IPS Academy, Indore

Institute of Engineering & Science

Mechanical Engineering Department

LAB MANUAL

Heat & Mass Transfer

(ME-501)

Name ………………………………………………

Session ……………Semester ……………………..

Enrollment No. ……………………………………..

Contents

Vision of the Institute

To be the fountainhead of novel ideas & innovations in science & technology & persist to be a foundation of pride for all Indians.

Mission of the Institute

M1: To provide value based broad Engineering, Technology and Science where education in students are urged to develop their professional skills.

M2: To inculcate dedication, hard work, sincerity, integrity and ethics in building up overall professional personality of our student and faculty.

M3: To inculcate a spirit of entrepreneurship and innovation in passing out students.

M4: To instigate sponsored research and provide consultancy services in technical, educational and industrial areas.

Vision of the Department

To be a nationally recognized, excellent in education, training, research and innovation that attracts, rewards, and retains outstanding faculty, students, and staff to build a Just and Peaceful Society.

Mission of the Department

M1: Imparting quality education to the students and maintaining vital, state-of-art research facilities for faculty, staff and students.

M2: Create, interpret, apply and disseminate knowledge for learning to be an entrepreneur and to compete successfully in today's competitive market.

M3: To inculcate Ethical, Social values and Environment awareness.

Program Education Objectives (PEOs)

PEO1: To enrich graduates with fundamental knowledge of Physics, Chemistry and advanced mathematics for their solid foundation in Basic Engineering science.

PEO2: To provide graduates to design the solution of engineering problems relevant to mechanical engineering design through the process of formulating, executing & evaluating a design solution as per need with socio-economic impact consideration and related constraints.

PEO3: To provide graduates with experience in learning and applying tools to solve theoretical and open ended mechanical engineering problems.

PEO4: To provide a contemporary grounding in professional responsibility including ethics, global economy, emerging technologies and job related skills such as written and oral communication skills and to work in multidisciplinary team.

PEO5: Prepare graduates to be interested, motivated, and capable of pursuing continued life-long learning through beyond curriculum education, short term courses and other training programme in interdisciplinary areas.

Program Outcomes (POs)

Engineering Graduates will be able to:

PO1: Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of Mechanical engineering problems.

PO2: Problem analysis: Identify, formulate, and analyze mechanical engineering problems to arrive at substantiated conclusions using the principles of mathematics, and engineering sciences.

PO3: Design/development of solutions: Design solutions for mechanical engineering problems and design system components, processes to meet the specifications with consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO4: Conduct investigations of complex problems: An ability to design and conduct experiments, as well as to analyze and interpret data.

PO5: Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to mechanical engineering problems with an understanding of the limitations.

PO6: The engineer and society: Apply critical reasoning by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the Mechanical engineering practice.

PO7: Environment and sustainability: Understand the impact of the Mechanical engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO8: Ethics: An understanding of professional and ethical responsibility.

PO9: Individual and teamwork: Function effectively as an individual, and as a member or leader in teams, and in multidisciplinary settings.

PO10: Communication: Ability to communicate effectively. Be able to comprehend and write effective reports documentation.

PO11: Project management and finance: Demonstrate knowledge and understanding of engineering and management principles and apply this to Mechanical engineering problem.

PO12: Life-long learning: ability to engage in life-long learning in the broadest context of technological change.

Program Specific Outcomes (PSOs)

PSO1: Engage professionally in industries or as an entrepreneur by applying manufacturing and management practices.

PSO2: Ability to implement the learned principles of mechanical engineering to analyze, evaluate and create advanced mechanical system or processes.

Course Outcomes (COs)

CO1 Define the basics of mechanism and their inversions and able to show the displacement, velocity and acceleration in different mechanisms.

CO2 Apply different principles and methods for kinematic and dynamic analysis of mechanisms.

CO3 Classify cams and followers & analyze the cam design.

CO4 Elaborate different modes of power transmission and use of friction in power transmission.

CO5 Classify different types of gears and evaluate their working in various gear trains. Also make use of balancing and vibration in mechanical systems.

Content beyond syllabus

1. Heat Pipe

Laboratory Regulations and Safety Rules

1. Read the instructions mentioned in the manual carefully and then proceed for the experiment.
2. Mishandling of lab equipment will not be tolerated at all. If any student is found guilty; he/she should be punished/ discarded from the lab.
3. Care must be taken while dealing with electrical connections.
4. Issued the needed/ supporting equipments by the concerned teacher/Lab. Technician & return the same duly before leaving the lab.
5. If any defect or discrepancy noticed in the particular instrument/equipment while the students are using, they will be fined/ punished for the same.
6. Put your bags on the rack outside the lab before entering in lab.
7. Switch off the lights, fans and all the equipments used, before leaving lab.
8. Students will replace their chairs to its specific position before leaving the lab.

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S. No.	Experiment Name	Date	Grade	Signature
1.	To determine the thermal conductivity of metal rod.			
2.	To determine the equivalent thermal conductivity of composite wall.			
3.	To determine the heat transfer coefficient in natural convection.			
4.	To determine the heat transfer coefficient in force convection.			
5.	To determine the heat transfer coefficient with the help of Stefan Boltzmann Apparatus.			
6.	To determine the heat transfer coefficient in Finned Tube Heat Exchanger.			
7.	To demonstrate the film-wise and drop-wise condensation and determination of heat transfer coefficient.			
8.	To calculate emissivity of the test plate by emissivity measurement apparatus.			
9.	To determine the heat transfer characteristics of a shell and tube Heat Exchanger.			
10.	To observe pool boiling phenomena and to determine the critical heat flux at different bulk temperature.			

Experiment No. 1

Object: To determine the thermal Conductivity of Metal Rod.

Introduction: Thermal conductivity is the physical property of the material denoting the case 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 substance or substances of which it is a composed the phase (i.e. gas, liquid or solid) in which it exist, it’s crystalline structure if a solid, the temperature & pressure to which it is subjected, & whether or not it is a homogenous material.

Apparatus: The experimental set up consists of a metal bar, one end of which is heated by an electric heater while the other end of bar projects inside the cooling water jacket. The middle portion of the bar is surrounded by cylindrical shell filled with insulating material. The temperature of the bar is measured at 6 different sections. While the radial temperature distribution is measured by separate thermocouples at two different sections in the insulating shell. The heater is provided with a dimmer stat for controlling the heat input. Water circulated through the jacket & flow temperature rise are noted.

Specification:

1. Length of the metal bar (total) - 500 mm.(appr)
2. Diameter of metal bar - 27.0 mm
3. No. of thermocouples mounted on the bar - 5
4. No. of thermocouples in the insulation shell - 2
5. Heater - Band type
6. Cooling jacket diameter - 103 mm
7. No. of thermocouples for water with chromal Alumal thermocouples.
   a. Position 1 to 5 - on the bar
   b. Position 6 to 7 - in the shell
   c. Position 8 to 9 - cooling water in & out
8. Dimmer stat for heat input - 2A

9. Voltmeter - 0-300 V
10. Ammeter - 0-5A

Procedure:

1. Start the supply.
2. Give input to heater by slowly rotating the dimmer stat & adjust it to 80 to 120 V
3. Start the cooling water supply through the jacket & kept valve fully open.
4. Go on checking the temperature after time intervals of 10 minutes & continue this till a steady state condition is reached.
5. Note the temperature readings 1 to 9
6. Note the mass flow rate of water.

Observations:

1. Diameter of metal bar - 27.0 mm
2. Material used - Copper.
3. Distance between two thermocouple - 40 mm
4. Area of metal bar - 286.39 X 10-4 m^2
5. Input voltage - V
6. Input current - A

Observation Table:

Temperatures Location	Time in minutes							
	10	20	30	40	50	60	70	80
1.								
2.								
3.								
4.								
5.								
6.								

7.								
8.								
9.								

Calculation

1. Power Supplied P

   P = V x I watts

   V = Voltage in Volts.

   I = Current in Temp.

2. Q = K x A x dt/dx General equation

   dt/dx = Temperature Gradient

   A = Area of rod in m^3

   Q = Power of rod in W

   K = Thermal Conductivity of Metal Rod W/m°K

3. Actual heat supplied

   Q_{act} = Power supplied – Heat dissipated to water – heat lost to Asbestos (Section AA, BB)

   = (VxI) – ($mc_p dt$) – $\frac{(2LK)dt}{\log(r_2/r_1)}$

4. Q = K x A x dt/dx

   dt = T_1-T_6

   r_2 = 100 mm

   r_1 = 50 mm

   L = 0.330 m (Length of shell)

   K = 0.22 w/m k (Ashes Powder)

   dx = 0.30 m

Result:

Precaution:

1. Operate selector switches of temperature indicator gently.
2. See the dimmer stat knob is on zero before starting the unit.
3. Never exceed dimmer above 120 V.

Questions

Q.1What is the value of thermal conductivity of silver.

Q.2 Is the value of thermal conductivity of liquid is greater than solid

Experiment No. 2

Aim: To determine the equivalent thermal conductivity of composite wall.

Introduction: Many engineering applications of practical utility involve heat transfer through a medium composed of two or more materials of different thermal conductivities arranged in series or parallel. Consider for example the walls of a refrigerator, hot cases, cold storage plants, hot water tank etc. Which always have some kind of insulating material between the inner and outer wall. A hot fluid flow inside the tube covered with a layer of thermal insulation is another example of composite system because in this case the thermal conductivities of tube metal and insulation are different. The problem of heat transfer through the composite system can be solved by the application of the thermal resistance concept.

The Procedure for solving one dimensional, steady state heat conduction problems for composite system comprising parallel plates, co axial cylinders or concentric spheres are dealt here.

Procedure:

1. Check the pressure applied to the plate manually.
2. Switch on the supply.
3. Give known steady input to the heater with the help of dimmer stat.
4. Keep initially 100v for 20 minutes almost and then reduce to 80 V till.
   Steady state is reached so that steady state can be reached within less time
5. Check the input to the heater with selector switch, Voltmeter & ammeter.
6. Note down the temperature every 5 minutes till a steady condition is reached.
7. Calculate the thermal resistance of the material based on the steady state condition readings.

Observation:

1. Diameter of slab = 0.3 m
2. Thickness of Backelite plate = 0.012 m
3. Thickness of Press Wood plate = 0.012 m
4. Thickness of MS Plate = 0.012 m
5. Temperature indicator = 0 - 300 °C
6. Ammeter = 0 – 5 A

7. Voltmeter = 0 – 300 V
8. Input Voltage (V) = 75 Volt
9. Input current (I) = 0.60 amp

Observation Table:

THERMOCOUPLE LOCATION	TIME									
T_1										
T_2										
T_3										
T4										
T_5										
T_6										
T_7										
T_8										

Calculation:

$$q_1 = \frac{VxI}{2}$$

V = Volume Reading (V)

I = ammeter reading (A)

L = Thickness of specimen (m)

A = Area of specimen (m^2)

K = Thermal Conductivity of Specimen

R = thermal resistance

$$q_2 = \frac{dt}{R} \text{ W/m}^2$$

But A_1, A_2, A_3 are Equal = A

$$T_a = (T_1+T_2)/2$$

$\mathbf{T_d = (T_7+T_8)/2}$

$$q_2 = \frac{T_a - T_d}{(L/A)\left(\frac{1}{K_1}+\frac{1}{K_2}+\frac{1}{K_3}\right)}$$

$$(L/A)\left(\frac{1}{K_1}+\frac{1}{K_2}+\frac{1}{K_3}\right) = R =$$ **Thermal resistance**

$\mathbf{dt = T_a - T_d}$

K_1 (MS) = 48 W/mK

K_2 (BKT) = 0.7 W/mK

K_3 (PW) = 0.2 W/mK

$$K = \frac{q_2 * dx}{A * dt}$$

$\mathbf{R_{the} = 1/K}$

dx =0.036
A = $0.07 m^2$
$dt = T_a - T_d$

Result:

Precautions:

1. Keep the dimmerstat at zero position before switch on the power supply.
2. Increase the voltage gradually.
3. Operate selector switch of temperature indicator gently.
4. Do not exceed 120 volts so as to avoid the fluctuating results.

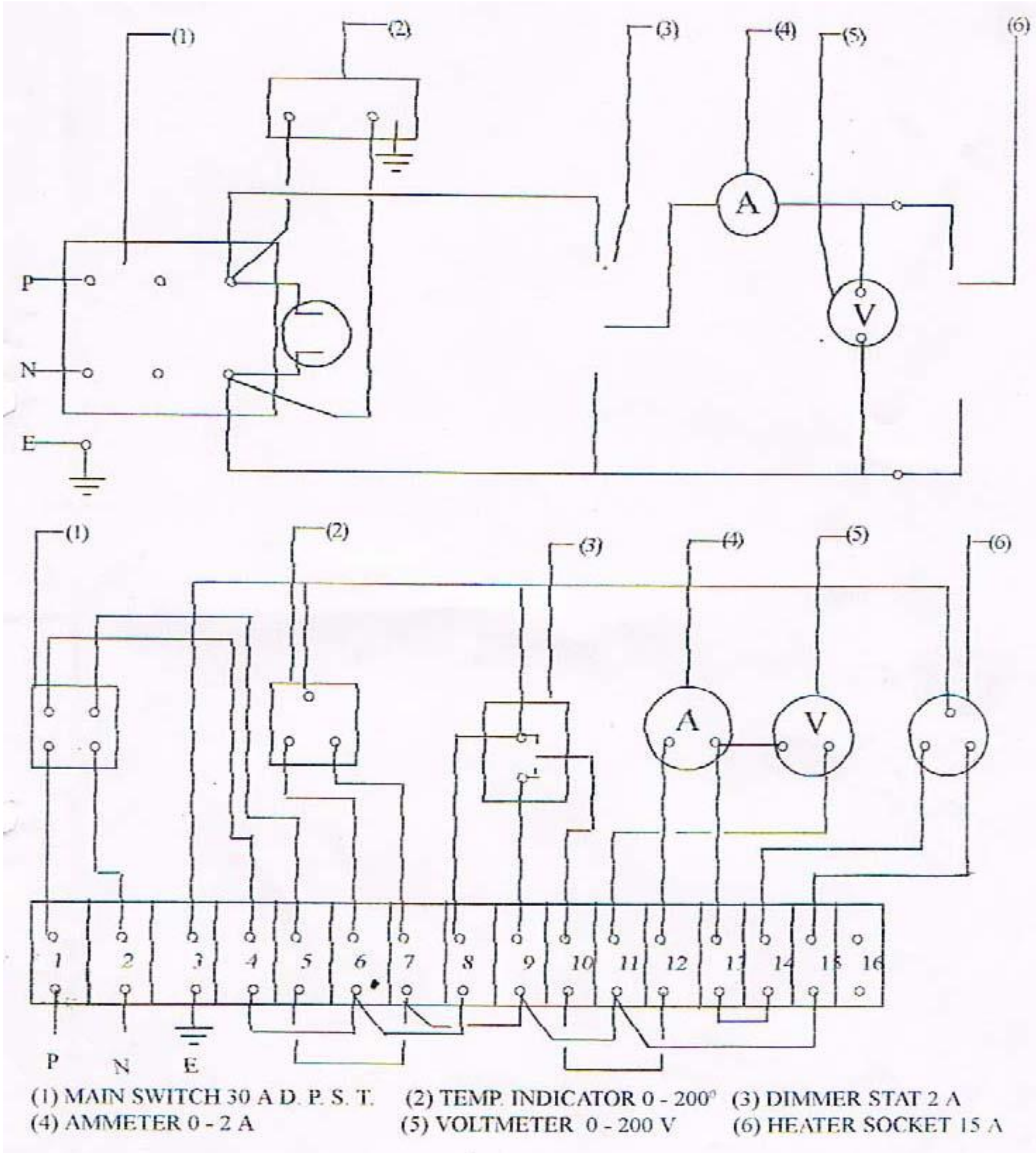


Fig. 3 Control Panel diagram of Composite Wall Apparatus

Questions:

Q.1 What do you mean by thermal conductivity?

Q.2 what is the value of thermal conductivity of air?

Experiment No.3

Aim: To determine the heat transfer coefficient in force convection by air.

Apparatus: The apparatus consists of blower unit fitted with the test pipe. The test section is surrounded by microbe band heater. Six thermocouples are placed in the air system at the entrance & exit of the test section & two thermocouples are embedded on the test section to measure the air temperature. Test pipe is connected to the delivery side of the blower along with the orifice to measure flow of air through the pipe. Input to the heater is given through a dimmer stat & measured by voltmeter & ammeter. A temperature indicator is provided to measure temperatures of pipe wall in the test section. Air flow is measured with the help of orifice meter & the water manometer fitted on the panel.

Specification:

1.	Delivery pipe diameter	- Di =	0.036 m
2.	Length of test section	- L =	0.45 m
3.	Blower	-	
4.	Orifice diameter	-	0.014 m
5.	Dimmerstat	-	
6.	Voltmeter	-	0- 300 V
7.	Ammeter	-	0 – 5A
8.	Thermocouples	-	Chromel - Alumel
9.	Temperature Indicator	-	0-300 ^{0}C
10.	Heater	-	Nichrome wire heater wounded on test

Procedure:

1. Start the supply.
2. Start the blower & adjust the flow by means of valve to some desired difference in manometer level. (preferably open control valve fully)
3. Start the heating of the test section with the help of dimmerstat & adjust desired heater input with the help of voltmeter & ammeter.(100 V)
4. Take the reading of all 8 thermocouples at an interval of 5 minutes until the study state is reached.

5. Also note down the heater input (in terms of voltage & current)

Thermo Couple Position:

$T_1 - T_6$ = Temperature of pipe wall in the test section.

T_7 = Air inlet temperature

T_8 = Air outlet temperature

Observations:

1. Input voltage = Volts
2. Input current =
3. Manometer reading H = m

Observation Table:

Temperatures	**Time**				
T_1					
T_2					
T_3					
T_4					
T_5					
T_6					
T_7					
T_8					

Calculation:

1. Bulk means Temperature of air

$$T_{bm} = \frac{(T_i + T_o)}{2} \ ^\circ C$$

We have following properties of air at T_{Bm}

ρ_a = Kg/m^3

Cp_a = KJ/Kg ^{0}K

Take these values from chart which is provided at the end

2. Calculation for discharge of air $Q_a(air) = C_d \times a_1 \times a_2 \sqrt{\frac{2gh \times \rho_w \rho_a}{a_1^2 - a_2^2}}$

dt/dx = Temperature Gradient

a_1 = Area of delivery pipe in $m^2 = 1.01 * 10^{-3}$

a_2 = area of orifice in $m^2 = 1.54*10^{-4}$ m^2

C_d = 0.65

ha = manometer reading in meter

g= 9.81 m/s^2

ρ_w = density of water 1000 kg/m^3

ρ_a = density of air at T_{bm} .

3. Mean mass flow rate of air (m)

$m = Q_n \times \rho_a$

4. Heat of air (q) kW

$q = m \times C_{pa} \times (To-Ti)$

5. heat transfer coefficient (h)

$$h = \frac{q}{A(T_s - T_{bm})} \text{ W/m}^2\text{K}$$

Where,

A = area of test section = π.d.L

d = 36 mm

L = 450 mm

$Ts = (T_1+T_2+\ldots\ldots\ldots..+T_6)/6$ ^{0}C

Result:

Precaution:

1. Keep the dimmer stat at zero position before switch on the power supply.
2. Increase the voltage gradually.
3. Do not stop the blower in between testing period.
4. Operate selector switch of temp. Indicator gently.
5. Do not exceed 100volts so as to avoid fluctuating results.

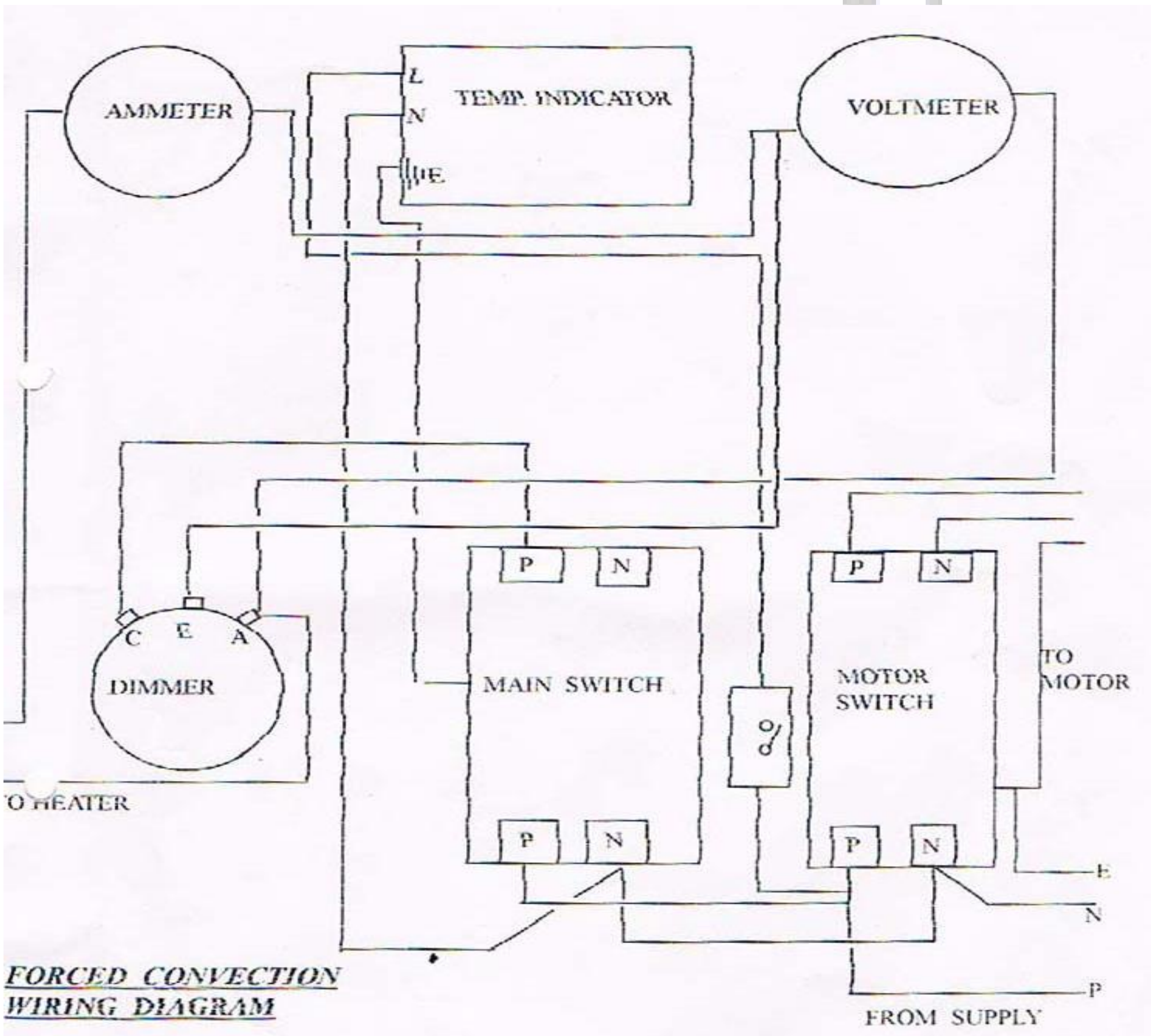
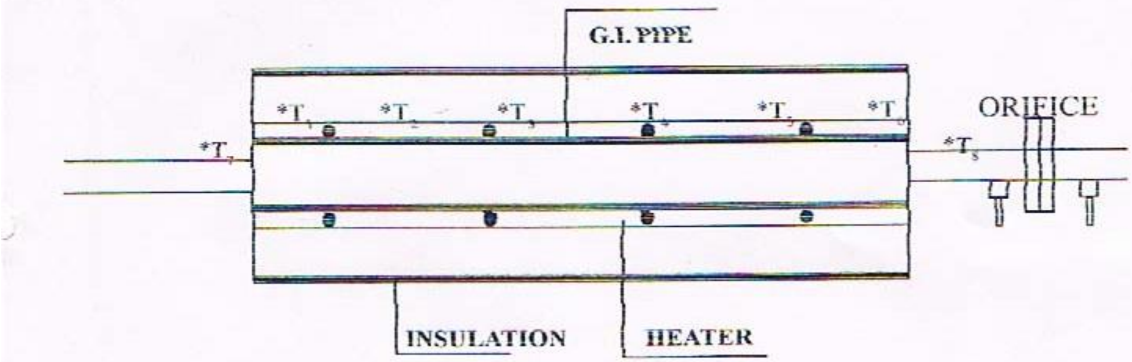


Fig. 1: Forced Convection Wiring



Distance between each thermocouple = 0.08 m

Fig. 1.1: Forced Convection Showing Thermocouple Location

Table A.2 Properties of Dry Air at Atmospheric Pressure

T	ρ	C_p	$\mu \times 10^{6}$	k	Pr	$\nu \times 10^{6}$
°C	kg/m³	kJ/kg-K	N-s/m²	W/m-K		m²/s
0	1.293	1.005	17.2	0.0244	0.707	13.28
10	1.247	1.005	17.7	0.0251	0.705	14.16
20	1.205	1.005	18.1	0.0259	0.703	15.06
30	1.165	1.005	18.6	0.0267	0.701	16.00
40	1.128	1.005	19.1	0.0276	0.699	16.96
50	1.093	1.005	19.6	0.0283	0.698	17.95
60	1.060	1.005	20.1	0.0290	0.696	18.97
70	1.029	1.009	20.6	0.0297	0.694	20.02
80	1.000	1.009	21.1	0.0305	0.692	21.09
90	0.972	1.009	21.5	0.0313	0.690	22.10
100	0.946	1.009	21.9	0.0321	0.688	23.13
120	0.898	1.009	22.9	0.0334	0.686	25.45
140	0.854	1.013	23.7	0.0349	0.684	27.80
160	0.815	1.017	24.5	0.0364	0.682	30.09
180	0.779	1.022	25.3	0.0378	0.681	32.49
200	0.746	1.026	26.0	0.0393	0.680	34.85
250	0.674	1.038	27.4	0.0427	0.677	40.61
300	0.615	1.047	29.7	0.0461	0.674	48.33
350	0.566	1.059	31.4	0.0491	0.676	55.46
400	0.524	1.068	33.0	0.0521	0.678	63.09
500	0.456	1.093	36.2	0.0575	0.687	79.38
600	0.404	1.114	39.1	0.0622	0.699	96.89
700	0.362	1.135	41.8	0.0671	0.706	115.4
800	0.329	1.156	44.3	0.0718	0.713	134.8
900	0.301	1.172	46.7	0.0763	0.717	155.1
1000	0.277	1.185	49.0	0.0807	0.719	177.1

Table: 1 Properties of Dry Air at Atmospheric Pressure

Questions:

Q.1 What do you mean by forced convection

Q.2 Is the forced convection only function of N_{re} Number.

Experiment No. 4

Aim: To determine heat transfer coefficient in natural convection

Apparatus: The apparatus consist of a brass tube fitted in a rectangular duct in a vertical fashion. The duct is open at the top and bottom and forms an enclosure and serves the purpose of undisturbed surrounding.Once side of the duct is made up of Perspex for visualization. An electric heating element is kept in the vertical tube which is intern heats the tube surface. The heat is lost from the tube to the surrounding air by natural convection. The temp of vertical tube is measured by seven thermocouples. The heat input of the heater is measured by an ammeter and voltmeter is varied by dimmerstat. The vertical cylinder with the thermocouples position as shown in fig1

Specification:

1. Diameter of tube : 38mm

2. Length of the tube : 530mm

3. No of thermocouples: 7 are shown as 1 to 7 and marked on temperature indicator switch

4. Thermocouple no 8 reads the temp of air in the duct

5. Temp indicator : 0-300 def C

6. Ammeter : 0-5A

7. Voltmeter : 0-300 V

8. Dimmerstat : 2A

Procedure:

1. Put on the supply and adjust the dimmerstat to obtain the required heat input.

2. Wait till the fairly steady state reached, which is confirmed from temperature readings (T_1-T_7)

3. Note down surface temperature at various points (T_1-T_7)

Observations:

1. O.D. of the cylinder (d) 38mm

2. Length of the cylinder 530mm

3. Input voltage

4. Input Current

Observation Table:

Thermocouple Location	**Time in min**					
1						
2						
3						
4						
5						
6						
7						
8 (T_a)						

Calculation:

Calculate the value of average heat transfer coefficient using equation

$$h_a = \frac{q}{As\ X\ [Ts - Ta]}\ \mathbf{W/m^2K}$$

Where,

h_a = Heat Transfer Coefficient

q = V×I

As = Surface area of cylinder in $m^2 2\pi rl$

R = Radius of pipe

l = length of pipe

T_s = Average of the surface temperature i.e. T_1-T_7

T_a = Ambient temperature i.e. T_8

Precautions:

1. Before starting the unit, keep dimmerstat are to zero volt position and increase it slowly.

2. Operate Selector switch of temperature indicator gently.

3. Never exceed 100 volts.

Questions

Q.1 what is the unit of heat transfer coefficient?

Q.2 Differentiate between free and forced convection.

Experiment No.5

Aim: To determine the heat transfer coefficient with the help of Stefan Boltzmann Apparatus.

Description: The apparatus consists of a flanged copper hemisphere fixed to a flat back elite plate, the outer surface of which, forms the jacket to heat it. Thermocouples are used to measure the temperature of the enclosure. Water heating tank is provided to supply hot water. A disc about 2 cm in diameter is introduced from the backelite base & its temperature is measured by thermocouples. The inner surface of the enclosure, base & disc are blackened to make their absorptivity equal to unity. When the enclosure is in equilibrium at temperature T, the radiant energy absorbed by disc equals the radiant energy it emits,

$$Q = \sigma A_d T^4$$

Where, A_d is the area of the disc.

If disc is reinserted at a later time when its temp. is T_1.

Then,

$$Q_1 = \sigma A_d (T^4 - T_1^4)$$

$$Q - Q_1 = \sigma \; Ad$$

If disc D has mass m & specific heat C then after a short time after Disc is inserted.

$$m.C \frac{dT}{dt} = \sigma A_d (T^4 - T_1^4)$$

$$\sigma = \frac{m \times C \times \frac{dT}{dt}}{A_d (T^4 - T_1^4)}$$

Where, dT/dt is the rise of temp of Disc at the instant when its temperature is T & it will be tangent at t = 0 of the curve between T & T_1.

Specification:

1.	Hemisphere dia.	-	0.2	m
2.	Base backelite plate	-	0.3	m
3.	Test disc dia.	-	0.02	m
4.	Thickness of test disc	-	0.002	m

5. Thermocouples on hemisphere - 4 Nos
6. Water tank of 8 liter capacity with immersion
7. Thermocouple on test disc - 1 no.
8. Temp indicator

Procedure:

1. First boil the water in the water tank with the help of immersion heater up to boiling temperature. (T_6 = 92 -95°C)
2. Then insert test disc in the backelite ; if not inserted (test disc is blackened totally)
3. Drop the boiled water on the hemisphere.
4. Take of test disc. i.e. T_5 when it starts increasing; with the help of the stop watch should after every 10 sec. till the steady state it reached i.e. 5 consequent readings should indicate same temp. (Approximately it takes 120 seconds.)
5. Immediately take the readings of thermocouples on the hemisphere.

Reasons for Low Value of Stefen's Boltzmann Constant:

1. There is no vacuum provided for the experimentation.

Observation:

1. Diameter of the test disc- d = 0.020 m
2. Mass of the test disc- m = 0.007 kg
3. Specific heat of test disc (Brass) C = 877 J/Kg k
4. Area of Test Disc- A_d = 3.14×10^{-4} m^2

Observation Table:

For Test Disc:

Thermocouple Location	Time in Sec.								
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
T_5									

For Hemisphere:

S. No.	Water Temp. (T_6)	Temp of the hemisphere			
		T_1	T_2	T_3	T_4

Calculations:

For calculating the Stefan Boltzmann Constant following equation is unused.

$$\sigma = \frac{m \times C \times \frac{dT}{dt}}{A_d\,(T^4 - T_a^4)}$$

Where,

σ - Stefan Boltzman Constant.

m - Mass of the test disc in Kg.

C - Specific heat of test disc (Brass)

A_d - Area of the test disc ($\frac{\pi}{4} \times d^2$)

T - Mean temp. of hemisphere. i.e.

$$T = \frac{(T_1 + T_2 + T_3 + T_4)}{4}$$

T_a = Avg. Temp. of test disc. i.e. T_5

$dT = T_{final} - T_{initial}$

T_{final} = Stead state reading of test disc

$T_{initial}$ = Temp. of disc from which it starts increasing

dt = Total time required for achieving the steady state from the time when temp. of the disc starts increasing.

Calculations:

Result:

Precaution:

1. Operate the selector switch of the temperature indicator gently.
2. Stir the water with stirrer before taking the reading. (Inside the water tank)

Questions

Q.1What is the value of Stefan–Boltzmann constant.

Q.2 State Stefan's Boltzmann Law.

Experiment No.6

Aim: To determine the heat transfer coefficient in Finned Tube Heat Exchanger.

Introduction: The heat which is conducted through a body must frequently be removed by some convection process. For example, the heat lost by conduction through a furnace wall must be dissipated to the surroundings through convection. In heat exchanger application, a finned tube arrangement might be used to remove heat from a hot fluid.

Theory: Finned tube heat exchangers are also known as extended surface heat exchangers in which outside area of tube is extended by fins and the outside area in contact with fluid thereby made much larger than the inside area. The fluid having the lower coefficient is brought into contact with extended surface and flows outside the tube while other fluid, having high coefficient, flows through the tubes.

Overall Heat Transfer Coefficient can be calculated by the formulae:

$$U = \frac{Q_{avg}}{A_o \ \ \Delta Tm}$$

Description: Present set up consist of horizontal finned tube double pipe heat exchanger. Hot water flows through the inner tube while cold water through annular space between inner tube and outer tube. Equipment can be operated in parallel are counter mode by changing the direction of cold water flow. Proper valve arrangement is provided to change the mode of operation. Water bath, made of SS is provided with heater and temperature sensor for hot water. Temperature of Welter in bath is maintained by Digital Temperature Controller. Hot and cold water flow rate are measured by separate Rotamater. Temperatures of hot and cold water are measured by digital temperature indicator provided with multi channel switch.

Experimental Procedure:

Starting Procedure:

1. Clean the apparatus and make water b"\tr. free from dust.
2. Close all the drain valves provided.
3. Fill water bath ¾ with clean water and ensure that no foreign particles are there.
4. Connect the cold water supply to valve provided before cold water Rotameter.
5. Ensure that all ON/OFF switches given on the panel are at OFF position.

6. Select the mode, parallel or counter flow and operate the ball Valves, given on the waterline, accordingly.
7. Switch ON heater by operating rotary switch given on the panel.
8. Set temperature of the water bath with the help of Digital Temperature Controller.
9. Open Flow Control Valve and By-Pass Valve for hot water supply.
10. Switch ON Magnetic Pump for hot water supply.
11. Adjust hot water flow rate with the help of Flow Control Valve and Rotameter.
12. Record the hot & cold water flow rate with *the* help of Rotameter.
13. Record the temperatures of hot and cold fluid inlet & outlet when steady state is achieved.
14. For second run again fix the valve position for parallel or counter.

Closing Procedure:

1. When experiment is over, switch OFF heater first.
2. Switch OFF Magnetic Pump for hot water supply.
3. Switch OFF power supply to panel.
4. Stop cold water supply.
5. Drain water bath with the help of Drain valve.

Observation & Calculation:

Data:

π	=	3.1416
D_o	=	0.064 m
D_i	=	0.02 m
L	=	1 m
Y	=	0.022 m
N_f	=	8

Observation Table:

S. No.	F_c LPH	F_h LPH	T_{hi} °C	T_{ho} °C	T_{ci} °C	T_{co} °C
1.						
2.						
3.						
4.						
5.						

$$Q_{avg} = \frac{Q_c + Q_h}{2}$$, W = -------------------- W

$$\Delta T_m = \frac{(\Delta T_1 - \Delta T_2)}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$, °C = -------------------- °C

$\Delta T_1 = (T_{ho} - T_{co})$ for parallel flow, °C = ---------------------- °C

$= (T_{ho} - T_{ci})$ for counter flow, °C = -------------------- °C

$\Delta T_2 = (T_{hi} - T_{ci})$ for parallel flow, °C = ------- --------------- °C

$= (T_{hi} - T_{co})$ for counter flow, °C = ----------------------- °C

$A_o = 2L(\pi D_o + 2N_F Y)$, m² = ---------------------- m²

$A_i = 2 \times \pi \times D_i \times L$, m² = ---------------------- m²

$$U_o = \frac{Q_{avg}}{A_o \times \Delta T_m}$$, W/m² °C = ----------------------- W/m² °C

$$U_i = \frac{Q_{avg}}{A_i \times \Delta T_m}$$, W/m² °C = -------------------------- W/m² °C

Find the properties of water at $T_h = \dfrac{T_{ho} + T_{hi}}{2}$

and $T_c = \dfrac{T_{co} + T_{ci}}{2}$ from data book.

ρ_h = ------- kg/m^3

C_{ph} = ------- $J/kg\ ^oC$

ρ_c = ------- kg/m^3

C_{pc} = ------- $J/kg\ ^oC$

$Q_c = W_c \times C_{pc} \times (T_{co} - T_{ci})$, W = ------------------- W

$W_c = \dfrac{F_c \times 10^{-3} \times \rho_c}{3600}$, kg/s = -------------------- kg/s

$Q_h = W_h \times C_{ph} \times (T_{hi} - T_{ho})$, W = ---------------------- W

$W_h = \dfrac{F_h \times 10^{-3} \times \rho_h}{3600}$, kg/s = --------------------- kg/s

Nomenclature:

A_i	=	Inside heat transfer area, m^2
A_o	=	Outside heat transfer area, m^2
C_{pc}	=	Specific heat of cold water, kJ/kg °c
C_{pc}	=	Specific heat of hot water, kJ/kg °c
D_o	=	Outer diameter of tube, m
D_i	=	Inner diameter of tube, m
F_h	=	Hot water flow rate, LPH
F_c	=	Cold water flow rate, LPH
L	=	Fin length, m
N_F	=	No. of fins per tube.
Q_{avg}	=	Average heat transfer, W
Q_c	=	Heat taken by cold water, W
Q_h	=	Heat loses by hot water, W
T_h	=	Mean temperature of hot water, ^oC
T_c	=	Mean temperature of cold water, ^oC
T_{hi}	=	Hot water inlet temperature, ^oC

T_{ho} = Hot water outlet temperature, ^oC

T_{ci} = Cold Water inlet temperature, ^oC

T_{co} = Cold Water outlet temperature, ^oC

dT_m = Logarithmic mean temperature difference, ^oC

U_i = Inside overall heat transfer coefficient, $W/m^2\ ^oC$

U_o = Outside overall heat transfer coefficient, $W/\ m^2\ ^oC$

W_c = Mass flow rate of cold water, kg/s

W_h = Mass floe rate of hot water, kg/s

Y = Fin height, m

ρ_h = Density of hot water, kg/m^3

ρ_c = Density of cold water, kg/m^3

Calculation:

Result:

Precautions & Maintenance Instructions:

1. Never run the apparatus if power supply is less than 180 volts and above 230 volts.
2. Never switch ON mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.
3. Operator selects or switch off temperature indicator gently.
4. Always keep the apparatus free from dust.

Questions

Q.1 What are the various type of heat exchangers?

Q.2 Define the term parallel and counter current flow.

Experiment No.7

Aim: To demonstrate the film-wise and drop-wise condensation and determination of heat transfer coefficient.

Introduction: Condensation is a phase change heat transfer process which occurs in mechanical and chemical engineering applications.

1. Drop Condensation
2. Film Condensation

Film And Drop Condensation: Condensation occurs whenever a vapor comes into contact with a surface at a temperature lower than the saturation temperature corresponding to its vapor pressure. The nature of the condensation depends upon whether the liquid thus formed wets or does not wet the solid surface. If the liquid wets the surface the condensate flows on the surface in the form of a film and the process is called film condensation. If on the other hands, the liquid does not wet the solid surface, the condensate collects in the form of droplets, which either grow in size or coalesce with neighboring droplets and eventually roll off the surface under the influence of gravity. This process is called drop condensation.

Apparatus: The apparatus is developed for finding heat transfer coefficients in Drop and Film condensation phenomenon. The two condensers made of copper tubes. One of the tube is chrome plated and the other is polished. Cooling water is circulated through each tube. These two tube are enclosed in a glass cylinder to observe the phenomenon of condensation Steam from a cooker enters the glass cylinder and comes in contact with the outer surface of the copper tube. A pressure gauge shows the pressure of steam entering the cylinder.

A Rotameter is used prior to the tube to note down the rate of flow of cooling water. A temperature indicator 3000C range and multichannel is used to measure the temp of water before it enters the copper tube, and temp at outlet of condensers. A thermocouple left in the glass cylinder measures the temperature of steam. Each copper tube carries a thermocouple to note down the temp of surface. In all 6 (Six) thermocouples are used.

However depending upon the type of tube we have to note down only 4 (four) temperatures. Flow control valves are used after the rotameter to control or stop low through the copper tube.

Operational Procedure:

1. Open the lid of cooker and if necessary fill sufficient water in it. Generally the water level should be 0.03- 0.035 m above the heater surface. If water level is sufficient close the lid.
2. Now put on the heater so that water will start boiling. Select the valves and start flow through either copper tube. Close the steam admitting valve and condenser drain valve. Note down the flow rate and see that there is no much variation.
3. Put on the temp. indicator and see that the thermocouples show proper temperature initially.
4. Wait for 10- 15 minutes until steam in generates and it's pressure is shown on the pressure gauge. If the desired pressure is achieved then admit the steam to the glass cylinder and note down the temperatures, when the steady state can be confirmed by the temp. no. T-3 which is the steam temperature.
5. Open the drain valve and let the condensate be drained. Close the valve.
6. After the reading is noted repeat the experiment for other copper tube.
7. When the experiment is over put off the heater switch and let water seen through both the copper tube (condensers) for about 10-15 minutes. Close the cooling water supply.

Nomenclature:

1. Steam Pressure = kg / cm^2
2. Water flow rate = LPH
3. Temperatures = ^{0}C

T_1 = Surface Temperature of Plated Condenser.

T_2 = Surface Temperature of Plain (copper) Condenser.

T_3 = Steam of Temp. in glass cylinder.

T_4 = Temp. of water leaving Plated Condenser

T_5 = Temp. of water leaving plain (copper) Condenser.

T_6 = Temp. of water inlet to condenser.

So while testing plated condenser we have to note temperatures T_1, T_3, T_4, and T_6, and while testing plain condenser we have to note down temperature T_2, T_3, T_5, T_6 Only.

$$\textbf{BULK MEAN TEMP} = \frac{(T_1 + T_2)}{2}$$

h_o = Outer Heat Transfer Coefficient at bulk mean temp.

$$= 0.943 \left[\frac{\lambda \rho^2 g k^3}{(T_s - T_w)\, \mu \times L}\right]^{0.25}$$

ρ_w	=	Density of water	Kg/m^3
K_w	=	Thermal Conductivity of water	w/m –K
μ	=	Viscosity of Condensate	$N - s/m^2$
Q	=	Heat of Evaporation	J/Kg
T_s	=	T_3	^0K
T_w	=	T_1	^0K
L	=	Length of condenser	m

Take ρ_w, K_w, μ, λ From chart provided at end.

Overall Heat Transfer Coefficient:

$$\frac{1}{U} = \frac{1}{h_i} + \frac{D_i}{D_o} \times \frac{1}{h_o} \quad W/m^2K$$

Where,

D_i = 0.017 m

Do = 0.020 m

Calculations:

Result:

Precautions

1. Before switching on the heater for steam cooker, confirm that sufficient water level is there.
2. Operate the valves properly.
3. Operate the selector switch of T.I. properly and gently.
4. After the experiment is over put off the heat switch and allow the cooling water to flow through both condensers for 10-15 min and then stop the flow.

Table A.1 Properties of Saturated Water

T	p	ρ	C_p	$\mu \times 10^6$	k	Pr	$\beta \times 10^4$	$\nu \times 10^8$	$\sigma \times 10^4$	λ
°C	kN/m²	kg/m³	kJ/kg-K	N-s/m²	W/m-K		K⁻¹	m²/s	N/m	kJ/kg
0	0.61	999.9	4.212	1787.8	0.551	13.67	—0.63	1.789	756	2502
10	1.23	999.7	4.191	1305.3	0.575	9.52	+0.70	1.306	742	2477
20	2.34	998.2	4.183	1004.2	0.599	7.02	1.82	1.006	727	2453
30	4.25	995.7	4.174	801.2	0.618	5.42	3.21	0.805	712	2430
40	7.38	992.2	4.174	653.1	0.634	4.31	3.87	0.659	696	2406
50	12.35	988.1	4.174	549.2	0.648	3.54	4.49	0.556	679	2382
60	19.94	983.2	4.179	469.8	0.659	2.98	5.11	0.478	662	2358
70	31.19	977.8	4.187	406.0	0.668	2.55	5.70	0.415	644	2334
80	47.39	971.8	4.195	355.0	0.675	2.21	6.32	0.365	626	2309
90	70.14	965.3	4.208	314.8	0.680	1.95	6.95	0.326	608	2283
100	101:33	958.4	4.220	282.4	0.683	1.75	7.52	0.295	589	2257
110	143	951.0	4.233	258.9	0.685	1.60	8.08	0.272	569	2230
120	199	943.1	4.250	237.3	0.686	1.47	8.64	0.252	549	2203
130	270	934.8	4.267	217.7	0.686	1.36	9.19	0.233	528	2174
140	360	926.1	4.287	201.0	0.685	1.26	9.72	0.217	507	2144
150	476	917.0	4.313	186.3	0.684	1.17	10.3	0.203	485	2113
160	618	907.4	4.346	173.6	0.683	1.10	10.7	0.191	463	2081
170	792	897.3	4.380	162.8	0.679	1.05	11.3	0.181	441	2048
180	1002	886.9	4.417	153.0	0.675	1.00	11.9	0.173	420	2013
190	1256	876.0	4.459	144.2	0.670	0.96	12.6	0.165	398	1977
200	1553	863.0	4.505	136.3	0.663	0.93	13.3	0.158	376	1939

Table: 1 Properties of Saturated Water

Questions

Q.1What do you mean by condensation?

Q.2 Is condensation is reverse of evaporation?

Experiment No.8

Aim: To calculate emissivity of the test plate by emissivity measurement apparatus.

Practical Relevance: The concept of a black body is only an idealization for comparison of real body performance. Most surfaces in engineering practice do not behave like black bodies. The emissivity of a surface is a measure of how it radiates on comparison with a black surface at the same temperature. The emissivity of a surface is a function of its nature and characteristics. It is essentially a surface property.

Theory: The emissivity of a material (usually written ε or *e*) is the relative ability of its surface to emit energy by radiation. It is the ratio of energy radiated by a particular material to energy radiated by a black body at the same temperature. It is a measure of a material's ability to radiate absorbed energy. A true black body would have a $\varepsilon = 1$while any real object would have$\varepsilon < 1$. Emissivity is a dimensionless quantity, so it does not have units. Emissivity depends on factors such as temperature, emission angle, and wavelength. A typical engineering assumption is to assume that a surface's spectral emissivity and absorptivity do not depend on wavelength, so that the emissivity is a constant. This is known as the "grey body assumption".

Procedure:

1. Note down the dimensions of the two plates and the specifications of all the instruments provided on the panel board.
2. Switch on the power supply. Adjust the power input to the black body and the test surface through dimmer stats so that next step for the heaters is almost equal.
3. Wait till the steady state is reached. Record the temperatures of the black surface T_1, T_2 ,T_3 and the test surface T_4 , T_5 , T_6 .Also measure the chamber temperature, T_7 .
4. Repeat the experiment for different input conditions.

Observation:

Diameter of black surface =

Diameter of test surface =

Area of black surface =

Area of test surface =

Power input to black surface =

Power input to test surface =

Temperature of black surface =

Temperature of test surface =

Ambient temperature =

Calculation:

Result:

Precaution:

1. Keep the dimmerstat at zero position before switch on the power supply
2. Take readings carefully when changing the input conditions.
3. Always keep the apparatus free from dust.

Questions

Q.1What do you mean by emissivity?

Q.2 What is the value of emissivity of oxidized surfaces?

Experiment No. 9

Aim: To determine the heat transfer characteristics of a shell and tube Heat Exchanger.

Introduction: Shell And Tube Heat Exchanger Mostly Used In Chemical Industries As A Condenser, Cooler, Heater. When The Heat Transfer Area Become More Than 10 M, One Has To Go For Shell And Tube Heat Exchanger, Which Occupies Less Space, Offers Reasonable Pressure Drop, Compared To Other Types Of Heat Exchangers, Because Of Its Wide Utility, Its Mechanical Design Has Been Standardized.

Theory: The Film Heat Transfer Coefficient Is A Function Of Velocity, Which Is Again Function Of Cross-Sectional Area Of The Fluid Path. Thus, Decreasing The Cross-Sectional Area Could Increase The Fluid Velocity. This Is Achieving Multi Passed Heat Exchangers, At The Cost Of Pressure Drop And Temperature Gradient Affecting Due To Concurrent Flow.

The Factor “Ft”, Is The Temperature Difference Correction Factor, When It Is Multiplied By The Counter Flow LMTD, The Product Is The Correct Mean Temperature Difference.

The Factor “Ft”, Is A Function Of Two Dimensionless Number R And S Which Are Defined As

R = $(T_{hi} - T_{ho})/(T_{co} - T_{ci})$

S = $(T_{CO} - T_{ci})/(T_{hi} - T_{ci})$

The Factor S Is The Heating Effectiveness Or The Ratio Of The Actual Temperature Rise Of The Cold Fluid To The Maximum Possible Temperature Rise Obtainable If The Warm-End Approach Were Zero (Based On Counter Current Flow).T He Factor R Is The Ratio Of The Fall In Temperature Of The Fluid To The Rise In Temperature Of The Cold Fluid.

By Varying The Flow Rates Of Shell Side And Tube Side Fluid, It Is Possible To Get The Outside Heat Transfer Coefficient And Inside Heat Transfer Coefficient At Various Conditions.

Apparatus:

The apparatus consists of:

Shell

Inner Dia.	=	230 mm
Thickness	=	6 mm
Material	=	M. S.

Tubes

O.D	=	16 mm
I.D	=	13 mm
Material	=	Copper
NO. of Tubes	=	32
Length	=	550 mm
NO. Of passes	=	2

For hot water 1 Geysers are provided.

I D	= Inside dia. of shell	= 230 mm
C	= Baffle clearance	= 35 mm
B	= Baffle spacing	= 465/5 = 93 mm
P	= Pitch	= 17 cm

The flow rate can be adjusted by valve on hot and cold side, the temperature at hot inlet and those at cold inlet and outlet are measured by thermometers.

Procedure:

1. Start the flow of water through hot and cold side.
2. Adjust it as per requirement.
3. Put on the geyser
4. Wait till the hot water temperature is rising and then take the readings.
5. Measure the Flow rates of hot & Cold Water.

Observations:

Sr. No.	Shell Side (Cold Water)			Tube Side(Hot Water)		
	Flow rate	Inlet temp.	Outlet temp.	Flow rate	Inlet temp	Outlet temp

Calculation:

1. **Hot Water Side**

   $$Q_h = m_h \times C_{ph} \times (T_{hi} - T_{ho})$$

   C_{ph} & C_{pc} = 4187 J/Kg ^{o}k

2. **Hot Water Side**

   $$Q_c = M_c \times C_{pc} \times (T_{co} - T_{ci})$$

3. $$LMDT = \frac{(dT_i - dT_e)}{(dT_i - dT_o)}$$

   $$dT_i = T_{hi} - T_c$$

   $$dT_o = T_{ho} - T_{co}$$

4. **Overall heat transfer coefficient U**

   $$Q = U \times A \times LMTD$$

$$U = \frac{Q}{A \times LMDT}$$

Then

$$Q = (Q_h + Q_c)/2$$

Calculation:

Result:

For Shell and tube type Heat Exchanger.

1. Heat transfer rate = q =
2. LMTD =
3. Do not put on geysers unless Over all heat transfer rate = U=

Precautions:

1. Do not put on geysers unless water flow is continuous.
2. Flow rates should not vary.
3. The Thermometer should be put in the pocket after little oil at base.
4. Equipment should be earthed properly.

Questions

Q.1 Suggest any industry where shell and tube heat exchanger is used

Q.2 What do you mean by LMTD.

Experiment No. 10

Aim: To observe pool boiling phenomena and to determine the critical heat flux at different bulk temperature.

Apparatus: Pool Boiling Apparatus with Bulk and Test Heater.

Procedure:

1. Check all the electrical connections and fill the water bath with tap water to almost 2/3 height.
2. Fill the glass tube with Silicon Oil.
3. Fix Ni-Cr wire between the test heater connections and dip it into the water bath filled with cold (ambient temperature) water.
4. Switch on the bulk heater (500 W) and observe the rise in temperature with the thermometer immersed in the bath. Switch off the heater after the desired temperature is reached.
5. Now switch on the test heater, slowly increase the voltage across the test heater and note the corresponding value of the current.
6. Observe the boiling phenomena at the surface of the heater and when pool boiling becomes predominant, slowly increase the voltage across the test heater.
7. At critical heat flux, the wire will simply burn off and break. Note down the Voltage, Current and Temperature reading at this moment.
8. Calculate the value of critical heat flux.

Observation:

1. Resistance of coil = 20 Ohm
2. Length of glass tube (L) = 140 mm
3. Diameter of glass tube (d) = 250 mm
4. Density of water at test temp. (ρ_L) = 958.4 kg/m^3
5. Density of vapour at test temp. (ρ_V) = 0.5955 kg/m^3
6. Latent heat of water (λ) = 2257 kJ/ kg
7. Surface tension of vapor (σ) = $58.9 * 10^{-3}$ N/m

Observation Table:

Sr. No.	Surface Temp. of coil T_w (°C)	Bulk Temp. of liquid T_s (°C)	$T_w - T_s$ (°C)	Current (I) Amp	Voltage (V) Volt	Heat Supplied Watt q =V×I	Heat Supplied per unit Area (Watt/ m^2) q/A
1							
2							
3							
4							

Calculation:

1. Area of the coil, A = π × d × L

2. Heat supplied, q = V × I

3. Heat supplied per unit area, (q/ A) =

4. $q_c = 0.131\lambda[\sigma g(\rho_l - \rho_v)\rho_v{}^2]^{(1/4)}$

   =

   =

Graph:

Plot the graph of (q/A) Vs. $\mathbf{T_w - T_s}$

Result:

Precautions :

1. Operate selector switch of temp. Indicator gently.
2. Never switch ON mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.
3. Do not exceed 120 volts so as to avoid the fluctuating results.

Questions

Q.1 What do you mean by heat flux?

Q.2 Is the heat rate scalar quantity?