GOVERNMENT COLLEGE OF ENGINEERING, KEONJHAR

(GCE KEONJHAR)

DEPARTMENT OF MECHANICAL ENGINEERING

HEAT TRANSFER LAB MANUAL

V-SEMESTER MECHANICAL

NAME: ____

REGISTRATION NUMBER: ______________________________

SUBJECT: ____

SEMESTER: ____________________ **YEAR:** ____________________

DEPARTMENT OF MECHANICAL ENGINEERING

HEAT TRANSFER LAB MANUAL

V-SEMESTER MECHANICAL

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Experiment No: - **Date: - / /**

Aim of the Experiment:

Determination of Critical Heat Flux during boiling heat transfer.

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 usual for a part of the liquid to change phase. This change of phase is called boiling. Boiling is of various types; the type depends upon the temperature difference the surface and the liquid.

Description:

The apparatus consists of a cylindrical glass container housing and the test heater (Nichrome wire). Test heater is connected also to mains via a dimmer. An ammeter is connected in series while a voltmeter across it to read the current and voltage. The glass container is kept on a stand, which is fixed on a metallic platform. There is provision of illuminating the heater wire can be viewed through the glass.

This experimental set up is designed to study the pool-boiling phenomenon up to critical heat flux point. 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 voltage across the test wire and the change over from natural convection to nucleate boiling can be seen.

The formation of bubbles and their growth in size and number can be visualized followed by the vigorous bubble formation and their immediate carrying over to surface and ending this in the braking of wire indicating the occurrence of critical heat flux point.

Specification:

- Glass container: Dia. 190 mm. & Height 95mm
- Nichrome wire size: 0.274 φ mm or 32 Gauge
- Distance between pools: 90mm
- Dimmer stat: 10 Amp, 230 volts.
- Voltmeter: 0 to 75 V
- Ammeter: 0 to 10 AMP
- Thermometer: 0 to 100 °C

Theory:

The heat flux supplied to the surface is plotted against (Tw - Ts) the difference between the temperature of the surface and the saturation temperature of the liquid. It is seen that the boiling curve can be divided into three regions:

1. Natural Convection Region
2. Nucleate Boiling Region
3. Film Boiling Region

The region of natural convection occurs at low temperature differences (of the order of 10 ℃ or less). Heat transfer from the heated surface to a liquid in its vicinity causes the liquid to be superheated.

The superheated liquid rises to the free liquid surface by natural convection, where vapour is produced by evaporation. As the temperature difference (Tw – Ts) is increased, nucleate boiling starts. In this region, it is observed that bubbles 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. They condense in the liquid and do not reach the free surface. In the second part, II – b, the rate of bubbles formation and 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 bubbles is so high, that they start to coalesce and blanket the surface with a vapour film. This is the beginning of the region III viz film boiling.

In the first part of this region III-a, the vapour film is unstable, so that the 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, III-b, a stable film covers the entire surface. The temperature difference in this region is of the order of 1000°C and consequently radiative heat transfer across the vapour film is also significant.

It will be observed that the heat flux does not increase in a regular manner with the temperature difference. In region I, the heat flux is proportional to $(Tw – Ts)^n$, where 'n' is slightly greater than unity. When the transition from natural convection to nucleate boiling occurs the heat flux starts to increase more rapidly with temperature difference, the value of n increasing to about 3.at the end of region II, the boiling curve reaches a peak. Beyond this, in the region II-A, in spite of increasing temperature difference, the heat flow increases with the formation of a vapour film. The heat flux passes through a minimum at the end of region III-a. it starts to increase again with (Tw – Ts) only when stable film boiling begins and radiation becomes increasingly important.

It is of interest to note how the temperature of the heating surface changes as the heat flux is steadily increased from zero. Up to point A, natural convection boiling and nucleate boiling occur and the temperature of the heating surface is obtained by reading off the value of (Tw – Ts) from the boiling curve and adding to it the value of Ts.

If the heat flux is increased even a little beyond the value of A, the temperature of the surface will shoot up to the value corresponding to the point C. it is apparent from figure 1 that the surface temperature corresponding to point C is high.

For most surfaces, it is high enough to cause the material to melt. Thus, in most practical situations, it is undesirable to exceed the value of heat flux corresponding to point A. This value is therefore of considerable engineering significance and is called the critical or peak heat flux. The pool-boiling curve as described above is known as Nukiyam pool Boiling Curve. The discussions so far have been concerned with the various type of boiling which occur in saturated pool boiling. If the liquid is below the saturation temperature, we say that sub-cooled pool boiling is taking place. Also in many practical situations, e.g., steam generators; one is interested in boiling in a liquid flowing through tubes. This is called forced convection boiling, may also be saturated or sub-cooled and of the nucleate or film type.

Thus, in order to completely specify boiling occurring in any process, one must state.

1. Whether it is forced convection boiling or pool boiling,
2. Whether the liquid is saturated, or sub cooled, and
3. Whether it is in the natural convection nucleate or film boiling region

Procedure:

Step-1:

Fill the tank with water.

Step-2:

Dip the Nichrome wire into the water and make the electrical connections.

Step-3:

Note the current reading in steps of 1 amp till a maximum current of 10 ampere.

Step-4:

Between each reading the time interval of two min is allowed for steady state to establish.

Step-5:

Water temperature is noted with a thermometer at the beginning and at the end of the experiment. The average of these two is taken as the bulk liquid average temperature.

Tabulation:

Sl. No.	Water / Bulk Temp T in ℃	Voltage (V)	Current (I)

Formulas:

• Q = heater power in Watts

Q = V X I Watts

• q = critical heat flux in w / m^2

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

Calculation:

Conclusion:

Heater wire in different regions up to the critical heat flux point at which the wire melts is found out to be ______________ w / m^2

Teacher's Signature

Experiment No: - **Date: - / /**

Aim of the Experiment:

Determination of heat transfer coefficient in forced convection of air in a tube.

Introduction:

In many practical situations and equipment, we invariably deal with flow of fluids in tubes e.g. boiler, super heaters and condensers of a power plant, automobile radiators, water and air heaters or coolers etc. the knowledge and evolution of forced convection heat transfer coefficient for fluid flow in tubes is essentially a prerequisite for an optional design of all thermal system.

Convection is the transfer of heat within a fluid by mixing of one portion of fluid with the other. Convection is possible only in a fluid medium and is directly linked with the transport of medium itself.

In forced convection, fluid motion is principally produced by some superimposed velocity field like a fan, blower or a pump, the energy transport is said due to forced convection.

Description:

The apparatus consists of a blower unit fitted with the test pipe. The test section is surrounded by a Nichrome band heater. Four thermocouples are embedded on the test section and two thermocouples are placed in the air stream at the entrance and exit of 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 and measured by meters.

It is to be noted that only a part of the total heat supplied is utilized in heating the air. A temperature indicator with cold junction compensation is provided to measure temperatures of pipe wall at various points in the test section. Airflow is measured with the help of orifice meter and the water manometer fitted on the board.

Specification:

Pipe diameter (Do): 33 mm

Pipe diameter (Di): 28 mm

Length of test section (L): 400 mm

Blower: 35 No. FHP motor

Orifice Diameter (d): 16 mm

Dimmer stat: 0-to-3-amp, 230-volt, AC

Temperature indicator: Digital type and range 0 - 200 °c

Voltmeter: 0 -100 /300v

Ammeter: 0 – 5 amp

Heater: Nichrome wire heater wound on Test Pipe (Band Type) 400 watt

Procedure:

Step1:

Switch ON the mains system

Step2:

Switch ON blower.

Step3:

Adjust the flow by means of gate valve to some desired difference in the manometer level.

Step4:

Switch ON heater

Step5:

Start the heating of the test section with the help of dimmer stat and adjust desired heat input with the help of Voltmeter and Ammeter.

Step6:

Take readings of all the six thermocouples when the steady state is reached.

Step7:

Note down the heater input.

Observation Table:

Sl No	Volt (V)	Current (A)	Temperatures in ℃						Manometer Reading (H_w)
			T_1	T_2	T_3	T_4	T_5	T_6	

Formulas:

Head of Air = $H_a = \frac{\rho_w}{\rho_a} H_w$

Velocity of Air = $v_a = \sqrt{2gH_a}$

Volume Flow Rate of Air = Q = $C_d\ A_O\ v_a$

Where A_O is Area of Orifice

Mass flow rate of air = m_a = Q ρ_a

Heat carried away by Air = $Q_a = m_a\ x\ C_p\ x\ \Delta T$

Where ΔT = Temperature rise in air = $T_6 - T_1$

Average Temperature of Air in °C = $T_a = \frac{T_1+T_6}{2}$

Average Surface Temperature in °C = $T_s = \frac{T_2+T_3+T_4+T_5}{4}$

Test Section Surface Area = $A_s = \pi \times D_i \times L$

Heat Transfer Coefficient = $h = \frac{Q}{A_s(T_s-T_a)}$

Theoretically,

h = heat transfer coefficient calculated by using the correlations

Nu = 0.023 $Re^{0.8}$ $Pr^{0.3}$ ………… For Re >10000

Nu = 0.036 $Re^{0.8}$ $Pr^{0.3}$ ………… For Re >2300

A_c = Cross Test Section Area in m^2

$A_c = \frac{\pi}{4} D_i^2$

V = Mean Velocity of Flow through tube in m / sec

$V = \frac{Q}{A_c}$

Re = Reynold's Number

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

Where v = Kinematic Viscosity at bulk mean temp in $\frac{m^2}{sec}$

Pr = Prandtl Number = $\frac{\mu C_p}{K}$

h. D_i = 0.023 x $Re^{0.8}$x $Pr^{0.3}$

Calculation:

Conclusion: -

Heat transfer coefficient in forced convection of air in a tube is found out to be __________

Teacher's Signature

Experiment No: - **Date: - / /**

Aim of the Experiment:

Performance test on Parallel flow and Counter flow heat exchanger.

Apparatus required:

Concentric type Heat exchanger, 1 Lt bicker, Stopwatch

Introduction:

Heat exchangers are the device in which the heat is transferred from one fluid to another. Exchange of heat is required at many industrial operations as well as chemical process. Common examples of heat exchangers are radiator of a car, condenser of a refrigeration unit, or colling coil of an air conditioner.

Heat exchangers are basically three types –

1. Transfer type – in which both fluids pass through the exchanger and heat gets transferred through the separating walls between the fluids,

2. Storage type- in this, firstly the hot water passes through a medium having high heat capacity and then cold fluid is passes through the medium to collect the heat. Thus, cold and hot fluid are alternately passed through the medium.

3. Direct contact type – in this type, the fluid are not separate but they mix with each other and heat passes directly from one fluid to another.

Transfer type heat exchangers are the type mostly used. In transfer type heat exchangers, three type of flow arrangements are used, viz. Parallel, Counter & Cross Flow. In parallel flow, the fluids flow in the same direction while in counter flow, they flows in the opposite direction. In cross flow, they flows at right angle to each other.

Description:

The apparatus consists of concentric heat exchanger tube. The hot fluid is hot water, which is obtained by an electric geyser. Hot water flows through the inner tube in one direction. Cold fluid is cold water, which flows the outer tube. Control valves are provided so that direction of cold water can be kept parallel or opposite to that of hot water. Thus, the heat exchanger can be operated either as parallel or counter flow heat exchanger. The temperatures are measured with temperature indicator and thermocouples.

Specifications:

Concentric tube – 1. Inner tube diameter = 12 mm

2. Outer tube diameter = 40 mm

3. Length of the exchanger = 164 cm

Valves for flow and direction control – 5 Nos

Thermocouples to measure temperatures – Digital type – 4 nos.

Measuring flask – 1Lt.

Procedure:

Step1:

Connect the power socket to the plug point.

Step2:

Start the water supply. Adjust the water supply on hot and cold sides.

Step3:

For parallel flow arrangement open the valve V1 and V3 and keep close the valves V_2 and V_4. For counter flow arrangement open the valves V_2 and V_4 and keep close the valves V_1 and V_3.

Step4:

Switch on the geyser. Temperature of water will start rising. After temperature become steady, note down the readings and fill up the observation table.

Step5:

You can repeat the experiment by changing the flow and have to take the temperature readings when it will be steady.

Tabulation:

Type of Flow	HOT WATER			COLD WATER		
	Temperatures (℃)		Time for 1 Lt water	Temperatures (℃)		Time for 1 Lt water
	Inlet T_2	Outlet T_3	X_h Sec	Inlet T_1	Outlet T_4	X_c Sec
Parallel Flow						
Counter Flow						

Formulas:

1. Mass flow rate of hot water (m_h) = 1 / X_h Kg/Sec

   Where mass of 1 Lt water = 1 Kg
2. Heat rejected by hot water = (Q_h) = m_h C_p (T_2 - T_3) Watts

   Where C_p = Specific heat of water = 4200 J/KgK
3. Heat gained by cold water = (Q_c) = m_c C_p (T_4 - T_1) Watts
4. Logarithmic mean temperature difference (LMTD) =

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

Where for parallel flow,

$T_i = T_2 – T_1$

$T_o = T_3 – T_4$

For counter flow,

$T_i = T_2 – T_4$

$T_o = T_3 – T_1$

5. Overall heat transfer coefficient (U)

   a) Inside overall heat transfer coefficient (U_i)

   $U_i = \frac{Q_h}{\Delta T_m} A_i$ W/m^2°C

   where inside diameter of the hot water tube is 11mm

   $A_i = \pi$ d L

   b) Outside overall heat transfer coefficient (U_o)

   $U_o = \frac{Q_c}{\Delta T_m A_o}$ W/m^2°C

   where outside diameter of the hot water tube is 12mm

   $A_o = \pi$ d L

6. Effectiveness of heat exchanger

   ε = Rate of heat transfer in heat exchanger/ Max. possible heat transfer rate $= \frac{m_h C_p (T_2 - T_3)}{[mC_p]_{min} (T_2 - T_1)}$

Calculation:

Conclusion:

The overall heat transfer coefficient and effectiveness of the heat exchanger found ____________ & _____________ in Parallel flow and ___________ & __________ in counter flow heat exchanger.

Teacher's Signature

Experiment No: - **Date: - / /**

Aim of the Experiment:

Verification of Stefan Boltzman's law.

Apparatus required:

Stefan Boltzman's apparatus

Introduction:

All the substance emits thermal radiation. When heat radiation is incident over a body, part of radiation is absorbed, transmitted through, and reflected by body. A surface which absorbs all thermal radiation incidents over it called black surface. For black surface, transmittivity and reflectivity are zero and absorptivity is unity. Stefan Boltzmann Law states that emissivity of a surface is proportional to fourth power of absolute surface temperature i.e.

$$E \propto T^4 \quad \text{or} \quad E = \sigma \varepsilon T^4$$

Where E = emissivity power of surface, W/m^2

T = absolute temperature

σ = Stefan Boltzmann Constant

ε = emissivity of the surface

Value of Stefan Boltzmann constant is taken as

$\sigma = 5.667 \times 10^{-8}\ W/m^2K^4$

For black surface $\varepsilon = 1$, hence above equation reduces to

$E = \sigma . T^4$

Description:

The apparatus consists of a water heated jacket of hemispherical shape. A copper test disc is fitted at the center of jacket. The hemisphere has contact with hot water tank where the water is heated with the help of an electric immersion heater. Therefore, temperature of hemisphere rises. The test disc is then inserted at the center. Thermocouples are fitted with hemisphere to average out hemisphere temperature. Another thermocouple fitted with the disc to measure its temperature; another thermocouple is there to check the temperature of water inside the water tank. Stopwatch is used to note down the temperatures at the time interval of 10 seconds.

Procedure:

Step1:

See that water outlet cock of water tank is closed and fill up enough water in the water tank.

Step2:

Put ON the water heater.

Step3:

Blacken the test disc with the help of lamp black and let it cool.

Step4:

Put the thermocouple and check the water temperature.

Step5:

Boil the water and switch OFF the heater.

Step6:

Note down the hemisphere temperatures.

Step7:

To note down the temperature of the disc, insert the disc at the center and start taking the temperature readings from temperature indicator in the interval of 10 Seconds with stopwatch.

Tabulation:

Hemisphere Temperature (℃)	
T_1	
T_2	
T_3	
T_4	
T_5	

Time Interval (Sec)	Test Disc Temperature (℃)
0	
10	
20	
30	
40	

Formulas:

1. Area of test disc (A) = $\pi/4 \times d^2$ m^2

   Where Diameter of disc = 15mm

2. Mass of test disc = 3.16×10^{-3}kg

3. Plot a graph of temperature rise of test disc with time as base and find out its slope at origin, i.e. $[dT/dt]_{at t=0}$ K/sec

   Hemisphere temperature, $T_h = \frac{T_1+T_2+T_3+T_4+T_5}{5} + 273.15$ K

4. Initial test disc temperature $T_d = T_6 + 273.15$ K

   As area of hemisphere is very large as compared to that disc, we can put $Q = \sigma\, \varepsilon\, A\, ({T_h}^4 - {T_d}^4)$

   Where Q = heat gained by disc/ Sec

   $Q = m\, C_p\, (dT/dt)_{t=0}$

   σ = Stefan Boltzmann Constant

   m = mass of test disc = 3.16×10^{-3}kg

   ε = emissivity of the surface = 1

   A = area of test disc

   C_p = specific heat of copper = 381 j/kg ℃

   $\sigma = \frac{m\, Cp\, (dT/dt)_{t=0}}{A\, ({T_h}^4 - {T_d}^4)}$

Calculation:

Conclusion:

Theoretically value of σ is 5.667×10^{-8} W/ m^2K^4. In the experiment this value may deviate due to reason like convection, temperature drop of hemisphere, heat loss etc.

But experimentally we got, Stefan Boltzmann's constant σ = __________ W/ m^2K^4.

Teacher's Signature

Experiment No: - **Date: - / /**

Aim of the Experiment:

To determine efficiency and effectiveness of a fin.

Apparatus required:

Pin fin apparatus (Natural Convection)

Introduction:

Extended surfaces or fins are used to increase the heat transfer rate from a surface to a fluid wherever it is not possible to increase the value of the surface heat transfer coefficient or the temperature difference between the surface and the fluid. The use of this is very common and they are fabricated in a variety of shapes circumferential fins around the cylinder of a motorcycle engine and fins attached to condenser tubes of a refrigerator are few familiar examples.

Description:

A brass fin of circular cross section is fitted across a rectangular duct. One end of the fin projects outside the duct and is heat by a heater. Temperature at six points along the length of the fin is measured by thermocouple and temperature indicator connected along the length of the fin. Input to the heater is given through a dimmer stat and measured by meters.

Specifications:

Diameter of the fin: 20mm

Length of the fin: 150mm

Temp. Indicator: 0-199.9°C

Thermal Conductivity of fin material (Brass):95 Kcal/hr-m-°c

Dimmer-stat for heat input control 230V, 2 Amps.

Voltmeter 0-250V

Ammeter 0-2A

Procedure:

Step1:

Start heating the fin by switching on the heater element and adjust the voltage on dimmer stat.

Step2:

Now the heater will start heating the fin, so wait till the temperature reaches steady state.

Step3:

When steady state is reached, record the final readings of Temperature Sensor No.1 to 6

Step4:

Repeat the same experiment with any other voltage.

Tabulation:

Voltage (V)	Current (I)	Temperature in ℃					
		T_1	T_2	T_3	T_4	T_5	T_6

Formulas:

Mean surface temperature $T_m = \frac{T_1+T_2+T_3+T_4+T_5}{5}$ ℃

$T_f = T_6$ ℃

Mean fluid temperature $T_{mf} = \frac{T_m + T_f}{2}$ ℃

Coefficient of expansion $\beta = 1 / T_{mf}$

Find out properties of air from data book at β.

$Gr = \frac{g\beta D\Delta T}{\vartheta^3}$

$Nu = 0.53 (Gr.Pr^{1/4})$

Heat transfer coefficient $h = \frac{Nu\,.\,K_{air}}{D}$ W/m²℃

$m = \sqrt{\frac{h\,C}{K_b.A}}$ m

Where Perimeter of the fin is $C = \pi D$

Area $A = \frac{\pi}{4} D^2$ m²

Efficiency $\eta = \frac{\tanh mL}{mL}$

Effectiveness $\varepsilon = \dfrac{\tanh mL}{\sqrt{\dfrac{hA}{KC}}}$

Calculation:

Conclusion:

Efficiency and effectiveness of the fin found as ___________ and ___________.

Teacher's Signature

Experiment No: - **Date: - / /**

Aim of the Experiment: -

Determination of Thermal conductivity of composite slab.

Apparatus Required:

Composite slab equipment

Description:

Composite walls comprise of a number of layers of different materials with different properties and thickness. The rate at which heat is transferred by conduction through a unit cross-section area of a material, when a temperature gradient exits perpendicular to the area is known as the thermal conductivity of that material.

The apparatus consists of a central heater sandwiched between two sheets. Three types of slabs are provided both sides of heater, which forms a composite structure. A frame is provided in which all slabs are tightened to ensure the perfect contact between the slabs. A dimmer-stat is provided for varying the input to the heater and measurement of input is carried out by a voltmeter, ammeter. Thermocouples are embedded between interfaces of the slabs, to read the temperature at the surface. The experiments can be conducted at various values of input and calculation can be made accordingly.

Specifications:

1. Slab assembly arranged symmetrically on both sides of heater.
2. Heater: Nichrome heater wound on mica former and insulation with control unit capacity 300 watt maximum.

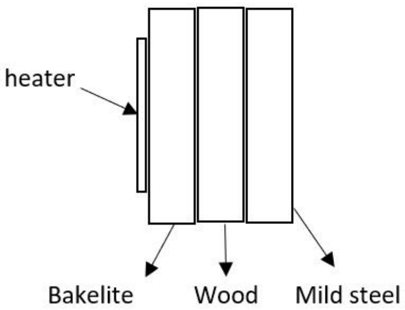
3. Heater Control Unit: 0-230V. Ammeter 0-2Amps. Single phase dimmer-stat (1No.).

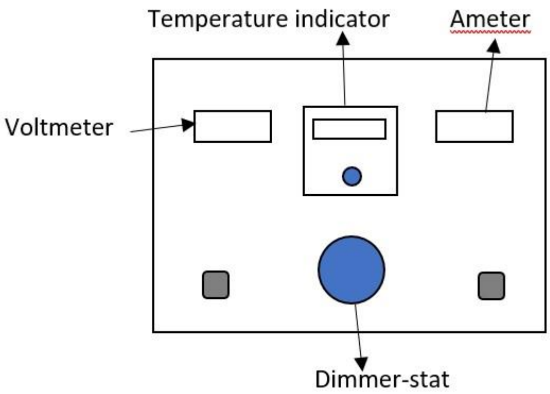
4. Voltmeter 0-100-200V. Ammeter 0-2Amps.

5. Temperature Indicator (digital type): 0-200^{0}C.

Service required – A. C. single phase 230 V. earthed electric supply.

Schematic Diagram:





Procedure:

Step-1:

Connect the single-phase plug-in power socket.

Step-2:

Switch on the main switch and heater switch present on the panel.

Step-3:

Start the supply of heater by varying the dimmer-stat; adjust the input at the desired value.

Step-4:

Take readings of all the thermocouples at steady temperatures are achieved and rate of rise is negligible.

Step-5:

Note down the reading in observation table.

Observations and observations table:

Composite slabs (contain two slabs of each material):

1. Thickness of each slab:

    a. Bakelite = 20mm

    b. Wood = 20mm

    c. Mild steel = 20mm

2. Slab diameter = 300mm.

Tabulation:

Voltage (V)	Current (A)	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8

Formulas:

Read the Heat supplied Q = V x I Watts (In S. I. Units) For calculating the thermal conductivity of composite walls, it is assumed that due to large diameter of the plates, heat flowing through central portion is unidirectional i. e. axial flow. Thus, for calculation, central half diameter area where unidirectional flow is assumed is considered.

Mean reading:

$T_A = \frac{(T_1+T_5)}{2}$ which is the input temperature to Bakelite

$T_B = \frac{(T_2+T_6)}{2}$ which is output temperature of Bakelite and input of wood

$T_C = \frac{(T_3+T_7)}{2}$ which is output temperature of wood and input of mild steel

$T_D = \frac{(T_4+T_8)}{2}$ which is output temperature of mild steel

As per Fouriesr's law

$$Q = -K\,A\,\frac{dT}{dX}$$

Area of the slab = A = $\frac{\pi}{4} \times d^2$

Rate of heat transfer = $Q = V \times I$

We also know that $Q = -K\,A\,\frac{\Delta T}{L}$

Thermal conductivity = K = $\frac{Q\,L}{A\,\Delta T}$ W/m K

As the thermal conductivity found is for the whole composite slab setup, which is having the heater coil at the center and it is symmetric in nature, so the actual thermal conductivity will be

$K_{act} = \frac{K}{2}$

Calculation:

Conclusion:

Thermal conductivity of the composite wall found as ___________.

Teacher's Signature