hot tube. 

Natural convection heat transfer from two horizontal cylinders experimentally studied by Olivier et al [6] for the range of (2 * 10^6 < Ra < 6 * 10^6). It is found that; the rising from the heated lower cylinder interacts with the upper cylinder and significantly affects on the surface heat transfer distribution.

Amir et al [7] investigated experimentally the effect of a perforated fin on natural convection heat transfer from a confined horizontal cylinder. The selected diameter is 19.5 mm. The considering parameters were the ratios between vertical position to diameter = 0.5, 1.5, 2, and 3. The Rayleigh number ranges (4.5 * 10^3 to 1.2 * 10^4).

Morgan [8] studied heat transfer by natural convection from a horizontal isothermal circular cylinder in air numerically and the range of Rayleigh 34.6 to 1.06 * 10^6 explanation the affect of the aspect ratio L/D on axial heat conduction. Comparison of mean experimental, correlation, and numerical values of the Nusselt number.

Mohamed et al [9] studied experimentally the effects of vertical confinement Rayleigh numbers ranging from 10^3 to 10^5. These authors found that; the heat flux around the cylinder increases with decreasing distance between the cylinder and the enclosure wall. P. Wang et al [10] displayed numerically and experimentally the natural convection fluid flow about a horizontal cylinder using splines for fairly high Rayleigh numbers (10^5 ≤ Ra ≤ 10^8). The heat transfer coefficient increases rapidly with increasing Rayleigh number, the convective activity becomes much stronger, and the boundary layer region become very thin. Ikuo tokura et al [11] demonstrated of free convection heat transfer from horizontal cylinder in vertical array set in free space between parallel walls experimentally. There experiment were carried out in room of dimensions 1000x765x1193 mm^3, and used five cylinders having equal spacing under the condition of constant surface temperature. The temperature difference between the surfaced of the cylinder at about 50°C, corresponded to a Grashof number based on the cylinder diameter in ranged 4 * 10^4 to 4 * 10^5. Thamir [12] studied experimentally, natural convection heat transfer from a horizontal cylinder array vertically aligned to and confined by a single wall and two walls. The range of Ra from 6.2 * 10^4 to 1.2 * 10^6.
The result showed that there was maximum heat transfer from each cylinder at a specific wall array a spacing and a spacing center to center spacing.

Y. brunet et al [13] displayed experimentally of heat transfer between two horizontal concentric cylinder. The outer cylinder rotating the inner at rest. The results are presented in terms of dimensionless parameters. This geometry simulates rotating liquid helium transfer and used in superconducting (AC) generators. Y. W. Lu et al [14] studied numerically Laminar natural convection heat transfer characteristics of salt around horizontal cylinder. Rayleigh number range $1.57 \times 10^2$ to $2.3 \times 10^6$. The effect of viscous decreased, so the other correlations that neglected the effect of viscous dissipation could also predict the natural convection of molten salt well.

Laith et al [15] displayed experimentally and theoretically natural convection heat transfer of heated square cylinder placed inside a cooled circular enclosure cylinder placed with air. The result showed that as aspect ratio increases the heat transfer rate and the average Nusselt number increased.
Chapter 3

3. Basic Models of Natural convection over cylinder

3.1. Convection

Convection is the mechanism of heat transfer through a fluid in the presence of bulk fluid motion. Convection is classified as natural (or free) and forced convection depending on how the fluid motion is initiated. In natural convection, any fluid motion is caused by natural means such as the buoyancy effect, i.e. the rise of warmer fluid and fall the cooler fluid as shown in Figure 3-1. Whereas in forced convection, the fluid is forced to flow over a surface or in a tube by external means such as a pump or fan.

![Convection Model](image)

Figure 3-1 The convection model

3.2. Classifications of convection:

The convection heat transfer can be classified depends on the fluid motion and the body shape itself. And the mean types of classifications are:
A. Based on geometry:
   External flow / Internal flow
B. Based on driving mechanism:
   Natural convection / forced convection
C. Based on number of phases:
   Single phase / multiple phase
D. Based on nature of flow:
   Laminar / turbulent

3.3. Classifications of convection Based on driving mechanism:

3.3.1. Force convection:
Convection heat transfer is complicated since it involves fluid motion as well as heat conduction. The forced convection can be divided to internal and external forced convection as shown in Figure 3-2

![Figure 3-2 Forced convection types](image)

The fluid motion enhances heat transfer (the higher the velocity the higher the heat transfer rate). The rate of convection heat transfer is expressed by Newton’s law of cooling:

\[ Q_{conv} = hA(T_s - T_\infty) \] (W)
Chapter 3. Basic Models of Natural convection over cylinder

The convective heat transfer coefficient $h$ strongly depends on the fluid properties and roughness of the solid surface, and the type of the fluid flow (laminar or turbulent) as shown in Figure 3-3.

![Figure 3-3 Velocity boundary layer](image)

3.3.2. Natural convection

Natural convection is a method, or type of heat transfer, in which the fluid motion is not generated by any external source but only by density differences in the fluid occurring due to temperature gradients. The fluid movement does not stop unless its temperature is equal. The movement of the fluid in free convection, whether it is a gas or a liquid, results from the buoyancy forces imposed on the fluid when its density in the proximity of the heat-transfer surface is decreased as a result of the heating process.

The buoyancy forces would not be present if the fluid were not acted upon by some external force field such as gravity. Although gravity is not the only type of force field that can produce the free-convection currents; a fluid enclosed in a rotating machine is acted upon by a centrifugal force field, and thus could experience free-convection currents if one or more of the surfaces in contact with the fluid were heated. The buoyancy forces that give rise to the free-convection currents are called body forces.

A hot radiator used for heating a room is one example of a practical device that transfers heat by free convection. The free convection can be classified as shown in Figure 3-4
3.4. **Natural convection over a horizontal cylinder:**

The boundary layer over a hot horizontal cylinder start to develop at the bottom, increasing in thickness along the circumference, and forming a rising plume at the top, as shown in Figure 3-5. Therefore, the local Nusselt number is highest at the bottom, and lowest at the top of the cylinder when the boundary layer flow remains laminar. The opposite is true in the case of a cold horizontal cylinder in a warmer medium, and the boundary layer in this case starts to develop at the top of the cylinder and ending with a descending plume at the bottom.

![Figure 3-5 Natural convection flow over a horizontal hot cylinder.](image-url)
3.5. The model:
A horizontal heated cylinder inside insulated square cavity have been studied experimentally and numerical. Horizontal aluminum cylinder \((d=14 \text{ mm})\) located in the center of square cavity (made from wood) used in this study as shown in Figure 3-6.

![Figure 3-6 Sketch of Cylinder inside Enclosure](image)

3.5.1. Governing equations for natural convection:

The governing equations are the mass, momentum and energy conservation equations which are:

Continuity equation:

\[
\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} = 0 \tag{3-1}
\]

X - Momentum:

\[
\rho \left( v \frac{\partial u}{\partial x} + u \frac{\partial u}{\partial y} \right) = - \frac{\partial p}{\partial x} + \mu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \tag{3-2}
\]
Y – Momentum:

\[ \rho \left( v \frac{\partial v}{\partial x} + u \frac{\partial v}{\partial y} \right) = - \frac{\partial p}{\partial x} + \mu \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) - \rho g \]  

(3-3)

Energy:

\[ v \frac{\partial T}{\partial x} + u \frac{\partial T}{\partial y} = \alpha \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) \]  

(3-4)

### 3.5.2. Empirical Equations of Nusselt number over horizontal hot cylinder:

Over the years, it has been found that; average free convection heat transfer coefficients can be represented in the following functional form for a variety of circumstances as shown in Table 3-1

<table>
<thead>
<tr>
<th>Table 3-1 Empirical Equations of Nusselt number over horizontal hot cylinder</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nu</strong> = 0.4((Gr \ Pr)^0)</td>
</tr>
<tr>
<td><strong>Nu</strong> = 0.53((Gr \ Pr)^{1/2})</td>
</tr>
<tr>
<td><strong>Nu</strong> = 0.13((Gr \ Pr)^{1/3})</td>
</tr>
<tr>
<td><strong>Nu</strong> = 0.85((Gr \ Pr)^{0.188})</td>
</tr>
<tr>
<td><strong>Nu</strong> = 0.48((Gr \ Pr)^{1/4})</td>
</tr>
<tr>
<td><strong>Nu</strong> = 0.125((Gr \ Pr)^{1/3})</td>
</tr>
</tbody>
</table>

A more complicated expression for use over a wider range of Gr and Pr is given by Churchill and Chu [3]:

\[ Nu^{1/2} = 0.60 + 0.387 \left( \frac{Gr \ Pr}{1 + (0.559/Pr)^{9/16}} \right)^{1/6} \text{ for } 10^{-5} < Gr \ Pr < 10^{-2} \]  

(3-5)

A simpler equation is available from Reference [3] but is restricted to the laminar range of \(10^{-6} < Gr \ Pr < 10^9\):
Chapter 3. Basic Models of Natural convection over cylinder

\[ Nu_d = 0.36 + \frac{0.518(Gr_d Pr)^{0.7}}{[1+(0.559/Pr)^{9/16}]^{4/9}} \]  

(3-6)

Heat transfer from horizontal cylinders to liquid metals may be calculated from Reference[4]:

\[ Nu = 0.53(Gr_d Pr^2)^{0.7} \]  

(3-7)

3.6. Non-dimensional parameters

The non-dimensional procedure is one of the formulas that have commonly been used. It is used for non-dimensional governing equations before their solution, especially for complex problems which have several variables. The non-dimensional process involves the choice of different parameters. The effects of the choice of these parameters on non-dimensional equations are very important in order to show the effect of physical properties and which parameters should be focused on in order to present these physical properties.

The two-dimensional flow and thermal fields are governed by the following non-dimensional equations:

Continuity equation:

\[ \left( \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} \right) = 0 \]  

(3-8)

X-momentum equation:

\[ \left( U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial y} \right) = -\frac{\partial p}{\partial x} + Pr \left( \frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2} \right) \]  

(3-9)

Y-momentum equation:

\[ \left( U \frac{\partial V}{\partial x} + V \frac{\partial V}{\partial y} \right) = -\frac{\partial p}{\partial y} + Pr \left( \frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} \right) + Ra \ast Pr \ast \theta \]  

(3-10)

Energy equation:

\[ U \frac{\partial \theta}{\partial x} + V \frac{\partial \theta}{\partial y} = \left( \frac{\partial^2 \theta}{\partial x^2} + \frac{\partial^2 \theta}{\partial y^2} \right) \]  

(3-11)
Chapter 3. Basic Models of Natural convection over cylinder

The above equations are converted into a non-dimensional form under the following dimensionless quantities:

\[ X = \frac{x}{L}, \quad Y = \frac{y}{L}, \quad U = \frac{uL}{\alpha}, \quad V = \frac{vL}{\alpha}, \quad P = \frac{pL^2}{\rho \sigma^2}, \]

\[ D = \frac{d}{L}, \quad Pr = \frac{v}{\alpha}, \quad Ra = \frac{g \beta \Delta T L^3}{v^2}, \quad \theta = \frac{T - T_c}{T_h - T_c} \quad (3-12) \]

Where all the symbols are defined in detail in the Nomenclature.

The local Nusselt number \((Nu_l)\) at the walls can be defined as follows:

\[ Nu_l = \left[-\frac{\partial T}{\partial X}\right]_x \quad (3-13) \]

The local Nusselt number, at any point of the cylinder surface, is estimated as:

\[ Nu_l = \left(-\frac{\partial T}{\partial R}\right)_{r=D/2} \quad (3-14) \]

and the average Nusselt number on the wall can be easily obtained from:

\[ Nu = \frac{hL}{K} = \int_0^1 \left(-\frac{\partial T}{\partial X}\right) \partial Y \quad (3-15) \]
Chapter 4

4. COMSOL Multiphysics Software

4.1. Introduction

Is the way in which the user understands the different concepts that he cannot see, such as a gas movement inside the cylinder or the movement of electrons and others. It is a simulation program that enables the user to conduct more than one simulation to prepare the work environment and equip the equipment and see the possibility of modification to obtain the best scientific and practical results. The COMSOL Multiphysics program, which is a useful in the field of scientific research, have been used in this study.

4.2. Modeling Instruction

A horizontal heated cylinder inside square cavity have been model using COMSOL Multiphysics5.2a. Non-dimensional equations have been selected for this model. To start the model from scratch, step by step guide should be following as shown below:

4.2.1. Create a new file

From the file menu, choose new then in the new window, click model wizard and chose 2D as shown in Figure 4-1.

COMSOL ↦ model wizard ↦ 2D
4.2.2. Select Physics

1. Laminar flow can be selected from select physical tree, as shown in Figure 4-2. Select physics → fluid flow → single physic flow → laminar flow → click add.
2- heat transfer in fluids can be selected from select physical tree, as shown in Figure 4-3
Select physic → heat transfer → heat transfer in fluids → click add → click study

![Figure 4-3 Select physics heat transfer in fluid](image)

After the new windows appear, a file can be saved and name it.

4.2.3. Global definition

Parameters and materials can be added from home tool bar or form global definition panel. Figure 4-4 shows the required parameters and can be selected from:
Model Builder → global definitions → parameters → then can add any parameter as variable (equation) or constant value.

![Figure 4-4 Definition of variables](image)
4.2.4. **Geometry 1**

In this model, the geometry is square filled with fluid and solid cylinder located in the center of square. To do that should following next steps.

### 4.2.4.1. *Square (sq1)*

1. On the geometry tool bar click primitives and choose square.
2. In the model builder windows, right click square 1.
3. Draw the square and determine its quality, and its location in the centre and choose building all objects as shown in Figure 4-5 or can be selected from:

   Model Builder → Component1 → Geometry1 → then select square

![Figure 4-5 Geometry Draw square](image)

### 4.2.4.2. *Circle1 (cl)*

4. On the geometry tool bar click primitives and choose Circle1.
5. In the model builder windows, right click Circle1.
6. Draw the circle and determine its quality, and its location in the centre and choose building all objects as shown in Figure 4-6 or can be selected from:

   Model Builder → Component1 → Geometry1 → then select Circle
4.2.4.3. Difference

1. On the geometry tool bar click primitives and choose difference.
2. Using the Boolean operation difference the geometry is finalized.
3. The circle and square shall be of one size and shall have square pierced by air.
4. The square is the foundation and then cut the circle out from the square as shown in Figure 4-7 or can be selected from:

Model Builder → Component1 → Geometry1 → Difference1 → in the setting difference panel, select the square in active number one pries on the square part and select the circle to be in the objects to subtract click circle than select build all object.
4.2.5. Heat transfer in fluids

To add the heat transfer in fluids flow, it have to go through:

Model Builder → Component1 → Heat Transfer in Fluids → Initial Values → In the setting Initial values window, select active the square and user define the temperature as shown in Figure 4-8.

Figure 4-8 add heat transfer in fluids and initial values

4.2.6. Thermal Insulation

To insulate the square cavity walls:

Model Builder → Component1 → Heat Transfer in Fluids → thermal insulation1 → In the setting thermal insulation window, select the walls of the square that want to insulated thermally shown in Figure 4-9.

Figure 4-9 Thermal insulation
4.2.7. **Hot temperature**

To insulate the square cavity walls:

Model Builder → Component1 → Heat Transfer in Fluids → Temperature1 → In the setting temperature window, select the circle in which the region that want to be constant temperature as shown in Figure 4-10.

![Figure 4-10 Hot temperature](image)

4.2.8. **Laminar flow**

To select the fluid flow as Laminar flow:

Model Builder → Component1 → Laminar flow → fluid properties1 → In the setting fluid properties window, locate the fluid properties section as shown in

![Figure 4-11](image)
4.2.9. Initial valves

Model Builder → Component1 → Laminar flow → initial valves1 → In the setting initial valves window, locate the Initial valves section as shown in Figure 4-12.

Figure 4-12 Initial values

4.2.10. Volume force

Model Builder → Component1 → Laminar flow → volume force1 → In the setting volume forces window, locate the volume forces section and specify the F vector as shown in Figure 4-13.

Figure 4-13 Volume force
4.2.11. **Wall**

Model Builder → Component1 → Laminar flow → wall → In the setting wall window, locate the wall section and select the boundary condition and select no slip as shown in Figure 4-14.

![Figure 4-14 Wall setting](image)

4.2.12. **Mesh**

Model Builder → Component1 → mesh1 → In the setting mesh window, from the element size list, choose extra finer as shown in Figure 4-15.

![Figure 4-15 mesh](image)
Chapter 5

5. The Experimental work

5.1. Introduction

This experiment carried out in heat transfer laboratory of mechanical department. Preparation of a laboratory device that can be used for the third stage student of the mechanics department to investigate the behavior of natural convection heat transfer over horizontal heated cylinder as shown in Figure 5-1.

5.2. The Components

1- Cylinder
2- Power supply
3- Thermocouple (K type)
4- Square cavity
5- Heater
6- Display screen
7- Structure
Chapter 5. The Experimental work

Figure 5-1 The experimental model

1- A heated horizontal cylinder made from aluminium have been selected in this study. The dimensions of the cylinder are D=14 mm, L=250 mm, and placed at the centre of enclosure, the surfaces of the cylinders were highly polished to assure smoothness to reduce of radiation heat transfer. The cylinder is mounted on the upper and lower movable bracket to change the cylinder position and heated by heater located inside cylinder as shown in Figure 5-2.

Figure 5-2 The hollow cylinder
2- A DC power supply have been used with variable current (0 to 10 A) and voltage power supply (0-32 V) as shown in Figure 5-3. It linked with heater and the maximum produced power on the heater was 110 w.

![Power supply](image)

**Figure 5-3 Power supply**

3- Thermocouple: Eight thermocouple sensors (type K) have used in this study; two of them used to measure the surface temperature of the cylinder, and another thermocouples put in the core of the air region to measure the temperature around the cylinder and near the wall.

4- Square cavity of dimensions 57 mm×57 mm×400 mm, while all the walls are insulated, the surfaces of the enclosure are made of wood.

5- A tungsten heater used inside the cylinder to increases its temperature by increasing the amount of current.

6- Display screen (TC800) indicator is designed for multi-point control of technological variables Figure 5-4. With its compact design, eight inputs and outputs TC800 successfully performs all the tasks of indicating, monitoring and signalling the level of several channels. The device input accepts thermo resistances, thermocouples or standard current and voltage signals. Additional discrete inputs are available for remote channel switching and tampering protection.
5.3. Experimental Procedure

1- Before turning heating, check all temperature reading (at all points 1-8). If the apparatus is in equilibrium with the room air, all temperature sensors should indicate the same temperature maybe with small measurement errors. Record the readings and use any consistent discrepancy for corresponding correction later.

2- Switch on the heater so that the power supplied. An optimum heating power should be found so that the relative lost to the surroundings by radiation and conduction is minimized.

3- Monitor thermocouples until steady state conditions are achieved ($T_7$ equal $T_8$).

4- Hook the temperature sensor connector to each one of the temperature sensors on the tube (number 7 and 8 cylinder surface, numbers 1 to 6 a fluid temperature and wait until the system reaches a steady state. Steady state means the temperature does not change with respect to time.

5- Record the readings.

6- Repeat the above experiment with different electrical power supply.
5.3.1. **The experimental Calculations:**

Different temperatures have been supplied on the cylinder surface using a power supply as shown in Table 5-1.

\[ Q_e = V \times I \text{ Watts} \]

Also \[ Q_c = h \times A_s \times (T_c - T_a) \]

\[ A_s = \pi \times D \times L \]

\[ T_c = \frac{(T_7 + T_8)}{2} + 273 \, ^\circ K \]

\[ T_a = \left( \frac{\sum T_i}{6} \right) + 273 \, ^\circ K \]

\[ T_f = \frac{(T_c + T_a)}{2} \, ^\circ K \]

\[ Gr = \frac{g \beta \Delta T D^3}{\nu^2} \]

\[ \bar{Nu} = 0.53 \times (Gr \times Pr)^{1/4} \quad \text{for} \ 10^4 < Gr \times Pr < 10^9 \]

\[ \bar{Nu} = 0.13 \times (Gr \times Pr)^{1/3} \quad \text{for} \ 10^9 < Gr \times Pr < 10^{12} \]

\[ \bar{h} = \frac{\bar{Nu} \times K}{D} \]

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**Table 5-1 Readings**

<table>
<thead>
<tr>
<th>Test No.</th>
<th>V Volt</th>
<th>I current</th>
<th>Q_e watt</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>T6</th>
<th>T7</th>
<th>T8</th>
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<td>4.72</td>
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<td>50</td>
<td>51</td>
<td>42</td>
<td>37</td>
<td>34</td>
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<td>97</td>
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<td>3.04</td>
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<td>42</td>
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<td>4.01</td>
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<td>47</td>
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<td>78</td>
</tr>
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<td>3.5</td>
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</tr>
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<td></td>
<td>72</td>
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<td>57</td>
<td>48</td>
<td>43</td>
<td>39</td>
<td>104</td>
<td>105</td>
</tr>
</tbody>
</table>

**Specifications**

Cavity dimensions 57*57*400 mm
Test cylinder length 250 mm
Test cylinder diameter 14 mm
From Test No.1

\[ Q_e = V \times I \text{ Watts} \]
\[ = 2.9 \times 4.72 = 12.7 \text{ w} \]

\[ A_s = \pi \times D \times L \]
\[ = \pi \times 0.014 \times 0.25 = 0.011 \text{ m}^2 \]

\[ T_c = \frac{(T_7 + T_8)}{2} + 273 \text{ K} \]
\[ = \frac{(97 + 97)}{2} + 273 = 369.5 \text{ K} \]

\[ T_a = \frac{\sum T_i}{6} + 273 \text{ K} \]
\[ = 324.33 \text{ K} \]

\[ \Delta T = T_c - T_a \]
\[ = 369.5 - 324.33 = 45.17 \text{ K} \]

\[ T_f = \frac{(T_c + T_a)}{2} \text{ °K} \]
\[ = \frac{(369.5 + 324.33)}{2} = 346.416 \text{ K} \]

From Tables in textbook, the air properties are:
\[ v = 20.5 \times 10^{-6} \text{ m}^2 / \text{s} \]
\[ k = 0.03 \text{ W/m. °C} \]
\[ Pr = 0.696 \]

\[ \beta = \frac{1}{T_f} = \frac{1}{346.416} = 2.886 \times 10^{-3} \]

Then
\[ Gr = \frac{g \beta \Delta T D^3}{v^2} = 8350.1 \]

\[ \overline{Nu} = 0.53 (Gr \times Pr)^{\frac{1}{2}} = 4.6276 \]

\[ \overline{h} = \frac{\overline{Nu} K}{D} \]
\[ \overline{h} = \frac{4.6276 \times 0.03}{0.014} \]
\[ \overline{h} = 9.916 \text{ W/m}^2 \cdot \text{°C} \]
\[ Q_e = h \times A_s \times (T_c - T_a) \]
\[ = 9.916 \times 0.014 \times 45.17 = 4.927 \]

The percentage error
\[ = \frac{Q_e - Q_c}{Q_e} = \frac{12.7 - 4.927}{12.7} = 6\% \]
6.3. Future studies

Many important studies on natural convection heat transfer for laminar heated cylinder.

One of this change the location of the heated cylinder was changed horizontally along the centerline of square cavity or diagonally along a diagonal line of the cavity enclosure.

Change the diameter of heated cylinder from (14mm to 35mm) with keeping aspect ratio (D/L) ≥ 10, or change enclosure shape into rectangular, triangle and circular
Bibliography


