Rajiv Gandhi University of Knowledge Technologies

Department of Chemical Engineering

Process Heat Transfer Lab

(CH2801)

Course Objectives:

- This lab will provide practical knowledge on various heat transfer process and equipment like heat exchangers and evaporators.
- Learn basic Heat transfer principles.
- Impart the knowledge in heat transfer measurements and different heat transfer equipment.
- Learn how the convection takes place in natural and forced convection and gain knowledge of the heat transfer taking place in different heat exchangers.

List of Experiments:

S.No	Name of the experiment
1.	Emissivity measurement apparatus
2.	Heat transfer in forced convection
3.	Heat transfer in natural convection
4.	Heat tansfer through composite wall
5.	Pool boiling apparatus
6.	Shell and tube heat exchanger
7.	Thermal conductivity of liquids
8.	Hermal conductivity of metal rod

Course Outcomes:

By the end of this course, the student should be able to:

- Understanding fundamentals of some major Heat transfer operation.
- Development of design processes
- Application of design principles for heat transfer devices.
- Learning operations of various heat transfer systems

Engineering Growth Connection

EMISSIVITY MEASUREMENT

APPARATUS (HT-111)

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Contents

EMISSIVITY MEASUREMENT APPARATUS

1. OBJECTIVE:

Study of radiation heat transfer by black plate and test plate.

2. AIM:

To calculate the emissivity of test plate.

3. INTRODUCTION:

All substances at all temperature emit thermal radiation. Thermal radiation is an electromagnetic wave and does not require any material medium for propagation. All bodies can emit radiation and have also the capacity to absorb all of a part of the radiation coming from the surrounding towards it.

4. THEORY:

An idealized black surface is one, which absorbs all the incident radiation with reflectivity and transmissivity equal to zero. The radiant energy per unit time per unit area from the surface of the body is called as the emissive power and is usually denoted by E. The emissivity of the surface is the ratio of the emissive power of the surface to the emissive power of a black surface at the same temperature. It is denoted by ε.

$$\varepsilon = \frac{E}{E_B}$$

Emissivity is a property of the surface depends on the nature of the surface and temperature.

$$E_S = E_B - \frac{(Q_B - Q_S)}{A \times \sigma \times (T_S^4 - T_D^4)}$$

From the above eq^n we can find the emissivity of test plate, Where E_B is emissivity of black body. Q_B, Q_S are heat input of the black plate and test plate. A is area of heat transfer σ is stefan boltzmaan constant, T_S, T_D are surface temperature and surrounding temperature.

5. DESCRIPTION:

The experimental set up consists of two plates, the test plate comprises of a mica heater. Black plate is identical with test plate, but its surface is blackened. As all the physical properties, dimension and temperature are equal. Both plates are supported on individual brackets in a wooden enclosure with one side glass to ensure steady atmospheric conditions. Temperature sensors are provided to measure the temperature of each plate and surrounding. Supply is given to heaters through separate variacs so that temperatures of both can be kept equal and is measured with digital voltmeter and digital ammeter.

6. UTILITIES REQUIRED:

6.1 Electricity Supply: Single Phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection.

6.2 Bench Area Required: 1m x 1m

7. EXPERIMENTAL PROCEDURE:

7.1 STARTING PROCEDURE:

7.1.1 Ensure that mains ON/OFF switch given on the panel is at OFF position & dimmer stat is at zero position.

7.1.2 Connect electric supply to the set up.

7.1.3 Switch ON the mains ON / OFF switch.

7.1.4 Set the test plate heater input by the dimmer stat, voltmeter in the range 40-100 V.

7.1.5 Set black plate heater input by dimmer stat, voltmeter, 2 volt above than test plate heater.

7.1.6 After 0.5 hrs. observe the difference in surface temperature of black plate and test plate, adjust the heater input of black plate to make both the sensor reading same.

7.1.7 Wait for 5 minutes every time after changing the black plate heater input and then again change the input if required.

7.1.8 At same surface temperature note down the reading of voltmeter, ampere meter and temperature sensors.

7.2 Closing Procedure:

7.2.1 When experiment is over set the dimmer stat to zero position.

7.2.2 Switch OFF the mains ON/OFF switch.

7.2.3 Switch OFF electric supply to the set up.

8. Observation & Calculation:

8.1 Data:

Stefan boltzmann constant σ = 5.67 x 10^{-8} $W/m^2 K^4$	Diameter of black plate D_B = 0.16m
Emissivity of black plate E_B = 1	Diameter of test plate D_S = 0.16 m

8.2 Observation Table:

Sr. No.	V_B (Volt)	I_B (Amp)	V_S (Volt)	I_S (Amp)	T_1 (°C)	T_2 (°C)	T_3 (°C)

8.3 Calculations: (At T_1=T_2)

$$Q_B = V_B \times I_B \text{ (W)}$$

$$Q_S = V_S \times I_S \text{ (W)}$$

$$A = \frac{\pi}{4} D_S^{\ 2} \text{ (m}^2\text{)}$$

$$T_S = T_1 + 273.15 \text{ (K)}$$

$$T_D = T_3 + 273.15 \text{ (K)}$$

$$E_S = E_B - \frac{(Q_B - Q_S)}{A \times \sigma \times (T_S^{\ 4} - T_D^{\ 4})}$$

CALCULATION TABLE:					
Sr. No.	**Q_B (W)**	**Q_S (W)**	**T_S (K)**	**T_D (K)**	**E_S**

9. NOMENCLATURE:

Nom	Column Heading	Units	Type
A	Heat transfer area of disc	m^2	Calculated
D_B	Diameter of black plate	m	Given
D_S	Diameter of test plate	m	Given
E_B	Emissivity of black plate		Given
E_S	Emissivity of test plate		Calculated
I_B	Ammeter reading of black plate	Amp	Measured
I_S	Ammeter reading of test plate	Amp	Measured
Q_B	Heat input to black plate	W	Calculated
Q_S	Heat input to test plate	W	Calculated
T_1	Surface temperature of black plate	°C	Measured
T_2	Surface temperature of test plate	°C	Measured
T_3	Ambient temperature of enclosure	°C	Measured
T_D	Ambient temperature of enclosure	K	Calculated
T_S	Surface temperature of discs	K	Calculated
V_B	Voltmeter reading of black plate	volts	Measured
V_S	Voltmeter reading of test plate	volts	Measured
σ	Stefan boltzmann constant	$W/m^2 K^4$	Given

10. PRECAUTION & MAINTENANCE INSTRUCTIONS:

10.1 Never run the apparatus if power supply is less than 200 volts and more than 230 volts.

10.2 Never switch ON mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.

10.3 Operate selector switch of temperature indicator gently.

10.4 Always keep the apparatus free from dust.

11. TROUBLESHOOTING:

11.1 If electric panel is not showing the input on the mains light, check the main supply.

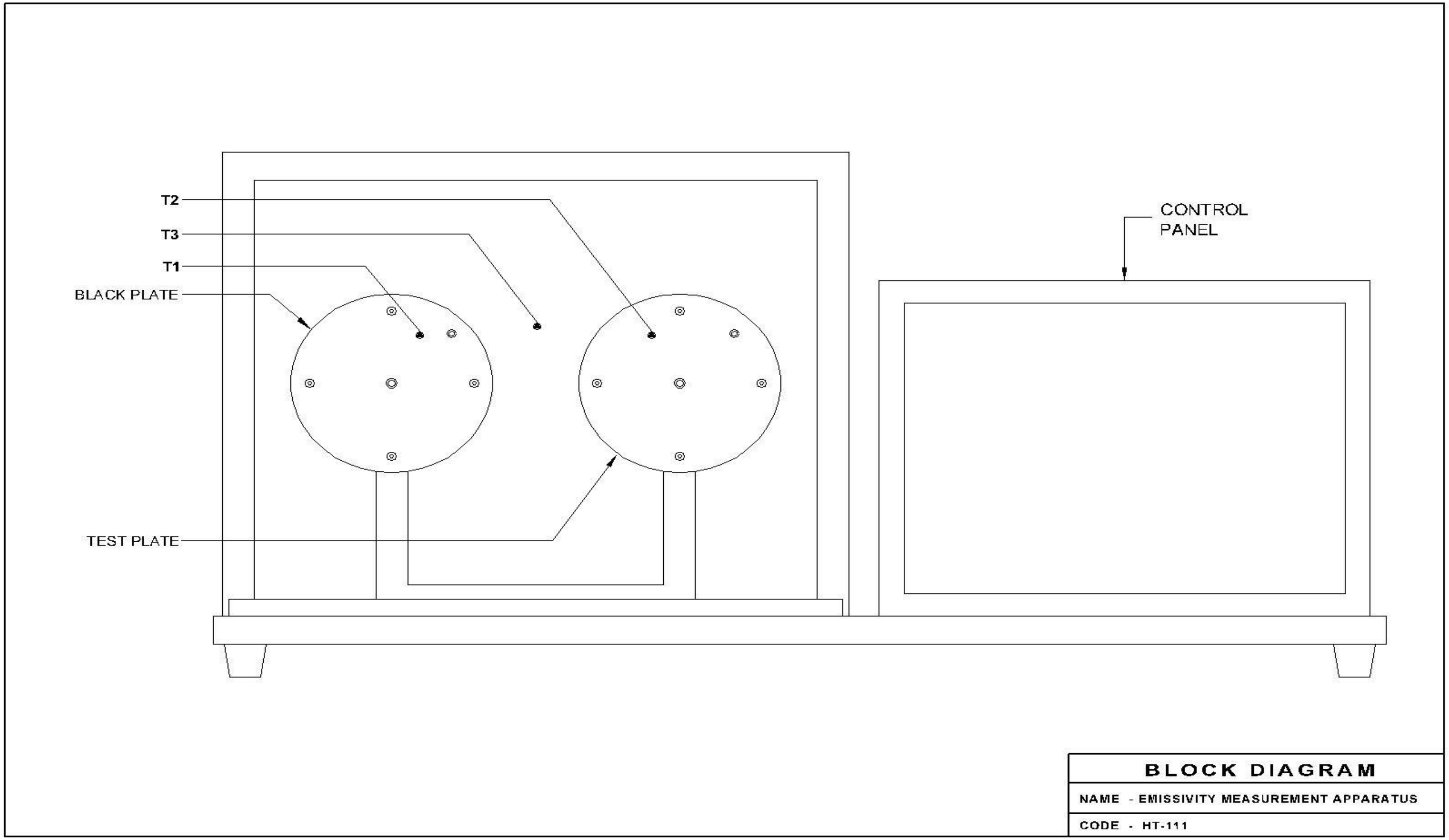
11.2 If voltmeter showing the voltage given to heater but ampere meter does not, check the connection of heater in control panel.

12. REFERENCES:

12.1 Holman, J.P (2008). *Heat Transfer*. 9th Ed. ND: McGraw Hill. pp 371-378.

12.2 Cengel, Y.A (2007). *Heat and Mass Transfer*. 3rd Ed. ND: Tata McGraw Hill. pp 27-29.

13. Block Diagram:



Engineering Growth Connection

HEAT TRANSFER IN FORCED CONVECTION (HT-109)

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Contents

HEAT TRANSFER IN FORCED CONVECTION

1. OBJECTIVE:

To study the heat transfer in forced convection.

2. AIM:

2.1 To calculate surface heat transfer coefficient for a pipe by forced convection.

2.2 To do comparison of heat transfer coefficient for different air flow rates and heat flow rates.

3. INTRODUCTION:

Convection is defined as process of heat transfer by combined action of heat conduction and mixing motion. Convection heat transfer is further classified as natural convection and forced convection. If the mixing motion takes place due to density difference caused by temperature gradient, then the process of heat transfer is known as natural or free convection. If the mixing motion is induced by some external means such as a pump or blower then the process of heat transfer is known as forced convention.

4. THEORY:

Air flowing into the heated pipe with very high flow rate the heat transfer rate increases. The temperature taken by the cold air from the bulk temperature and rises its temperature. Thus, heat flow rate by air is expressed in terms of temperature difference by inlet to outlet temperature of air.

$$q = \dot{m} C_P (T_2 - T_1)$$

Heat transfer coefficient can be calculated by following:

$$U = \frac{q}{A(T_s - T_a)}$$

Where T_a, T_s are surrounding temperature and surface temperature respectively. A is heat transfer area, q is heat flow rate and U is overall heat transfer coefficient.

$$F_x = 2\rho A V^2$$

5. DESCRIPTION:

The apparatus consists of blower unit fitted with the test pipe. The test section is surrounding by nichrome heater. Four temperature sensors are embedded on the test section and two temperature sensors are placed in the air stream at the entrance and exit of the test section. Test pipe is connected to the delivery side of the blower along with the orifice. Input to the heater is given through a dimmerstat and measured by volt meter & ampere meter. Digital temperature indicator is provided to measure temperature. Airflow is measured with the help of orifice meter and the water manometer fitted on the board. Control valve is provided to control the flow rate.

6. UTILITIES REQUIRED:

6.1 Electricity Supply: Single Phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection.

6.2 Floor Area Required: 1.5 m x 0.5 m

7. EXPERIMENTAL PROCEDURE:

7.1 STARTING PROCEDURE:

7.1.1 Ensure that mains ON/OFF switch given on the panel is at OFF position & dimmer stat is at zero position.

7.1.2 Connect electric supply to the set up.

7.1.3 Fill water in manometer up to half of the scale, by opening PU pipe connection from the air flow pipe and connect the pipe back to its position after doing so.

7.1.4 Switch ON the mains ON / OFF switch.

7.1.5 Set the heater input by the dimmer stat, voltmeter in the range 40 to 100 volt.

7.1.6 Switch ON the blower.

7.1.7 Set the flow of air by operating the valve V_1.

7.1.8 After 0.5 hrs. note down the reading of voltmeter, ampere meter, manometer and temperature sensors at every 10 minutes interval (till observing change in consecutive readings of temperatures ±0.2 ^{o}C).

7.1.9 Repeat the experiment for different flow rate of air.

7.2 Closing Procedure:

7.2.1 When experiment is over set the dimmer stat to zero position.

7.2.2 Switch OFF the blower.

7.2.3 Switch OFF the mains ON/OFF switch.

7.2.4 Switch OFF the power supply to the set up.

8. Observation & Calculation:

8.1 Data:

Diameter of pipe d_p	= 0.028 m
Diameter of orifice d_o	= 0.014 m
Length of test section L	= 0.4 m
Coefficient of discharge C_o	= 0.64
Density of water ρ_w	= 1000 kg/m^3

8.2 Observation Table:

Sr. No.	V (volts)	I (amp)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)	h_1 (cm)	h_2 (cm)

8.3 Calculations:

$$T_a = \frac{T_1 + T_6}{2} \; (^\circ C)$$

Find the properties of air (ρ_a, C_p) at temperature T_a from data book

C_P = ______ (J/kg °C)

ρ_a = ______ (kg/m^3)

$$T_s = \frac{T_2 + T_3 + T_4 + T_5}{4} \ (^oC)$$

$$A = \pi d_p L \ (m^2)$$

$$\Delta H = \frac{h_1 - h_2}{100}\left(\frac{\rho_w}{\rho_a} - 1\right) \ (m)$$

$$a_o = \frac{\pi}{4} d_o^2 \ (m^2)$$

$$a_p = \frac{\pi}{4} d_p^2 \ (m^2)$$

$$Q = \frac{C_o a_p a_o \sqrt{2g\Delta H}}{\sqrt{a_p^{\,2} - a_o^{\,2}}} \ (m^3/sec)$$

$$M = Q \times \rho_a \ (kg/sec)$$

$$Q_a = M C_P (T_6 - T_1) \ (W)$$

$$U = \frac{Q_a}{A(T_s - T_a)} \ (W/m^2\ °C)$$

CALCULATION TABLE:			
S.No.	**Q (m^3/sec)**	**Q_a (W)**	**U (W/m^2 °C)**

9. NOMENCLATURE:

Nom	Column Heading	Units	Type
A	Heat transfer area	m^2	Calculated
a_o	Cross- sectional area of orifice	m^2	Calculated
a_p	Cross – sectional area of pipe	m^2	Calculated
C_o	Coefficient of discharge	*	Given
C_p	Specific heat of air	kJ/kg^{o}C	Calculated

d_o	Diameter of orifice	m	Given
d_p	Diameter of pipe	m	Given
h_1-h_2	Manometer readings	cm	Measured
I	Ammeter reading	Amp	Measured
L	Length of test section	m	Given
M	Mass flow rate of air	kg/sec	Calculated
Q	Flow rate of air	m^3/sec	Calculated
Q_a	Heat taken by air	W	Calculated
T_1	Air inlet temperature	^oC	Measured
T_2-T_5	Surface temperature of test section	^oC	Measured
T_6	Air outlet temperature	^oC	Measured
T_a	Average temperature of air	^oC	Calculated
T_s	Average surface temp of test pipe	^oC	Calculated
U	Heat transfer coefficient	$W/m^2{}^oC$	Calculated
V	Voltmeter reading	volt	Measured
ρ_a	Density of air	kg/m^3	Calculated
ρ_w	Density of water	kg/m^3	Given
ΔH	Head loss	m	Calculated

* Symbols represent unitless quantity.

10. Precaution & Maintenance Instructions:

10.1 Never run the apparatus if power supply is less than 200 volts and more than 230 volts.

10.2 Never switch ON mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.

10.3 Operate selector switch of temperature indicator gently.

10.4 Always keep the apparatus free from dust.

11. Troubleshooting:

11.1 If electric panel is not showing the input on the mains light, check the main supply.

11.2 Voltmeter showing the voltage given to heater but ampere meter does not, check the connection of heater in control panel.

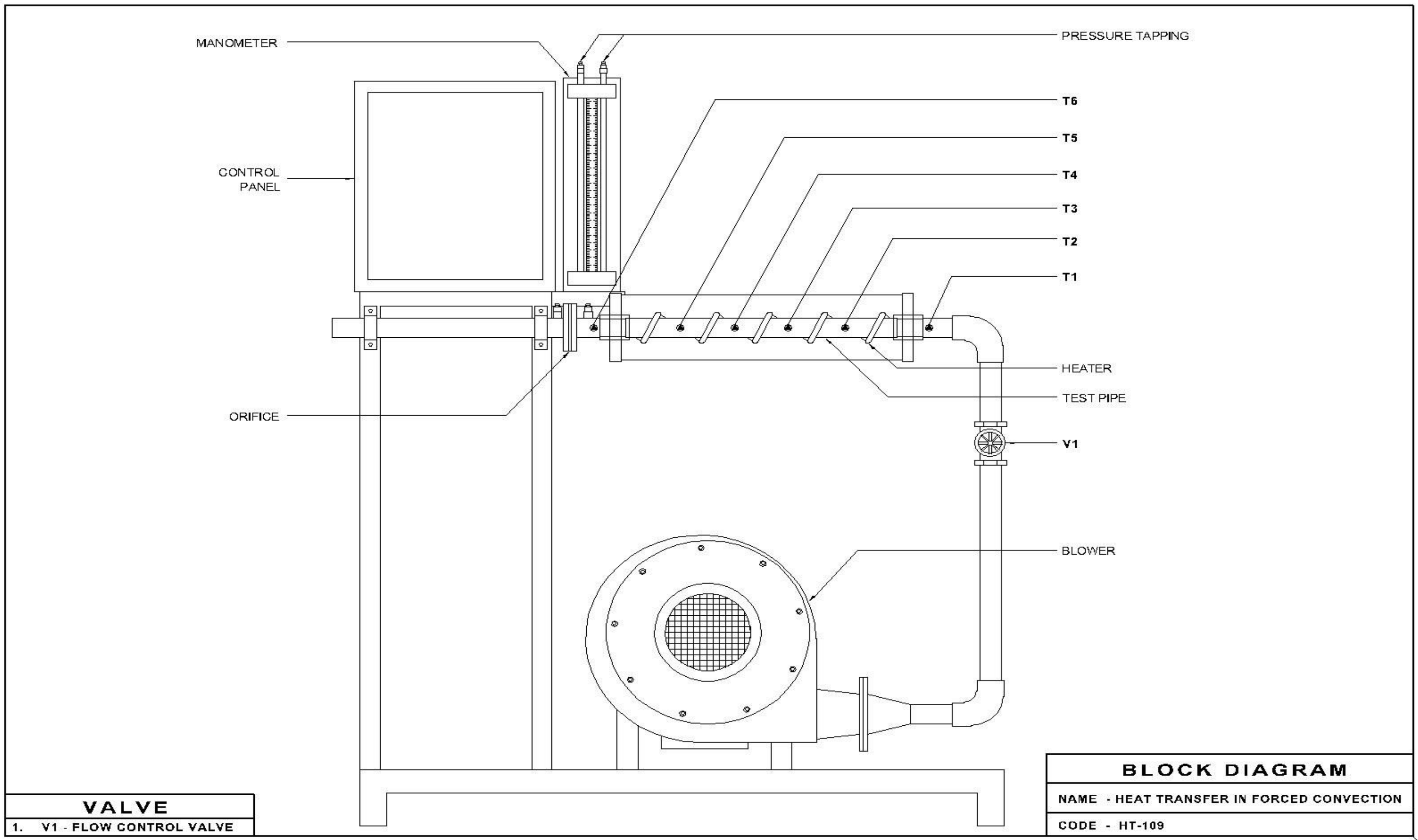
12. REFERENCES:

12.1 McCabe, Smith, Harriott (2005). *Unit Operations of Chemical Engineering*. 7th Ed. NY: McGraw Hill. pp 296, 357-363.

12.2 Cengel, Y.A (2007). *Heat and Mass Transfer*. 3rd Ed. ND: Tata McGraw Hill. pp Page 25-26.

12.3 Domkundwar A (2003). *A Course in Heat & Mass Transfer*. 6th Ed. NY: S.C Dhanpat Rai & Co. (P) Ltd. pp A.6, A.10

13. BLOCK DIAGRAM:



Engineering Growth Connection

HEAT TRANSFER IN NATURAL CONVECTION (HT-110)

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Contents

HEAT TRANSFER IN NATURAL CONVECTION

1. OBJECTIVE:

To study the heat transfer in natural convection.

2. AIM:

To calculate the average heat transfer co-efficient of vertical cylinder under natural convection.

3. INTRODUCTION:

Convection is defined as process of heat transfer by appreciable motion of molecules. Convection heat transfer is further classified as natural convection and forced convection. If the mixing motion takes place due to density difference caused by temperature gradient, then the process of heat transfer is known as heat transfer by natural or free convection. If the mixing motion is induced by some external means such as a pump or blower then the process is known as heat transfer by forced convection.

4. THEORY:

Natural convection phenomenon is due to the temperature difference between the surface and the fluid and is not created by any external agency. The setup is designed and fabricated to study the natural convection phenomenon from a vertical cylinder in terms of average heat transfer coefficient.

The average heat transfer coefficient is given by.

$$h = \frac{Q_a}{A(T_s - T_a)}$$

Where Q_a, T_s, T_a and A are amount of heat transfer, surface temperature, ambient temperature and area of heat transfer respectively.

5. DESCRIPTION:

The apparatus consists of a test pipe fitted in a rectangular duct in a vertical fashion. Heater is provided in the middle of test pipe. The duct is open at the top and bottom and forms an enclosure and serves the purpose of undisturbed surrounding. Seven temperature sensors are provided to measure the temperature of test pipe surface and one is for duct surface. Digital ammeter and digital voltmeter with variac are provided to measure the heat input given by heater.

6. Utilities Required:

6.1 Electricity Supply: Single Phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection.

6.2 Bench Area Required: 1m x 1m

7. Experimental Procedure:

7.1 Starting Procedure:

7.1.1 Ensure that mains ON/OFF switch given on the panel is at OFF position & dimmer stat is at zero position.

7.1.2 Connect electric supply to the set up.

7.1.3 Switch ON the mains ON / OFF switch.

7.1.4 Set the heater input by the dimmer stat, voltmeter in the range 40 to 100 volts.

7.1.5 After 1.5 hrs. note down the reading of voltmeter, ampere meter and temperature sensors in the observation table after every 10 minutes interval till observing change in consecutive readings of temperatures (± 0.2 ^{o}C).

7.2 Closing Procedure:

7.2.1 When experiment is over set the dimmer stat to zero position.

7.2.2 Switch OFF the mains ON/OFF switch.

7.2.3 Switch OFF electric supply to the set up.

8. Observation & Calculation:

8.1 Data:

Length of cylinder L	= 0.5 m
Diameter of cylinder d	= 0.038 m

8.2 Observation Table:

Sr. No.	V (volts)	I (amp)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)	T_7 (°C)	T_8 (°C)

8.3 Calculations:

$Q = V \times I$ (W)

$A = \pi d L$ (m²)

$$T_s = \frac{T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7}{7} \text{ (°C)}$$

$T_a = T_8$ (°C)

$$h = \frac{Q}{A(T_s - T_a)} \text{ (W/m}^2\text{ °C)}$$

Calculation Table:

Sr. No.	h (W/m² °C)

9. Nomenclature:

Nom	Column Heading	Units	Type
A	Heat transfer area	m^2	Calculated
D	Diameter of cylinder	m	Given
h	Average heat transfer coefficient	W/m^2 °C	Calculated
I	Ampere reading	Amp	Measured
L	Length of cylinder	m	Given
Q	Amount of heat transfer	W	Calculated

T_1 - T_7	Surface temperatures of test pipe	°C	Measured
T_8/T_a	Temperature of air in duct	°C	Measured
T_s	Average surface temperature of test pipe	°C	Calculated
V	Voltmeter reading	Volts	Measured

10. PRECAUTION & MAINTENANCE INSTRUCTIONS:

10.1 Never run the apparatus if power supply is less than 200 volts and more than 230 volts.

10.2 Never switch ON mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.

10.3 Operate selector switch of temperature indicator gently.

10.4 Always keep the apparatus free from dust.

11. TROUBLESHOOTING:

11.1 If electric panel is not showing the input on the mains light, check the main supply.

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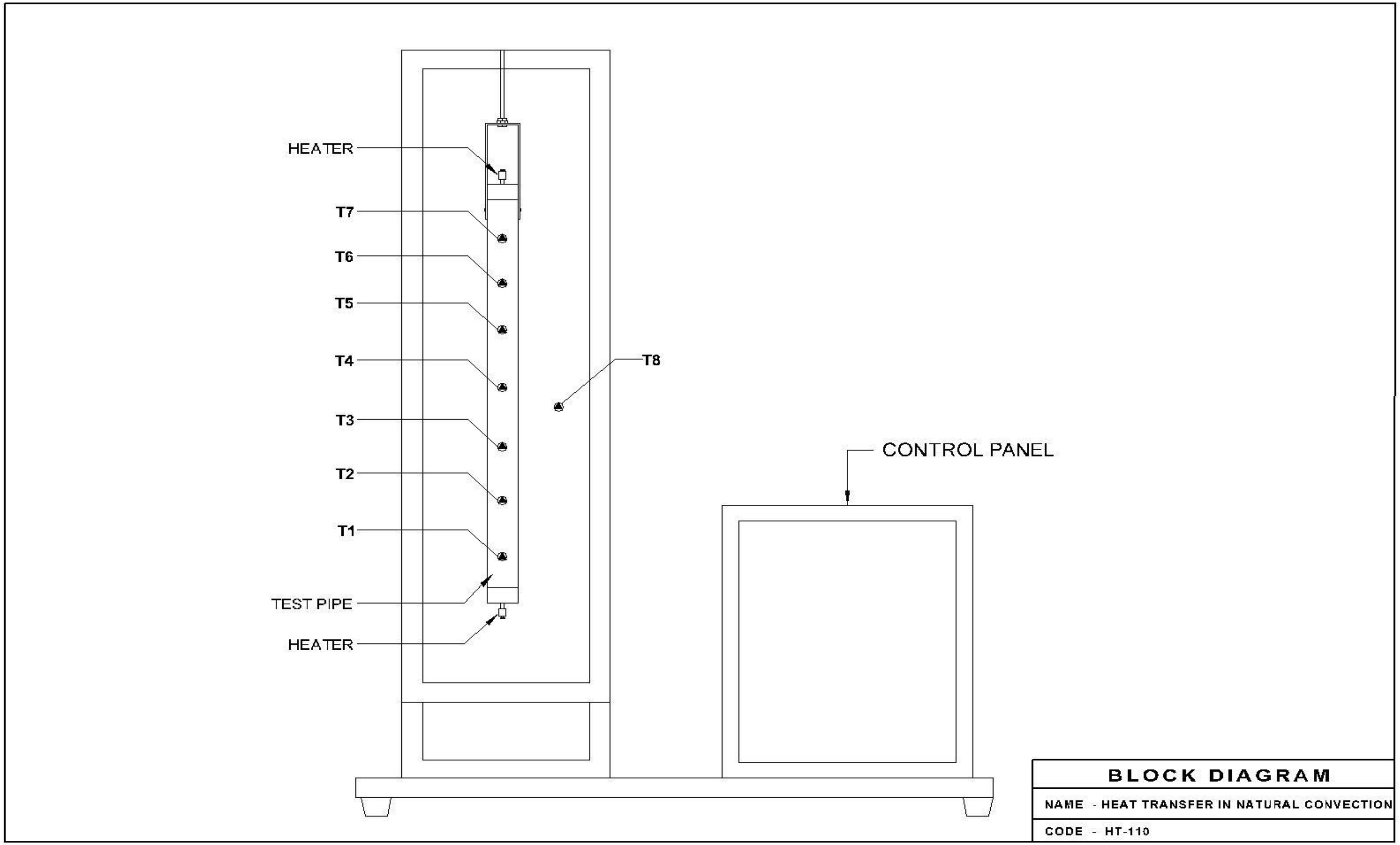
12.2 Cengel, Y.A, (2007). *Heat and Mass Transfer*. 3rd Ed. ND: Tata McGraw Hill. pp 25-26.

13. BLOCK DIAGRAM:



HEAT TRANSFER THROUGH

COMPOSITE WALL (HT-101)

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Contents

HEAT TRANSFER THROUGH COMPOSITE WALL

1. OBJECTIVE:

To study the heat transfer through conduction in composite wall.

2. AIM:

2.1 To calculate total thermal resistance of composite wall.

2.2 To calculate total thermal conductivity of composite wall.

2.3 To calculate thermal conductivity of one material in composite wall.

2.4 To plot the temperature profile along the composite wall.

3. INTRODUCTION:

When a temperature gradient exists in a body, there is an energy transfer from the high temperature region to the low temperature region. Energy is transferred by conduction and heat transfer rate per unit area is proportional to the normal temperature gradient:

$$\frac{q}{A} \alpha \frac{\Delta T}{\Delta X}$$

When the proportionality constant is inserted,

$$q = -kA\frac{\Delta T}{\Delta X}$$

Where q is the amount of heat transfer and ΔT/ ΔX is the temperature gradient in the direction of heat flow. The constant k is called thermal conductivity of the material.

4. THEORY:

A direct application of fourier's law is the plane wall.

Fourier's equation:

$$Q = \frac{-kA}{\Delta X}\left(T_2 - T_1\right)$$

Where the thermal conductivity is considered constant. The wall thickness is ΔX, Q, A are amount of heat transfer and heat transfer area respectively. T_1 and T_2 are surface temperatures. If more than one material is present, as in the multilayer wall, the analysis would proceed as follows:

The temperature gradients in the three materials (A, B, C), the heat flow may be written

$$Q = -k_A A \frac{\Delta T_A}{\Delta X_A} = -k_B A \frac{\Delta T_B}{\Delta X_B} = -k_C A \frac{\Delta T_C}{\Delta X_C}$$

$$q = \frac{Q}{A}$$

For material A thermal conductivity can be calculated as following:

$$k_A = \frac{q \Delta X_A}{\Delta T_A}$$

5. DESCRIPTION:

The apparatus consists of a heater sandwiched between two asbestos sheets. Three slabs of different material are provided on both sides of heater, which forms a composite structure. A small press- frame is provided to ensure the perfect contact between the slabs. A variac is provided for varying the input to the heater and measurement of input power is carried out by a digital voltmeter & digital ammeter. Eight temperature sensor are embedded between inter faces of the slab, to read the temperature at the surface.

6. UTILITIES REQUIRED:

6.1 Electricity Supply: Single Phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection.

6.2 Bench Area Required: 1m x 1m.

7. EXPERIMENTAL PROCEDURE:

7.1 STARTING PROCEDURE:

7.1.1 Ensure that mains ON/OFF switch given on the panel is at OFF position & dimmer stat is at zero position.

7.1.2 Connect electric supply to the set up.

7.1.3 Switch ON the mains ON / OFF switch.

7.1.4 Set the heater input by the dimmer stat, voltmeter in the range 40 to 100 volt.

7.1.5 After 1.5 hrs. note down the reading of voltmeter, ampere meter and temperature sensors in the observation table after every 10 minutes interval till observing change in consecutive readings of temperatures (± 0.2 ^oC).

7.2 Closing Procedure:

7.2.1 When experiment is over set the dimmer stat to zero position.

7.2.2 Switch OFF the mains ON/OFF switch.

7.2.3 Switch OFF the power supply to the set up.

8. Observation & Calculation:

8.1 Data:

Thermal conductivity of cast iron k_1 = 52 W/m^{o}C	Cast iron thickness X_1 = 0.02 m
Thermal conductivity of bakelite k_2 = 1.4 W/m^{o}C	Bakelite thickness X_2 = 0.015 m
Diameter of slab d = 0.25 m	Press wood thickness X_3 = 0.012 m

8.2 Observation Table:

Sr. No.	V (Volt)	I (Amp)	T_1 (^oC)	T_2 (^oC)	T_3 (^oC)	T_4 (^oC)	T_5 (^oC)	T_6 (^oC)	T_7 (^oC)	T_8 (^oC)

8.3 Calculations:

$$W = V \times I \text{ (W)}$$

$$Q = \frac{W}{2} \text{ (W)}$$

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

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

$$\Delta T = \frac{(T_1 - T_7) + (T_2 - T_8)}{2} \ (^{o}\text{C})$$

$$R_t = \frac{\Delta T}{q} \ (^{o}\text{C m}^2\text{/W})$$

$$\Delta X = X_1 + X_2 + X_3 \ (\text{m})$$

$$K_{eff} = \frac{q \times \Delta X}{\Delta T} \ (\text{W/m } ^{o}\text{C})$$

$$k_3 = \frac{X_3}{\left[\frac{\Delta T}{q} - \left(\frac{X_1}{k_1} + \frac{X_2}{k_2}\right)\right]} \ (\text{W/m } ^{o}\text{C})$$

$$X_A = 0 \ (\text{m})$$

$$X_{A1} = X_A + X_1 \ (\text{m})$$

$$X_{A2} = X_A + X_1 + X_2 \ (\text{m})$$

$$X_{A3} = X_A + X_1 + X_2 + X_3 \ (\text{m})$$

$$T_{A1} = \frac{(T_1 + T_2)}{2} \ (^{o}\text{C})$$

$$T_{A2} = \frac{(T_3 + T_4)}{2} \ (^{o}\text{C})$$

$$T_{A3} = \frac{(T_5 + T_6)}{2} \ (^{o}\text{C})$$

$$T_{A4} = \frac{(T_7 + T_8)}{2} \ (^{o}\text{C})$$

CALCULATION TABLE:									
Sr. No	**Q (W/m^2)**	**ΔT (^oC)**	**R_t ($^oCm^2/W$)**	**k_{eff} (W/m^oC)**	**k_3 (W/m^oC)**	**T_{A1} (^oC)**	**T_{A2} (^oC)**	**T_{A3} (^oC)**	**T_{A4} (^oC)**

To plot the graph of length (X_A, X_{A1}, X_{A2}, X_{A3}) vs temperature (T_{A1}, T_{A2}, T_{A3}, T_{A4}).

9. NOMENCLATURE:

Nom	Column Heading	Units	Type
A	Area of heat transfer	m^2	Calculated
D	Diameter of slab	m	Given
I	Ammeter reading	Amp	Measured
K_{eff}	Total thermal conductivity of composite wall	$W/m\ ^oC$	Calculated
k_1	Thermal conductivity of cast iron	$W/m\ ^oC$	Given
k_2	Thermal conductivity of bakelite	$W/m\ ^oC$	Given
k_3	Thermal conductivity of press wood	$W/m\ ^oC$	Calculated
Q	Amount of heat transfer	W	Calculated
q	Heat flux	W/m^2	Calculated
R_t	Total thermal resistance of composite wall	$^oC\ m^2/W$	Calculated
T_1-T_2	Interface temperature of cast iron and heater	^oC	Measured
T_3-T_4	Interface temperature of cast iron and bakelite	^oC	Measured
T_5-T_6	Interface temperature of bakelite and press wood	^oC	Measured
T_7-T_8	Top surface temperature of press wood	^oC	Measured
T_{A1}	Average temperature at the interface of cast iron slab and heater	^oC	Calculated
T_{A2}	Average temperature at the interface of cast iron slab and bakelite slab	^oC	Calculated
T_{A3}	Average temperature at the interface of bakelite slab and press wood slab	^oC	Calculated
T_{A4}	Average temperature at the surface of press wood slab	^oC	Calculated
V	Voltmeter reading	Volt	Measured

W	Heat supplied by the heater	W	Calculated
X_1	Cast iron thickness	m	Given
X_2	Bakelite thickness	m	Given
X_3	Press wood thickness	m	Given
X_A	Reference point to measure distances	m	Calculated
X_{A1}	Distance of reference point to cast iron slab	m	Calculated
X_{A2}	Distance of reference point to bakelite slab	m	Calculated
X_{A3}	Distance of reference point to press wood slab	m	Calculated
ΔT	Overall temperature difference	^oC	Calculated
ΔX	Total thickness of wall	m	Calculated

10. Precaution & Maintenance Instructions:

10.1 Never run the apparatus if power supply is less than 200 volts and more than 230 volts.

10.2 Never switch ON mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.

10.3 Operate selector switch of temperature indicator gently.

10.4 Always keep the apparatus free from dust.

11. Troubleshooting:

11.1 If electric panel is not showing the input on the mains light, check the main supply.

11.2 If voltmeter showing the voltage given to heater but ampere meter does not, check the connection of heater in control panel.

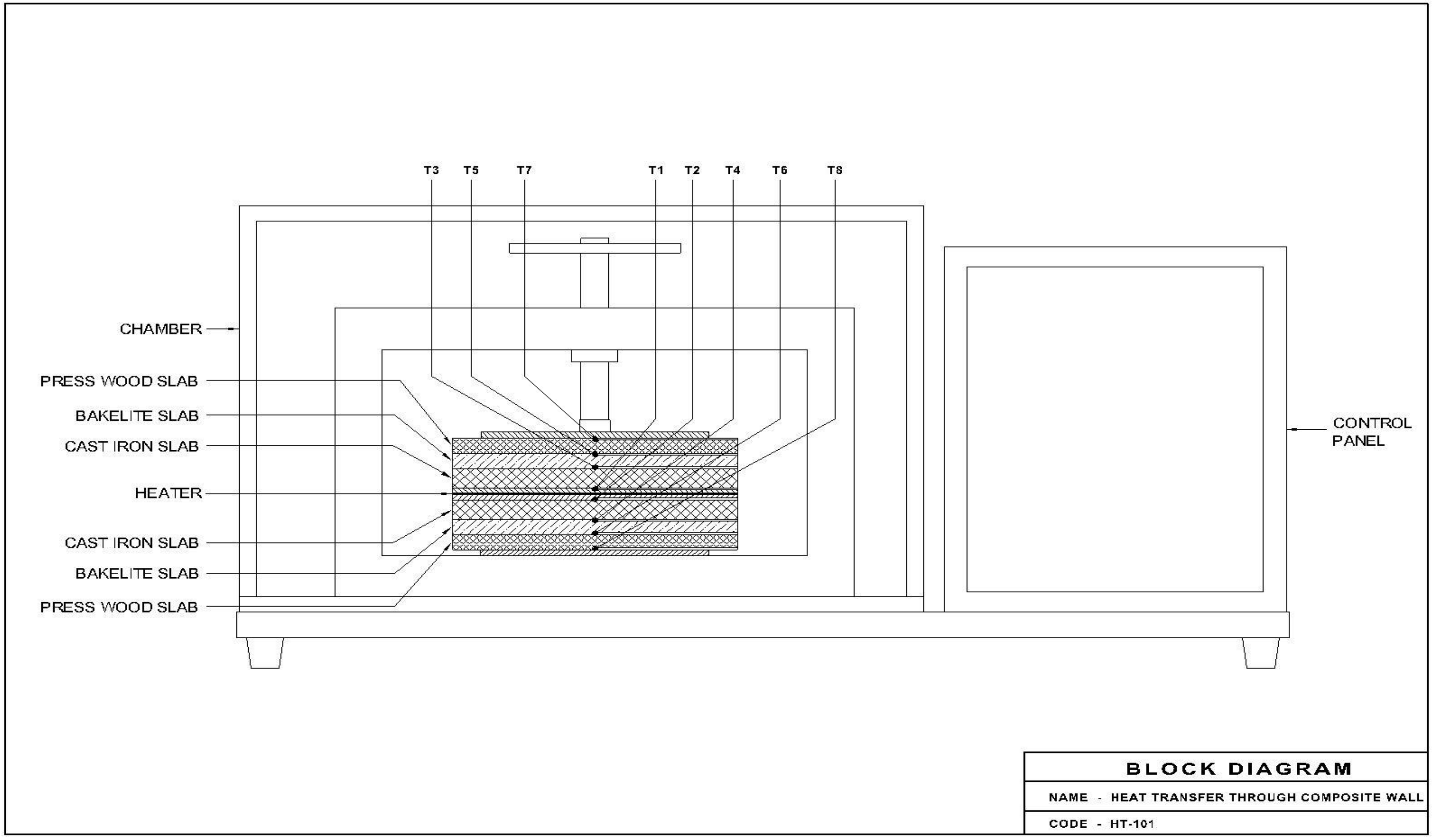
12. References:

12.1 Holman, J.P (2008). *Heat Transfer*. 9th Ed. ND: McGraw Hill. pp 23-24.

12.2 Kern, D.Q (2007). *Process Heat Transfer*. 16th Ed. ND: McGraw Hill. pp 14-15.

12.3 Domkundwar A (2003). *A Course in Heat & Mass Transfer*. 6th Ed. NY: S.C Dhanpat Rai & Co. (P) Ltd. pp A.4 – A.5.

13. Block Diagram:



Engineering Growth Connection

POOL BOILING APPARATUS

(HT-251)

Foreword

Welcome to the fast growing family of K.C. product owners. We appreciate your interest in us and thank you for buying our product.

You have chosen the finest quality product in the market which is produced using latest techniques and has underwent strict quality control tests. It is a product that we are proud to build and you are proud to own it.

Our products are easy to understand and operate. They are excellent for students who are trying to gain practical knowledge through experiments.

However your comfort and safety are important to us, so we want you have an understanding of proper procedure to use the equipment. For the purpose, we urge you to read and follow the step-by-step operating instructions and safety precautions in this manual. It will ensure that your favourite product delivers reliable, superior performance year after year.

This manual includes information for all options available on this model. Therefore, you may find some information that does not apply to your equipment.

All information, specifications and illustrations in this manual are those in effect at the time of printing. We reserve the right to change specifications or design at any time without notice.

Customer satisfaction is our primary concern. Feel Free to contact us for any assistance. So what are you waiting for, roll up your sleeves and let us get down to work!

K.C. Engineers Pvt. Ltd.

Important Information About This Manual

Reminder for Safety

Modification on Equipment:

This equipment should not be modified. Modification could affect its performance, safety or disturbance. In addition damage or performance problems resulting from modification may not be covered under warranties.

Precautions and Maintenance:

This is used to indicate the presence of a hazard that could cause minor or moderate personal injury or damage to your equipment. To avoid or reduce the risk, the procedures must be followed carefully.

Contents

POOL BOILING APPARATUS

1. OBJECTIVE:

To study about the critical flux in a pool boiling apparatus.

2. AIM:

To determine the critical heat flux of a given wire.

3. INTRODUCTION:

When heat is added to a liquid from a submerged solid surface which is at a temperature higher than the saturation temperature of the liquid, it is used for the part of the liquid to change phase. This change of phase is called ‘Boiling’. Boiling of various types, the depending upon the temperature difference between the surface and the liquid.

4. THEORY:

This experimental set-up is designed to study the pool boiling phenomenon up to critical heat flux. The pool boiling over the heater wire can be visualized in the different regions up to the critical heat flux point at which the wire melts. The heat flux from the wire is slowly increased by gradually increasing the applied convection to nucleate boiling can be seen. The formation of bubbles and their growth in size and number can be visualized followed by vigorous bubble formation and their immediate carrying over to surface and ending this in the breaking of wire indicating the occurrence of critical heat flux point. This is repeated for various temperatures of the water in the container.

The different types experimental boiling curve obtained in a saturated pool of liquid.

The heat flux supplied to the surface is plotted against (T_w-T_1) (The difference between the temperature of the surface and the boiling temperature of the liquid.)

It is seen that the boiling curve can be divide into three regions;

4.1 Natural Convection Region

4.2 Nucleate Boiling Region

4.3 Film Boiling Region.

4.1 Natural Convection Region:

The region of natural convection occurs at low temperature differences (of the order of 10 ^{o}C or less). Heat transfer from the heated surface to liquid in its vicinity causes the liquid to be superheated. This superheated liquid rises to the free liquid surface by natural convection, where vapour is produced by evaporation.

4.2 Nucleate Boiling Region:

As the temperature difference ($T_w - T_1$) is increased, nucleate boiling starts. In this region, it is observed that bubble start to form at certain locations on the heated surface. Region II consists of two parts. In the first part, II-a, the bubbles formed are very few in number. In the second part, II-b, the rate of bubble formation as well as the number of locations where they are formed, increase. Some of the bubbles now rise all the way to the free surface. With increasing temperature difference a stage is finally reached when the rate of formation of bubble is so high, that they start to collapse and blanked the surface with a vapour film. This the beginning of region III.

4.3 Film Boiling Region:

In the first part of region III, the vapour film is unstable, so that film boiling may be occurring on a portion of the heated surface area, while nucleate boiling may be occurring on the remaining area. In the second part of region III, a stable film covers the entire surface. The temperature difference in this region is the order of 100^{o} deg C and consequently radiative heat transfer across the vapour film is also significant.

5. Description:

The apparatus consists of water bath with heater and test wire. Heater is also connected to mains via a dimmer stat and a voltmeter. Temperature sensor is provided to measure the temperature. A micro controller based peak detector has been provided to measure the maximum current during the process. The heater wire can be viewed through a transparent window.

6. Utilities Required:

6.1 Electricity Supply: Single Phase, 220 V AC, 50 Hz, 5-15 Amp. combined socket with earth connection

6.2 Water Supply (Initial Fill).

6.3 Floor Drain Required

6.4 Floor Area Required : 1.5m x 1m

7. EXPERIMENTAL PROCEDURE:

7.1 STARTING PROCEDURE:

7.1.1 Close the valve V_1.

7.1.2 Fill the water bath with water up to $3/4^{th}$ of its capacity.

7.1.3 Ensure that ON/OFF switches given on the panel are at OFF position.

7.1.4 Connect the test heater wire.

7.1.5 Connect electric supply to the set up.

7.1.6 Set the desired bath temperature with the help of DTC (50^o - 80^oC).

7.1.7 Switch ON the heater and wait till desired temperature achieved.

7.1.8 Initialize the process monitor indicator by pressing the button provided.

7.1.9 Switch-ON the test heater.

7.1.10 Very gradually increase the voltage across it by slowly changing the variac from one position to the other and stop a while at each position to observe the boiling phenomena on wire.

7.1.11 Go on increasing the voltage till wire breaks and carefully note down the voltage and current at this point.

7.1.12 Bring the variac to zero voltage.

7.1.13 Repeat the experiment for different water bath temperature.

7.2 CLOSING PROCEDURE:

7.2.1 When experiment is over, switch OFF the heater.

7.2.2 Switch OFF the main power supply.

7.2.3 Drain the water bath by opening the valve V_1.

8. Observation & Calculation:

8.1 Data:	
Diameter of test heater wire d	= 1.219×10^{-4} m
Length of the test heater wire L	= 0.08 m

Observation:

T_1 = _______ (^oC)

8.2 Observvtion Table:

S. No.	V (Volt)	I (Amp)

8.3 Calculations:

$$W = V \times I \text{ (W)}$$

$$A = \pi \times d \times L \text{ (m}^2\text{)}$$

$$q_c = \frac{W}{A} \text{ (W/m}^2\text{)}$$

Calculation Table:

Sr. No.	q_c (W/m^2)

9. Nomenclature:

Nom	Column Heading	Units	Type
A	Area of test heater wire	m^2	Calculated
d	Diameter of test heater wire	m	Given

I	Ampere meter reading	Amp	Measured
L	Length of the test heater wire	m	Given
q_c	Critical heat flux	W/m^2	Calculated
T_1	Boiling temperature	^oC	Measured
V	Voltmeter reading	volt	Measured
W	Heat supplied by the heater	W	Calculated

10. PRECAUTION & MAINTENANCE INSTRUCTIONS:

10.1 Never run the apparatus if power supply is less than 200 volts and more than 220 volts.

10.2 Never switch ON mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.

10.3 Slowly increase the voltage of heater.

10.4 Always keep the apparatus free from dust.

11. TROUBLESHOOTING:

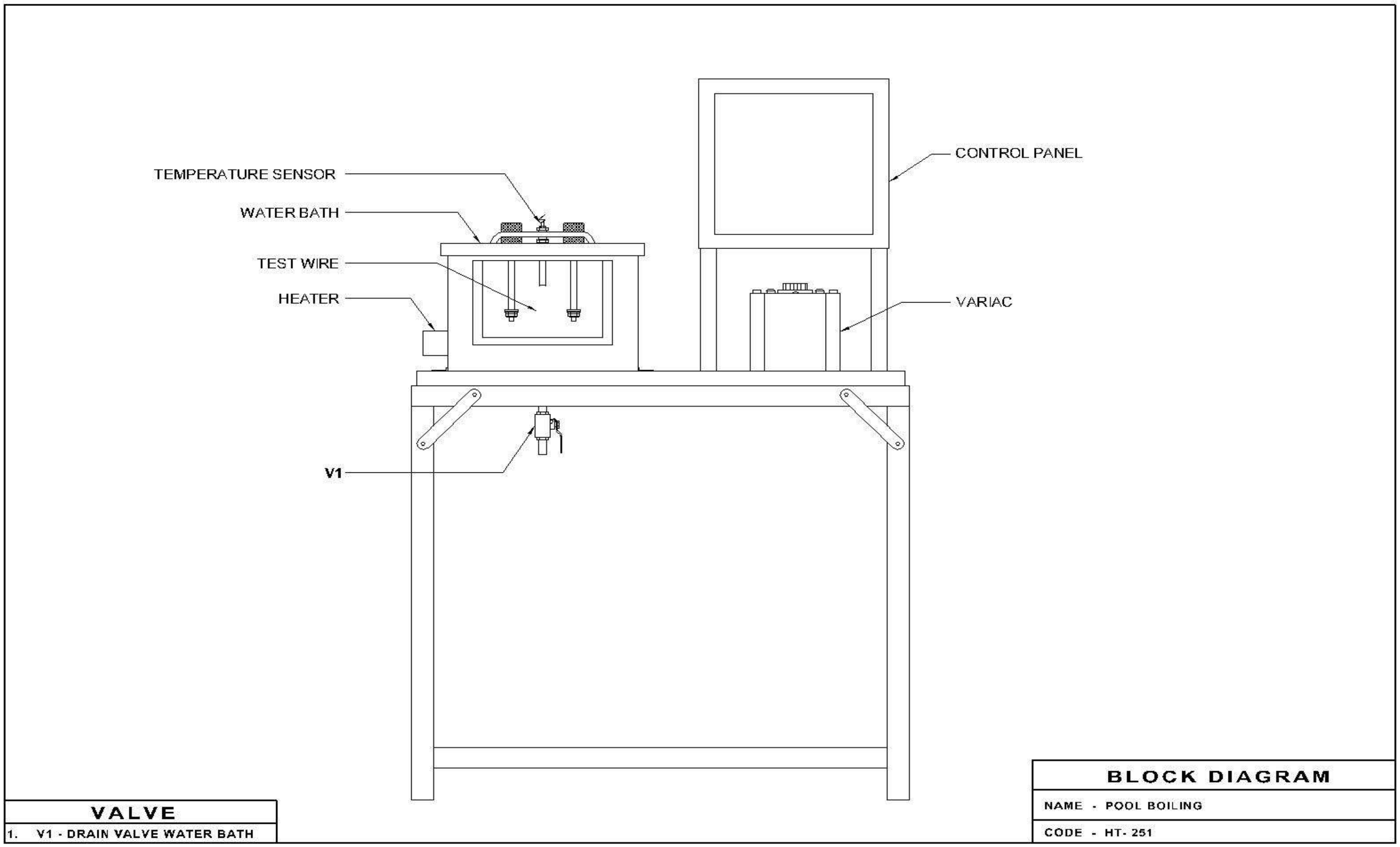
11.1 If electric panel is not showing the input on the mains light. Check the main supply.

12. REFERENCES:

12.1 McCabe, Smith, Harriott (2005). *Unit Operations of Chemical Engineering*. 7th Ed. NY: McGraw Hill. pp 400-403.

12.2 Kumar, D.S (2008). *Heat & Mass Transfer*. 7th Ed. ND: S.K Kataria & Sons. pp 664-669.

13. Block Diagram:



SHELL & TUBE HEAT EXCHANGER (HT-115)

Engineering Growth Connection

Foreword

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Contents

SHELL & TUBE HEAT EXCHANGER

1. OBJECTIVE:

To study of heat transfer in shell and tube heat exchanger.

2. AIM:

2.1 To calculate the LMTD.

2.2 To calculate the heat transfer rate.

2.3 To calculate the overall heat transfer coefficient.

3. INTRODUCTION:

Heat exchanger is device in which heat is transferred from one fluid to another. The necessity for doing this arises in a multitude of industrial applications. Common examples of heat exchangers are the radiator of a car, the condenser at the back of a domestic refrigerator and the steam boiler of a thermal power plant.

Heat exchangers are classified in three categories:

3.1 Transfer Type.

3.2 Storage Type.

3.3 Direct Contact Type.

4. THEORY:

A transfer type of heat exchanger is one on which both fluids pass simultaneously through the device and heat is transferred through separating walls. In practice, most of the heat exchangers used are transfer type ones.

The transfer type exchangers are further classified according to flow arrangement as -

4.1 Single Pass.

4.2 Multiple Pass

A simple example of transfer type of heat exchanger can be in the form of a tube type arrangement in which one of the fluids is flowing through the inner tube and the other through the annulus surroundings it. The heat transfer takes place across the walls of the inner tube.

Heat transfer rate, LMTD and overall heat transfer coefficient can be calculated as follows:

$$Q = M\, C_p\, (T_o - T_i)$$

$$\Delta T_m = \frac{\Delta T_o - \Delta T_i}{\ln \frac{\Delta T_o}{\Delta T_i}}$$

$$U = \frac{Q}{A\, \Delta T_m}$$

Where Q is amount of heat transfer, U is overall heat transfer coefficient and ΔT_m is log mean temperature difference. M, C_p, T_o, T_i are mass flow rate, specific heat, outlet temperature and inlet temperature respectively. ΔT_o, ΔT_i and A are outlet temperature difference, inlet temperature difference and heat transfer area respectively.

5. DESCRIPTION:

The apparatus consists of fabricated shell inside which tubes with baffles on outer side are fitted. The present set-up is 1-2 pass shell and tube heat exchanger. The hot water flow through the inner tube while the cold water flowing through the shell side. Valves are provided to control the flow rate of hot and cold water. For flow measurement rotameter are provided at inlet of cold water and outlet of hot water line. A magnetic drive pump is given to circulate the hot water from a recycled type water tank, which is fitted with heater and digital temperature controller.

6. UTILITIES REQUIRED:

6.1 Electricity supply: Single phase, 220 V AC, 50 Hz, 32 Amp MCB with earth connection.

6.2 Water supply: Continuous @ 5 LPM at 1 Bar.

6.3 Floor drain required.

6.4 Floor area required: 1.5 m x 0.75 m.

7. Experimental Procedure:

7.1 Starting Procedure:

7.1.1 Close all the valves V_1-V_6.

7.1.2 Open the lid of hot water tank, fill the tank with water and put the lid back to its position.

7.1.3 Ensure that switches given on the panel are at OFF position.

7.1.4 Connect electric supply to the set up.

7.1.5 Set the desired water temperature in the DTC by operating the increment or decrement and set button of DTC.

7.1.6 Open by pass valve V_3 and switch ON the pump.

7.1.7 Switch ON the heater and wait till desired temperature achieves.

7.1.8 Connect cooling water supply to the set up.

7.1.9 Connect the outlet of cooling water from heat exchanger to drain.

7.1.10 Open the valve V_1 for circulation of cold water and adjust the flow rate.

7.1.11 Allow hot water to flow through heat exchanger and adjust the flow rate by valve V_2-V_3.

7.1.12 At steady state (constant temperature) record the temperatures & flow rate of hot and cold water.

7.1.13 Repeat the experiment for different flow rate of hot & cold water.

7.1.14 Repeat the experiment for different temperature of DTC.

7.2 Closing Procedure :

7.2.1 When experiment is over switch OFF the heater.

7.2.2 Switch OFF the pump.

7.2.3 Stop cooling water supply by close the valve V_1.

7.2.4 Drain the water from hot water tank by open the valve V_6.

7.2.5 Drain the water from shell side by open the valve V_5.

7.2.6 Drain the water from tube side by open the valve V_4.

8. OBSERVATION & CALCULATION:

8.1 DATA:

Length of tube L	= 0.5 m
Number of tubes N	= 24
Outer diameter of tube D_o	= 0.016 m
Inner diameter of tube D_i	= 0.013 m

8.2 OBSERVATION TABLE :

Sr. No.	Hot water side			Cold water side		
	F_h (LPH)	T_1 (°C)	T_2 (°C)	F_C (LPH)	T_3 (°C)	T_4 (°C)

8.3 CALCULATIONS :

$$T_h = \frac{T_1 + T_2}{2} \quad (^{o}\text{C})$$

$$T_c = \frac{T_3 + T_4}{2} \quad (^{o}\text{C})$$

Find the properties of water (ρ_h , C_{ph}) at temperature T_h and (ρ_c , C_{pc}) at temperature T_c from data book.

$\rho_h =$ ______ (kg/m^3)

$C_{ph} =$ ______ (J/kg ^{o}C)

$\rho_c =$ ______ (kg/m^3)

$C_{pc} =$ ______ (J/kg ^{o}C)

$$M_h = \frac{F_h \times \rho_h}{3600 \times 1000} \text{ (kg/sec)}$$

$$Q_h = M_h C_{ph} (T_1 - T_2) \text{ (W)}$$

$$M_c = \frac{F_c \times \rho_c}{3600 \times 1000} \text{ (kg/sec)}$$

$$Q_c = M_c C_{pc} (T_4 - T_3) \text{ (W)}$$

$$Q = \frac{Q_h + Q_c}{2} \text{ (W)}$$

$$\Delta T_1 = T_1 - T_3 \ (^oC)$$

$$\Delta T_2 = T_2 - T_4 \ (^oC)$$

$$\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln \frac{\Delta T_1}{\Delta T_2}} \ (^oC)$$

$$A_i = \pi D_i L \ (m^2)$$

$$A_o = \pi D_o L \ (m^2)$$

$$U_i = \frac{Q}{A_i \Delta T_m} \ (W/m^2 \, ^oC)$$

$$U_o = \frac{Q}{A_o \Delta T_m} \ (W/m^2 \, ^oC)$$

CALCULATION TABLE :

Sr. No.	Q_c (W)	Q_h (W)	Q (W)	ΔT_m (^oC)	U_i ($W/m^2 \, ^oC$)	U_o ($W/m^2 \, ^oC$)

9. NOMENCLATURE:

Nom	Column Heading	Units	Type
A_i	Inside heat transfer area	m^2	Calculated
A_o	Outside heat transfer area	m^2	Calculated

C_{pc}	Specific heat of cold water at mean temperature	J/kg ^oC	Calculated
C_{ph}	Specific heat of hot water at mean temperature	J/kg ^oC	Calculated
D_i	Inner diameter of tube	m	Given
D_o	Outer diameter of tube	m	Given
F_c	Flow rate of cold water	LPH	Measured
F_h	Flow rate of hot water	LPH	Measured
L	Length of tube	m	Given
M_c	Mass flow rate of the cold water	kg/sec	Calculated
M_h	Mass flow rate of the hot water	kg/sec	Calculated
N	Number of tubes	*	Given
Q	Average heat transfer from the system	W	Calculated
Q_c	Heat gained by the cold water	W	Calculated
Q_h	Heat loss by the hot water	W	Calculated
T_1	Inlet temperature of the hot water	^oC	Measured
T_2	Outlet temperature of the hot water	^oC	Measured
T_3	Inlet temperature of the cold water	^oC	Measured
T_4	Outlet temperature of the cold water	^oC	Measured
T_c	Mean temperature of cold water	^oC	Calculated
T_h	Mean temperature of hot water	^oC	Calculated
U_i	Inside overall heat transfer coefficient	$W/m^2\,^oC$	Calculated
U_o	Outside overall heat transfer coefficient	$W/m^2\,^oC$	Calculated
ρ_c	Density of cold water at mean temperature	kg/m^3	Calculated
ρ_h	Density of hot water at mean temperature	kg/m^3	Calculated
ΔT_1	Temperature difference at inlet of hot water	^oC	Calculated
ΔT_2	Temperature difference at outlet of hot water	^oC	Calculated
ΔT_m	Log mean temperature difference	^oC	Calculated

* Symbols are unitless

10. PRECAUTION & MAINTENANCE INSTRUCTIONS:

10.1 Never run the apparatus if power supply is less than 200 volts and more than 230 volts.

10.2 Never switch ON mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.

10.3 Operator selector switch OFF temperature indicator gently.

10.4 Always keep the apparatus free from dust.

11. TROUBLESHOOTING:

11.1 If electric panel is not showing the input on the mains light, check the main supply.

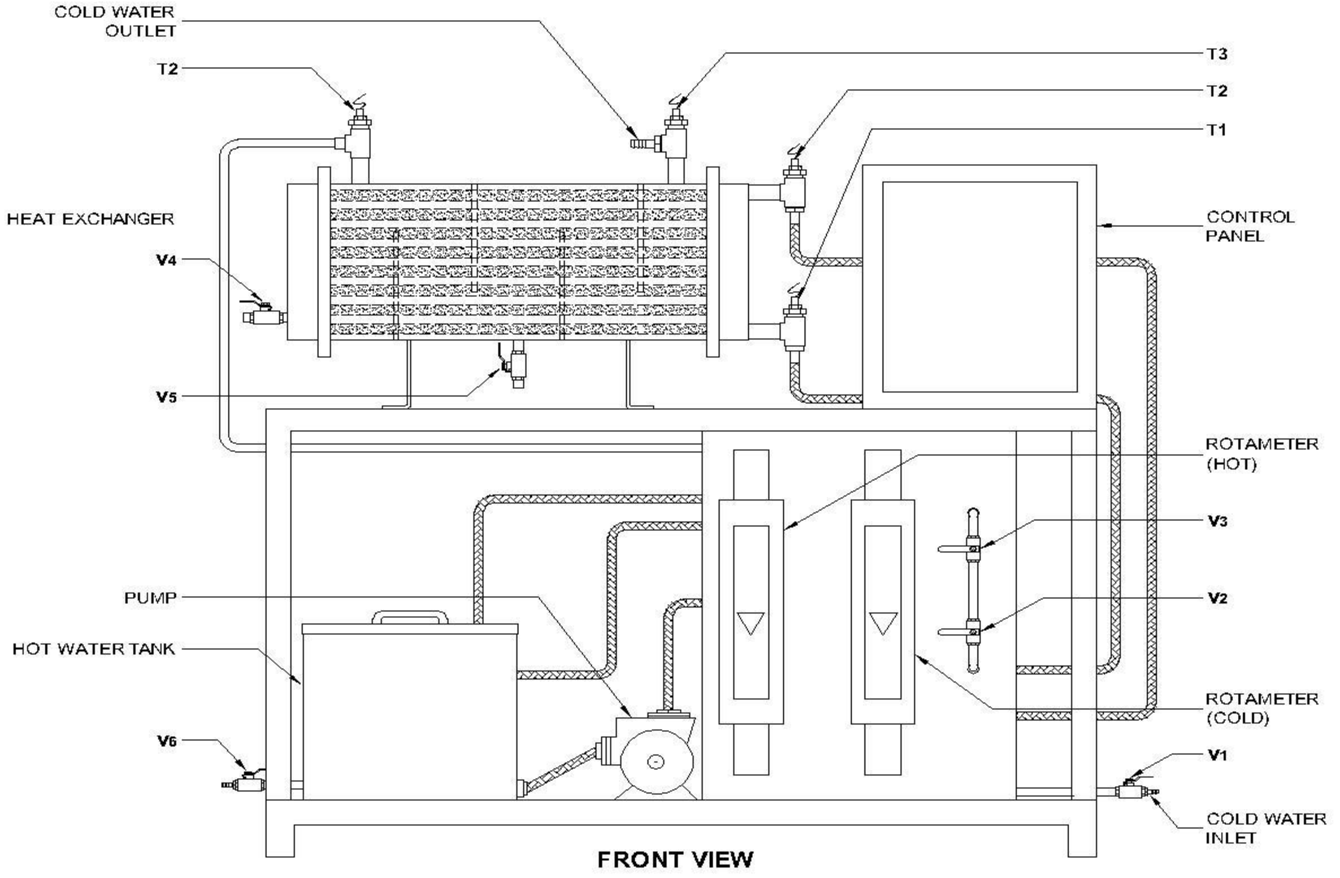
12. REFERENCES:

12.1 Holman, J.P (2008). *Heat Transfer*. 9th Ed. ND: McGraw Hill. pp 525-527, 528-531.

12.2 McCabe, Smith, Harriott (2005). *Unit Operations of Chemical Engineering*. 7th Ed. NY: McGraw Hill. pp 441-447.

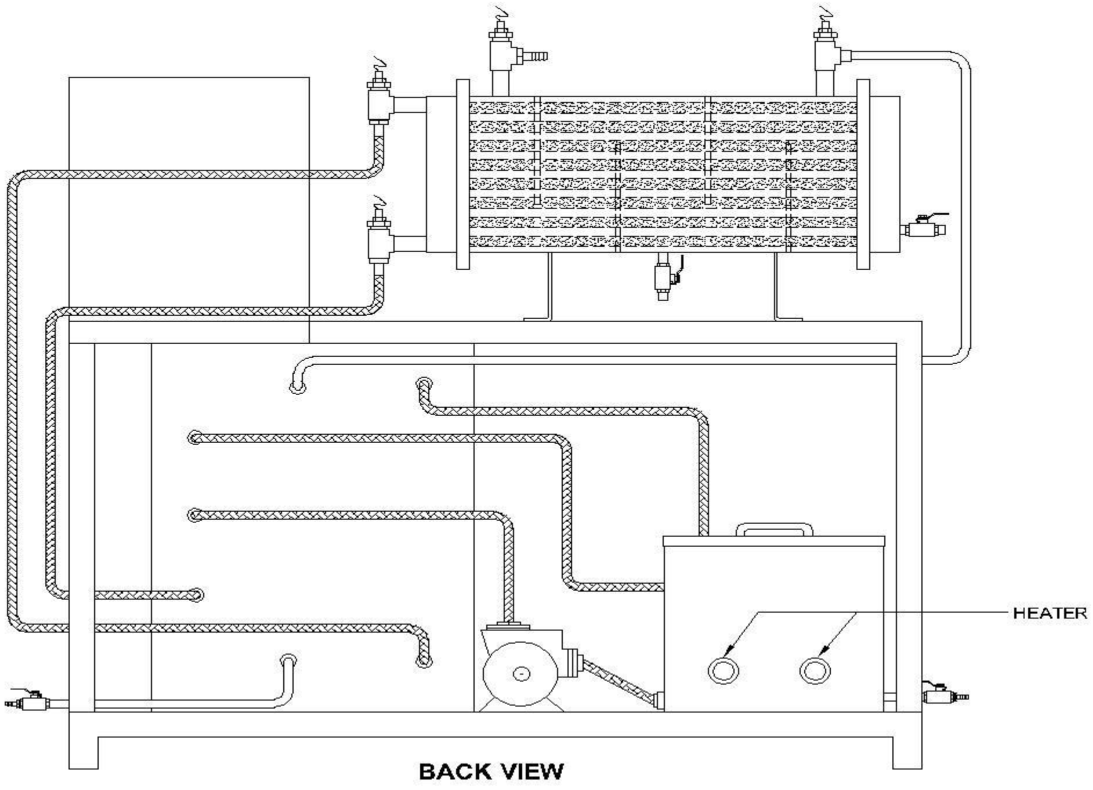
12.3 Domkundwar A (2003). *A Course in Heat & Mass Transfer*. 6th Ed. NY: S.C Dhanpat Rai & Co. (P) Ltd. p A.6

13. Block Diagram:



VALVE	
1.	V1 - COLD WATER FLOW CONTROL VALVE
2.	V2 - HOT WATER FLOW CONTROL VALVE
3.	V3 - HOT WATER BY PASS VALVE
4.	V4 - DRAIN VALVE FOR TUBES
5.	V5 - DRAIN VALVE FOR SHELL
6.	V6 - DRAIN VALVE FOR HOT WATER TANK

BLOCK DIAGRAM
NAME - SHELL & TUBE HEAT EXCHANGER
CODE - HT-115



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4.	V4 - DRAIN VALVE FOR TUBES
5.	V5 - DRAIN VALVE FOR SHELL
6.	V6 - DRAIN VALVE FOR HOT WATER TANK

BLOCK DIAGRAM
NAME - SHELL & TUBE HEAT EXCHANGER
CODE - HT-115

Engineering Growth Connection

THERMAL CONDUCTIVITY OF LIQUIDS (HT-107)

Foreword

Welcome to the fast growing family of K.C. product owners. We appreciate your interest in us and thank you for buying our product.

You have chosen the finest quality product in the market which is produced using latest techniques and has underwent strict quality control tests. It is a product that we are proud to build and you are proud to own it.

Our products are easy to understand and operate. They are excellent for students who are trying to gain practical knowledge through experiments.

However your comfort and safety are important to us, so we want you have an understanding of proper procedure to use the equipment. For the purpose, we urge you to read and follow the step-by-step operating instructions and safety precautions in this manual. It will ensure that your favourite product delivers reliable, superior performance year after year.

This manual includes information for all options available on this model. Therefore, you may find some information that does not apply to your equipment.

All information, specifications and illustrations in this manual are those in effect at the time of printing. We reserve the right to change specifications or design at any time without notice.

Customer satisfaction is our primary concern. Feel Free to contact us for any assistance. So what are you waiting for, roll up your sleeves and let us get down to work!

K.C. Engineers Pvt. Ltd.

Important Information About This Manual

Reminder for Safety

Modification on Equipment:

This equipment should not be modified. Modification could affect its performance, safety or disturbance. In addition damage or performance problems resulting from modification may not be covered under warranties.

Precautions and Maintenance:

This is used to indicate the presence of a hazard that could cause minor or moderate personal injury or damage to your equipment. To avoid or reduce the risk, the procedures must be followed carefully.

Contents

THERMAL CONDUCTIVITY OF LIQUIDS

1. OBJECTIVE:

To study the heat transfer through liquids.

2. AIM:

To calculate the thermal conductivity of a liquid.

3. INTRODUCTION:

When a temperature gradient exists in a body, there is an energy transfer from the high temperature region to the low temperature region. Energy is transferred by conduction and heat transfer rate per unit area is proportional to the normal temperature gradient.

$$\frac{q}{A} \alpha \frac{\Delta T}{\Delta X}$$

When the proportionality constant is inserted,

$$q = -kA\frac{\Delta T}{\Delta X}$$

Where q is the amount of heat transfer and ΔT/ΔX is the temperature gradient in the direction of heat flow. The constant k is called thermal conductivity of the material.

4. THEORY:

For thermal conductivity of liquids using fourier's law, the heat flow through the liquid from hot fluid to cold fluid is the heat transfer through conductive fluid medium.

Fourier's equation:

$$q = \frac{-kA}{\Delta X}(T_2 - T_1)$$

Fourier's law for the case of liquid

At steady state, the average face temperatures are recorded (T_h and T_c) along with the amount of heat transfer (Q) knowing, the heat transfer area (A_h) and the thickness of the sample (ΔX) across which the heat transfer takes place, the thermal conductivity of the sample can be calculated using fourier's law of heat conduction.

$$Q = kA\,\frac{(T_h - T_C)}{\Delta X}$$

$$k = \frac{Q \times \Delta X}{A \times (T_h - T_C)}$$

5. DESCRIPTION:

The apparatus consists of a heater, it heats a thin layer of liquid. Funnel is provided with valve for fill the liquid. Drain valve is given for maintain the liquid level. Plate is for circulation of water. Flow control vale is provided for control the flow of water. Six temperature sensors are provided to measure the temperature across the liquid layer.

6. UTILITIES REQUIRED:

6.1 Electricity Supply: Single Phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection.

6.2 Water Supply: Continuous @ 2 LPM at 1 Bar.

6.3 Floor drain required.

6.4 Bench area required: 1 m x 1 m.

7. EXPERIMENTAL PROCEDURE:

7.1 STARTING PROCEDURE:

7.1.1 Close all the valves V_1-V_3.

7.1.2 Connect continuous water supply to the inlet of water chamber.

7.1.3 Connect outlet of chamber to drain.

7.1.4 Open the valve V_2.

7.1.5 Fill the liquid (whose thermal conductivity have to be measure) through funnel till the liquid retain in funnel.

7.1.6 Adjust the valve V_3 to keep the liquid at axis level.

7.1.7 Ensure that mains ON/OFF switch given on the panel is at OFF position & dimmer stat is at zero position.

7.1.8 Connect electric supply to the set up.

7.1.9 Switch ON the mains ON / OFF switch.

7.1.10 Start the water supply and adjust the flow of water by valve V_1.

7.1.11 Set the heater input by the dimmer stat, voltmeter in the range 40 to 100 V.

7.1.12 After 1.5 hrs. note down the reading of voltmeter, ampere meter and temperature sensors in the observation table after every 10 minutes interval till observing change in consecutive readings of temperatures (± 0.2 ^oC).

7.1.13 Repeat the experiment for different liquids.

7.2 Closing Procedure:

7.2.1 When experiment is over set the dimmer stat to zero position.

7.2.2 Switch OFF the mains ON/OFF switch.

7.2.3 Switch OFF electric supply to the set up.

7.2.4 Stop flow of water by closing the valve V_1.

7.2.5 Drain the water by open the valve V_3.

8. Observation & Calculation:

8.1 Data:

Thickness of liquid ΔX	= 0.018 m
Diameter of plate D	= 0.165 m

8.2 Observation Table:

Sr. No	V (volts)	I (amp)	T_1 (^oC)	T_2 (^oC)	T_3 (^oC)	T_4 (^oC)	T_5 (^oC)	T_6 (^oC)

8.3 CALCULATIONS:

$$Q = V \times I \text{ (W)}$$

$$A = \frac{\pi}{4} D^2 \text{ (m}^2\text{)}$$

$$T_h = \frac{T_1 + T_2 + T_3}{3} \text{ (}^o\text{C)}$$

$$T_c = \frac{T_4 + T_5 + T_6}{3} \text{ (}^o\text{C)}$$

$$k = Q \frac{\Delta X}{A\,(T_h - T_c)} \text{ (W/m }^o\text{C)}$$

CALCULATION TABLE:

Sr. No	k (W/m ^{o}C)

9. NOMENCLATURE:

Nom	Column Heading	Units	Type
A	Heat transfer area	m^2	Calculated
D	Diameter of plate	m	Given
I	Ammeter reading	Amp	Measured
k	Thermal conductivity of liquid	W/m ^{o}C	Calculated
Q	Heat supplied by heater	W	Calculated
T_1-T_3	Temperature of the temperature sensors on the hot side	^{o}C	Measured
T_4-T_6	Temperature of the temperature sensors on the cold side	^{o}C	Measured
T_c	Cold face average temperature	^{o}C	Calculated
T_h	Hot face average temperature	^{o}C	Calculated
V	Volt meter reading	volts	Measured
ΔX	Thickness of liquid	m	Given

10. Precaution & Maintenance Instructions:

10.1 Never run the apparatus if power supply is less than 200 volts and more than 230 volts.

10.2 Never switch ON mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.

10.3 Operate selector switch of temperature indicator gently.

10.4 Always keep the apparatus free from dust.

11. Troubleshooting:

11.1 If electric panel is not showing input on the mains light, check the main supply.

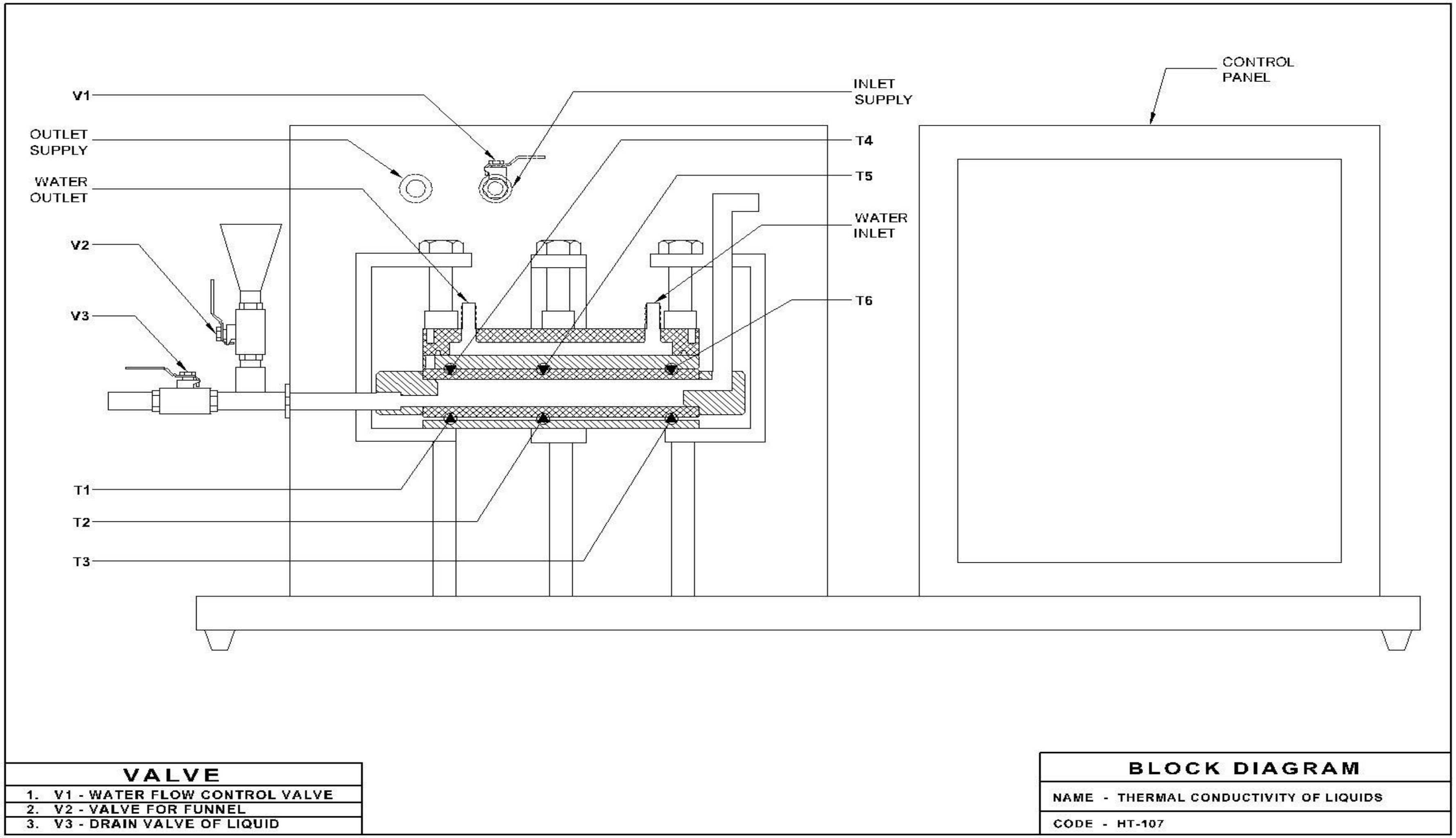
11.2 If voltmeter showing the voltage given to heater but ampere meter does not, check the connection of heater in control panel.

12. References:

12.1 Cengel, Y.A (2007). *Heat and Mass Transfer*. 3rd Ed. ND: Tata McGraw Hill. pp 17-19.

12.2 Kern, D.Q (2007). *Process Heat Transfer*. 16th Ed. ND: McGraw Hill. pp 6-9

13. BLOCK DIAGRAM:



THERMAL CONDUCTIVITY OF METAL ROD (HT-105)

Foreword

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Contents

THERMAL CONDUCTIVITY OF METAL ROD

1. OBJECTIVE:

To study the heat transfer through conduction in metal rod.

2. AIM:

2.1 To calculate the thermal conductivity of metal rod.

2.2 To plot the temperature distribution along the length of rod.

3. INTRODUCTION:

Thermal conductivity of substance is a physical property, defined as the ability of a substance to conduct heat. Thermal conductivity of material depends on chemical composition; state of matter, crystalline structure of a solid, the temperature, pressure and weather.

4. THEORY:

The heater will heat the rod on its one end and heat will be conducted through the rod to the other end. Since the rod is insulated from outside, it can be safely assumed that the heat transfer along the copper rod is mainly due to axial conduction and at steady state the heat conducted shall be equal to the heat absorbed by water at the cooling end. The heat conducted at steady state shall create a temperature profile within the rod. (T = f (x))The steady state heat balance at the rear end of the rod is:

Heat absorbed by cooling water,

$$Q = MC_p \Delta T$$

Heat conducted through the rod in axial direction:

$$Q = -kA\frac{dT}{dX}$$

At steady state:

$$Q = -kA\frac{dT}{dX} = MC_p \Delta T$$

So thermal conductivity of rod may be expressed as:

$$k = \frac{MC_p \Delta T}{-A\left(\frac{dT}{dX}\right)}$$

5. Description:

The apparatus consists of a metal rod, one end of which is heated by an electric heater while the other end of the rod projects inside the cooling water jacket. The middle portion of the rod is surrounded by a cylindrical shell filled with the asbestos insulating powder. Six temperature sensors are provided to measure temperature of rod at different section. The heater is provided with a dimmer stat for controlling the heat input. Water under constant head conditions is circulated through the jacket and its flow rate and temperature rise are noted by two temperature sensors provided at the inlet and outlet of the water.

6. Utilities Required:

6.1 Electricity Supply: Single Phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with Earth connection.

6.2 Water Supply: Continuous @ 2 LPM at 1 Bar.

6.3 Floor Drain Required.

6.4 Bench Area Required: 1m x 1m.

6.5 Stop watch.

7. Experimental Procedure:

7.1 Starting Procedure:

7.1.1 Close all the valves V_1-V_2.

7.1.2 Connect continuous water supply to the inlet of water chamber.

7.1.3 Ensure that mains ON/OFF switch given on the panel is at OFF position & dimmer stat is at zero position.

7.1.4 Connect electric supply to the set up.

7.1.5 Switch ON the mains ON / OFF switch.

7.1.6 Set the heater input by the dimmer stat, voltmeter in the range 40 to 100 V.

7.1.7 Open the valve V_1 and start the flow of water.

7.1.8 Start the stop watch and collect the water in measuring cylinder.

7.1.9 Note down the time and volume of water.

7.1.10 After 1.5 hrs. note down the reading of voltmeter, ampere meter and temperature sensors at every 10 minutes interval (till observing change in consecutive readings of temperatures ± 0.2 ^{o}C) .

7.2 Closing Procedure:

7.2.1 When experiment is over set the dimmer stat to zero position.

7.2.2 Stop the water supply by closing the valve V_1.

7.2.3 Switch OFF the mains ON/OFF switch.

7.2.4 Switch OFF electric supply to the set up.

7.2.5 Drain the water by open the valve V_2.

8. Observation & Calculation:

8.1 Data:

Specific heat of water C_p	= 4186 J/kg ^{o}C
Density of water ρ_w	= 1000 kg/m^3
Diameter of rod d	= 0.025 m
Distance of first temperature sensor (T_1) from the one end point of pipe X_1	= 0.035 m
Distance of second temperature sensor (T_2) from the one end point of pipe X_2	= 0.075 m
Distance of third temperature sensor (T_3) from the one end point of pipe X_3	= 0.115 m
Distance of fourth temperature sensor (T_4) from the one end point of pipe X_4	= 0.155 m
Distance of fifth temperature sensor (T_5) from the one end point of pipe X_5	= 0.195 m
Distance of sixth temperature sensor (T_6) from the one end point of pipe X_6	= 0.235 m

8.2 Observation Table:

V = ________ Volts						I = ________ Amp.					
Sr. No	F (ml)	t_1 (sec)	t (sec)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)	T_7 (°C)	T_8 (°C)

8.3 Calculations:

$$M = \frac{F \times \rho \times 10^{-6}}{t_1} \text{ (kg/sec)}$$

$$Q = MC_p(T_8 - T_7) \text{ (W)}$$

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

Plot a graph of temperature (T_1, T_2, T_3, T_4, T_5, T_6) vs. length (X_1, X_2, X_3, X_4, X_5, X_6)

and find slope $\left(\frac{dT}{dX}\right)$.

$$k = \frac{Q}{-A \times \left(\frac{dT}{dX}\right)} \text{ (W/m }^{o}\text{C)}$$

Calculation Table:

Sr. No.	Q (W)	k (W/m °C)

9. NOMENCLATURE:

Nom	Column Heading	Units	Type
A	Cross-sectional area of the metal rod	m^2	Calculated
C_p	Specific heat of water	J/kg ^oC	Given
d	Diameter of rod	m	Given
$\frac{dT}{dX}$	Slope of graph temperature (T_1, T_2, T_3, T_4, T_5, T_6) vs. length (X_1, X_2, X_3, X_4, X_5, X_6).	$^oC/m$	Calculated
F	Volume of water collected for flow measurement	ml	Measured
I	Ammeter reading	Amp	Measured
k	Thermal conductivity of metal rod	W/m ^oC	Calculated
M	Mass flow rate of cooling water	kg/sec	Calculated
Q	Heat gained by water	W	Calculated
t	Time	sec	Measured
T_1-T_6	Temperature of metal rod along the length from heater to cooling jacket	^oC	Measured
T_7	Inlet temp of cold water	^oC	Measured
T_8	Outlet temp of cold water	^oC	Measured
t_1	Time taken to collect volume of water	sec	Measured
V	Volt meter reading	volts	Measured
X_1	Distance of first temperature sensor (T_1) from the one end point of pipe	m	Given
X_2	Distance of second temperature sensor (T_2) from the one end point of pipe	m	Given
X_3	Distance of third temperature sensor (T_3) from the one end point of pipe	m	Given
X_4	Distance of fourth temperature sensor (T_4) from the one end point of pipe	m	Given
X_5	Distance of fifth temperature sensor (T_5) from the one end point of pipe	m	Given
X_6	Distance of sixth temperature sensor (T_1) from the one end point of pipe	m	Given
ρ_w	Density of water	kg/m^3	Given

10. PRECAUTION & MAINTENANCE INSTRUCTIONS:

10.1 Never run the apparatus if power supply is less than 200 volts and more than 230 volts.

10.2 Never switch ON mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.

10.3 Operate selector switch of temperature indicator gently.

10.4 Always keep the apparatus free from dust.

11. TROUBLESHOOTING:

11.1 If electric panel is not showing the input on the mains light. Check the main supply.

11.2 If voltmeter showing the voltage given to heater but ampere meter does not, check the connection of heater in control panel.

12. REFERENCES:

12.1 D.S Kumar, **"Heat & Mass Transfer"**, 7th ed, S.K Kataria & Sons, ND, 2008, Page 5.

13. Block Diagram: