HEAT TRANSFER ON A RECIPROCATING VERTICAL PLATE BY NATURAL CONVECTION

A Project report submitted in partial fulfillment of the requirements For the Award of the Degree of

BACHELOR OF ENGINEERING

In

MECHANICAL ENGINEERING

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ABSTRACT

Measurements have been conducted for experimentally determining the heat transfer coefficient caused due to free convection on reciprocating vertical plate. For determining the heat transfer coefficient the plates are attached by placing the heating element between them. The reciprocating vertical plate has 15cm length and 10cm width and 2cm thickness. The power input to the heating element is obtained by measuring the input voltage and current. Temperature measurement for varying heat inputs is done using K-type thermocouples. Heat transfer co-efficient is computed from the measured data. Numerical computation and graphical illustrations are used in order to study the effects of heat input on heat transfer coefficient and steady state temperatures. The observations made are tabulated in suitable tables.

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CHAPTER 1

INTRODUCTION

1 INTRODUCTION

1.1 Introduction

Free or natural convection is a fluid motion that arises solely as a result of density variation caused by the thermal expansion of fluid in non-uniform temperature field. It is a natural phenomenon occurring everywhere within the atmosphere of the earth where inequalities of temperature exist. Investigations of free convection in air have been of little interest except to meteorologists or astrophysicists up until the past quarter century. Progress in other applications has been gradual due primarily to two causes. First, the interaction of the dynamics and thermodynamics leads to a rather complex analysis and second, in most problems of interest, the prime factors governing natural convection namely the buoyancy force, fluid volumetric expansion coefficient and the temperature are small.

With the advent of jet propulsion and nuclear power, the three prime factors governing the natural convection can all very greatly exceed their previously considered bounds. Hence, in many practical present day problems in the field of aeronautics, atomic power, magneto hydrodynamics, electronics and chemical engineering, the natural convection phenomenon can be important. Accordingly, more interest has recently been shown in natural convection phenomenon.

The natural convection flows are particularly important in atmospheric and oceanic circulation, in the design of spaceships, filtration process, the drying of porous materials in textile industries, electric machinery, and nuclear reactors cooling systems, heated or cooler enclosures, electronic power supplies, solar energy collectors and nuclear reactors. Besides the importance of the natural convection flows in many areas of interest in technology and nature, a study of natural convection processes is important in the problems of heat rejection and removal in many devices, process and systems.

1.2 Heat Transfer

Heat transfer is the process of transfer of heat from high temperature reservoir to low temperature reservoir. In terms of the thermodynamic system, heat transfer is the movement of heat across the boundary of the system due to temperature difference between the system and the surroundings. The heat transfer can also take place within the system due to temperature difference at various points inside the system. The difference in temperature is considered to be ‘potential’ that causes the flow of heat and the heat itself is called as flux.

Heat is defined in physics as the transfer of thermal energy across a well-defined boundary around a thermodynamic system. The thermodynamic free energy is the amount of work that a thermodynamic system can perform. Enthalpy is a thermodynamic potential, designated by the letter ‘H’ that is the sum of internal energy of the system (U) plus the product of pressure (P) and volume (V). Joule is a unit to quantify energy, work, or the amount of heat.

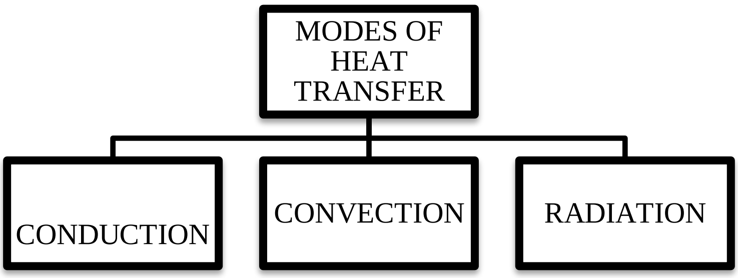
Heat transfer is a process function (or path function), as opposed to functions of state, therefore, the amount of heat transferred in a thermodynamic process that changes the state of a system depends on how that process occurs, not only the net difference between the initial and final states of the process.

Thermodynamic and mechanical heat transfer is calculated with the heat transfer coefficient, the proportionality between the heat flux and the thermodynamic driving force for the flow of heat. Heat flux is a quantitative, vectorial representation of heat-flow through a surface.

In engineering contexts, the term heat is taken as synonymous to thermal energy. This usage has its origin in the historical interpretation of heat as a fluid that can be transferred by various causes, and that is also common in the language of laymen and everyday life.

The transport equations for thermal energy, momentum equation and mass transfer are similar, and analogies among these three transport processes have been developed to facilitate prediction of conversion from any one to the others. Thermal engineering concerns the generation, use, conversion, and exchange of heat transfer. As such, heat transfer is involved in almost every sector of the economy.

1.3 Modes of heat transfer



1.3.1 Conduction:

Conduction is the method of transfer of heat within a body or from one body to the other due to the transfer of heat by molecules vibrating at their mean positions. The bodies through which heat transfer must be in contact with each other. There is no actual movement of matter while transferring heat from one location to the other.

Conduction occurs usually in solids where molecules in the structure are held together strongly by intermolecular forces of attraction amongst them and so they only vibrate about their mean positions as they receive heat energy and thus pass it to the surrounding molecules by vibrations.

1.3.2 Convection:

Convection is the mode of heat transfer which occurs mostly in liquids and gases. In this method, heat transfer takes place with the actual motion of matter from one place within the body to the other. Often when we boil water we have seen bubbles and currents develop in the water on careful observation.

This is the apt example of the convection process. The hot water at the bottom becomes lighter and moves upwards forcing the cold and denser water at the top to come down and thus get heated up.

Figure 1.1 Convection

1.4 Types of convection:

Convection is mainly classified into three types

i. Natural or free convection

ii. Forced Convection

iii. Mixed convection

1.4.1 Natural convection:

When fluid motion is caused by buoyancy forces that result from the density variations due to variations of thermal temperatures in the fluid. In the absence of an internal source when the fluid is in contact with a hot surface, its molecules separate and scatter, causing the fluid to be less dense. As a consequence, the fluid is displaced while the cooler fluid gets denser and the fluid sinks. Thus, the hotter volume transfers heat towards the cooler volume of that fluid. Familiar examples are the upward flow of air due to a fire or hot object and the circulation of water in a pot that is heated from below.

1.4.2 Forced convection

Forced convection is a mechanism, or type of transport in which fluid motion is generated by an external source (like a pump, fan, suction device, etc.). Alongside natural convection, thermal radiation and thermal conduction it is one of the methods of heat transfer and allows significant amounts of heat energy to be transported very efficiently.

1.4.3 Mixed convection:

Mixed convection is a combination of forced and free convections which is the general case of convection when a flow is determined simultaneously by both an outer forcing system (i.e., outer energy supply to the fluid streamlined body system) and inner volumetric (mass) forces, viz., by the non-uniform density distribution of a fluid medium in a gravity field.

The most vivid manifestation of mixed convection is the motion of the temperature stratified mass of air and water of the earth that the traditionally studied in geophysics. However, mixed convection is found in the systems of much smaller scales, i.e., in many engineering devices.

On heating or cooling of channel walls, and at the small velocities of a fluid flow that are characteristic of a laminar flow, mixed convection is almost always realized. In any forced convection situation, some amount of natural convection is always present whenever there is gravitational forces present (i.e., unless the system is in free fall). When the natural convection is not negligible, such flows are typically referred to as mixed convection.

1.5 Radiation

Radiation is a form of heat transfer. It does not require any medium and can be used for transfer of heat in a vacuum as well. This method uses electromagnetic waves which transfer heat from one place to the other. The heat and light from the sun in our solar system reach our planet using radiation only.

In fact, radiation is the most potential method of heat transfer. In winters when we sit near a fire we feel warm without actually touching the burning wood. This is possible by radiation only.

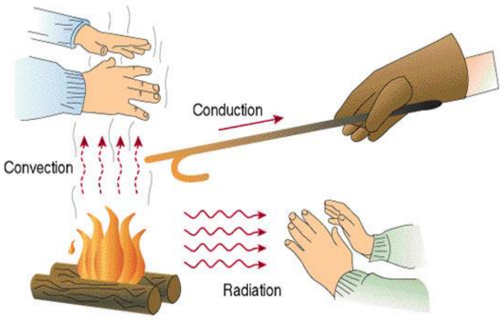


Figure 1.2 Radiation

1.6 Newton's law of cooling

Newton's law of cooling states that the rate of heat loss of body is directly proportional to the difference in temperatures between the body and its surrounding provided the temperature difference is small and nature of radiating surface remains same.

$$Q = h\,A\,\Delta T$$

Where Q is the heat flow

h is the heat transfer coefficient (W/m^2K)

ΔT is the temperature difference between body and its surrounding

A is the surface area from which convection is occurring

1.6.1 Significance of heat transfer coefficient:

Convective heat transfer coefficient (h) is very important heat transfer parameter to be understood in a convection phenomenon. So, I will explain what information we can obtain if we know convection heat transfer coefficient (h) of any convection problem.

- So if we know **h**, we can say from a given surface of unit area and a unit temperature difference, what is the rate of heat transfer. Suppose water is flowing with certain velocity across a pipe of surface area of some meter sq and a surface temperature of some value. So, let's assume, h = 10 W/ m2 K. So what information we got from here? If everything is made to unit value in convection equation, then rate of heat transfer to water here is 10 W. So, we can know, at what rate heat is transferring between a surface and a fluid ,if we know the value of '**h**'

- Everyone may have seen bike engine with fins. So, an engine has to be maintained at certain temperature. Heat transfer occurs by forced convection, when we are driving bike. If we know h between the surface of engine and air, we can know, at what rate the heat transfer is occurring between engine and wind.

- In case of design. Suppose you want to heat water flowing in a pipe having surface temperature of 70 ^{o}C of diameter 3 cm at a rate of 1 kg/s from 30 ^{o}C to 40 ^{o}C. So you want to supply heat of 42 kW. So you know the velocity of flowing of water. Main problem is, what length of pipe you need to choose for the process. Till now, we do not know because we don't know value of h**.** But if you know that value of h, we can calculate it easily. Let's say h = 150 W/m^2 K. Then the value of length can be easily calculated. Here, by simple calculation, length will be obtained as 85 m. So what we wanted to say is, for every convection problem, '**h**' is very important parameter. Without, '**h**' we cannot solve convective heat transfer problem.

1.7 Dimensionless numbers

1.7.1 Nusselt number

Nusselt number (Nu) is the ratio of conduction resistance of a material to convection resistance of the same material.

$$\mathbf{Nu} = \frac{\text{convective heat transfer}}{\text{conductive heat transfer}} = \mathbf{hL/k}$$

Where

Nu is the Nusselt number

h is the heat transfer coefficient

K is the thermal conductivity of the fluid

L is the characteristic length

Nusselt number is required to find 'h' which is convective heat transfer coefficient. The physical interpretation of Nusselt number is the enhancement of heat transfer due to convection over conduction alone. If Nu=1, then the fluid is stationary and all heat transfer is by conduction.

1.7.2 Reynolds number

The Reynolds number is the ratio of inertial forces to viscous forces within a fluid which is subjected to relative internal movement due to different fluid velocities, which is known as a boundary layer in the case of a bounding surface such as the interior of a pipe.

The Reynolds number is defined as

$$\mathbf{Re} = \frac{\rho u L}{\mu}$$

Where:

- ρ is the density of the fluid (kg/m^3)
- u is the velocity of the fluid with respect to the object (m/s)
- L is a characteristic linear dimension (m)
- μ is the dynamic viscosity of the fluid (Pa-s or $N \cdot s/m^2$ or kg/m-s)

Reynolds number helps in determining whether the fluid is turbulent or laminar and also foreseeing the patterns in the fluid's behaviour.

1.7.3 Grashof number

The Grashof number (Gr) is a dimensionless number in fluid dynamics and heat transfer which approximates the ratio of the buoyancy to viscous force acting on a fluid. It frequently arises in the study of situations involving natural convection and is analogous to the Reynolds number.

Grashof number (Gr) = $[g\beta L^3 \Delta T]/\upsilon^2$

Where g is acceleration due to gravity

β is volumetric coefficient

ΔT is temperature difference

υ is kinematic viscosity

Grashof number is significant in cases of fluid flow due to natural convection. This means that the fluid motion is caused not due to an external source but due to the difference in densities between two points.

1.7.4 Prandtl number

Prandtl number is defined as ration momentum diffusivity to thermal diffusivity.

$Pr = \mu C_p/K$

Where μ is dynamic viscosity

C_p is specific heat

K is thermal conductivity

In heat transfer problems, the Prandtl number controls the relative thickness of the momentum and thermal boundary layers. When 'Pr' is small, it means that the heat diffuses quickly compared to the velocity (momentum).

1.7.5 Rayleigh number

The Rayleigh number (Ra) is a dimensionless number associated with buoyancy-driven flow, also known as free or natural convection. When the Rayleigh number is below a critical value for that fluid, heat transfer is primarily in the form of conduction; when it exceeds the critical value, heat transfer is primarily in the form of convection.

The Rayleigh number is defined as the product of the Grashof number, which describes the relationship between buoyancy and viscosity within a fluid, and the Prandtl number, which describes the relationship between momentum diffusivity and thermal diffusivity. Hence it may also be viewed as the ratio of buoyancy and viscosity forces multiplied by the ratio of momentum and thermal diffusivities.

$$Ra = Gr*Pr$$

Where Gr is Grashof number

Pr is Prandtl number

1.7.6 Biot number

The Biot number (Bi) is a dimensionless quantity used in heat transfer calculations. It gives a simple index of the ratio of the heat transfer resistances inside of and at the surface of a body. This ratio determines whether or not the temperatures inside a body will vary significantly in space, while the body heats or cools over time, from a thermal gradient applied to its surface.

In general, problems involving small Biot numbers (much smaller than 1) are thermally simple, due to uniform temperature fields inside the body. Biot numbers much larger than 1 signal more difficult problems due to non-uniformity of temperature fields within the object. It should not be confused with Nusselt number, which employs the thermal conductivity of the fluid and hence is a comparative measure of conduction and convection, both in the fluid.

The Biot number has a variety of applications, including transient heat transfer and use in extended surface heat transfer calculations.

$$Bi = hL_c/k$$

Where h is heat transfer coefficient

L_c is characteristic length

K is thermal conductivity

1.8 Natural Convection

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 and by thermal expansion 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 a 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 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 raising 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, plate tectonics, oceanic currents (thermohaline circulation) and sea-wind formation (where upward convection is also modified by Coriolis 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.

1.8.1 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 = height of the vertical surface (m)

k = thermal conductivity (W/m. K)

Grashof Number = $Gr = [g\beta L^3 (t_s - t_\infty)]/ \upsilon^2$

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)

υ = 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 Grashof Number because the value has been replaced by its approximation, which applies for ideal gases only (a reasonable approximation for air at ambient pressure).

CHAPTER 2
LITERATURE REVIEW

2 LITERATURE REVIEW

Abid Hussanan, Muhammad Imran Anwar, Farahad Ali, Ilyas khan, Sharidan Shafie. [1] In this paper an exact analysis of unsteady natural convection flow of viscous fluid past an oscillating plate with Newtonian heating is presented. The mathematical model with radiation effects is reduced to a system of linear partial differential equations. And these equations are solved exactly using Laplace transform technique. Expressions for velocity and temperature are determined and they satisfy all imposed initial and boundary conditions. Along with velocity and temperature, skin friction coefficient and Nusselt number are evaluated analytically as well as numerically. Numerical results for velocity and temperature are shown graphically. This works gives the variation of velocity with effective Prandtl number, Grashof number and time, variation of temperature with effective Prandtl number and time, variation of Nusselt number with effective Prandtl number and time.

M Narahari and A Ishak. [2] In this paper the influence of unsteady natural convection flow of an viscous incompressible fluid past a moving vertical plate with Newtonian heating is investigated. For detailed analysis of the problem, three important cases of flow are considered namely (1) motion with uniform heating (2) uniformly accelerated motion (3) exponentially accelerated motion of the plate have been considered. The dimensionless governing equations are solved using Laplace transform technique and the numerical results are shown graphically. The results show that in all the three cases increase in radiation parameter leads to decrease in velocity and temperature. Also an increase in radiation parameter in all the three cases leads to increase in Nusselt number and skin friction coefficient at the plate.

P.M.Patil, S. Roy and I. Pop [3] In this paper, a numerical investigation on a steady two-dimensional mixed convection boundary layer flow along a moving semi-infinite plate is presented. The plate is assumed to move with constant velocity. The influence of internal heat generation is also included in the analysis. The nonlinear partial differential equations governing the flow are solved using implicit finite difference scheme in combination with the quasi-linearization technique. The effect of various parameters on the velocity and temperature profiles are reported. In addition to them numerical results of skin friction coefficient and nusselt number are also presented.

Ilyas khan, Nehad Ali Shah, Asifa Tassaddiq, Norzieha Mustapha, Seripah Awang Kechil [4] In this paper heat transfer analysis caused due to free convection in a vertically oscillating cylinder have been studied. Exact solutions are determined using Laplace and finite Henkel transforms. These solutions satisfy both initial and boundary conditions. Numerical computations and graphical illustrations are used in order to study the effects of Prandtl number and Grashof numbers on velocity and temperature for various times. Increasing Prandtl number Pr, the temperature decreases. The Nusselt number increases if the Prandtl number increases. Fluid velocity increasing with Grashof number but decreasing with Prandtl number.

Ilyas khan, Nehad Ali Shah, Yasir Mahsud, Dumitru Vieru [5] – This paper is focused on heat transfer analysis in the unsteady flow of a generalized Maxwell fluid over an oscillating vertical flat plate with constant temperature. Mathematical formulation is done by using fractional derivatives of caputo and fabrizio. Exact solutions of the dimensionless problem has been obtained by using Laplace transform. Similar solutions for classical Maxwell and Newtonian fluids and generalized Newtonian fluid performing the same motion are obtained as limiting cases of general results. Graphical illustrations show that the velocity profiles corresponding to a generalized Maxwell fluid are similar to those for an ordinary Maxwell fluid when the fraction order approaches. In this paper a comparison of four different fluids is also shown graphically.

CHAPTER 3

EXPERIMENTAL SETUP

3 EXPERIMENTAL SETUP

The experimental setup consists of

(i) Data Acquisition System
  1. Ammeter
  2. Voltmeter
  3. Thermocouple
  4. Temperature indicator
  5. Voltage Regulator
  6. Selector switch

(ii) Specimen plate

(iii) Battery Eliminator

(iv) Slider Crank Mechanism

(v) Battery Eliminator

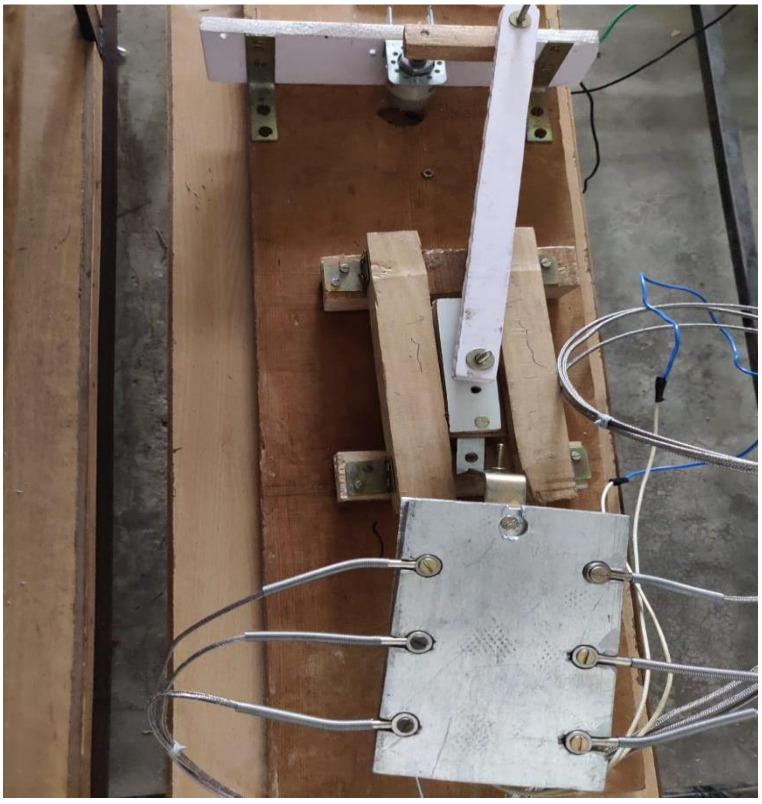


Figure 3.1 experimental setup part-1

3.1 Data Acquisition system

Data Acquisition systems abbreviated by DAS or DAQ, typically convert analog waveforms into digital values for processing. The components of data acquisition systems include sensors to convert physical parameters to electrical signals.

Figure 3.2 experimental setup part-2 view 2

Figure 3.3 experimental setup part-2 view 1

3.1.1 Ammeter

The meter uses for measuring the current is known as the ammeter. The current is the flow of electrons whose unit is ampere. Hence the instrument which measures the flows of current in ampere is known as ampere meter or ammeter.

The ideal ammeter has zero internal resistance. But practically the ammeter has small internal resistance. The measuring range of the ammeter depends on the value of resistance.

Figure 3.4 symbolic representation of ammeter

The ammeter is connected in series with the circuit so that the whole electrons of measured current passes through the ammeter. The power loss occurs in ammeter because of the measured current and their internal resistance.

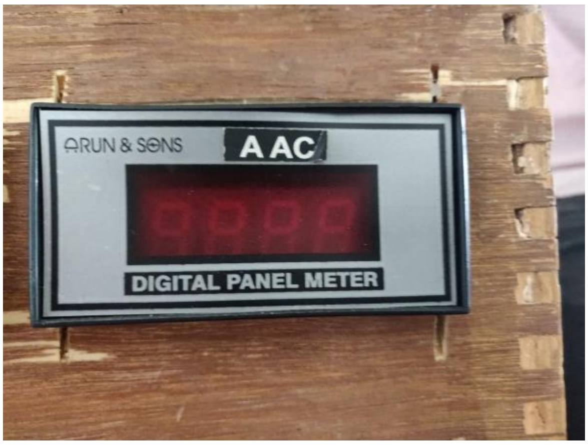


Figure 3.5 ammeter

3.1.2 Voltmeter

The instrument which measures the voltage or potential difference in volts is known as the voltmeter. It works on the principle that the torque is generated by the current which induces because of measured voltage and this torque deflects the pointer of the instrument. The deflection of the pointer is directly proportional to the potential to the potential difference between the points. The voltmeter is always connected in parallel with the circuit.

Symbolic representation:

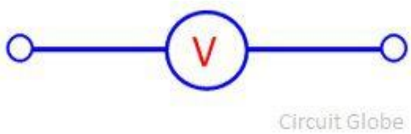


Figure 3.6 symbolic representation of voltmeter

The voltmeter constructs in such a manner that their internal resistance always remains high. If it connects in series with the circuit, it minimizes the current which flows because of the measured voltage. Thus, disturb the reading of the voltmeter.

The voltmeter always connected in parallel with the circuit so that the same voltage drop occurs it. The high resistance of the voltmeter combines with the impedance of the element across which it is connected and overall impedance of the system is equal to the impedance that the element had. Thus, no obstruction occurs in the circuit because of the voltmeter, and the meter gives the correct reading.

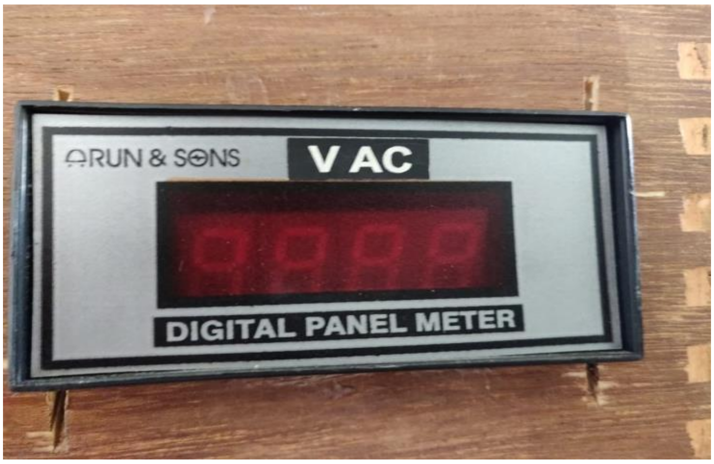


Figure 3.7 voltmeter

3.1.3 Thermocouple

The thermocouple is a temperature measuring device. It uses for measuring the temperature at one particular point. In other words, it is a type of sensor used for measuring the temperature in the form of an electric current or EMF.

The thermocouple consists two wires of different metals which are welded together at the ends. The welded portion was to create the junction and this junction can be used to measure the temperature. The variation in temperature of the wire induces the voltages.

3.1.3.1 Working principle of thermocouple

The working principle of the thermocouple depends on the three effects.

Seeback effect: the see back effect occurs between two different metals, the electrons start flowing from hot metal to cold metal. Thus, direct current induces in the circuit. In short, it is the phenomenon in which the temperature difference between the two different metals induces the potential differences between them.

Peltier effect: The Peltier effect states that the temperature difference can be created between any two different conductors by applying the potential differences between them.

Thompson effect: The Thompson effect states that when two dissimilar metals joins together and if they create two junctions then the voltage induces the entire length of the conductor because of the temperature gradient. The temperature gradient is a physical term which shows the direction and rate of change of temperature at a particular location.

Figure 3.8 Thermocouple

3.1.4 Temperature indicator

Temperature indicators are installation instruments which can process signals from temperature sensors and shows them on the display. Temperature indicators enable easy and economic valuation of resistance sensors, such as Pt100 or different thermos element types. These sensors can be directly connected to temperature indicators to avoid the installation of transducer. Universally temperature indicators are very flexible devices because they can be used with many different temperature sensors and can also process normalized signals.

Figure 3.9 Temperature indicator

3.1.5 Voltage Regulator

A voltage regulator is a system designed to automatically maintain a constant voltage level. A voltage regulator may use a simple feed forward design or may include negative feedback. It may use an electromechanical mechanism, or electronic components. Depending on the design, it may be used to regulate one or more AC or DC voltages.

Figure 3.10 Voltage regulator

3.1.6 Selector switch

A rotary switch is a switch operated by rotation. These are often chosen when more than two positions are needed, such as a three- speed fan or a cb radio with multiple frequencies of reception or channels. A rotary switch consists of a spindle or rotor that has a contact arm or spoke which projects from its surface like a cam. It has an array of terminals, arranged in a circle around the rotor, each of which serves as a contact for the spoke through which anyone of a number of different electrical circuits can be connected to the rotor. The switch is layered to allow the use of multiple poles, each layer is equivalent to one ole. Usually such a switch has detent mechanism so it clicks from one active position to another rather than stalls in an intermediate position. Thus a rotary switch provides greater pole and throw capabilities than simpler switches do.

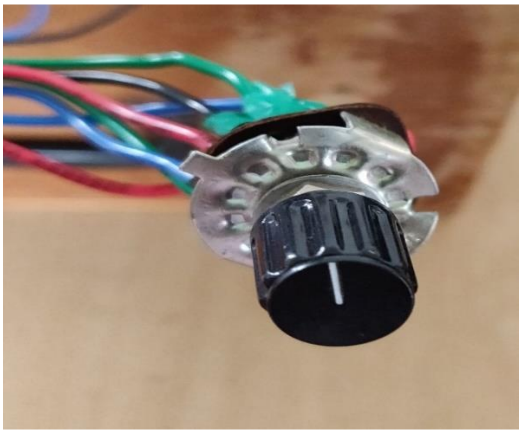


Figure 3.11 Selector switch

3.2 Specimen plate

The specimen plate is a rectangular plate made by sandwiching a heating element with two layers of aluminum plates each 5mm thick on either sides. Arrangements are made for inserting thermocouples on the outer surface of the plate. So that we can find the temperatures of the plate at different locations. The final resemblance of the plate is shown in the figure.

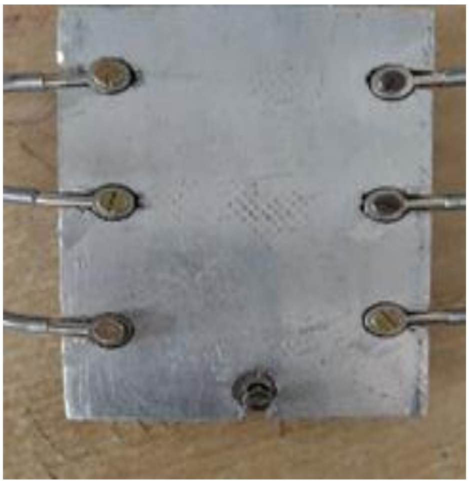


Figure 3.12 specimen plate

3.2 Battery eliminator

A battery eliminator is a device powered by an electrical source other than a battery, which then converts the source to a suitable DC voltage that may be used by a second device designed to be powered by batteries. A battery eliminator eliminates the need to replace batteries but may remove the advantage of portability. A battery eliminator is also effective in replacing obsolete battery designs.

Some examples of battery eliminators include the nine volt mains power supply, the size and shape of a PP9 battery, originally intended to replace the battery in portable radios in the 1960s. A solar panel providing power for a portable appliance may also be considered a battery eliminator. The term is also sometimes used as a misnomer when using a bigger battery for more runtime when branching out a power supply to wired electrical equipment using DC input.

Figure 3.13 Battery eliminator

3.3 Slider crank mechanism

A slider crank linkage is a four link mechanism with three revolute joints and one prismatic, or sliding, joint. The rotation of the crank drives the linear movement the slider, or the expansion of gases against a sliding piston in a cylinder can drive the rotation of the crank.

There are two types of slider cranks: in-line and offset.

1. **In line:** An in-line slider crank has its slider positioned so the line of travel of the hinged Joint of the slider passes through the base joint of the crank. This creates a symmetric slider movement back and forth as the crank rotates.
2. **Offset:** If the line of travel of the hinged joint of the slider does not pass through the base pivot of the crank, the slider movement is not symmetric. It moves faster in one direction than the other. This is called quick return mechanism.

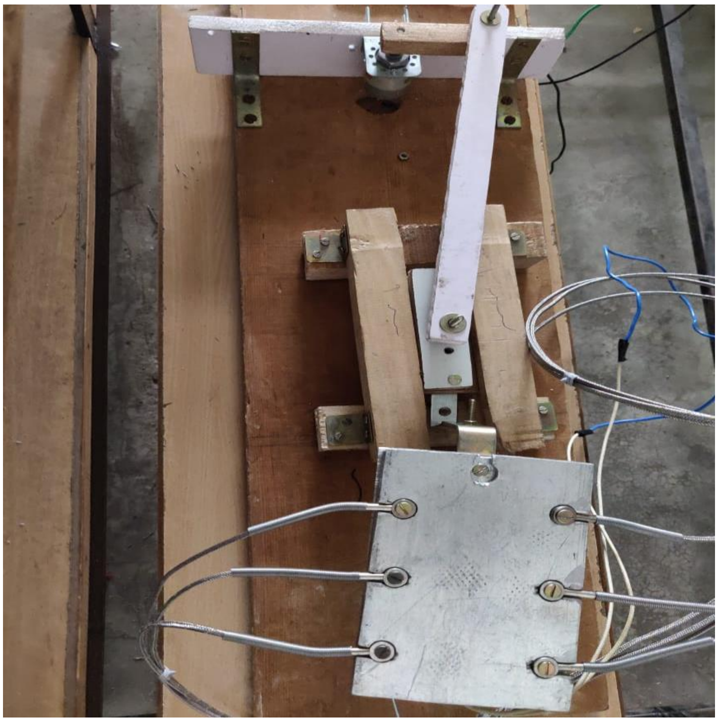


Figure 3.14 Slider crank mechanism

3.4 Circuit Diagram:

The circuit diagram for the experimental setup involving connections of ammeter, voltmeter, temperature indicator, selector switch, specimen plate and variac is shown in the figure 3.15.

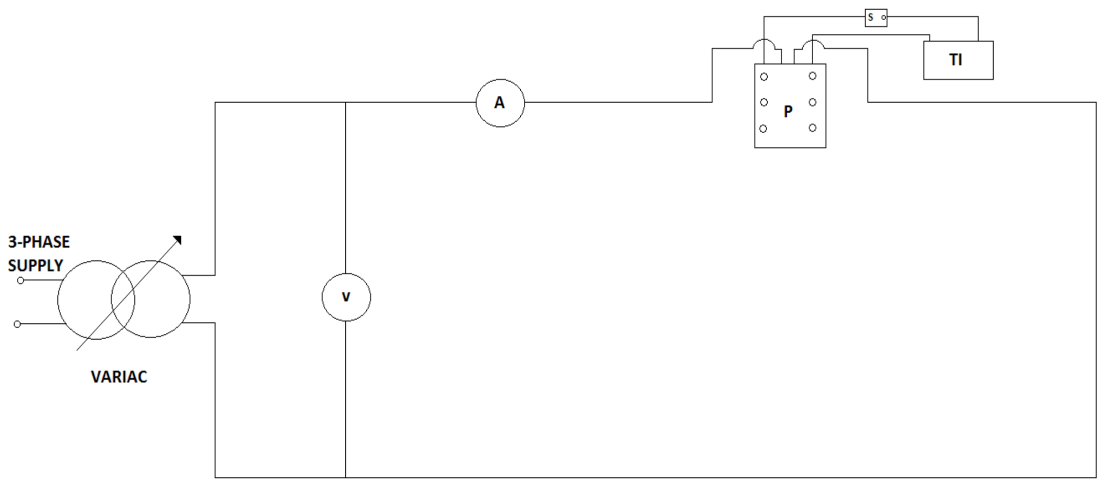


Fig.3.15 Circuit Diagram

V- VOLTMETER

A- AMMETER

TI- TEMPERATURE INDICATOR

P- PLATE ARRANGED WITH THERMOCOUPLES

S-SELECTOR SWITCH

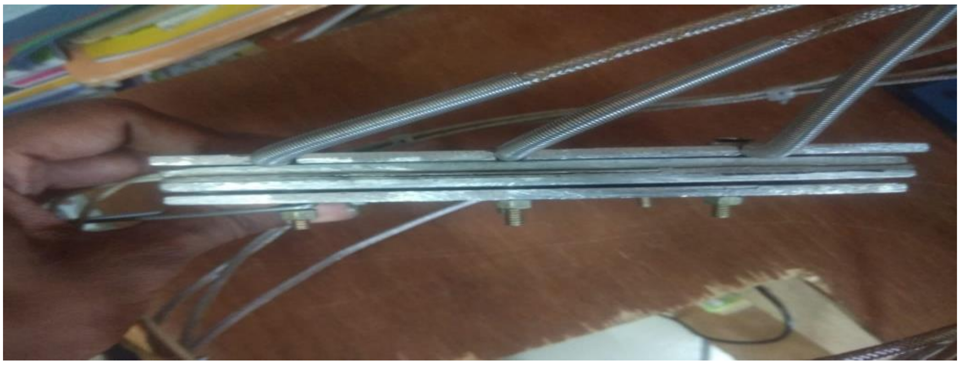
The required heat (power supply) is given to the specimen plate through a variac. The readings of the current and voltage can be observed through ammeter and voltmeter which are arranged in series and parallel to the plate respectively. The connections of the thermocouples present on the plate are made with temperature indicator through a temperature selector switch in such a way that the temperature of the required thermocouple can be obtained directly on the indicating screen of the temperature indicator. The temperature of the required thermocouple can be obtained by selecting the respective thermocouple by rotating the selector knob.

CHAPTER 4

METHODOLOGY

4 METHODOLOGY

- This experiment aims at comparing temperature profiles for heat transfer over stationary and reciprocating plate.
- Consider a flat plate of dimensions 10cm*15cm*0.5cm. Initially the plate is at uniform temperature and then it is subjected to natural convection cooling when the plate is stationary as well as when the plate is in reciprocating motion.
- The apparatus consists of K-Type thermocouples attached to the aluminum plate at various locations. Four aluminum plates were considered. Heating element is placed between two plates and they are kept together by riveting. And one plate is bolted on each side.



- To give constant temperature input to heating element the power is supplied to heating element by varying the voltage and current using voltage regulator.

Ammeter, voltmeter, temperature indicator are connected in series with the power source.

- The plate is reciprocated by using slider crank mechanism. Plate is attached to slider end and the crank is connected to motor. The crank is 5cm and the slider reciprocates with maximum amplitude of 10cm. The power is supplied to motor by connecting it to 12V eliminator and as the motor rotates, the crank rotates and the slider reciprocates.
- Thermocouples are used to find the temperatures by connecting it to thermal sensor and rotary switch. By using the rotary switch we can take readings of multiple thermocouples by rotating the rotary knob.
- The experiment is done in two cases one is by keeping the plate in steady position and providing the constant heat supply the readings of temperature with respect to time are noted until it reaches the steady state and the values are tabulated.
- And the other is by making the plate reciprocate by connecting the plate horizontally to the slider by giving constant heat supply. The readings of temperature with respect to time while reciprocating are noted until it reaches steady state and values are tabulated.

CHAPTER 5

EXPERIMENTAL OBSERVATIONS AND CALCULATIONS

5 EXPERIMENTAL OBSERVATIONS AND CALCULATIONS

Observations and calculations are done for various heat inputs 21.84W, 17.5 W, 12.1

5.1 Basic formulae for calculation of 'h' for stationary plate:

1. $T_{avg} = (T_1+T_2+T_3+T_4+T_5+T_6)/6$
2. T_∞ = Surrounding ambient temperature ^0C
3. T_m = mean temperature = $(T_{avg}+T_\infty)/2$
4. **4.** Obtain air properties at mean temperature.
5. Volumetric coefficient $\beta = \frac{1}{T_m}$
6. Grashof number Gr = $\frac{(g\beta L^3 \Delta T)}{\nu^2}$
7. Rayleigh number (Ra) = Gr*Pr
8. Nusselt number (Nu) = $0.56\,(Ra)^{1/4}$ for $10^5 < Ra < 10^8$

   $= 0.53\,(Ra)^{1/4}$ for $Ra < 10^5$

   $= 0.13\,(Ra)^{1/3}$ for $10^8 < Ra < 10^{12}$
9. Heat transfer coefficient = $\frac{(Nu*K)}{L}$
10. Heat input Q = V*I

5.2 Basic formulae for calculation of 'h' for reciprocating vertical plate:

1. $T_{avg} = (T_1+T_2+T_3+T_4+T_5+T_6)/6$
2. T_∞ = Surrounding ambient temperature ^0C
3. T_m = mean temperature = $(T_{avg}+T_\infty)/2$
4. Obtain air properties at mean temperature.
5. Volumetric coefficient $\beta = \frac{1}{T_m}$
6. Grashof number Gr = $\frac{(g\beta L^3 \Delta T)}{\nu^2}$
7. Reynolds number Re = $\frac{\rho v l}{\mu}$
8. Richardson number Ri = $\frac{Gr}{Re^2}$
9. Rayleigh number (Ra) = Gr*Pr
10. Nusselt number (Nu) = $0.56\,(Ra)^{1/4}$ for $10^5 < Ra < 10^8$

    $= 0.53\,(Ra)^{1/4}$ for $Ra < 10^5$

    $= 0.13\,(Ra)^{1/3}$ for $10^8 < Ra < 10^{12}$

11. Heat transfer coefficient = $\frac{(Nu*K)}{L}$

12. Heat input Q = V*I

5.3 At heat input 21.84 W

Table 1:When the plate is stationary

Voltage (V)	Current (A)	Temperature of the specimen (^{0}C)					
		T1	T2	T3	T4	T5	T6
80	0.30	31	31	31	32	33	32
80	0.30	40	40	39	41	42	41
79	0.30	46	46	46	47	47	47
77	0.29	52	52	52	53	54	53
78	0.28	56	56	55	57	57	57
78	0.28	59	59	58	60	61	60
78	0.28	62	62	60	62	63	62
78	0.28	63	63	62	64	65	64
78	0.29	65	64	63	65	66	65
78	0.28	65	64	63	65	67	65

5.3.1 Calculations:

T_{avg}= (T_1+T_2+T_3+T_4+T_5+T_6)/6

At steady state:

T_{avg}= 64.833 ^{0}C

T_∞=33^{0}C

T_m= (T_{avg}+T_∞)/2 = 49.9165 ^{0}C= 323.0665 K

β = (1/T_m) = 0.003095

At T_m from heat transfer data book (ν) = 17.95*10^{-6} m^2/s

Prandtl number (Pr) = 0.698

Thermal conductivity (K) = 0.02826 W/m-K

Gr = $(g\beta L^3 \Delta T)/\nu^2$ =2.2615*10^4

Rayleigh number (Ra) = Gr*Pr = 1.5785*10^4

Nusselt number (Nu) = 0.59 $(Ra)^{1/4}$

Nu = 6.6133

But Nu =hL_c/K

Heat transfer coefficient (h) = 9.344 W/m^2-K

Table 2:When the plate is in vertical position and in reciprocating motion

Voltage	Current	T1	T2	T3	T4	T5	T6
80	0.30	32	32	32	33	33	33
80	0.30	39	39	40	41	41	40
79	0.30	46	46	47	48	48	47
79	0.29	51	51	51	52	53	52
78	0.28	55	55	55	56	57	56
78	0.28	58	58	58	58	59	59
78	0.28	60	60	60	60	61	62
78	0.28	61	61	62	62	63	64
78	0.28	62	62	63	63	64	65
78	0.28	63	63	64	64	65	66
78	0.28	63	63	64	64	65	66

5.3.2 Calculations:

T_{avg}= 66.66 ^oC

T_∞ = 33 ^oC

T_m = 49.833 ^oC = 322.833 K

At mean temperature Pr = 0.6979

ν = 17.93*10^{-6} m^2/s

K = 0.02824 W/m-K

Gr = 2.5456*10^4

Ra = 1.7768*10^4

Nu = 6.8118

h = 9.618 W/m^2-K

5.4 At heat input 17.5 W

Table 3:When plate is in stationary

Voltage	Current	T1	T2	T3	T4	T5	T6
70	0.25	30	31	30	31	31	31
70	0.25	35	35	34	35	36	35
70	0.25	40	41	34	40	40	39
70	0.25	44	44	43	44	45	44
70	0.25	47	47	46	47	47	46
70	0.25	49	49	48	49	49	49
70	0.25	51	51	49	51	51	49
70	0.25	51	52	50	51	52	50
70	0.25	52	53	51	53	53	52
70	0.25	53	54	52	54	54	52
70	0.25	53	53	52	53	54	52

5.4.1 Calculations:

T_{avg}= (T_1+T_2+T_3+T_4+T_5+T_6)/6

At steady state:

T_{avg}= 52.833 ^{0}C

T_∞=35^{0}C

T_m= (T_{avg}+T_∞)/2 = 43.6665^{0}C = 316.6665 K

β = (1/T_m) = 3.157*10^{-3}

At T_m from heat transfer data book (ν) = 17.32*10^{-6} m^2/s

Prandtl number (Pr) = 0.698

Thermal conductivity (K) = 0.02781 W/m-K

Gr = $(g\beta L^3 \Delta T)/\nu^2$ =1.4315* 10^4

Rayleigh number (Ra) = Gr*Pr = 9.992*10^4

Nusselt number (Nu) =

Nu = 5.8130

But Nu = hL_c/K

Heat transfer coefficient (h) = 8.0830 W/m^2-K

Table 4:When plate is vertical and is in reciprocating motion

Voltage	**Current**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
70	0.25	27	28	27	28	28	28
70	0.25	34	35	33	34	35	34
70	0.25	41	41	39	40	41	40
70	0.25	45	46	44	45	46	45
70	0.25	49	50	48	49	49	48
70	0.25	52	53	51	52	53	51
70	0.25	54	55	53	54	54	53
70	0.25	55	56	54	55	56	54
70	0.25	56	57	56	56	57	55
70	0.25	56	57	56	56	57	55

5.4.2 Calculations:

T_{avg}= 56.166^{0}C

T_∞ = 35^{0}C

T_m = 45.583^{0}C = 318.583 K

At mean temperature Pr = 0.698

ν = 17.51*10^{-6} m^2/s

K = 0.02795 W/m-K

Gr = $1.7001*10^4$

Ra = $1.1866*10^4$

Nu = 6.1579

h = 8.605 W/m^2-K

5.5 At heat input 12.18 W

Table 5: When the plate is stationary

Voltage	**Current**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
60	0.22	27	27	27	28	28	28
60	0.22	32	31	32	32	33	32
58	0.22	35	35	35	35	36	35
58	0.21	38	36	37	37	38	37
58	0.21	39	38	38	38	40	38
58	0.21	41	40	40	40	42	41
58	0.21	43	41	42	42	43	41
58	0.21	43	42	42	42	43	43
58	0.21	43	42	42	42	44	43
58	0.21	43	43	43	43	44	43

5.5.1 Calculations:

T_{avg}= $(T_1+T_2+T_3+T_4+T_5+T_6)/6$

At steady state:

T_{avg}= 44.466^0C

T_∞=33 ^0C

T_m= $(T_{avg}+T_\infty)/2$ = 38.083^0C = 311.083 K

β = ($1/T_m$) = $3.214*10^{-3}$

At T_m from heat transfer data book (ν) = $16.77*10^{-6}$ m^2/s

Prandtl number (Pr) = 0.699

Thermal conductivity (K) = 0.02740 W/m-K

$Gr = (g\beta L^3 \Delta T)/\nu^2$ $=9.117*10^3$

Rayleigh number (Ra) = Gr*Pr = $6.373*10^3$

Nu = 5.2679

But Nu $=hL_c/K$

Heat transfer coefficient (h) = 7.217 W/m^2-K

Table 6:When the plate is in vertical and is in reciprocating motion

Voltage	**Current**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
60	0.21	28	28	28	28	29	27
60	0.21	32	32	30	32	32	31
60	0.22	36	36	36	36	36	36
60	0.21	39	39	38	39	39	38
60	0.22	41	41	40	41	41	40
60	0.22	43	44	42	44	42	42
60	0.22	45	45	44	45	45	44
60	0.22	45	46	44	45	46	45
60	0.22	46	47	45	45	46	45

5.5.2 Calculations

$T_{avg}= 45.66^0C$

$T_\infty = 33\ ^0C$

$T_m= 39.33^0C = 312.33$ K

At mean temperature Pr = 0.698

$\nu = 17.52*10^{-6}\ m^2/s$

K = 0.02795 W/m-K

$Gr = 1.0363*10^4$

$Ra = 7.233*10^3$

$Nu = 5.414$

$h = 7.567\ W/m^2\text{-}K$

Table 7:Observations when the plate is in vertical position and reciprocating

Heat input (Watts)	Steady state temperature (^oC)	Heat Transfer Coefficient (W/m^2-K)
21.84 W	66.66	9.618
17.5 W	56.166	8.605
12.18 W	45.66	7.567

CHAPTER 6

RESULTS

6 RESULTS

Figure 6.1 Heat input vs heat transfer coefficient for stationary plate:

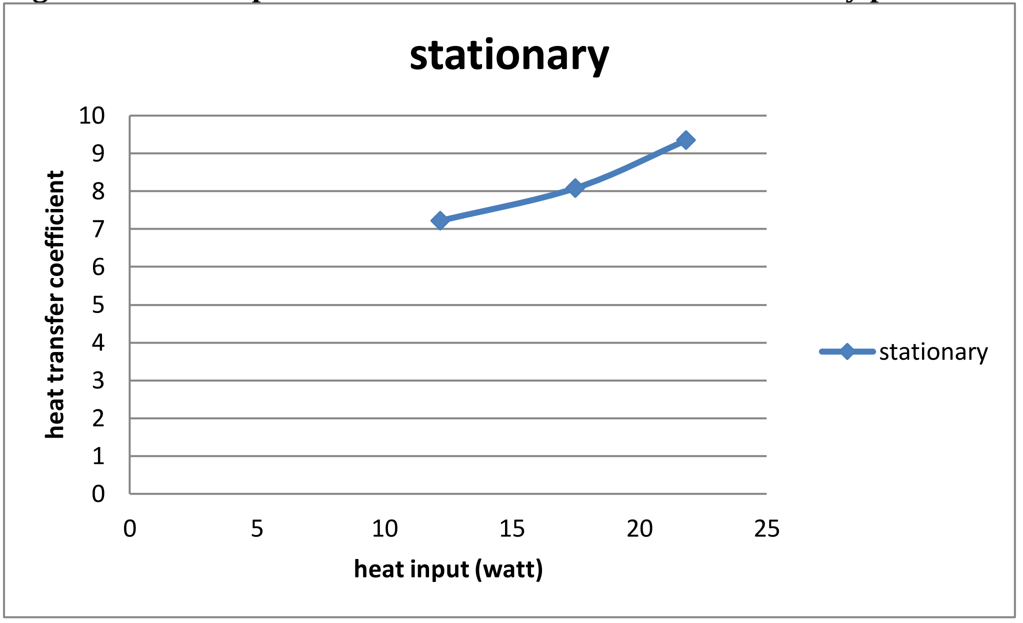


Figure 6.2 Heat input vs heat transfer coefficient for reciprocating vertical plate:

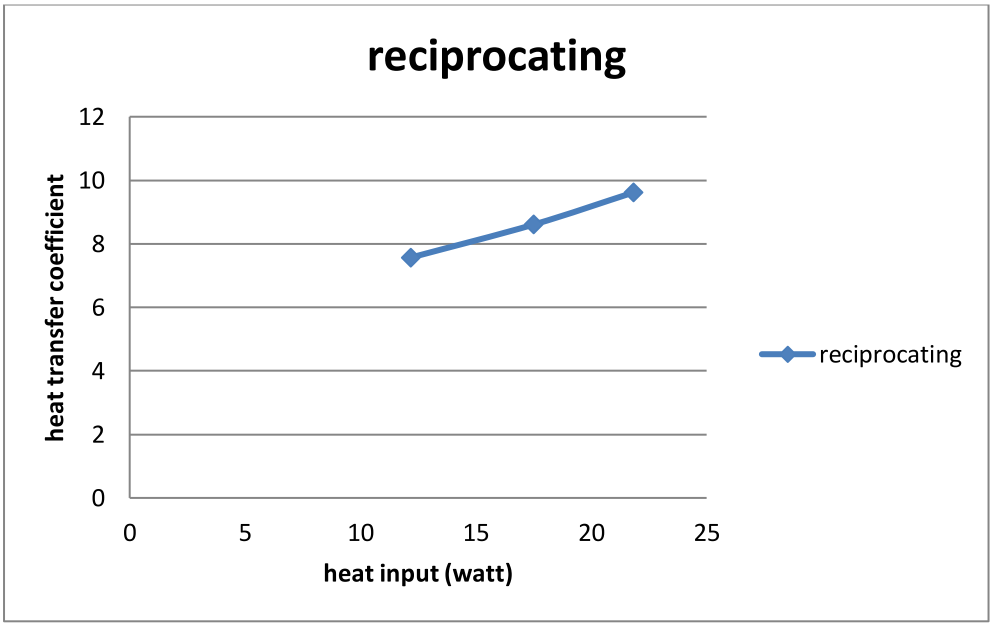


Figure 6.3 Heat input vs heat transfer coefficient comparison graph for both stationary and reciprocating plate

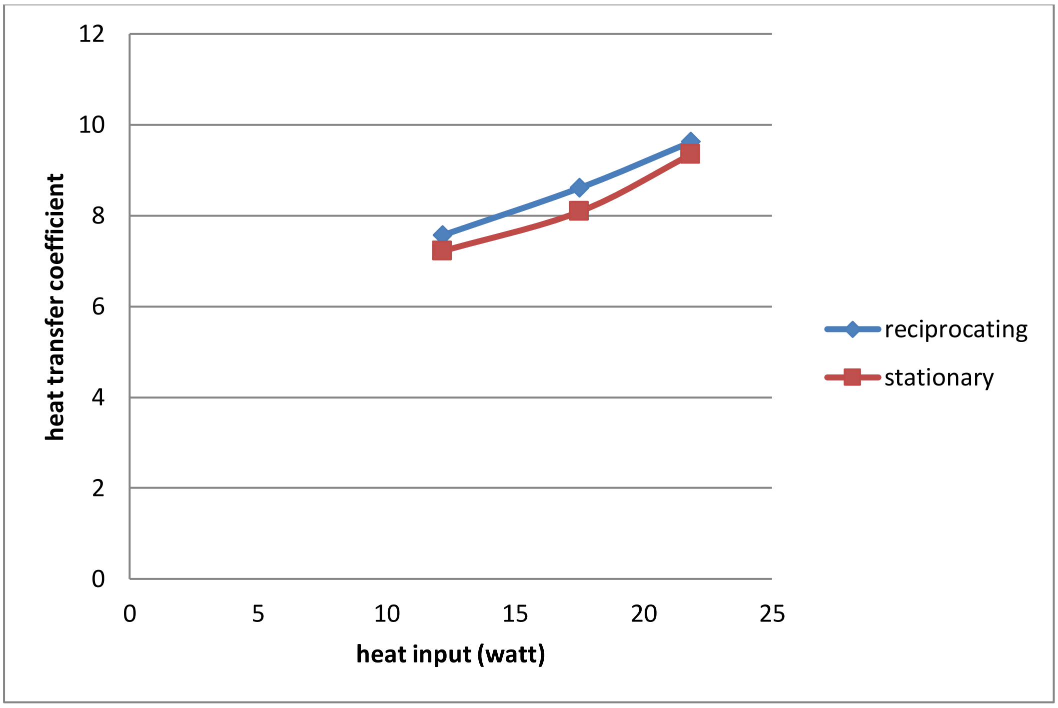


Figure 6.4 Heat input vs steady state temperatures graph for stationary plate

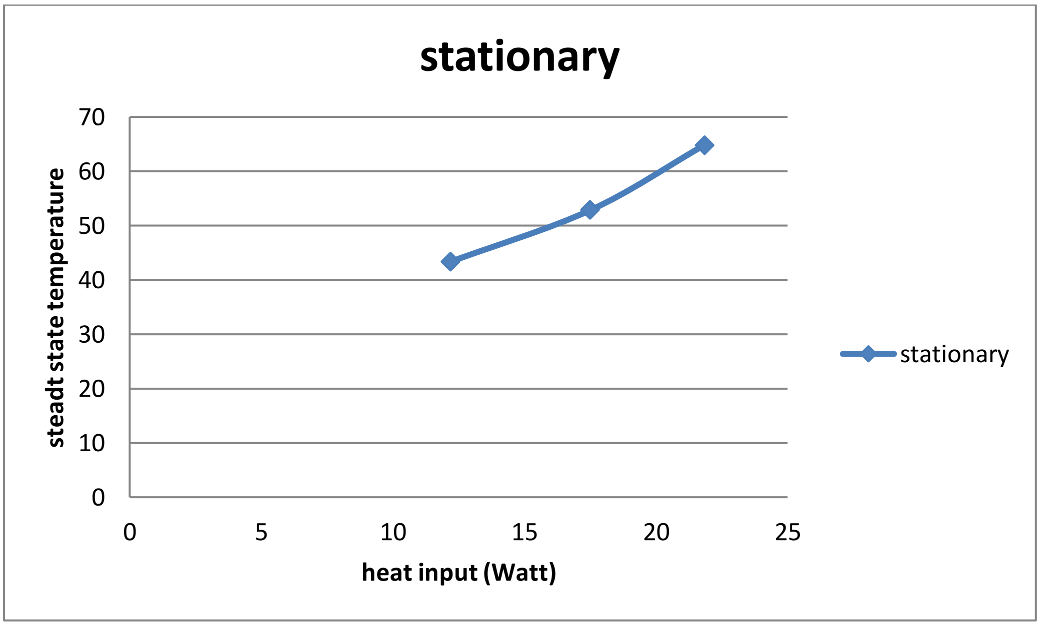


Figure 6.5Heat input vs steady state temperatures graph for reciprocating vertical plate:

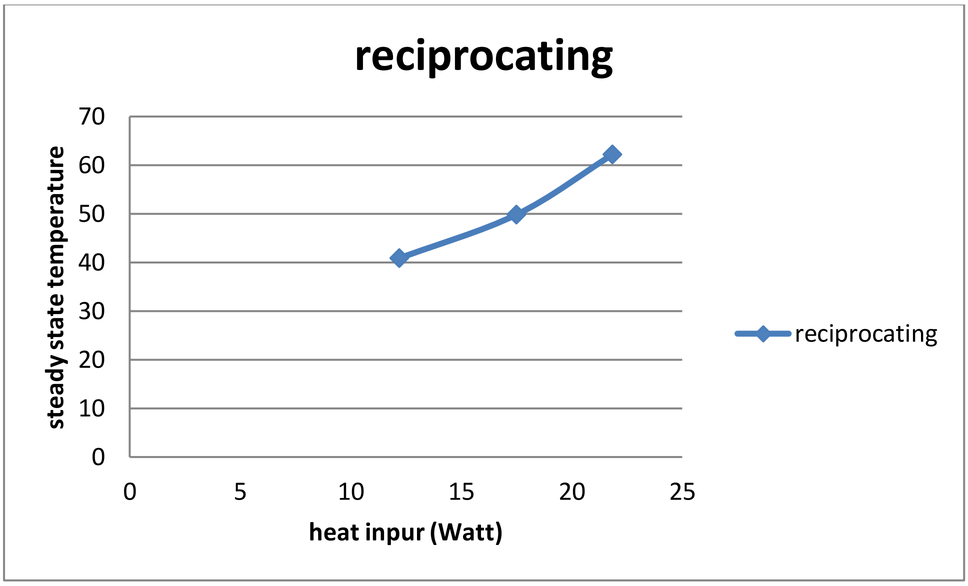
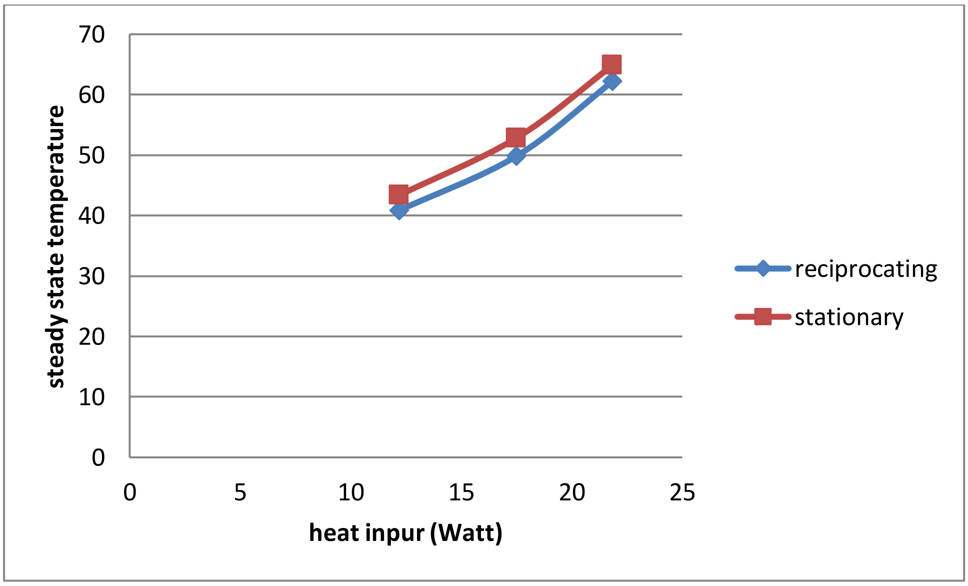


Figure 6.6 Heat input vs steady state temperatures comparison graph for both stationary and reciprocating vertical plate:



CHAPTER 7

CONCLUSIONS

7 CONCLUSIONS

In this study the variations of heat transfer coefficient for a flat plate in two conditions namely, when the plate is in rest position and when the vertical plate is made to reciprocate, have been found. The effects of heat input on heat transfer coefficient and steady state temperatures have been studied.

- Heat transfer coefficient for reciprocating vertical plate and stationary plate has been found out.
- Values of heat transfer coefficient and steady state temperatures with respect to heat input have been compared for flat plate when it is stationary and in reciprocating motion.
- Values of heat transfer coefficient with respect to heat input have been compared for vertical reciprocating plate and vertical reciprocating plate.
- An in-house experimental setup has been developed to carry out the experimentation with the purpose of validating the present numerical investigations.

CHAPTER 8

FUTURE SCOPE

8 FUTURE SCOPE

The future scope for this work involves:

- Instead of reciprocating it with slider crank mechanism a different mechanism can be used.
- Instead of reciprocating the plate, the plate can be oscillated or kept in any other motion.
- Different materials of the plates can be used in order to study the corrosion resistances and for how long the plates can withstand the process of continuous heating and cooling process.
- The slider velocity is kept constant in this study which can be varied to study its effect on heat transfer.

9 REFERENCES

1. **Abid Hussanan, Muhammad Imran Anwar, Farahad Ali, Ilyas khan, SharidanShafie**– Natural convection flow past an oscillating plate with Newtonian heating, heat transfer research vol-45, 119-137, November 2, 2014.
2. **M Narahari and A Ishak –** Radiation effects on free convection flow near a moving vertical plate with Newtonian heating, Journal of applied sciences 11(7) 1096-1104, 2011
3. **Ilyas Khan, Nehad Ali Shah, Yasir Mahsud and Dumitru Vieru**–Heat transfer analysis in a maxwell fluid over an oscillating vertical plate using fractional caputo – fabrizio derivatives, European physical journal plus,132:194, April 2017
4. **Ilyas khan, Nehad Ali Shah, AsifaTassaddiq, Norzieha Mustapha, Seripah Awang Kechil-** Natural convection heat transfer on an oscillating vertical cylinder, PLoS ONE 13(1) e0188656, January 5, 2018.
5. **Kaveh Habibi, Ali Mosahebi, HossienShokouhmand –** Heat transfer characteristics of reciprocating flows in channels partially filled with porous medium,Transp porous med,89:139-153, 12 April , 2011
6. **H shokouhmand, A. mosahebi, B karami-** Numerical simulation and optimization of heat transfer in reciprocating flows in two-dimensional channels. Proceedings of world congress on engineering,Vol-2, july 4, 2008.
7. **O G Martynenko, A.A Berezovsky, Yu A Sokovishin -** Laminar free convection from a vertical plate, Int.J.Heat Mass transfer – Vol-27, no-6, 1984.
8. **Mahdi Fahiminia, Mohammad Mahdi Naserian, Hamid Reza Goshayeshi, DavoodMajidian-** Investigation of natural convection heat transfer coefficient on extended vertical base plates, Energy and power engineering, 2011, 3, 174-180.
9. **M.J Sable, S.J Jagtap, P.S. Patil, P.R Baviskar, S.B Barve-** Enhancement of natural convection heat transfer on vertical heated plate by multiple v- fin array, IJRRAS 5(2) November 2010.