

# **HEAT TRANSFER LAB MANUAL**



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**INDEX**

<b>S.NO.</b>	<b>NAME OF THE EXPERIMENT</b>	<b>PAGE NOS.</b>
1	HEAT TRANSFER THROUGH COMPOSITE WALL	03-08
2	CRITICAL HEAT FLUX APPARATUS	09-12
3	MEASUREMENT OF SURFACE EMISSIVITY	13-18
4	HEAT TRANSFER THROUGH FORCED CONVECTION	19-25
5	HEAT PIPE DEMONSTRATION	26-27
6	HEAT TRANSFER THROUGH LAGGED PIPE	28-31
7	HEAT TRANSFER THROUGH NATURAL CONVECTION	32-38
8	PARALLEL & COUNTER FLOW HEAT EXCHANGER	39-45
9	HEAT TRANSFER THROUGH PIN-FIN	46-49
10	STEFAN BOLTZMAN'S APPARATUS	51-54
11	THERMAL CONDUCTIVITY OF CONCENTRIC SPHERE	55-58
12	THERMAL CONDUCTIVITY OF METAL ROD	59-63
13	TRANSIENT HEAT CONDUCTION APPARATUS	64-70
14	CONDENSATION APPARATUS	71-83

## 1. HEAT TRANSFER THROUGH COMPOSITE WALL

### INTRODUCTION:

In engineering applications, we deal with many problems. Heat Transfer through composite walls is one of them. It is the transport of energy between two or more bodies of different thermal conductivity arranged in series or parallel. For example, a fastener joining two mediums also acts as one of the layers between these mediums. Hence, the thermal conductivity of the fastener is also very much necessary in determining the overall heat transfer through the medium. An attempt has been made to show the concept of heat transfers through composite walls.

### DESCRIPTION OF THE APPARATUS:

The apparatus consists of three slabs of Mild Steel, Bakelite and Aluminum materials of thickness 25, 20 & 12mm respectively clamped in the center using screw rod.

At the center of the composite wall a heater is fitted. End losses from the composite wall are minimized by providing thick insulation all round to ensure unidirectional heat flow.

Front **transparent acrylic enclosure** to minimize the disturbances of the surrounding and also for safety of the composite slab when not in use.

Control panel instrumentation consists of:

- a. **Mains on indicator**
- b. **Console On switch** for activation of the control panel.
- c. **Scanner for measurement of**
  - i. Temperatures at various locations of the slab.
  - ii. Input Voltage.
  - iii. Input Current.
- d. **Heater regulator** to regulate the input voltage.

With this the whole arrangement is mounted on an aesthetically designed self-sustained Nova pone control panel.

**AIM:** To determine

1. The overall thermal conductance (C) for a composite wall and to compare with theoretical value.
2. Temperature distribution across the width of the composite wall.

**PROCEDURE : MANUAL**

1. Symmetrically arrange the plates and ensure perfect contact between the plates.
2. Give necessary electrical connections to the instruments.
3. Switch ON mains and the CONSOLE.
4. Set the heater regulator to the known value.
5. Wait for sufficient time to allow temperature to reach steady values.
6. Note down the Temperatures, voltage and current using the Data logger.
7. Calculate the overall conductance using the formulae given below.
8. Repeat the experiment for different heat input.

**OBSERVATIONS:**

Sl. No.	Temperatures °C						Heater Input	
	T1	T2	T3	T4	T5	T6	V	I
1								
2								
3								
4								
5								

**PROCEDURE: COMPUTERIZED****READINGS – COMPUTERIZED**

1. Symmetrically arrange the plates and ensure perfect contact between the plates.
2. Give necessary electrical connections to the instruments.
3. Switch ON mains and the CONSOLE.
4. Set the heater regulator to the known value.
5. Wait for sufficient time to allow temperature to reach steady values.
6. Turn on the computer switch on the panel.
7. Switch on the computer.

8. Open the “HEAT TRANSFER Software” from the installed location a welcome screen will be displayed
9. Follow the below steps to operate through software
  - a. Login using the given password into the software
  - b. Screen will display the concept of the equipment. Now login to the experiment by clicking the “Click to login” button on the screen.
  - c. Give required username for the experiment to be conducted.
  - d. Once the software is opened, the main screen will be displaced
  - e. Now, press “START” button, and the small screen will opened for any messages and also Specifications to be entered.
  - f. Enter the parameters listed for particular test under study.
  - g. Now, set the heater regulator to known valve.
  - h. Wait for sufficient time to allow temperature to reach steady values.
  - i. The software starts displaying the calculated values which can be cross verified based on the formulae give after.
10. Click the “store” button to store, the value can be viewed anytime later.
11. After completion of the Experiment, press the “STOP” Button.
12. To view the stored data follow the procedure in Annexure.

**CALCULATIONS ARE BASED ON THE BELOW FORMULAE:**

**1. HEAT FLUX,**

$$q = \frac{V \times I}{A} \text{ Watts}$$

Where,

V = voltmeter reading, volts

I = ammeter reading, amps

A = Area of the plate/s =  $(\pi d^2/4) \text{ m}^2$ , d = 0.2m

**2. AVERAGE TEMPERATURES:**

$$T_A = T_1$$

$$T_B = (T_2 + T_3)/2$$

$$T_C = (T_4 + T_5)/2$$

$$T_D = T_6$$

Where,

$T_A$  = Average inlet temperature to Aluminium.

$T_B$  = Average outlet temperature from Aluminium.

Average inlet temperature of MS

$T_C$  = Average outlet temperature to MS.

Average inlet temperature to Bakelite.

$T_D$  = Average outlet temperature to Bakelite.

### **3. THERMAL CONDUCTANCE:**

#### **PRACTICAL:**

$$C = \frac{Q}{(T_A - T_D)} \text{ W/m}^0 \text{ K}$$

Where,

Q = heat input in watts

$(T_A - T_D)$  = Temperature difference as calculated.

#### **THEORETICAL:**

$$C = \frac{1}{\frac{1}{A} \left( \frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3} \right)} \text{ W/m}^0 \text{ K}$$

$K_1 = 205 \text{ W/m}^0 \text{ K}$   
 $K_2 = 25 \text{ W/m}^0 \text{ K}$   
 $K_3 = 0.08 \text{ W/m}^0 \text{ K}$   
 $L_1 = 12 \text{ mm}$     $L_2 = 25 \text{ mm}$     $L_3 = 20 \text{ mm}$

### **4. OVERALL THERMAL CONDUCTIVITY OF THE SLAB, K**

$$\frac{Q \times B}{T_A - T_D} \text{ W/m}^0 \text{ K}$$

Where, B = thickness of the plates on one side = 0.057m

**TROUBLE SHOOTING: General causes and remedies**

CAUSES	REMEDY
Mains on indicator not glowing	Check input electrical connection.
No power to indicators	Switch on the console, still not working call the supplier.
Still unable to start, call the supplier	

**Data management system/Unable to acquire data properly**

CAUSES	REMEDY
Readings cannot be taken.	Un – install then Re-Install the software.
Low Voltage (minimum should be 220V)	Switch off the system till the voltage is stabilized to proper value.
Variation in the VOLTAGE (should not be more than 10V)	Check and stabilize it
Earthing not properly made.	Check and stabilize it.
Magnetic parts and induction equipments near the Indicators.	Remove it and place 5m away from the equipment.
Unable to take the printout	Check the printer connection. Still unable to so, check the printer software settings and redefine if necessary.
Still unable to acquire, call the supplier	

**Indicators not showing proper values – IN CASE USED**

CAUSES	REMEDY
Not calibrated properly	Check for any loose connection in the wire and also check for any air gap in the tubes of the pressure tapping points.
Indicator not working properly	Check the sensor wire and connection.
Still unable to find the problem, call the supplier	

DO'S	DON'Ts
Check the electrical connections before switching on the panel.	Switch on the panel if the voltage is low as specified.
Ensure water flow to the equipment and continue the flow for 15min before and after the experiment.	Run the equipment without supply of water to the transducer.
Grease the mating parts regularly.	Touch the rotating parts when equipment is running.
Keep the equipment clean and run at least 15min for every week.	Keep the equipment idle for more days as this may clog the moving parts.
Run the equipment in the Temperature limit of 200C.	Over temperature to the equipment, as this may cause damage to the whole system.
Still unable to find the problem, call the supplier	

**LIMITATIONS & PRECAUTIONS**

1. Maximum Load is limited to 120V.
2. This is a general equipment for study in undergraduate level, for consideration of higher level studies you can add any extra parameter required. For adding the parameters call the supplier.
3. Don't run the equipment if the voltage is less than 180V.
4. 230V, 1ph with neutral and proper earthing to be provided.
5. Don't alter the equipment without the supervision of the supplier.

**Reference:**

1. Heat and Mass transfer by Arora & Domkundwar
2. Chemical Engineers' Handbook, by  
Robert H. Perry / Cecil H. Chilton

Publication: McGraw – Hill Book Company (6<sup>th</sup> edition)



## EXPT-2

**CRITICAL HEAT FLUX APPARATUS****1. INTRODUCTION:**

Boiling and Condensation are the specific convection processes which is associated with change of phase. The co – efficient of heat transfer are correspondingly very high when compared to natural conventional process while the accompanying temperature difference are small (quite).

However, the visualization of this mode of heat transfer is more difficult and the actual solutions are still difficult than conventional heat transfer process.

Commonly, this mode of heat transfer with change of phase is seen in Boilers, condensers in power plants and evaporators in refrigeration system.

**2. DESCRIPTION OF APPARATUS**

1. The apparatus consists of a specially designed **Glass Cylinder**.
2. An arrangement above the Cylinder in the form of **Bakelite plate** is provided to place the main **Heater** and the Nichrome wire heater arrangement.
3. The base is made of MS and is powder coated with Rubber cushion to place the Glass cylinder.
4. **Heater regulator** to supply the regulated power input to the heater.
5. **Digital Voltmeter and Ammeter** to measure power input of the heater.
6. **Thermocouples** at suitable position to measure the temperatures of body and the air.
7. **Digital Temperature Indicator** with channel selector to measure the temperatures.
8. The whole arrangement is mounted on an Aesthetically designed sturdy frame made of MS tubes and NOVAPAN Board with all the provisions for holding the tanks and accessories.

**AIM:**

1. To observe the formation of pool boiling and
2. To draw the graph of heat flux Vs. Bulk Temperature upto Burnout (Critical) condition.

**i. PROCEDURE:**

1. Fill in the Glass Cylinder with **Distilled Water** above the heater level.
2. Connect the **Nichrome Wire** (Test Wire) of suitable length.
3. Keep the heater regulator to the minimum position.
4. Connect the power cable to 1Ph, 220V, 10 Amps with earth connection.
5. Switch on the Mains On to activate the control panel.
6. By using the Main Heater heat the water to the known temperature and switch off the same.
7. Now, using the Dimmer provided start heating the **Test Wire** by slowly rising the Current till the wire breaks.
8. Meanwhile, record the temperature, voltage and Current till the wire breaks. (also note the above parameters even at the break point.)
9. Repeat the above experiment by replacing the **Test Wire** and for Different Temperatures of Water.

**OBSERVATIONS**

Sl. No.	Temperatures °C			Heater Input	
	T1	T2	T3	V	I
1					
2					
3					
4					
5					

**CALCULATIONS:****1. Surface Area of the Wire, A**

$$a = \pi DL \text{ m}^2$$

where d = diameter of Test Wire.

L = Length of Test Wire.

**2. Heat Input, Q**

$$Q = V \times I \text{ Watts.}$$

Where,

V = Voltage in Volts.

I = Current in Amps.

**3. Heat Flux, q**

$$q = \frac{Q}{A} \text{ W/m}^2$$

**4. Heat Transfer Co-efficient, h**

$$h = 1.54q^{0.75} \text{ W/m}^2 \text{ K}$$

Where,

q = Heat Flux

**5. Temperature Excess,  $\Delta T$** 

$$\Delta T = \sqrt{\left(\frac{h}{5.58}\right)} \text{ K}$$

**TABULAR COLUMN**

SI No	Heat Flux, q	Temperature Excess, $\Delta T$

**RESULTS:**

- Draw the Graph of  $q$  vs.  $\Delta T$  and
- Compare  $\Delta T$  with the experimental Values i.e.,  
(Difference of Water Temperature and the Test Wire/Boiling Temperature)

**PRECAUTIONS**

1. Clean the tank regularly after every use.
2. Do not run the equipment if the voltage is below 180V.
3. Check all the electrical connections before running.
4. Do not attempt to alter the equipment as this may cause damage to the whole system.

Note: For any further clarifications on how to run the equipment or for

up gradation, please write to us at:

### **3. MEASUREMENT OF SURFACE EMISSIVITY**

#### **INTRODUCTION:**

Radiation is one of the modes of heat transfer, which does not require any material medium for its propagation. All bodies can emit radiation & have also the capacity to absorb all or a part of the radiation coming from the surrounding towards it. The mechanism is assumed to be electromagnetic in nature and is a result of temperature difference. Thermodynamic considerations show that an ideal radiator or black body will emit energy at a rate proportional to the fourth power of the absolute temperature of the body. Other types of surfaces such as glossy painted surface or a polished metal plate do

not radiate as much energy as the black body, however the total radiation emitted by these bodies still generally follow the fourth power proportionality. To take account of the gray nature of such surfaces, the factor called emissivity ( $\epsilon$ ), which relates the radiation of the gray surface to that of an ideal black surface, is used. The emissivity of the surface is the ratio of the emissive power of the surface to the emissive power of the black surface at the same temperature. Emissivity is the property of the surface and depends upon the nature of the surface and temperature.

#### **DESCRIPTION OF THE APPARATUS:**

The setup consists of a **200mm dia two copper plates** one surface blackened to get the effect of the black body and other is plated to give the effect of the gray body. Both the plates with **mica heaters** are mounted on the ceramic base covered with chalk powder for maximum heat transfer. Two Thermocouples are mounted on their surfaces to measure the temperatures of the surface and one more to measure the enclosure/ambient temperature. This complete arrangement is fixed in an **acrylic chamber** for visualization. Temperatures are indicated on the digital temperature indicator with channel selector to select the temperature point. Heater regulators are provided to control and monitor the heat input to the system with voltmeter and ammeter for direct measurement of the heat inputs. The heater controller is made of complete aluminium body having fuse.

With this, the setup is mounted on an aesthetically designed frame with control panel to monitor all the processes. The control panel consists of mains on indicator, Aluminium body heater controllers, change over switches, digital Data logger is used to measure the temperature, voltage and current of the Black body and grey body and other necessary instrumentation. The whole arrangement is on the single bench considering all **safety and aesthetics factors**.

**EXPERIMENTATION:**

**AIM:** The experiment is conducted to determine the emissivity of the non – black surface and compare with the black body.

**PROCEDURE:**

1. Give necessary electrical connections and switch on the MCB and switch on the console on to activate the control panel.
2. Switch On the heater of the black body and set the voltage (say 30V) using the heater regulator
3. Switch On the heater of the Gray body and set the voltage (say 30V) using the heater regulator.
4. Observe temperatures of the black body and test surface in close time intervals and adjust power input to the test plate heater such that both black body and test surface temperatures are same.

**NOTE:** This procedure requires trial and error method and one has to wait sufficiently long (say 2hours or longer) to reach a steady state.

5. Wait to attain the steady state.
6. Note down the temperatures at different points and also the voltmeter and ammeter readings.
7. Tabulate the readings and calculate the surface emissivity of the non – black surface.

**PROCEDURE : COMPUTERIZED****TAKING READINGS – COMPUTERIZED**

1. Switch on the panel.
2. Switch on the computer.
3. Open the “ **HEAT TRANSFER Software**” from the installed location a welcome screen will be displayed
4. Follow the below steps to operate through software

Once the software is opened, the main screen will be displaced

Now, press “**START**” button, and the small screen will opened

Enter the parameters listed for particular test under study.

the software starts displaying the calculated values which can be cross verified based on the formulae give after.

5. Switch On the heater of the black body and set the voltage (say 30V) using the heater regulator
6. Switch On the heater of the Gray body and set the voltage (say 30V) using the heater regulator.
7. Observe temperatures of the black body and test surface in close time intervals and adjust power input to the test plate heater such that both black body and test surface temperatures are same.
8. Wait to attain the steady state.
9. Click the “store” button to store the value can be viewed anytime later.
10. After completion of the Experiment to press the stop button

**OBSERVATIONS:**

Sl. No.	Heater input				Temperature, °C				
	Black body		Gray body						
	Voltage, 'v' volts	Current 'I' amps	Voltage 'v' volts	Current 'I' amps	T1	T2	T3	T4	T5
1									
2									
3									
4									
5									

**CALCULATIONS:**

1. HEAT INPUT TO THE BLACK BODY,  $Q_B$

$$_Q B = V \times I \quad \text{Watts.}$$

2. HEAT INPUT TO THE GRAY BODY,  $Q_G$

$$_Q G = V \times I \quad \text{Watts.}$$

3. EMMISSIVITY OF THE GRAY BODY,  $\epsilon_G$ 

$$\epsilon_G = 1 - \frac{0.86 \times (Q_B - Q_G)}{\sigma \times A \times (T^4 - T_A^4)}$$

$\sigma$  = Stefan Boltzmann constant =  $5.67 \times 10^{-8} \text{ W/m}^2 \text{ K}^4$ .

$Q_G$  = Heat input to the gray body.

$Q_B$  = Heat input to the black body.

$A$  = Area of plates =  $(\pi d^2/4) \text{ m}^2$ ,  $d = 0.2 \text{ m}$

$T = (T_1 + T_2 + T_3 + T_4)/4$

$T_A$  = enclosure temperature =  $T_5$

0.86 = constant, which takes into account various factors such as radiation shape factor, effect of conduction and free convection losses and other factors (such as non uniformities in enclosure temperature) which cause deviations from the typical radiation heat transfer experiment.

**RESULT :**

The emissivity of the gray body is  $\epsilon_G = \underline{\hspace{2cm}}$ .

**NOTE;**

IF YOU FIND THE ABOVE METHOD TO BE MORE TEDIOUS, USE **ALTERNATE PROCEDURE AND CALCULATIONS.**

**ALTERNATE PROCEDURE:**

Give necessary electrical connections and switch on the MCB and switch on the console on to activate the control panel.

1. Switch On the heater of the Gray body and set the voltage (say 45V) using the heater regulator and digital voltmeter.
2. Switch On the heater of the Black body and set the voltage or current (say higher than gray body) using the heater regulator and digital voltmeter.
3. Wait to attain the steady state.
4. Note down the temperatures at different points and also the voltmeter and ammeter readings.
5. Tabulate the readings and calculate the surface emissivity of the non – black surface.



**ALTERNATE OBSERVATIONS:**

Sl. No.	Heater input				Temperature, °C				
	Black body		Gray body		T1	T2	T3	T4	T5
	Voltage, 'v' volts	Current 'I' amps	Voltage 'v' volts	Current 'I' amps					
1									
2									
3									
4									

**ALTERNATE CALCULATIONS:**

1. HEAT INPUT TO THE BLACK BODY,  $Q_B$

$$Q_B = V \times I \quad \text{Watts.}$$

2. HEAT INPUT TO THE GRAY BODY,  $Q_G$

$$\underline{\hspace{2cm}} Q_G = V \times I \quad \text{Watts.}$$

3. EMMISSIVITY OF THE GRAY BODY,  $\epsilon_G$

$$\epsilon_G = \frac{Q_G (T_B^4 - T_A^4)}{Q_B (T_G - T_A)}$$

$Q_G$  = Heat input to the gray body.

$Q_B$  = Heat input to the black body.

A = Area of plates =  $(\pi d^2/4) \text{ m}^2$ , d = 0.2m

$T_B$  = Temperature of black body =  $(T_1+T_2)/2$

$T_G$  =  $(T_3+T_4)/2$

$T_A$  = Ambient temperature =  $T_5$

4. **RESULT** :

The emissivity of the gray body is  $\epsilon_g$  = \_\_\_\_\_.

**Reference:**

- 1) Heat and Mass transfer by Arora & Domkundwar
- 2) Chemical Engineers' Handbook, by  
Robert H. Perry / Cecil H. Chilton  
Publication: McGraw – Hill Book Company (6<sup>th</sup> edition)

**PRECAUTIONS:**

1. Check all the electrical connections.
2. Do not run the equipment if the voltage is below 180V.
3. Make sure that heater regulator is at the minimum position before switching on the console.
4. After finishing the experiment open the acrylic door to remove the heat from the chamber.
5. Do not attempt to alter the equipment as this may cause damage to the whole system.

## 4. HEAT TRANSFER THROUGH FORCED CONVECTION

### INTRODUCTION:

Heat transfer can be defined as the transmission of energy from one region to another as a result of temperature difference between them. There are three different modes of heat transfer; namely,

**HEAT CONDUCTION** : The property which allows the passage for heat energy, even though its parts are not in motion relative to one another.

**HEAT CONVECTION** : The capacity of moving matter to carry heat energy by actual movement.

**HEAT RADIATION** : The property of matter to emit or to absorb different kinds of radiation by electromagnetic waves.

Out of these types of heat transfer the convective heat transfer which of our present concern, divides into two categories, viz.,

**NATURAL CONVECTION:** If the motion of fluid is caused only due to difference in density resulting from temperature gradients without the use of pump or fan, then the mechanism of heat transfer is known as "Natural or Free Convection".

**FORCED CONVECTION:** If the motion of fluid is induced by some external means such as a pump or blower, then the heat transfer process is known as "Forced Convection".

The Newton's law of cooling in convective heat transfer is given by,

$$q = h A \Delta T$$

Where,  $q$  = Heat transfer rate, in watts

$A$  = Surface area of heat flow, in  $m^2$

$\Delta T$  = Overall temperature difference between the wall and fluid, in  $^{\circ}C$

$h$  = Convection heat transfer coefficient, in  $watts/m^2 ^{\circ}C$

This setup has been designed to study heat transfer by forced convection.

**DESCRIPTION OF THE APPARATUS:**

The apparatus consists of

**Heat exchanger tube** made of **copper** which is thermally insulated outside to prevent heat transfer losses to the atmosphere.

**Band heaters** of 500watts capacity.

**Heater regulator** to supply the regulated power input to the heater.

Data logger is used to measure the Temperature, Voltage ,current and Air flow rat .

**Thermocouples** at suitable position to measure the temperatures of body and the air.

**Blower** unit to blow air through the heat exchanger with orifice meter and Differential Pressure Transducer to measure the air flow rate from the blower. A control valve is provided to regulate the air flow.

Control panel to house all the instrumentation.

With this the whole arrangement is mounted on an aesthetically designed self-sustained frame with a separate NOVAPAN Board control panel.

**EXPERIMENTATION:**

**AIM:** To determine convective heat transfer coefficient in forced convection.

**PROCEDURE : MANUAL**

1. Switch on the MCB and then console on switch to activate the control panel.
2. Switch on the blower unit first and adjust the flow of air using wheel valve of blower to a desired difference in manometer.
3. Switch on the heater and set the voltage (say 80V) using the heater regulator.
4. Wait for reasonable time to allow temperatures to reach steady state.
5. Measure the voltage, current and temperatures from  $T_1$  to  $T_6$  at known time interval.
6. Calculate the convective heat transfer co-efficient using the procedure given.
7. Repeat the experiment for different values of power input to the heater and blower air flow rates.

**OBSERVATIONS:**

SL No.	Manometer Reading, mm of water	HEAT INPUT		Air temperature, °C		TEMPERATURE, °C			
	H	V	I			SURFACE			
				T4	T5	T1	T2	T3	T4
1.									
2.									
3.									
4.									

Where : V = Voltage, volts and I = Current, amps

**PROCEDURE : COMPUTERIZED****TAKING READINGS – COMPUTERIZED**

- 1) Switch on the panel.
- 2) Switch on the computer.
- 3) Open the “**HEAT TRANSFER Software**” from the installed location a welcome screen will be displayed
- 4) Follow the below steps to operate through software  
Once the software is opened, the main screen will be displaced  
Now, press “**START**” button, and the small screen will opened  
Enter the parameters listed for particular test under study.  
the software starts displaying the calculated values which can be cross verified based on the formulae give after.
- 5) Switch on Blower And adjust the air Flow rate By using the Valve See the Air flow rate in Indicator.
- 6) Switch on the heater and set the voltage (say 40V) using heater regulator.
- 7) Wait for sufficient time to allow temperature to reach steady values.

- 8) Repeat the experiment for different heat inputs and also for horizontal position with different heat inputs.
- 9) Wait to attain the steady state.
- 10) Click the “store” button to store the value can be viewed anytime later.
- 11) After completion of the Experiment to press the stop button.

**CALCULATIONS:**

**PRACTICAL**

$$1. \quad h = \frac{Q}{A (T_i - T_o)}$$

where, Q = heat given to the heater = V x I watts.

$$A = \text{Area of the tube surface} = \pi d L$$

$$d = 0.036\text{m and } L = 0.5\text{m}$$

$$T_i = \text{mean temperature} = (T_1 + T_2 + T_3 + T_4) / 4$$

$$T_o = (T_5 + T_6) / 3$$

**THEORETICAL**

$$h = (0.023 \times Pr^{0.4} \times Re^{0.8} \times k) / D$$

Where,

$$Re = \frac{\rho v D}{\mu} \quad Pr = \frac{\mu C_p}{K}$$

where ,

$$D = \text{inner diameter of the tube} = 0.036$$

$$v = \frac{\text{mass flow rate of air}}{\text{Flow area}} \quad \text{m/s}$$

Mass flow rate of air is calculated as follows:

$$= 0.62 \times a \times \sqrt{2gH}$$

where, a =  $\frac{\pi d^2}{4}$  , d= 0.015

$$H = \frac{\text{(h) m of air column}}{1.293}$$

Flow area is calculated as follows:

$$= \frac{\pi D^2}{4} , D= 0.036$$

All the properties of air should be taken at  $(T_i + T_o)/2$  from the data hand book.

**RESULT:**

\_Draw the graph of 'h' versus 'Tm' for theoretical and practical calculations and compare the results.

**TROUBLE SHOOTING:General causes and remedie**

CAUSES	REMEDY
Mains on indicator not glowing	Check input electrical connection.
No power to indicators	Switch on the console, still not working call the supplier.
Still unable to start, call the supplier	

**Data management system/Unable to acquire data properly**

CAUSES	REMEDY
Readings cannot be taken.	Un – install then Re-Install the software.
Low Voltage  (minimum should be 220V)	Switch off the system till the voltage is stabilized to proper value.

Variation in the VOLTAGE (should not be more than 10V)	Check and stabilize it
Earthing not properly made.	Check and stabilize it.
Magnetic parts and induction equipments near the Indicators.	Remove it and place 5m away from the equipment.
Unable to take the printout	Check the printer connection. Still unable to so, check the printer software settings and redefine if necessary.
Still unable to acquire, call the supplier	

**Indicators not showing proper values – IN CASE USED**

CAUSES	REMEDY
Not calibrated properly	Check for any loose connection in the wire and also check for any air gap in the tubes of the pressure tapping points.
Indicator not working properly	Check the sensor wire and connection.
Still unable to find the problem, call the supplier	

**DO's & DON'Ts**

DO's	DON'Ts
Check the electrical connections before switching on the panel.	Switch on the panel if the voltage is low as specified.
Ensure water flow to the equipment and continue the flow for 15min before and after the experiment.	Run the equipment without supply of water to the transducer.
Grease the mating parts regularly.	Touch the rotating parts when equipment is running.
Keep the equipment clean & dry and run at least 15min for every week.	Keep the equipment idle for more days as this may clog the moving parts.
Run the equipment in the Temperature limit of 200C.	Over temperature to the equipment, as this may cause damage to the whole system.
Still unable to find the problem, call the supplier	



**LIMITATIONS & PRECAUTIONS**

- 1) Maximum Load is limited to 150V.
- 2) This is a general equipment for study in undergraduate level, for consideration of higher level studies you can add any extra parameter required. For adding the parameters call the supplier.
- 3) Don't run the equipment if the voltage is less than 180V.
- 4) 230V, 1ph with neutral and proper earthing to be provided.
- 5) Don't alter the equipment without the supervision of the supplier.

**Reference:**

- 1) Heat and Mass transfer by Arora & Domkundwar
- 2) Chemical Engineers' Handbook, by Robert H. Perry / Cecil H. Chilton

Publication: McGraw – Hill Book Company (6<sup>th</sup> edition)

## 5.HEAT PIPE DEMONSTRATION

### INTRODUCTION:

One of the main objectives of energy conversion systems is to transfer energy from a receiver to some other location where it can be used to heat a working fluid. The heat pipe is a novel device that can transfer large quantities of heat through small surface areas with small temperature differences. Here in this equipment an attempt has been made to show the students, how the heat pipe works with different methods.

### DESCRIPTION OF THE APPARATUS:

The apparatus consists of a **Solid Copper Rod** of diameter (d) 25mm and length (L) 500mm with a Source at one end and condenser at other end.

Similarly, **Hollow copper pipe without wick and with wick (SS mesh of 180microns)** with same outer dia and length is provided.

**Thermocouples** are fixed on the tube surface with a phase angle of  $90^\circ$  on each pipe.

Control panel instrumentation consists of:

- e. **Digital Temperature Indicator** with channel selector.
- f. **Digital Voltmeter & Ammeter** for power measurement.
- g. **Heater regulator** to regulate the input power.

With this, the setup is mounted on an aesthetically designed MS Powder coated frame with MOVAPAN Board control panel to monitor all the processes considering all **safety and aesthetics factors**.

### EXPERIMENTATION:

#### AIM:

To determine the axial heat flux in a heat pipe using water as the working fluid with that of a solid copper with different temperatures.

#### PROCEDURE:

- 1) Provide the necessary electrical connection and then CONSOLE ON switch.
- 2) Switch on the heater and set the voltage (say 40V) using heater regulator and the digital voltmeter.
- 3) Wait for sufficient time to allow temperature to reach steady values.
- 4) Note down the Temperatures 1 to 6 using the channel selector and digital temperature indicator.
- 5) Note down the ammeter and voltmeter readings.
- 6) Calculate the axial heat flux for all the pipes.
- 7) Repeat the experiment for different heat inputs and compare the results.

**OBSERVATIONS:**

Sl. No.	Temperatures °C						Heater Input	
	T1	T2	T3	T4	T5	T6	V	I
1								
2								
3								
4								
5								

Where : V = Voltage, volts and I = Current, amps

**CALCULATIONS:**

1. Calculation of heat flux, q

$$q = \frac{Q}{A} = \frac{k \times \Delta T}{\Delta x} \text{ W/m}^2$$

where, k = Thermal conductivity of copper = 375 W/m K

dt = Temperature difference.

dx = Length b/w thermocouples.

**RESULT:**

\_Draw the graph of 'q' versus 'Temperature difference' for different heat inputs.

**Reference:**

1) Heat and Mass transfer by Arora & Domkundwar

2) Chemical Engineers' Handbook, by

Robert H. Perry / Cecil H. Chilton

Publication: McGraw – Hill Book Company (6<sup>th</sup> edition)

**PRECAUTIONS:**

- 1) Check all the electrical connections.
- 2) Do not run the equipment if the voltage is below 180V.
- 3) Make sure that heater regulator is at the minimum position before switching on the console.
- 4) Do not attempt to alter the equipment as this may cause damage to the whole system.

## 6. HEAT TRANSFER THROUGH LAGGED PIPE

### INTRODUCTION:

The costs involved in insulating either heated or refrigerated equipment, air-conditioned rooms, pipes, ducts, tanks, and vessels are of a magnitude to warrant careful consideration of the type and quantity of insulation to be used. Economic thickness is defined as the minimum annual value of the sum of the cost of heat loss plus the cost of insulation, or, in more general terms, as the thickness, of a given insulation that will save the greatest cost of energy while paying for itself within an assigned period of time. At low values of thickness, the amortized annual cost of insulation is low, but the annual cost of heat energy is high. Additional thickness adds to the cost of insulation but reduces the loss of heat energy, and therefore, its cost. At some value of insulation thickness, the sum of the cost of insulation and the cost of heat loss will be a minimum, curve C rises because the increased cost insulation is no longer offset by the reduced cost of heat loss.

The calculation of economic thickness for an industrial installation is not easy, owing to the large number of variables and separate calculations involved. This has all been reduced to manual form in "How to determine economic thickness of insulation", published by National Insulation Manufacturers Association, New York.

### CRITICAL THICKNESS OF INSULATION:

It must not be taken for granted that insulation only retards the rate of heat flow. The addition of small amount of insulation to small diameter wires or tubes frequently increases the rate of heat flow through the tube to the ambient air. It was shown elsewhere in the standard books with experiment that the rate of heat loss was increased by the addition of the asbestos sheet.

### CRITICAL THICKNESS OF INSULATION FOR CYLINDER:

When a solid cylinder of radius  $R_1$  is insulated with an insulation of thickness  $(R_2 - R_1)$ , then the heat flow from the surface of the solid cylinder to the surrounding is given by

$$Q = \frac{2 \pi L (T_{input} - T_{outlet})}{\frac{1}{K_2 \log_e \frac{R_{outer}}{R_{inner}}} + \frac{1}{R_{outer} h_o}} \quad W$$

Where,  $L$  is the length of the cylinder,

$K_2$  is the conductivity of the insulation, and

$h_o$  is the combined (convection and radiation) heat transfer

co-efficient on the outer surface of the insulation.

**DESCRIPTION:**

The experimental set-up consists of a copper pipe of 38mm diameter divided into four zones of 150mm each. The zone 1 is a bare pipe, and zone 2 is wound with asbestos rope to 60mm dia, and that of zone 3 to 90mm dia and zone 4 to 110mm dia. The heater of 500 watts is centred along the length of the pipe (150x4=600mm).

**Heater regulator** to supply the regulated power input to the heater. **Digital Voltmeter and Ammeter** to measure power input of the heater. **Thermocouples** at suitable position to measure the temperatures of body and the air. **Digital Temperature Indicator** with channel selector to measure the temperatures.

Control panel to house all the instrumentation.

With this the whole arrangement is mounted on an aesthetically designed self-sustained MS powder coated frame with a separate NOVAPAN Board control panel.

**EXPERIMENTATION:****AIM:**

To determine combined convective and radiation heat transfer coefficient at each zone and compare them to decide the critical thickness of insulation.

**PROCEDURE:**

1. Switch on the MCB and then console on switch to activate the control panel.
2. Switch on the heater and set the voltage (say 40V) using the heater regulator and digital voltmeter.
3. Wait for reasonable time to allow temperatures to reach steady state.
4. Measure the voltage, current and temperatures from  $T_1$  to  $T_7$  at known time interval.
5. Calculate the heat transfer co-efficient using the procedure given.
6. Repeat the experiment for different values of power input to the heater.

**7. OBSERVATIONS:**

SL No.	HEAT INPUT		TEMPERATURE, °C						
	V	I	SURFACE						
			T1	T2	T3	T4	T5	T6	T7
1.									
2.									
3.									
4.									

Where : V = Voltage, volts and I = Current, amps

T1 : Bare Point Inner Temperature

T2 : Zone I Inner Temperature

T3 : Zone I Outer Temperature

T4 : Zone II Inner Temperature

T5 : Zone II Outer Temperature

T6 : Zone III Inner Temperature

T7 : Zone III Outer Temperature

**CALCULATIONS:**

$$Q = \frac{2 \pi L (T_{input} - T_{outlet})}{\frac{1}{K_2} \log_e \frac{R_{outer}}{R_{inner}} + \frac{1}{R_{outer} h_o}} \quad W$$

where, Q = heat given to the heater = V x I watts.

$R_{outer/inner}$  indicates respective radius of the zones.

$T_{input/outlet}$  indicates respective temp. of the zones.

L = 0.150m

$K_2$  = Thermal conductivity of insulation.

**RESULT:**

\_Draw the graph of 'h' versus 'Tm' for theoretical and practical calculations and compare the results.

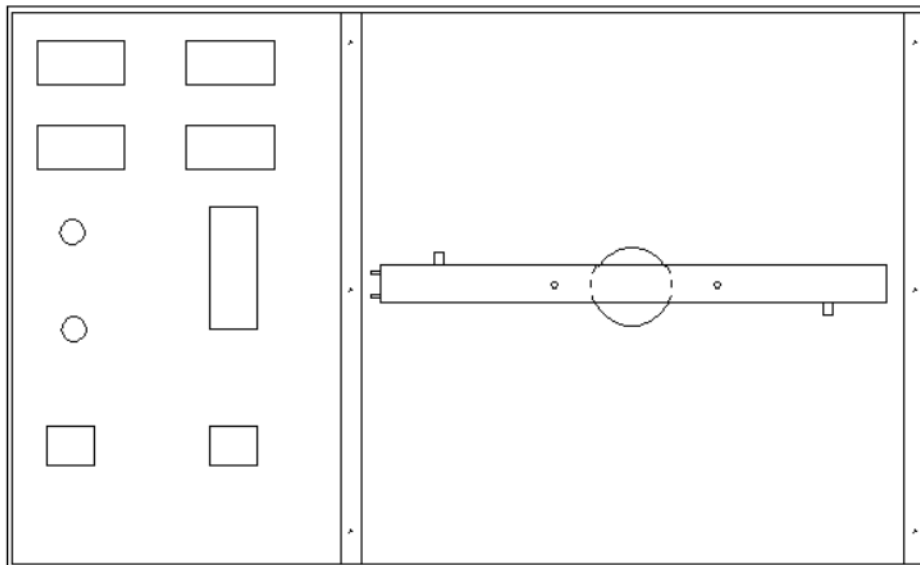
**Reference:**

1. Heat and Mass transfer by Arora & Domkundwar
2. Chemical Engineers' Handbook, by Robert H. Perry / Cecil H. Chilton

Publication: McGraw – Hill Book Company (6<sup>th</sup> edition)

**PRECAUTIONS:**

1. Check all the electrical connections.
2. Do not run the equipment if the voltage is below 180V.
3. Make sure that heater regulator is at the minimum position before switching on the console.
4. Do not attempt to alter the equipment as this may cause damage to the whole system.



## 7. HEAT TRANSFER THROUGH NATURAL CONVECTION

### INTRODUCTION:

There are certain situations in which the fluid motion is produced due to change in density resulting from temperature gradients. The mechanism of heat transfer in these situations is called free or natural convection. Free convection is the principal mode of heat transfer from pipes, transmission lines, refrigerating coils, hot radiators etc.

The movement of fluid in free convection is due to the fact that the fluid particles in the immediate vicinity of the hot object become warmer than the surrounding fluid resulting in a local change of density. The colder fluid creating convection currents would replace the warmer fluid. These currents originate when a body force (gravitational, centrifugal, electrostatic etc) acts on a fluid in which there are density gradients. The force, which induces these convection currents, is called a buoyancy force that is due to the presence of a density gradient with in the fluid and a body force. Grashoffs number a dimensionless quantity plays a very important role in natural convection.

### DESCRIPTION OF THE APPARATUS:

The apparatus consists of a **Chromium plated Copper tube** of diameter (d) 38mm and length (L) 500mm with a Special electrical heater along the axis of the tube for uniform heating.

Four **thermocouples** are fixed on the tube surface with a phase angle of 90°.

An arrangement to change the position of the tube to vertical or horizontal position is provided.

Front **transparent acrylic enclosure** to minimize the disturbances of the surrounding and also for safety of the tube when not in use.

Contol panel instrumentation consists of:

- h. Mains on, console on
- i. Data logger is used to measure the Temp, Voltage and current.
- j. **Heater regulator** to regulate the input power.

With this, the setup is mounted on an aesthetically designed frame with NOVAPAN Board control panel to monitor all the processes considering all **safety and aesthetics factors**.



**EXPERIMENTATION:****AIM:**

To determine the natural heat transfer coefficient ' $h$ ' from the surface of the tube in both vertical and horizontal position.

**PROCEDURE : MANUAL**

1. Keep the tube in the vertical position.
2. Switch on MCB and then CONSOLE ON switch.
3. Switch on the heater and set the voltage (say 40V) using heater regulator.
4. Wait for sufficient time to allow temperature to reach steady values.
5. Note down the Temperatures 1 to 4 using the Data logger
6. Note down the Voltage and Current.
7. Calculate the convection heat transfer co-efficient using the procedure given below.
8. Repeat the experiment for different heat inputs and also for horizontal position with different heat inputs.

**OBSERVATIONS:**

Sl. No.	Position	Temperatures °C				Heater Input	
		T1	T2	T3	T4	V	I
1							
2							
3							
4							
5							

Where : V = Voltage, volts and I = Current, amps

**PROCEDURE : COMPUTERIZED**

**TAKING READINGS – COMPUTERIZED**

1. Switch on the panel.
2. Switch on the computer.
3. Open the “**HEAT TRANSFER Software**” from the installed location a welcome screen will be displayed
4. Follow the below steps to operate through software
5. Once the software is opened, the main screen will be displaced
6. Now, press “**START**” button, and the small screen will opened
7. Enter the parameters listed for particular test under study.
8. the software starts displaying the calculated values which can be cross verified based on the formulae give after.
9. Switch on the heater and set the voltage (say 40V) using heater regulator.
10. Wait for sufficient time to allow temperature to reach steady values.
11. Repeat the experiment for different heat inputs and also for horizontal position with different heat inputs.
12. Wait to attain the steady state.
13. Click the “**store**” button to store the value can be viewed anytime later.
14. After completion of the Experiment to press the stop button

**CALCULATIONS ARE BASED ON THE BELOW FORMULAE:****PRACTICAL**

$$1. \quad h = \frac{Q}{A (T_m - T_a)}$$

where, Q = heat given to the heater = V x I watts.

$$A = \text{Area of the tube surface} = \pi d L$$

$$d = 0.038\text{m and } L = 0.5\text{m}$$

$$T_m = \text{mean temperature} = (T_1 + T_2 + T_3 + T_4) / 4$$

T<sub>a</sub> = Ambient air temperature.

**THEORETICAL**

1. VERTICAL POSITION: for  $10^4 < Gr.Pr < 10^9$

$$h_v = (0.59 \times (Gr.Pr)^{0.25} \times k) / L$$

2. HORIZONTAL POSITION: for  $10^4 < Gr.Pr < 10^9$

$$h_h = (0.53 \times (Gr.Pr)^{0.25} \times k) / L$$

Where,

$$Pr = \frac{\mu C_p}{k} \qquad Gr = \frac{L^3 \rho^2 \beta (T_m - T_a)}{\mu^2}$$

$$\beta = 1/(273 + T_m)$$

All the properties of air should be taken at  $(T_m + T_a)/2$  from the data hand book.

Here , L is the characteristic length and is given as:

$$L = L = 0.5\text{m for vertical position.}$$

$$L = d = 0.038 \text{ for horizontal position.}$$

**RESULT:**

Draw the graph of 'h' versus 'T<sub>m</sub>' for vertical and horizontal positions of the tube actually and theoretically calculated and compare the results.

**TROUBLE SHOOTING:**

- **General causes and remedies**

CAUSES	REMEDY
Mains on indicator not glowing	Check input electrical connection.
No power to indicators	Switch on the console, still not working call the supplier.
Still unable to start, call the supplier	

**Data management system/Unable to acquire data properly**

CAUSES	REMEDY
Readings cannot be taken.	Un – install then Re-Install the software.
Low Voltage (minimum should be 220V)	Switch off the system till the voltage is stabilized to proper value.
Variation in the VOLTAGE (should not be more than 10V)	Check and stabilize it
Earthing not properly made.	Check and stabilize it.
Magnetic parts and induction equipments near the Indicators.	Remove it and place 5m away from the equipment.
Unable to take the printout	Check the printer connection. Still unable to so, check the printer software settings and redefine if necessary.
Still unable to acquire, call the supplier	

- **Indicators not showing proper values – IN CASE USED**

CAUSES	REMEDY
Not calibrated properly	Check for any loose connection in the wire and also check for any air gap in the tubes of the pressure tapping points.
Indicator not working properly	Check the sensor wire and connection.
Still unable to find the problem, call the supplier	

- **DO's & DON'Ts**

DO's	DON'Ts
Check the electrical connections before switching on the panel.	Switch on the panel if the voltage is low as specified.
Ensure water flow to the equipment and continue the flow for 15min before and after the experiment.	Run the equipment without supply of water to the transducer.
Grease the mating parts regularly.	Touch the rotating parts when equipment is running.
Keep the equipment clean and run at least 15min for every week.	Keep the equipment idle for more days as this may clog the moving parts.
Run the equipment in the Temperature limit of 200C.	Over temperature to the equipment, as this may cause damage to the whole system.
Still unable to find the problem, call the supplier	

**SPECIAL NOTE:**

1. The experiment should be carried out in the absence of wind flow through the window as well as in the absence of fan for better results.
2. For better result, the horizontal and vertical experiments should be conducted after the tube is cooled down to almost room temperature.
3. For comparison of results in horizontal and vertical position the temperatures should be considered for equal interval of time, in both cases.

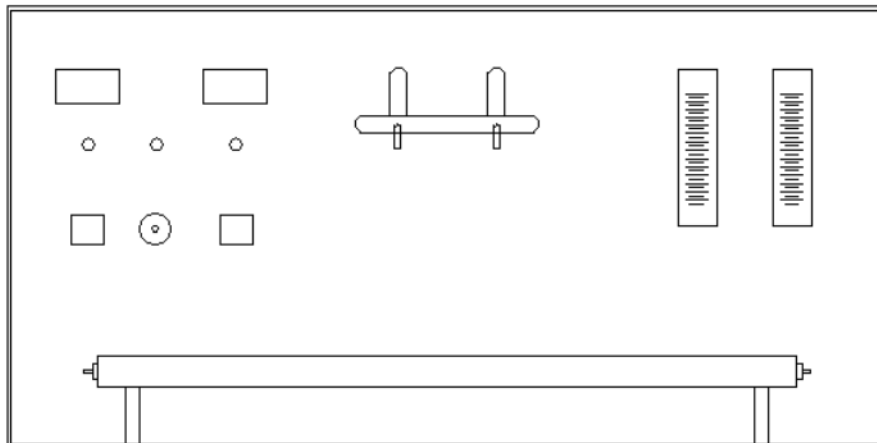
**LIMITATIONS & PRECAUTIONS**

1. Maximum Load is limited to 120V.
2. This is a general equipment for study in undergraduate level, for consideration of higher level studies you can add any extra parameter required. For adding the parameters call the supplier.
3. Don't run the equipment if the voltage is less than 180V.
4. 230V, 1ph with neutral and proper earthing to be provided.
5. Don't alter the equipment without the supervision of the supplier.

**Reference:**

1. Heat and Mass transfer by Arora & Domkundwar
2. Chemical Engineers' Handbook, by Robert H. Perry / Cecil H. Chilton

Publication: McGraw – Hill Book Company (6<sup>th</sup> edition)



## **8. PARALLEL & COUNTER FLOW HEAT EXCHANGER**

### **INTRODUCTION:**

Heat exchangers are devices in which heat is transferred from one fluid to another. The fluids may be in direct contact with each other or separated by a solid wall. Heat Exchangers can be classified based on its principle of operation and the direction of flow. The temperature of the fluids changes in the direction of flow and consequently there occurs a change in the thermal head causing the flow of heat.

The temperatures profiles at the two fluids in parallel and counter flow are curved and have logarithmic variations. LMTD is less than the arithmetic mean temperature difference. So, it is always safer for the designer to use LMTD so as to provide larger heating surface for a certain amount of heat transfer.

### **DESCRIPTION OF THE APPARATUS:**

The apparatus consists of **concentric tubes**. The inner tube is made of **copper** while the outer tube is made of **Stainless Steel**.

**Insulation** is provided with **mica sheet** and **asbestos rope** for effective heat transfer.

Provision has been made for **hot water generation** by means of geyser.

**Change - Over Mechanism** is provided to change the direction of flow of cold water in a single operation.

**ACRYLIC Rotameters** of specific range is used for direct measurement of water flow rate.

**Thermocouples** are placed at appropriate positions which carry the signals to the temperature indicator. A **data logger indicator** is provided to measure the temperature.

The whole arrangement is mounted on an **Aesthetically designed self sustained sturdy frame** made of **NOVAPAN board control panel**. The control panel houses all the indicators, accessories and necessary instrumentations.

**EXPERIMENTATION:****AIM:**

To determine **LMTD & Effectiveness** of the **heat exchanger** under parallel and counter Flow arrangement.

**PROCEDURE:**

1. Switch ON mains and the CONSOLE.
2. Start the flow on the hot water side.
3. Start the flow through annulus also.
4. Set the exchanger for parallel or counter flow using the
  - a. change over mechanism.
5. Switch ON the heater of the geyser.
6. Set the flow rate of the hot water (say 1.5 to 4 Lpm) using
  - a. the rotameter of the hot water.
7. Set the flow rate of the cold water (say 3 to 8 Lpm) using the
  - a. rotameter of the cold water.
8. Wait for sufficient time to allow temperature to reach steady
  - a. values.
9. Note down the Temperatures 1 to 4 using the Scanner.
10. Note down the flow rates of the water and tabulate.
11. Now, change the direction of flow for the same flow rates and
  - a. repeat the steps 9 to 11.
12. Repeat the experiment for different flow rates of water.

**PROCEDURE : COMPUTERIZED****TAKING READINGS – COMPUTERIZED**

1. Switch on the panel.
2. Switch on the computer.
3. Open the “**HEAT TRANSFER Software**” from the installed location a welcome screen will be displayed
4. Follow the below steps to operate through software
5. Once the software is opened, the main screen will be displaced
6. Now, press “**START**” button, and the small screen will opened
7. Enter the parameters listed for particular test under study.



8. Start the flow on the hot water side.
9. Start the flow through annulus also.
10. Set the exchanger for parallel or counter flow using the
  - a. change over mechanism.
11. Switch ON the heater of the geyser.
12. Set the flow rate of the hot water (say 1.5 to 4 Lpm) using
  - a. the rotameter of the hot water.
13. Set the flow rate of the cold water (say 3 to 8 Lpm) using the
  - a. rotameter of the cold water.
14. Wait for sufficient time to allow temperature to reach steady
  - a. values.
13. The software starts displaying the calculated values which can be cross verified based on the formulae give after.
14. Click the “**store**” button to store the value can be viewed anytime later.
15. After completion of the Experiment to press the stop button
16. Finally switch of the gyser.

**OBSERVATIONS:**

Sl. No.	Flow Direction	Temperatures °C				Flow rate, LPM	
		T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>	Hot water, H	Cold Water, C
1							
2							
3							
4							
5							

**NOTE:**

**T<sub>3</sub> = COLD WATER INLET TEMPERATURE (in case of parallel flow)**

**COLD WATER OUTLET TEMPERATURE (in case of counter flow)**

T4 = COLD WATER OUTLET TEMPERATURE (in case of parallel flow)

COLD WATER INLET TEMPERATURE (in case of counter flow)

T1 = HOT WATER INLET TEMPERATURE.

T2 = HOT WATER OUTLET TEMPERATURE.

### CALCULATIONS:

#### 1. HEAT TRANSFER RATE, Q

$$Q = \frac{Q_H \times Q_C}{2} \text{ WATTS}$$

WHERE,

$Q_H$  = heat transfer rate from hot water and is given by:

$$= m_H \times C_{PH} \times (T_1 - T_2) \text{ W}$$

Where,

$m_h$  = mass flow rate of hot water = H/60 kg/sec.

$C_{PH}$  = Specific heat of hot water from table at temp.  $(T_1+T_2)/2$

$Q_C$  = heat transfer rate from cold water and is given by:

$$= m_C \times C_{PC} \times (T_4 - T_3) \text{ W (for parallel flow)}$$

$$= m_C \times C_{PC} \times (T_3 - T_4) \text{ W (for counter flow)}$$

Where,

$m_c$  = mass flow rate of cold water = C/60 kg/sec.

$C_{PC}$  = Specific heat of cold water from table at temp.  $(T_3+T_4)/2$

#### 2. LMTD – Logarithmic mean temperature difference:

$$\Delta T_M = \frac{\Delta T_I - \Delta T_O}{\ln(\Delta T_I / \Delta T_O)}$$

Where,

$$\Delta T_I = (T_1 - T_3) \text{ for parallel flow}$$

$$\Delta T_I = (T_1 - T_4) \text{ for counter flow}$$

$$\Delta T_O = (T_2 - T_4) \text{ for parallel flow}$$

$$\Delta T_O = (T_2 - T_3) \text{ for counter flow}$$

**NOTE:** The suffix H = HOT WATER

C = COLD WATER

I = INLET

O = OUTLET

**3. OVERALL HEAT TRANSFER CO-EFFICIENT:**

$$U = \frac{Q}{A \times \Delta T_M} \text{ W/m}^2 \text{ } ^\circ\text{K}$$

Where,

Q = heat transfer rate

$A = \pi \times D_o \times L \text{ m}^2$  where,  $D_o = 0.02\text{m}$  &  $L = 1\text{m}$ .

$\Delta T_M = \text{LMTD}$ .

**4. EFFECTIVENESS OF HEAT EXCHANGER, E**

**EXPERIMENTAL:**

$$E_{\text{EXP}} = \frac{(T_{\text{CO}} - T_{\text{CI}})}{(T_{\text{HI}} - T_{\text{CI}})} \quad \text{if } C_{\text{max}} > C_{\text{min}}$$

$$E_{\text{EXP}} = \frac{(T_{\text{HI}} - T_{\text{HO}})}{(T_{\text{HI}} - T_{\text{CI}})} \quad \text{IF } C_{\text{max}} < C_{\text{min}}$$

**THEORETICAL:**

$$E_{\text{TH}} = \frac{1 - e^{-NTU(1+R)}}{(1 + R)} \quad \text{For PARALLEL FLOW}$$

$$E_{\text{TH}} = \frac{1 - e^{-NTU(1-R)}}{1 - R e^{-NTU(1-R)}} \quad \text{For COUNTER FLOW}$$

Where,

$$C_{\text{MAX}} = m_H \times C_{\text{PH}}$$

$$C_{MIN} = m_c \times C_{PC}$$

$$R = C_{MIN} / C_{MAX}$$

NTU = No. of Transfer units is given by

$$= \frac{U \times A}{C_M}$$

$C_M$  = minimum of  $C_{MIN}$  &  $C_{MAX}$

Other notations have their usual meaning.

#### 5. PERCENTAGE OF ERROR, %ERROR

$$\%ERROR = \quad \times 100 \quad \frac{E_{TH} - E_{EXP}}{E_{TH}}$$

#### Reference:

1. Heat and Mass transfer by Arora & Domkundwar
2. Chemical Engineers' Handbook, by Robert H. Perry / Cecil H. Chilton

Publication: McGraw – Hill Book Company (6<sup>th</sup> edition)

#### PRECAUTIONS:

1. Check all the electrical connections.
2. Do not run the equipment if the voltage is below 180V.
3. Do not attempt to alter the equipment as this may cause damage to the whole system.

## 9. PIN-FIN APPARATUS

### INTRODUCTION:

A spine or pin-fin is an extended surface of cylindrical or conical shape used for increasing the heat transfer rates from the surfaces, whenever it is not possible to increase the rate of heat transfer either by increasing heat transfer co-efficient or by increasing the temperature difference between the surface and surrounding fluids.

The fins are commonly used on engine heads of scooter, motorcycles, as well as small capacity compressors. The pin type fins are also used on the condenser of a domestic refrigerator.

### DESCRIPTION OF THE APPARATUS:

The apparatus consists of

**Pin type fin** of dia 12mm and 150 mm long made of **copper** with suitable temperature points.

**Heater** of 250watts capacity.

**Heater regulator** to supply the regulated power input to the heater.

**Digital Data logger is used** to measure power input to the heater.

**Thermocouples** at suitable position to measure the surface temperatures of the fin.

**Blower** unit to blow air through the duct with orifice meter and **acrylic manometer** to measure the air flow rate from the blower. A control valve is provided to regulate the air flow.

Control panel to house all the instrumentation.

With this the whole arrangement is mounted on an aesthetically designed self-sustained MS powder coated frame with a separate control panel.

## EXPERIMENTATION:

### AIM:

1. To find out the temperature distribution along the given fin for constant base temperature under natural and force flow conditions.
2. To find out effectiveness of the fin under both conditions.

### PROCEDURE:

1. Switch on the MCB and then console on switch to activate the control panel.
2. Switch on the heater and regulate the power input using the heater regulator.
3. Switch on the blower unit and adjust the flow of air using gate valve of blower to a desired difference in manometer (**for forced flow only otherwise skip to step 4**).
4. Wait for reasonable time to allow temperatures to reach steady state.
5. Measure the voltage, current and temperatures from  $T_1$  to  $T_6$  at known time interval.
6. Calculate the effectiveness & efficiency of the fin using the procedure given.
7. Repeat the experiment for different values of power input to the heater and blower air flow rates.

### PROCEDURE : COMPUTERIZED

#### TAKING READINGS – COMPUTERIZED

1. Switch on the panel.
2. Switch on the computer.
3. Open the “**HEAT TRANSFER Software**” from the installed location a welcome screen will be displayed
4. Follow the below steps to operate through software
5. Once the software is opened, the main screen will be displaced
6. Now, press “**START**” button, and the small screen will opened
7. Enter the parameters listed for particular test under study.
8. the software starts displaying the calculated values which can be cross verified based on the formulae give after.
9. Select the Process Natural or Forced If you selected forced Switch on the Blower. U selected Natural Air Flow is not Required .Switch of the Blower.

10. Switch on Blower And adjust the air Flow rate By using the Valve See the Air flow rate in Indicator.
11. Switch on the heater and set the voltage (say 40V) using heater regulator.
12. Wait for sufficient time to allow temperature to reach steady values.
13. Repeat the experiment for different heat inputs and also for horizontal position with different heat inputs.
14. Wait to attain the steady state.
15. Click the “store” button to store the value can be viewed anytime later.
16. After completion of the Experiment to press the stop button

**OBSERVATIONS:**

SL No.	Manometer Reading, m of water		HEAT INPUT		Air temperature, °C	TEMPERATURE, °C		
	H1	H2	V	I		SURFACE		
					T4	T1	T2	T3
1.								
2.								
3.								
4.								

**CALCULATIONS:**

**NATURAL CONVECTION**

$$\begin{aligned}
 N_u &= &= & 1.1 (Gr.Pr)^{1/6} & \text{when } 10^{-1} < Gr.Pr < 10^4 \\
 & &= & 0.53 (Gr.Pr)^{0.25} & \text{when } 10^4 < Gr.Pr < 10^9 \\
 & &= & 0.13 (Gr.Pr)^{0.33} & \text{when } 10^9 < Gr.Pr < 10^{12}
 \end{aligned}$$

Where,

$$Pr = \frac{\mu C_p}{k} \quad Gr = \frac{L^3 \rho^2 \beta (T_m - T_a) g}{\mu^2}$$

$$\beta = 1/(273 + T_m)$$

where ,

$T_m$  = mean effective temperature of the fin.

$T_a$  = ambient temperature of the chamber.

All the properties of air should be taken at  $(T_m + T_a)/2$  from the data hand book.

### **FORCED CONVECTION**

$$N_U = 0.615(R_e)^{0.466} \text{ when } 40 < Re < 4000$$

$$N_U = 0.174(R_e)^{0.168} \text{ when } 4000 < Re < 40 \times 10^3$$

$$\rho V D$$

$$Re = \frac{\rho V D}{\mu}$$

$$\mu$$

where ,

$D$  = inner diameter of the tube =

$$V = \frac{\text{mass flow rate of air}}{\text{Flow area}} \text{ m/s}$$

**Mass flow rate of air is calculated as follows:**

$$= 0.62 \times a \times \sqrt{2gH}$$

$$\text{where, } a = \frac{\pi d^2}{4}, \quad d = 0.020$$

$$H = \frac{(H_1 - H_2) \times 1000}{1.293} \text{ m of air column}$$

**Flow area is calculated as follows:**



$$= \frac{\pi D^2}{4}, \quad D = 0.050$$

All the properties of air should be taken at  $(T_m + T_a)/2$  from the data hand book.

**Now after doing the above steps find the following:**

TEMPERATURE DISTRIBUTION ALONG THE FIN

The temperature distribution along the fin is given by,

$$\frac{T_x - T_1}{T_1 - T_6} = \frac{\text{Cosh}m(L - x)}{\text{Cosh}(mL)}$$

Where

$T_x$  = is the temperature along the fin at a distance 'x'

measured from the base,

$T_1$  = is the fin base temperature,

$T_6$  = is surrounding air temperature

x = is the distance of the unknown temperature point and

L = is the length of the fin = 0.11m

$$m = \sqrt{\frac{hp}{K_f A_c}}$$

Where

$A_c$  = is the Cross-section area of the fin

$$= \frac{\pi D_c^2}{4}, \quad D_c = 0.012$$

P = is perimeter of the fin =  $\pi D_c$ ,

$K_f$  = is conductivity of fin material = 380 W/m - °K

$h =$  is the heat transfer co-efficient of fin

$$h = \frac{Nu \times K_{air}}{D_c}$$

where,

Nu = Nusselt Number calculated

$K_{air}$  = from the property tables

$D_c$  = diameter of the fin = 0.012

After calculating the value of 'h' find the value of 'm' and then find out  $T_x$  at distances from the base of the fin and compare with the obtained reading

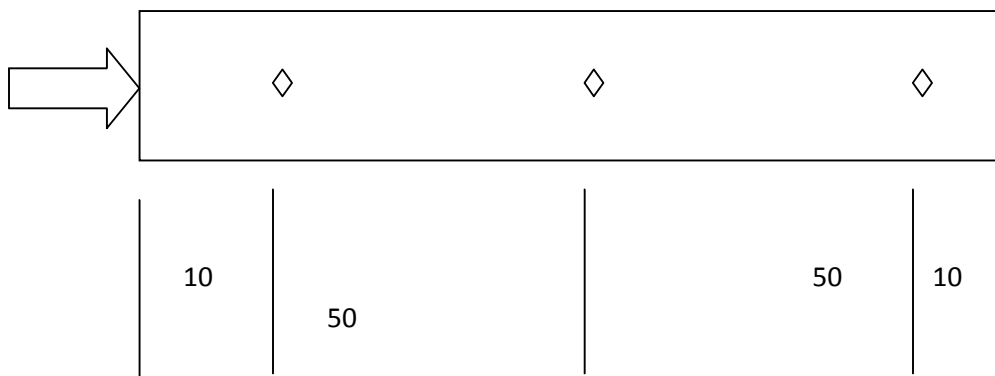
#### RATE OF HEAT TRANSFER FROM THE FIN

$$Q = \sqrt{hPK_f A} \times (T_m - T_a) \times \tanh (mL)$$

Where the units have their usual meaning

#### EFFICIENCY OF THE FIN

$$H_{mech} = \frac{\tanh h (ml)}{ml}$$



## 10. STEFAN BOLTZMAN'S APPARATUS

### INTRODUCTION:

The most commonly used relationship in radiation heat transfer is the Stefan Boltzman's law which relates the heat transfer rate to the temperatures of hot and cold surfaces.

$$q = \sigma A ( T_H^4 - T_C^4 )$$

Where,

$q$  = rate of heat transfer, watts

$\sigma$  = Stefan Boltzman's constant =  $5.669 \times 10^{-8}$  watts/m<sup>2</sup> °K<sup>4</sup>

$A$  = Surface area, m<sup>2</sup>

$T_H$  = Temperature of the hot body, °K

$T_C$  = Temperature of the cold body, °K

The above equation is applicable only to black bodies (for example a piece of metal covered with carbon black approximates this behavior) and is valid only for thermal radiation. Other types of bodies (like a glossy painted surface or a polished metal plate) do not radiate as much energy as the black body but still the total radiation emitted generally follow temperature proportionality.

### DESCRIPTION OF THE APPARATUS:

The apparatus consists of

**Copper** hemispherical enclosure with insulation.

**SS jacket** to hold the hot water.

**Over head water heater** with quick release mechanism and the thermostat to generate and dump the hot water.

**Thermostat** to supply the regulated power input to the heater.

**Thermocouples** at suitable position to measure the surface temperatures of the absorber body. **PID Indicator** is used to measure the temperatures. Control panel to house all the instrumentation. With this the whole arrangement is mounted on an aesthetically

designed self-sustained frame with a separate control panel.

## **EXPERIMENTATION:**

### **AIM:**

To determine the Stefan Boltzman's constant.

### **PROCEDURE:**

1. Fill water slowly into the overhead water heater.
2. Switch on the supply mains and console.
3. Switch on the heater and regulate the power input using the heater regulator. (say 60 – 85 °C)
4. After water attains the maximum temperature, open the valve of the heater and dump to the enclosure jacket.
5. Wait for about few seconds to allow hemispherical enclosure to attain uniform temperature – the chamber will soon reach the equilibrium. Note the enclosure temperature.
6. Insert the Test specimen with the sleeve into its position and record the temperature at different instants of time using the stop watch.
7. Plot the variation of specimen temperature with time and get the slope of temperature versus time variation at the time  $t = 0$  sec
8. Calculate the Stefan Boltzman's constant using the equations provided.
9. Repeat the experiment 3 to 4 times and calculate the average value to obtain the better results.

## **PROCEDURE : COMPUTERIZED**

### **TAKING READINGS – COMPUTERIZED**

1. switch on the panel.
2. Switch on the computer.
3. Open the “ **HEAT TRANSFER Software**” from the installed location a welcome screen will be displayed
4. Follow the below steps to operate through software
5. Once the software is opened, the main screen will be displaced On the main screen press “**PORT**” button and select the USB port connected,
6. Now, press “**START**” button, and the small screen will opened
7. Enter the parameters listed for particular test under study.
8. Now, set the temp by using thermostat regulator to known valve.

9. Now press "START BUTTON" on the screen so the software automatically starts recording the temperatures and other values.
10. Switch on the heater and regulate the power input using the heater regulator. (say 60 – 85 °C)
11. After water attains the maximum temperature, open the valve of the heater and dump to the enclosure jacket.
12. Wait for about few seconds to allow hemispherical enclosure to attain uniform temperature – the chamber will soon reach the equilibrium. Note the enclosure temperature.
13. Also, the software starts displaying the calculated values which can be cross verified based on the formulae give there after.
14. Enter the **STORE BUTTON** to store the values.
15. Press report button to see the stored values
16. finally thermostat you kept at 0 \*C

### **OBSERVATIONS:**

Enclosure Temperature,  $T_e =$

Initial Temperature of the specimen,  $T_s =$

Time, t	Specimen Temperature, $T_s$
5	
10	
15	
20	
25	
30	

### **CALCULATIONS:**

**STEFAN BOLTSMAN'S CONSTANT IS CALCULATED USING THE RELATION:**

$$\sigma = \frac{m C_p (dT_s/dt)}{A_D (T_e^4 - T_s^4)}$$

Where,  $m =$  mass of the test specimen = 0.0047Kg

$C_p =$  Specific heat of the specimen = 410 J/Kg °C

$T_e$  = Enclosure temperature, °K

$T_s$  = Initial temperature of the specimen, °K

$(dT_a/dt)$  = calculated from graph.

$A_D$  = Surface area of the test specimen

$$= \pi d^2/4$$

where  $d = 0.015\text{m}$

**RESULT:**

Stefan Boltzman's constant is \_\_\_\_\_

**Reference:**

1. Heat and Mass transfer by Arora & Domkundwar
2. Chemical Engineers' Handbook, by Robert H. Perry / Cecil H. Chilton

Publication: McGraw – Hill Book Company (6<sup>th</sup> edition)

**PRECAUTIONS:**

1. Check all the electrical connections.
2. Do not run the equipment if the voltage is below 180V.
3. Do not switch on the heater without water in the overhead tank.
4. Do not turn the heater regulator to the maximum as soon as the equipment is started.
5. Do not attempt to alter the equipment as this may cause damage to the whole system.

## 11.THERMAL CONDUCTIVITY OF CONCENTRIC SPHERE

### INTRODUCTION:

Thermal conductivity is the physical property of material denoting the ease with a particular substance can accomplish the transmission of thermal energy by molecular motion.

Thermal conductivity of a material is found, to depend on the chemical composition of the substances of which it is composed, the phase (i.e. gas, liquid or solid) in which its crystalline structure if a solid, the temperature & pressure to which it is subjected and whether or not it is homogeneous material.

Thermal energy in solids may be conducted in two modes. They are:

- LATTICE VIBRATION:
- TRANSPORT BY FREE ELECTRONS.

In good electrical conductors a rather large number of free electrons move about in a lattice structure of the material. Just as these electrons may transport electric charge, they may also carry thermal energy from a high temperature region to low temperature region. In fact, these electrons are frequently referred as the electron gas. Energy may also be transmitted as vibrational energy in the lattice structure of the material. In general, however, this latter mode of energy transfer is not as large as the electron transport and it is for this reason that good electrical conductors are almost always good heat conductors, for eg: ALUMINIUM, COPPER & SILVER.

With the increase in temperature, however the increased lattice vibrations come in the way of electron transport by free electrons and for most of the pure metals the thermal conductivity decreases with the increase in the temperature.

### DESCRIPTION OF THE APPARATUS:

The apparatus consists of the **COPPER sphere of 150mm dia and 250mm dia concentrically placed.** Heat is provided by means of **oil bath heater** arrangement. **Thermocouples** are provided at the suitable points to measure the surface and inner temperatures. Proper **insulation** is provided to **minimize the heat loss.** The temperature is shown by means of the DATA LOGGER on the control panel, which also consists of **heater regulator** and other accessories instrumentation having good aesthetic looks and safe design.

**EXPERIMENTATION:****AIM:**

To determine the THERMAL CONDUCTIVITY of given concentric sphere.

**PROCEDURE:**

1. Give necessary electrical and water connections to the instrument.
2. Switch on the MCB and console ON to activate the control panel.
3. Give input to the heater by slowly rotating the heater regulator.
4. Note the temperature at different points, when steady state is reached.
5. Repeat the experiment for different heater input.
6. After the experiment is over, switch off the electrical connections.

**PROCEDURE : COMPUTERIZED****TAKING READINGS – COMPUTERIZED**

1. Switch on the panel.
2. Switch on the computer.
3. Open the “**HEAT TRANSFER Software**” from the installed location a welcome screen will be displayed
4. Follow the below steps to operate through software
5. Once the software is opened, the main screen will be displaced
6. Now, press “**START**” button, and the small screen will opened
7. Enter the parameters listed for particular test under study.
8. the software starts displaying the calculated values which can be cross verified based on the formulae give after.
9. Before switch on the Heater Please check the Oil.
10. Switch on the heater and set the voltage (say 40V) using heater regulator.
11. Wait for sufficient time to allow temperature to reach steady values.
12. Repeat the experiment for different heat inputs and different heat inputs.
13. Wait to attain the steady state.
14. Click the “**store**” button to store the value can be viewed anytime later.
15. After completion of the Experiment to press the stop button



**TABULAR COLUMN**

SL No.	Heat Input		TEMPERATURE, °C		
			Inner	Surface	
	V volts	I amps	T1	T2	T3
1.					
2.					
3.					
4.					

**CALCULATIONS:**

1. HEAT INPUT TO THE SYSTEM, Q<sub>i</sub>

Heat input to the system = Heat carried away by water

$$Q = V \times I \quad \text{Watts}$$

Where,

V = Voltage

I = Current

2. THERMAL CONDUCTIVITY OF THE Concentric Sphere, K

$$Q = \frac{4\pi r_2 r_1 K (T_1 - T_{avg})}{(r_2 - r_1)} \quad \text{Watts}$$

Where,

r<sub>1</sub> = radius of the inner sphere = 0.075m

r<sub>2</sub> = radius of the outer sphere = 0.125m

K = Thermal conductivity of COPPER sphere

T<sub>1</sub> = Temp. of the inner sphere

T<sub>avg</sub> = Temp of the outer sphere

$$= (T_2 + T_3) / 2$$

## **PRECAUTIONS:**

1. Input should be given very slowly.
2. Do not run the equipment if the voltage is below 180V.
3. Check all the electrical connections before running.
4. Before starting and after finishing the experiment the heater controller should be in off position.
5. Do not attempt to alter the equipment as this may cause damage to the whole system.

## **Reference:**

1. PROCESS HEAT TRANSFER, by
2. Wareh L. McCabe
3. Julian C. Smith
4. Peter Harioth
5. Publication: McGraw Hill (6<sup>th</sup> edition)
6. Heat and Mass transfer by Arora & Domkundwar
7. Chemical Engineers' Handbook, by
8. Robert H. Perry / Cecil H. Chilton  
Publication: McGraw – Hill Book Company (6<sup>th</sup> edition)

## 12.THERMAL CONDUCTIVITY OF METAL ROD

### INTRODUCTION:

Thermal conductivity is the physical property of material denoting the ease with a particular substance can accomplish the transmission of thermal energy by molecular motion.

Thermal conductivity of a material is found, to depend on the chemical composition of the substances of which it is composed, the phase (i.e. gas, liquid or solid) in which its crystalline structure if a solid, the temperature & pressure to which it is subjected and whether or not it is homogeneous material.

Thermal energy in solids may be conducted in two modes. They are:

- LATTICE VIBRATION:
- TRANSPORT BY FREE ELECTRONS.

In good electrical conductors a rather large number of free electrons move about in a lattice structure of the material. Just as these electrons may transport may transport electric charge, they may also carry thermal energy from a high temperature region to low temperature region. In fact, these electrons are frequently referred as the electron gas. Energy may also be transmitted as vibrational energy in the lattice structure of the material. In general, however, this latter mode of energy transfer is not as large as the electron transport and it is for this reason that good electrical conductors are almost always good heat conductors, for eg: ALUMINIUM, COPPER & SILVER.

With the increase in temperature, however the increased lattice vibrations come in the way of electron transport by free electrons and for most of the pure metals the thermal conductivity decreases with the increase in the temperature.

### DESCRIPTION OF THE APPARATUS:

The apparatus consists of the **COPPER rod of 200mm test section**. Heat is provided by means of **band heater** at one end and released through **water jacket** arrangement. **Thermocouples** are provided at the suitable points to measure the surface and water temperatures. Proper **insulation** is provided to **minimize the heat loss**. The temperature is shown by means of the Data logger on the control panel, which also consists of **heater regulator** and other accessories instrumentation having good aesthetic looks and safe design.

**EXPERIMENTATION:****AIM:**

To determine the THERMAL CONDUCTIVITY of given metal rod.

**PROCEDURE:**

1. Give necessary electrical and water connections to the instrument.
2. Switch on the MCB and console ON to activate the control panel.
3. Give input to the heater by slowly rotating the heater regulator.
4. Start the cooling water supply through the water jacket (make sure not to exceed 3 lpm).
5. Note the temperature at different points, when steady state is reached.
6. Repeat the experiment for different heater input.
7. After the experiment is over, switch off the electrical connections, allow the water to flow for some time in the water jacket and then stop it.

**PROCEDURE : COMPUTERIZED****TAKING READINGS – COMPUTERIZED**

1. Turn on the computer switch on the panel.
2. Switch on the computer.
3. Open the “HEAT TRANSFER Software” from the installed location a welcome screen will be displayed
4. Follow the below steps to operate through software
5. Once the software is opened, the main screen will be displaced
6. Now, press “START” button, and the small screen will opened
7. Enter the parameters listed for particular test under study.
8. the software starts displaying the calculated values which can be cross verified based on the formulae give after.
9. Give input to the heater by slowly rotating the heater regulator.
10. Start the cooling water supply through the water jacket (make sure not to exceed 3 lpm).
11. Click the “store” button to store the value can be viewed anytime later.
12. After completion of the Experiment to press the stop button.

**TABULAR COLUMN**

SL No.	Rotameter Reading, R lpm	Water temperature, °C		TEMPERATURE, °C			
				SURFACE			
		T5	T6	T1	T2	T3	T4
1.							
2.							
3.							
4.							

**CALCULATIONS:**

- 3.
- CROSS – SECTIONAL AREA OF METAL ROD:

$$A = \frac{\pi d^2}{4} m^2$$

Where,

d = diameter of the of the metal rod = 0.05 m. $\pi$  = constant

- 4.
- MASS FLOWRATE OF WATER, mw

$$m_w \frac{R}{60} kg/sec$$

Where,

R = Rotameter reading in lpm.

- 5.
- HEAT INPUT TO THE SYSTEM, Qi

Heat input to the system = Heat carried away by water

$$Q_i = Q_w$$

$$Q_w = m_w \times C_{pw} \times \Delta T_w \quad \text{Watts.}$$

Where,

m<sub>w</sub> = mass flowrate of water, kg/sec.C<sub>pw</sub> = Specific heat of water = 4180 J/kg °K .

$\Delta T_w$  = Temperature difference of water inlet and outlet from  
the water jacket.

$$= (T_1 - T_2) ^\circ K$$

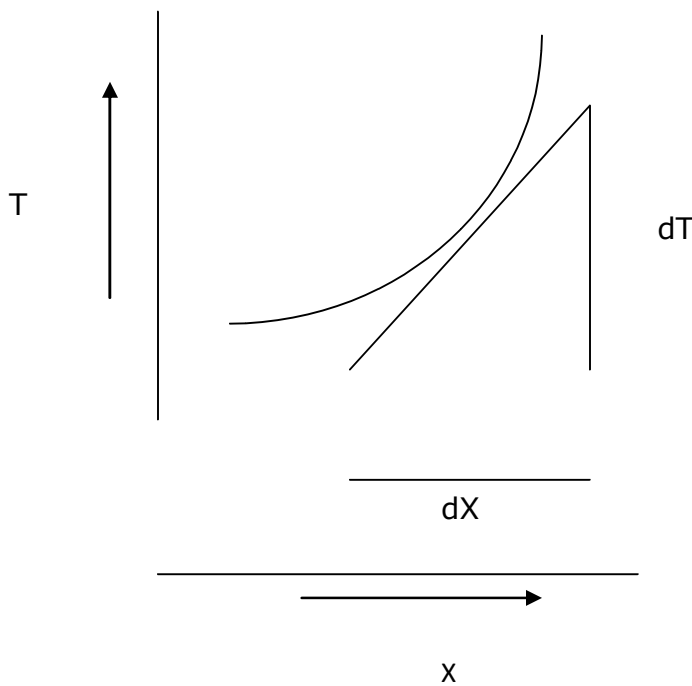
6. THERMAL CONDUCTIVITY OF THE METAL ROD, K

$$K = \frac{Q_l}{A X \left(\frac{dt}{dx}\right)} \text{ w/m}^0\text{K}$$

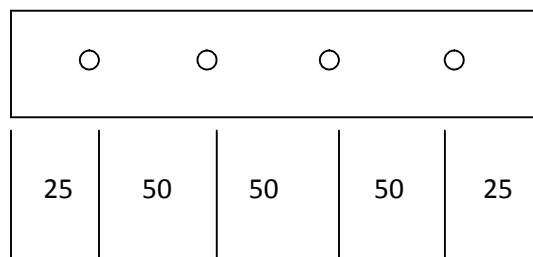
Where,

A = cross – sectional area of the rod

$(dT/dX)_A$  = slope calculated from graph. (shown in the diagram)



Where 'X' = test length with thermocouple points as shown below



**PRECAUTIONS:**

1. Do not give heater input without the supply of water.
2. Input should be given very slowly.
3. Run the water in the jacket for about 5 min after the experiment.
4. Do not run the equipment if the voltage is below 180V.
5. Check all the electrical connections before running.
6. Before starting and after finishing the experiment the heater controller should be in off position.
7. Do not attempt to alter the equipment as this may cause damage to the whole system.

**Reference:**

- 1 PROCESS HEAT TRANSFER, by  
Wareh L. McCabe

Julian C. Smith

Peter Harioth

Publication: McGraw Hill (6<sup>th</sup> edition)

- 2 Heat and Mass transfer by Arora & Domkundwar

- 3 Chemical Engineers' Handbook, by  
Robert H. Perry / Cecil H. Chilton

Publication: McGraw – Hill Book Company (6<sup>th</sup> edition)

## 13. TRANSIENT HEAT CONDUCTION APPARATUS

### INTRODUCTION:

When a body is subjected to heating or cooling, irrespective of the material it requires certain time to attain steady state. Hence the other way of expressing is that the unsteady process will occur till it attains the steady process. In unsteady process the temperature will change with respect to time. Although, temperature of the body is generally expressed as the function of 3 different axis and time, it is not easy to solve.

Unsteady state heating or cooling can be categorized as:

- **PERIODIC HEAT FLOW** : where the temperature within the system undergoes periodic changes which may be regular or irregular.
- **NON – PERIODIC HEAT FLOW** : where the temperature at any point within the system changes non – linearly with respect to time.

Unsteady state heat flow is very common in all heating or cooling problems at the beginning of the system. Hardening by quenching, cooling of IC engine cylinders, and heating of boiler tubes are common examples of unsteady state heat flow.

### **2. DESCRIPTION OF APPARATUS:**

- The apparatus consists of a specially designed **Stainless Steel Tank with heater arrangement**.
- An **ALUMINIUM sphere** is provided to study the experiment with the stand to place in the heater tank.
- **Heater regulator with Thermostat** to supply the regulated power input to the heater and to set the temperature.
- **Thermocouples** at suitable position to measure the temperatures.
- **Digital data logger** used to measure the temperatures.
- The whole arrangement is mounted on an Aesthetically designed sturdy frame made of NOVAPAN Board with all the provisions for holding the tanks and accessories.



### 3. EXPERIMENTATION:

#### AIM:

- To determine heat transfer coefficient and instantaneous heat transfer rate for transient heat conduction and draw the graph of temperature variation with time

#### PROCEDURE : MANUAL

1. Take the fluid (water or oil) in the tank.
2. Heat the fluid to the required temperature say 70°C in case of water and more than 100 °C in case of oil.
3. Note down the initial temperature of sphere and hot fluid.
4. Immerse the sphere in hot fluid bath for heating.
5. Note down the surface temperature of the sphere at every 10 seconds till it attains fluid temperature.
6. Take out the sphere from hot fluid and cool it in atmospheric air.
7. Repeat the experiment for different temperatures of fluid.

#### PROCEDURE : COMPUTERIZED

#### TAKING READINGS – COMPUTERIZED

1. switch on the panel.
2. Switch on the computer.
3. Open the “ **HEAT TRANSFER Software**” from the installed location a welcome screen will be displayed
4. Follow the below steps to operate through software
5. Once the software is opened, the main screen will be displaced On the main screen press “**PORT**” button and select the USB port connected,
6. Now, press “**START**” button, and the small screen will opened
7. Enter the parameters listed for particular test under study.
8. Now, set the temp by using thermostat regulator to known valve.
9. Now press “**START BUTTON**” on the screen so the software automatically starts recording the temperatures and other values.
10. Also, the software starts displaying the calculated values which can be cross verified based on the formulae give there after.

11. Enter the **STORE BUTTON** to store the values.

12. Press report button to see the stored values

13. finally thermostat you kept at 0 °C

**OBSERVATIONS**

Initial Temp. of the fluid,  $T_1 = \text{_____} \text{ } ^\circ\text{C}$

Initial Temp. of the sphere,  $T_2 = \text{_____} \text{ } ^\circ\text{C}$

Sl. No.	Temperatures °C		Time, t sec
	T1	T2	

**CALCULATIONS:****5. Determination of Heat Transfer Co-efficient, h**

$$h = \frac{N_u K}{D} \quad W/m^2 K$$

Where,

Nu = Nusselt Number and is given by

$$N_u = 2 + 0.43 (G_r P_r)^{0.25} \quad \text{for } 1 < GrPr < 10^5$$

$$N_u = 2 + 0.50 (G_r P_r)^{0.25} \quad \text{for } 3 \times 10^5 < GrPr < 8 \times 10^5$$

Pr = Prandtl Number from handbook

Gr = Grashoff's Number &amp; is given by

$$G_r = \frac{D^3 \rho^2 \beta g \Delta T}{\mu^2}$$

D = Diameter of sphere = 0.075 m

K = Thermal conductivity of fluid, W/mK,  
water or oil in case of heating,  
air in case of cooling $\rho$  = Density of fluid, kg/m<sup>3</sup> $\beta$  = Volumetric thermal expansion coefficient, /K  
=  $1/(T_f + 273)$  $T_f$  = Mean film temperature, °C

$$= (T_o + T_\infty)/2$$

 $\Delta t$  = Temp. difference between sphere and fluid, °C

$$= (T_o \sim T_\infty)$$

 $\mu$  = Absolute viscosity of fluid, N-s/m<sup>2</sup>**NOTE:**Properties of fluid such as  $\rho$ ,  $\mu$ , K,  $P_r$  are obtained from HMT data book at  $T_f$

**6. Determination of Instantaneous Heat Flow, Q**

Where, 
$$Q_i = -hA(T_i - T_\infty)e^{-B_i F_o} \text{ Watts}$$

$$B_i = \text{Biot Number} = \frac{h r}{K_s}$$

$$F_o = \text{Fourier Number} = \frac{\alpha t}{r^2}$$

h = heat transfer co-efficient, W/m<sup>2</sup>K

A = Surface area of the sphere =  $4\pi r^2$ .

$\alpha$ =Thermal diffusivity of sphere material =  $84.18 \times 10^{-6} \text{ m}^2/\text{s}$

t = Time at the given instant, sec

r = Radius of the sphere, m

$T_i = T_1$  = Temperature of the sphere at given time instant, °C,

$T_\infty = T_2$  = Initial temperature of hot fluid or cold fluid

$K_s$  = Thermal conductivity of sphere = 205 W/mK

**7. Determination of Theoretical Temperatures, T**

$$\frac{(T - T_\infty)}{(T_i - T_\infty)} = e^{-B_i F_o}$$

T = Temperature of the sphere in the given time, °C

$F_o$  is obtained at different time instants

**RESULTS:**

- The heat transfer coefficient for transient heat conduction heat transfer.

**GRAPHS:**

- Experimental temperature v/s time,
- Theoretical temperature v/s time

**TROUBLE SHOOTING:****General causes and remedies**

CAUSES	REMEDY
Mains on indicator not glowing	Check input electrical connection.
No power to indicators	Switch on the console, still not working call the supplier.
Still unable to start, call the supplier	

○ **Data management system/Unable to acquire data properly**

CAUSES	REMEDY
Readings cannot be taken.	Un – install then Re-Install the software.
Low Voltage (minimum should be 220V)	Switch off the system till the voltage is stabilized to proper value.
Variation in the VOLTAGE (should not be more than 10V)	Check and stabilize it
Earthing not properly made.	Check and stabilize it.
Magnetic parts and induction equipments near the Indicators.	Remove it and place 5m away from the equipment.
Unable to take the printout	Check the printer connection. Still unable to so, check the printer software settings and redefine if necessary.
Still unable to acquire, call the supplier	

○ **Indicators not showing proper values – IN CASE USED**

CAUSES	REMEDY
Not calibrated properly	Check for any loose connection in the wire and also check for any air gap in the tubes of the pressure tapping points.
Indicator not working properly	Check the sensor wire and connection.
Still unable to find the problem, call the supplier	

DO's	DON'Ts
Check the electrical connections before switching on the panel.	Switch on the panel if the voltage is low as specified.
Ensure water flow to the equipment and continue the flow for 15min before and after the experiment.	Run the equipment without supply of water to the transducer.
Grease the mating parts regularly.	Touch the rotating parts when equipment is running.
Keep the equipment clean and run at least 15min for every week.	Keep the equipment idle for more days as this may clog the moving parts.
Run the equipment in the Temperature limit of 200C.	Over temperature to the equipment, as this may cause damage to the whole system.
Still unable to find the problem, call the supplier	

**LIMITATIONS & PRECAUTIONS**

1. Maximum Load is limited to 70°C.
2. This is a general equipment for study in undergraduate level, for consideration of higher level studies you can add any extra parameter required. For adding the parameters call the supplier.
3. Don't run the equipment if the voltage is less than 180V.
4. 230V, 1ph with neutral and proper earthing to be provided.
5. Don't alter the equipment without the supervision of the supplier.

**Reference:**

- 1 Heat and Mass transfer by Arora & Domkundwar
- 2 Chemical Engineers' Handbook, by Robert H. Perry / Cecil H. Chilton

Publication: McGraw – Hill Book Company (6<sup>th</sup> edition)

## 14.CONDENSATION APPARATUS

### INTRODUCTION:

Condensation is the process of change of state free vapour to liquid. Condensation occurs on a surface when the vapour saturation temperature is higher than the temperature of surface. The temperature of the condensate so formed will be less than the saturation temperature of the vapour and becomes sub-cooled. More vapour starts condensing on the exposed surface or on the previous condensate, since the temperature of the previous condensate is lower.

The phenomenon of condensation heat transfer is more complex, which involves change of phase and additional characteristics / variables that control the condensation process.

There are two basic types of condensation - Film Condensation and Dropwise Condensation.

#### **a) Film Condensation :**

When the condensate tends to "wet" the surface, then it is called "film condensation". In this process, the liquid condensate distributes itself as a continuous thin film on the cooled surface. This happens when the surface tension between the liquid and the solid material is sufficiently small for example, condensation of steam on a clean metallic surface, when the surface is clean and grease / oil free.

In film condensation, heat transfer from the vapour to the cooling surface takes place through the condensate film formed on the surface. As the new condensate formed joins the film existing on the surface, the film thickness increases. The heat is transferred from the vapour to the condensate by convection and further from condensate to the surface by conduction. This combined mode of heat transfer by conduction and convection reduce the rate of heat transfer in film

condensation process. Hence, the rate of heat transfer is lower in film condensation (as compared to dropwise condensation).

**b) Dropwise Condensation :**

When the condensate does not wet the surface, it forms the droplets on the surface, it is known as "dropwise condensation". When the surface tension is large, the condensate coalesces into a multitude of droplets of different sizes. With time, each droplet grows as more vapour condenses on its exposed surface. The formation of each droplet is initiated at a point of surface imperfection (pit, scratch, etc.) and such sites are called "nucleation sites". At some time, the tangential pull of gravity, or sheer force exerted by the vapour stream, dislodges the droplet and carries it downstream. The moving droplet devours the smaller droplets in its path, thereby creating a clean trail ready for the generation of new droplets of smaller sizes. This surface renewal process occurs periodically as the droplets accumulate and grow in size. Since the condensation rate is the highest in the absence of condensate on the surface, the periodic cleaning performed by the large drops renews finite size regions of the surface for the restart of the condensation. This surface renewal process is the main reason why dropwise condensation is a highly effective heat transfer mechanism. The heat transfer coefficient is roughly ten times greater than the corresponding condensation in the form of thin film.

In the design of condensers, whose function is to cool a vapour stream and to convert it into liquid, there is a great advantage to promote the breakup of the condensate into droplets. This can be achieved by :

- a) Coating the solid surface with an organic substance like wax, oil, oleic acid, etc.
- b) Injecting non-wetting chemicals into the vapour, which get deposited on the surface of the condenser.



- c) Coating the surface with a polymer of low surface energy like teflon, silicone, etc. or with a noble metal like gold, silver, etc.

The mechanism of dropwise condensation is complex because of its intermittent time dependent character, effect of surface tension (due to drop size and shape) and the uncertainty associated with the location of nucleation sites and the time when the largest droplet will start its downstream movement. Hence, a unifying theory of dropwise condensation has not been developed.

### **DESCRIPTION OF THE APPARATUS:**

The apparatus consists of

**Heat exchanger tube** made of **copper** which is placed inside the **GLASS CHAMBER** of dimension  $\phi 100 \times 200\text{mm}$ .

**Steam Generator with necessary fittings and accessories** to generate and supply the steam.

**Rotameter** to directly measure the flowrate of the water into the condensate tube.

**Thermocouples** at suitable position to measure the temperatures of body and the air.

**Digital Temperature Indicator** with channel selector to measure the temperatures.

Control panel to house all the instrumentation.

With this the whole arrangement is mounted on an aesthetically designed self-sustained MS powder coated frame with a separate control panel.

## EXPERIMENTATION:

**AIM:**

- To determine overall heat transfer coefficient ( $U_o$ )
- To determine steam side film coefficient ( $h_s$ )
- To determine cold fluid heat transfer coefficient ( $h_I$ )
- To draw Wilson's plot and hence calculate the value of  $h_I$  theoretical from graph.(optional)

**PROCEDURE:**

1. Fill water slowly into the water tank and steam generator.
2. Switch on the supply mains and console.
3. Switch on the heater of steam generator to generate the steam.
4. Once the steam is generated follow the steps below.
5. Open the inlet valve and allow the cold fluid to flow through the condenser.
6. Adjust the flowrate of cold fluid to minimum.
7. \*Open the steam inlet valve and keep steam pressure constant (say  $0.2\text{kg/cm}^2$ ) throughout the experiment.
8. After cold fluid temperature becomes steady state, note down the inlet temperature, out let temperature and flowrate of cold fluid and also note down the volume of condensate collected at the given time interval(say 1min).

9. Keeping steam pressure constant take 4 – 5 readings for different cold fluid flow rate from minimum to maximum.
10. Repeat the experiment at another constant steam pressure Say, (0.3kg/cm<sup>2</sup>).

• **NOTE THAT WHILE DOING SO FOLLOWING THE PRECAUTIONS BELOW**

1. Initially, close the valve on the top of the condenser unit
2. Start the steam and then open the valve at the top of the condenser unit and close it as soon as the steam is filled.
3. Also make sure to open the water connection of the condenser unit to which the steam is released and close the steam valve of other unit.

**OBSERVATIONS:**

Sl. No.	Steam pressure. 'P' kg/cm <sup>2</sup>	Cold fluid temperature °C		Flow rate of cold fluid 'W' Lpm	Volume of condensate collected at given time interval, 'Vc' kg
		t <sub>1</sub>	t <sub>2</sub>		

**CALCULATIONS:**1. MASS FLOW RATE OF COLD FLUID

$$M_w = \frac{W}{60} \text{ Kg/s}$$

where,

W = Cold fluid flow rate, lpm

2. HEAT CARRIED AWAY BY COLD FLUID

$$Q_c = M_w \times C_{pw} \times \Delta T_w \text{ Watt.}$$

Where,

$M_w$  = mass flow rate of cold fluid, Kg/s.

$C_{pw}$  = Specific heat of cold fluid, KJ/Kg - °K.

$\Delta T_w$  = Cold fluid temperate difference, ( $t_2 - t_1$ ) °K

3. MASS FLOW RATE OF CONDENSATE FLUID

$$M_c = \frac{V_c}{T} \text{ Kg/s}$$

Where

$M_c$  = mass flow rate of condensate, Kg/s.

$V_c$  = volume of condensate collected, Kg

T = Time interval, sec.

4. HEAT LOST BY THE STEAM

$$Q_s = M_c \times \lambda \text{ Watt.}$$

$$\frac{\quad}{1000}$$

Where,

$M_c$  = mass flow rate of condensate, Kg/s.

$\lambda$  = obtained from steam table for given pressure, kJ/Kg.

5. OVERALL HEAT TRANSFER CO - EFFICIENT

$$U_o = \frac{Q_c}{\quad} \text{ W/m}^2 \text{ - } ^\circ\text{K.}$$

$$A \times \Delta t_{LMTD}$$

Where,

$Q_c$  = heat carried away by water, Watt.

$A$  = Area occupied by the inner tubes,  $m^2$ .

$= \pi D_o \times L \times N$  where,  $D_o$  = outer dia of inner tube

$L$  = Length of the tube

$N$  = No. of tubes.

$\Delta t_{LMTD}$  = Logarithmic mean temp. difference.

$$= \frac{(T_s - t_1) - (T_s - t_2)}{\quad}$$

$$\frac{(T_s - t_1)}{\quad}$$

$$\frac{(T_s - t_2)}{\quad}$$

where,  $T_s$  = Temp. obtained from steam tables at given pressure.

Find  $C_p$ ,  $\mu$ ,  $\rho$  and  $K$ . @  $T_{avg} = \frac{(t_1 + t_2)}{2}$  from hand book.

6. COLD FLUID HEAT TRANSFER CO - EFFICIENT:

$$h_I = 0.023 \times (Re)^{0.8} \times (Pr) \times (K/D_I) \quad \text{W/m}^2 - ^\circ\text{K}.$$

Where,

$Re$  = Reynolds number.

$$Re = \frac{\rho V D_I}{\mu} \quad \text{where, } D_I = \text{inner dia of the inner tube} = 36\text{mm}.$$

$\mu$

$V$  = Velocity of the cold fluid,

=

$M_w$

$\rho \times A_T$

$^2$

$A_T = \pi \times D_I^2 \quad \text{m}^2.$

$4$

$\rho$  = density of the fluid,  $\text{kg/m}^3$ .

$\mu$  = viscosity of fluid,  $C_p$

$Pr$  = Prandlt Number.

$$Pr = \frac{\mu \times C_p}{K}$$

11. STEAM SIDE HEAT TRANSFER CO - EFFICIENT

$$h_s = \left[ \frac{0.943}{\mu L \Delta T} \right]^{0.25} \mathbf{K^3 \rho^2 g \lambda} \quad \mathbf{W/m^2 - ^\circ K.}$$

Where,

$$\Delta T = (T_s - T_w) \quad ^\circ K.$$

$$\text{where, } T_w = \frac{T_s + T_{C \text{ avg}}}{2}$$

L = Length of the condenser = 0.18 m.

$$T_{C \text{ avg}} = (t_1 + t_2)/2$$

TABULATE THE READING

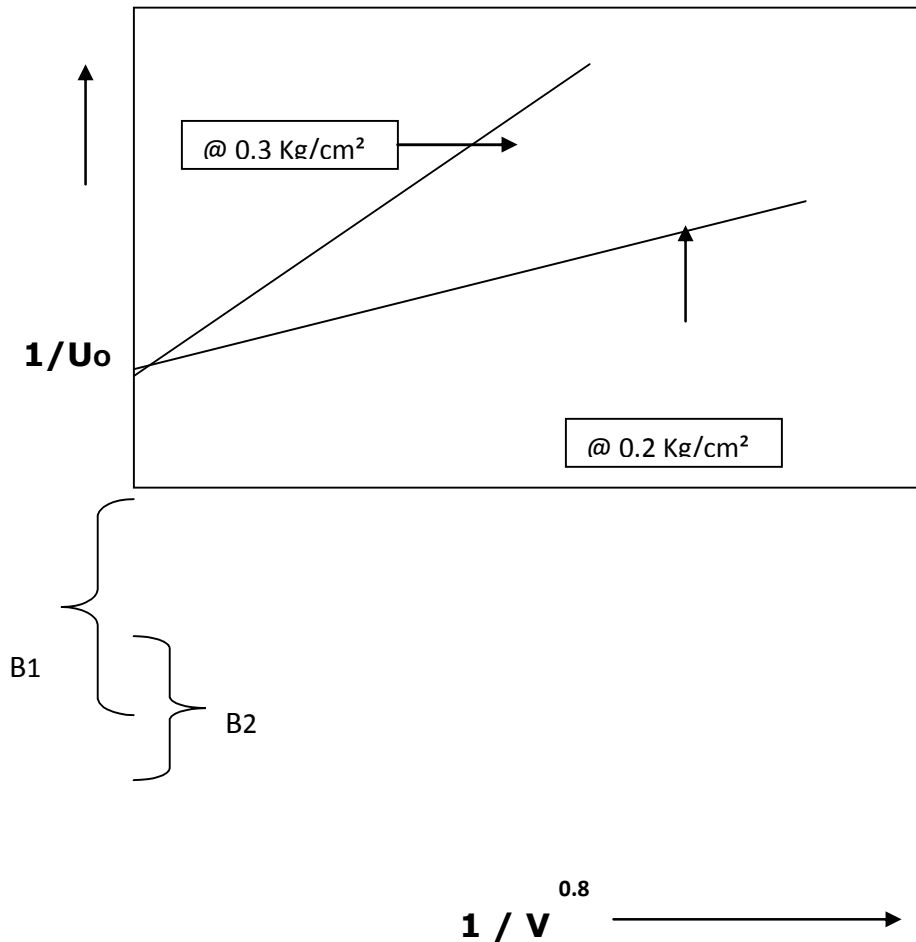
Sl. No	HEAT CARRIED AWAY BY COLD FLUID, 'Q <sub>C</sub> ' watt	HEAT LOST BY STEAM, 'Q <sub>s</sub> ' watt	LOGARITHM MEAN DIFFERENCE 'Δt <sub>LM</sub> ' °K.	OVERALL HEAT TRANSFER COEFFICIENT 'UO' W/m <sup>2</sup> - °K	1 / UO	VELOCITY OF THE COLD FLUID, 'V'	RENOLD NUMBER R, Re	PRANDTL NUMBER R, Pr	COLD FLUID SIDE HEAT TRANSFER COEFFICIENT 'h <sub>c</sub> '	STEAM SIDE HEAT TRANSFER COEFFICIENT 'h <sub>s</sub> '



12. GRAPH\* ( WILSON'S GRAPH) :

- Draw the graph of  $\frac{1}{V}^{0.8}$  Vs  $\frac{1}{U_o}$

\* draw for different steam pressures.



13. CALCULATION OF THEORETICAL COLD FLUID HEAT TRANSFER CO-EFFICIENT :

- Find  $R_D$  using the WILSON'S Graph, i.e.,

$$R_D = \frac{1}{u} - \frac{1}{h_i F_{xn}} \dots\dots\dots 1$$

Where ,  $1/U$  = intercept at higher pressure, say B1.

$h_{i \text{ Exp}}$  = heat transfer co-efficient at cold fluid side.

- Now, to find the Theoretical cold fluid heat transfer Co-efficient at other pressures, use the same above

Formula ,

$$R_D = \frac{1}{u} - \frac{1}{h_{i \text{ Theo}}}$$

Where,  $1/U$  = intercept at the given pressure.

$R_D$  = from equation 1.

#### **PRECAUTIONS:**

6. Check all the electrical connections.
7. Do not run the equipment if the voltage is below 180V.
8. Do not give continuous steam without running the cold water.
9. Run the water in the condensate tube for about 5 min after the experiment.
10. Do not run the equipment if the voltage is below 180V.
11. Check all the electrical connections before running.
12. Before starting and after finishing the experiment the steam valve should be in shut position.
13. Do not attempt to alter the equipment as this may cause damage to the whole system.

**Reference:**

3. PROCESS HEAT TRANSFER, by  
Wareh L. McCabe

Julian C. Smith

Peter Harioth

Publication: McGraw Hill (6<sup>th</sup> edition)

4. Heat and Mass transfer by Arora & Domkundwar

5. Chemical Engineers' Handbook, by  
Robert H. Perry / Cecil H. Chilton

Publication: McGraw – Hill Book Company (6<sup>th</sup> edition)