PVP 23

Code: 23ME3601

III B.Tech - II Semester - Regular Examinations – APRIL 2026

HEAT TRANSFER
(MECHANICAL ENGINEERING)

Duration: 3 hours Max. Marks: 70

Note: 1. This question paper contains two Parts A and B.
2. Part-A contains 10 short answer questions. Each Question carries 2 Marks.
3. Part-B contains 5 essay questions with an internal choice from each unit. Each Question carries 10 marks.
4. All parts of Question paper must be answered in one place.

BL – Blooms Level CO – Course Outcome

PART – A

		BL	CO
1.a)	Enumerate some important areas which are covered under the discipline of heat transfer.	L2	CO1
1.b)	What are the applications of fins?	L1	CO1
1.c)	What is the physical significance of the Nusselt number?	L2	CO2
1.d)	Describe the physical mechanism of convection. How is the convection heat transfer coefficient related to this mechanism?	L2	CO2
1.e)	Define the prandtl number.	L1	CO3
1.f)	What is meant by hydrodynamic boundary layer?	L1	CO3
1.g)	What are the factors affecting Nucleate boiling?	L2	CO4
1.h)	Define heat exchanger effectiveness and explain its significance.	L1	CO4
1.i)	List out any two shape factor algebra.	L1	CO5
1.j)	Distinguish between a black body and gray body.	L2	CO5

PART – B

			BL	CO	Max. Marks
UNIT-I					
2	A spherical container of negligible thickness holding a hot fluid at 140^0C and having an outer diameter of 0.4 m is insulated with three layers of each 50 mm thick insulation of k_1 = 0.02 W/m K, k_2 = 0.06 W/m K and k_3 = 0.16 W/m K. (Starting from inside). The outside surface temperature is 30^0C. Determine (i) the heat loss and (ii) interface temperatures of insulating layers.		L3	CO1	10 M
OR					
3	a)	What do you mean by critical radius of insulation and obtain critical radius of insulation for insulated cylinder.	L2	CO1	5 M
	b)	State and explain: (i) efficiency of fins (ii) effectiveness of fins	L2	CO1	5 M
UNIT-II					
4	A wall [α = 0.46 x 10^{-5} m^2/s, k =0.65 W/m ^{0}C, density = 2300 kg/m^3] of 10.0 cm thick is initially at a uniform temperature of 300^0C is suddenly placed in a controlled environment at 30^0C. The convection heat-transfer coefficient is 60 W/m^2 ^{0}C. Calculate the center temperature at 20min. and 60 min. after the exposure to the environment.		L3	CO2	10 M

OR					
5	a)	What is the significance of Biot number and Fourier number?	L2	CO2	5 M
	b)	What is the significance of Reynolds number and how flows are determined by Reynolds number?	L2	CO2	5 M
UNIT-III					
6	a)	What is convective heat transfer? Distinguish between free and forced convection.	L2	CO3	5 M
	b)	Explain thermal boundary layer with neat sketch.	L2	CO3	5 M
OR					
7	A 350 mm long glass plate is hung vertically in the air at 24^0C while its temperature is maintained at 80^0C. Calculate the boundary layer thickness at the trailing edge of the plate. If a similar plate is placed in a wind tunnel and air is blown over it at a velocity of 6m/s. Find the boundary layer thickness at its trailing edge, Also determine the average heat transfer coefficient for natural and forced convection.		L2	CO3	10 M
UNIT-IV					
8	Explain in detail about boiling regimes with a neat sketch?		L2	CO4	10 M
OR					

9	A counter flow heat exchanger is employed to cool 0.55 kg/s (C_p = 2.45 kJ/kg ^{0}C) of oil from 115^{0}C to 40^{0}C by the use of water. The inlet and outlet temperatures of cooling water are 15^{0}C and 75^{0}C respectively. The overall heat transfer coefficient is expected to be 1450 W/m^2 ^{0}C. Using NTU method calculate the following: i) The mass flow rate of water ii) The effectiveness of the heat exchanger iii) The surface area required.		L3	CO4	10 M
UNIT-V					
10	a)	What is Stefan Boltzmann Law? Explain the concept of total emissive power of a surface.	L2	CO5	5 M
	b)	State and explain Kirchhoff's identity. What are the conditions under which it is applicable?	L2	CO5	5 M
OR					
11	Two circular discs of diameter 20cm are placed 2m apart. Calculate the radiant heat exchange for these discs if these are maintained at 800^{0}C and 300^{0}C respectively and their corresponding emissivity's are 0.3 and 0.5		L3	CO5	10 M

III B.Tech - II Semester - Regular Examination

Heat Transfer - 23ME3601

Mechanical Engineering

April - 20

Scheme of valuation

1.a any two points — 2 marks

1.b any two points — 2 marks

1.c definition — 2 marks

1.d definition — 2 marks

1.e definition — 2 marks

1.f definition (or) diagram — 2 marks

1.g any two points — 2 marks

1.h definition (or) formula — 2 marks

1.i any two points — 2 marks

1.j any two points — 2 marks

2. Given Data — 4 marks } — 10 marks
   Solution — 6 marks }

3.a definition — 2 marks } — 5 marks
    derivation — 3 marks }

3.b efficiency definition — 2.5 marks } — 5 marks
    effectiveness definition — 2.5 marks }

4. Given Data — 4 marks } — 10 marks
   Solution — 6 marks }

5.a Biot number definition — 2.5 marks } — 5 marks
    Fourier number definition — 2.5 marks }

5.b Reynolds Number definition — 2 marks } — 5 marks
Flows — 3 marks

6.a any five points — 5 marks

6.b diagram — 2.5 marks } — 5 marks
explanation — 2.5 marks

7. Given data — 3 marks } — 10 marks
Forced convection — 3.5 marks
Free convection — 3.5 marks

8. diagram — 4 marks
Explanation — 6 marks

9. Given Data — 4 marks
solution — 6 marks

10.a definition — 2.5 marks } — 5 marks
emissive power definition — 2.5 marks

10.b definition — 2 marks } — 5 marks
derivation — 3 marks

11. Given Data — 3 marks } — 10 marks
solution — 7 marks

III B.Tech - II Semester - Regular Examinations.

Heat Transfer - 23ME3601

Mechanical Engineering April-2026

Scheme of valuation

1. a (i) Design of Thermal and nuclear power plants.
(ii) Internal combustion engines
(iii) Refrigeration and air conditioning unit
(iv) Heating and cooling of fluids etc in chemical operation.
(v) Heat treatment of metals.
(vi) Thermal control of space vehicles.
(vii) Dispersion of atmospheric pollutants.

1.b (i) Radiators of automobiles.
(ii) Air cooled engine cylinder heads.
(iii) Economisers for steam power plants.
(iv) small capacity compressors.
(v) Transformers and electronic equipments.
(vi) Electric motor bodies.
(vii) cooling coils and condenser coils in refrigerators and air conditioners.

1.c The ratio of convective heat transfer to conductive heat transfer, $Nu = \frac{hL}{K}$ (or) $\frac{hd}{K}$.

1.d (i) convection is heat transfer by the physical movement of fluid molecules (liquid or gas), driven by density differences, buoyancy or external forces.

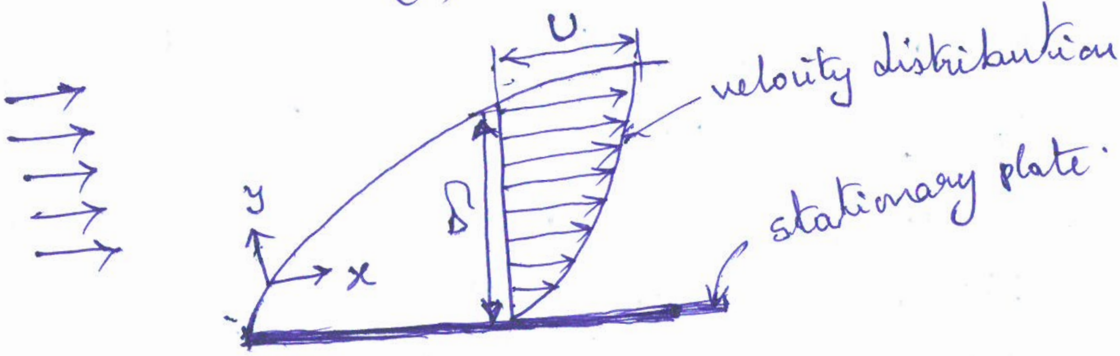
(ii) The convection heat transfer coefficient (h) quantifies the rate of heat transfer between a surface and moving fluid, directly relating the heat flux to the temperature difference.

1.e : The ratio of Molecular diffusivity of momentum to Molecular diffusivity of heat.

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

1.f : The hydrodynamic boundary layer is the thin region of fluid near a solid surface where viscous forces are significant, causing velocity to increase from zero to 99% of free stream velocity.

(or)



1.g (i) Surface characteristics — roughness, wettability.

(ii) fluid properties — Thermal conductivity, viscosity, surface tension.

(iii) Operating conditions — pressure, excess temperature.

1.h. The ratio of actual heat transfer to maximum possible heat transfer

(or)

$$\epsilon = \frac{\dot{m}_h C_{ph} (T_{h_1} - T_{h_2})}{C_{min} (T_{h_1} - T_{c_1})} = \frac{\dot{m}_c C_{pc} (T_{c_2} - T_{c_1})}{C_{min} (T_{h_1} - T_{c_1})}$$

→ It signifies efficiency, allowing for optimal energy savings, reduced operational costs and precise temperature control in systems.

1.i (I) two parallel planes: $\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1$

(II) two concentric cylinders (or) spheres : $\frac{1}{\epsilon_1} + \frac{A_1}{A_2}\left(\frac{1}{\epsilon_2} - 1\right)$

1.j : Black body :- It is a perfectly absorbing body and it absorbs all types of radiating energies.

Gray body: Gray body is defined as one whose absoptivity of a surface does not vary with temperature and wavelength of the incident radiation.

2. <u>Given Data</u>

$T_1 = 140°C$

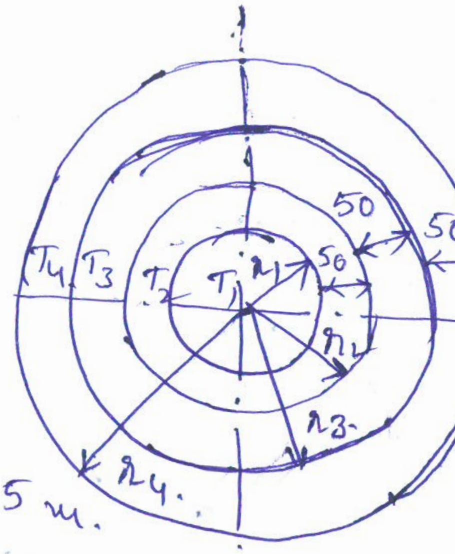
$T_4 = 30°C$ $\quad t = 0.05\ m$

$r_1 = 0.4\ m.$

$r_2 = 0.4 + 50 \times 10^{-3} = 0.45\ m.$

$r_3 = r_2 + t = 0.45 + 0.05 = 0.5\ m.$

$r_4 = r_3 + t = 0.5 + 0.05 = 0.55\ m.$



$K_1 = 0.02\ W/mK.$

$K_2 = 0.06\ W/mK.$

$K_3 = 0.16\ W/mK.$

$$R_1 = \frac{r_2 - r_1}{4\pi K_1 r_1 r_2}$$

$$R_1 = \frac{0.45 - 0.4}{4\pi\, 0.02 \times 0.45 \times 0.4} = 1.1052\ K/W$$

$$R_2 = \frac{r_3 - r_2}{4\pi K_2 r_2 r_3} = \frac{0.5 - 0.45}{4\pi\, 0.06 \times 0.5 \times 0.45} = 0.294$$

$$R_3 = \frac{r_4 - r_3}{4\pi K_3 r_3 r_4} = \frac{0.55 - 0.5}{4\pi \times 0.16 \times 0.55 \times 0.5} = 0.090\ K/W$$

$$Q = \frac{\Delta T}{R_{th}} = \frac{T_1 - T_4}{R_1 + R_2 + R_3} = \frac{140 - 30}{1.1052 + 0.294 + 0.090}$$

$Q = 73.86$ watts.

$$Q = \frac{\Delta T}{R_1} \Rightarrow 73.86 = \frac{T_1 - T_2}{R_1} \Rightarrow 73.86 = \frac{140 - T_2}{1.1052}$$

$T_2 = 140 - (73.86 \times 1.1052) = 58.36°C$

$$Q = \frac{\Delta T}{R_2} \Rightarrow Q = \frac{T_2 - T_3}{R_2}$$

$$73.86 = \frac{58.36 - T_3}{0.294}$$

$$T_3 = 58.36 - (73.86 \times 0.294) = 36.64$$

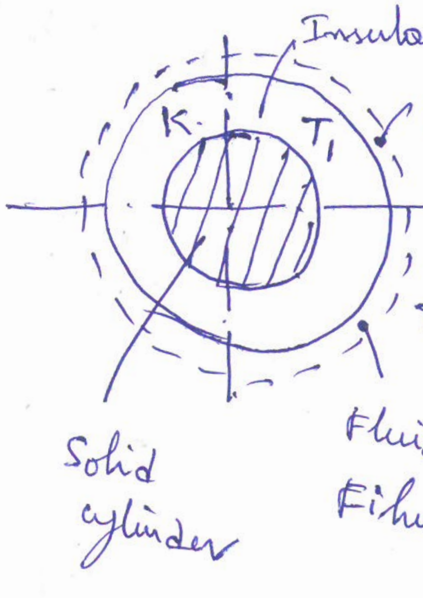
(i) Heat loss, $Q = 73.86$ watts.

(ii) Intermediate Temperatures,

$T_2 = 58.36^\circ C$.

$T_3 = 36.64^\circ C$.

3. a The thickness upto which heat flow increa[ses] and after which heat flow decreases is termed critical thickness.



Consider a solid cylinder of radius r_1 insulated with an insulation of thickness $r_2 - r_1$

Let L = Length of the cylinder

T_1 = Surface temperature of the cylinder.

T_∞ = Temperature of air

h_o = Heat transfer coefficient at the outer surface of the insulation.

K = Thermal conductivity

The rate of heat transfer

$$Q = \frac{2\pi L (T_1 - T_\infty)}{\frac{\ln(r_2/r_1)}{K} + \frac{1}{h_o r_2}}$$

It is evident that as r_2 increases, the fa

$\frac{\ln(r_2/r_1)}{K}$ increases, but the factor $\frac{1}{h_o r_2}$ dec

The q becomes maximum when denominator

$\left[\frac{\ln(r_2/r_1)}{K} + \frac{1}{h_o r_2}\right]$ becomes minimum.

$$\frac{d}{dr_2}\left[\frac{\ln(r_2/r_1)}{K} + \frac{1}{h_o r_2}\right] = 0$$

$$\frac{1}{K}\cdot\frac{1}{r_2} + \frac{1}{h_o}\left(\frac{-1}{r_2^2}\right) = 0$$

$$\frac{1}{K} - \frac{1}{h_o r_2} = 0 \Rightarrow h_o r_2 = K.$$

$$\boxed{\therefore r_2 = r_c = \frac{k}{h_o}}$$

3·b <u>Efficiency of fin (η_{fin})</u> :— It is defined as the ratio of the actual heat transferred by the fin to the maximum heat transferrable by fin.

infinitely long fin, $\eta_{fin} = \frac{1}{mL}$

<u>Effectiveness of fin</u> (ϵ_{fin}) :- It is defined a

ratio of the fin heat transfer rate to the heat

fer rate without fin.

$$\epsilon_{fin} = \sqrt{\frac{PK}{hA_{c/s}}} \rightarrow \text{infinitely long fin}$$

$$\epsilon_{fin} = \sqrt{\frac{2K}{hy}} \rightarrow \text{rectangular fin of thi}$$

of y and width b.

4.

<u>Given Data</u>

$\alpha = 0.46 \times 10^{-5}$ m^2/sec

$K = 0.65$ $W/m^{\circ}C$.

$\rho = 2300$ kg/m^3

$2L = 10$ cm. $\Rightarrow L = 0.05$ m.

$T_0 = 300^{\circ}C$

$T_\infty = 30^{\circ}C$

$h = 60$ $W/m^2\,^{\circ}C$.

$t = 20$ min $= 20 \times 60 = 1200$ sec

$t = 60$ min $= 60 \times 60 = 3600$ sec

characteristic length, $L_c = \frac{V}{A} = \frac{A \times 2L}{2A} = L = 0.05$ m

$Bi = \frac{hL_c}{K} = \frac{60 \times 0.05}{0.65} = 4.615 > 0.1$

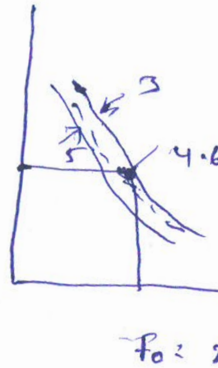
(lumped assumption not suitable)

$$F_o = \frac{\alpha t}{L_c^2} = \frac{0.46\times10^{-5}\times1200}{0.05^2} = 2.208$$

From graph or chart

$$\frac{T-T_\infty}{T_0-T_\infty} = 0.04$$

$$\frac{T-30}{300-30} = 0.04 \Rightarrow T = 40.8^\circ C$$



at $t = 60$ min

$$F_o = \frac{\alpha t}{L_c^2} = \frac{0.46\times10^{-5}\times3600}{0.05^2} = 6.624$$

$$\frac{T-T_\infty}{T_0-T_\infty} = 0.00 \text{ (approximately)}$$

$$\frac{T-30}{300-30} = 0.00 \Rightarrow T = 30^\circ C$$

5.a **Biot Number, Bi** :- Biot Number is defined as the ratio of internal conduction resistance to surface convection resistance. $Bi = \frac{hL_c}{k}$

where, h = heat transfer coefficient $W/m^2{}^\circ C$

L_c = characteristic length, m.

K = Thermal conductivity, $W/m^\circ C$.

- **Fourier Number, F_o** :- Fourier number is defined as the ratio of characteristic body dimension to temperature wave penetration depth in time.

$$Fo = \frac{\alpha t}{L_c^2}$$

where, α = Thermal diffusivity (m^2/sec)

t = Time, sec.

L_c = characteristic length, m

5.b

Reynolds number is defined as the ratio of inertia force to viscous force.

Reynold's number, $Re = \frac{\rho V d}{\mu} = \frac{Vd}{\gamma}$

where, ρ = density, m^3/Kg.

V = velocity, m/sec

d = diameter, m.

μ = dynamic viscosity, $\frac{N\text{-}S}{m^2}$

γ = Kinematic viscosity m^2/sec

→ If the Reynold's number is less than 5×10^5 then the flow is Laminar flow → External flow.

→ If the Reynolds number is greater than 5×10^5 then the flow is turbulent flow → External flow.

→ If the Reynolds number is Less than 2300 then the flow is Laminar flow → Internal flow.

→ If the Reynolds number is greater than 2300 then the flow is turbulent flow → Internal flow.

6·a :- convection is the process of heat transfer in which heat transfer takesplace by the movement of molecules of the fluid.

Free convection.	Forced convection.
(1) If the fluid motion is caused by temperature difference and due to density difference then it is known as natural convection.	(1) If the fluid motion is caused by an external device like a fan, pump or blower then it is known as forced convection.
(2) The driving forces are buoyancy forces	(2) The driving forces are external mechanical forces.
(3) velocity of fluid is low.	(3) velocity of fluid is high.
(4) Heat transfer rate is low	(4) Heat transfer rate is high.
(5) convective heat transfer coefficient is low	(5) convective heat transfer coefficient is high.
(6) Difficult to control flow speed	(6) Easily controlled by adjusting flow speed.
(7) In free convection $Nu = f(Gr\ Pr)$	(7) In forced convection $Nu = f(Re, Pr)$

6.b whenever a flow of fluid takes place past a heated (or) cold surface, a temperature field is set up in the field next to the surface. If the surface of the plate is hotter than fluid. The zone or thin layer wherein the temperature field exists is called the Thermal boundary layer.

Due to the exchange of heat between the plate and the fluid temperature gradient occurs.

The thermal boundary layer thickness (δ_{th}) is arbitrarily defined as the distance y from the plate surface at which

$$\frac{T_s - T}{T_s - T_\infty} = 0.99.$$

The thermal boundary layer depends upon the viscosity, velocity of flow, specific heat and thermal conductivity of the fluid.

7. Given Data

Length, $L = 350\,mm = 0.35\,m$.

$T_\infty = 24^\circ C$

$T_s = 80^\circ C$

Velocity, $V = 6\,m/sec$.

$$T_b = \frac{T_s + T_\infty}{2} = \frac{80 + 24}{2} = 52^\circ C$$

The properties of air at 52°C

$\rho = 1.093\ kg/m^3$. $P_r = 0.698$

$\mu = 19.61 \times 10^{-6}\ Ns/m^2$ $C_p = 1005\ J/kg \cdot K$.

$\nu = 17.95 \times 10^{-6}\ m^2/sec$ $K = 0.02826\ W/mK$.

$\alpha = 25.722 \times 10^{-6}\ m^2/sec$ $\beta = \frac{1}{T_f + 273} = \frac{1}{52+273}$

Free convection. $\beta = 3.076 \times 10^{-3}\ K^{-1}$

$$Gr = \frac{g \beta x^3 (T_s - T_\infty)}{\nu^2} = \frac{9.81 \times 3.076 \times 10^{-3} \times 0.35^3 \times (80-24)}{(17.95 \times 10^{-6})^2}$$

$$Gr = \frac{0.0724}{3.22 \times 10^{-10}} = 224844720.5$$

$$Gr \cdot P_r = 224844720.5 \times 0.698 = 156941614.9$$

$Gr\,P_r < 10^9 \rightarrow$ Laminar

boundary layer thickness

$$\delta_x = 3.93 x\ P_r^{-0.5} \times (0.952 + P_r)^{0.25} \times (Gr_x)^{-0.25}$$

$$= 3.93 \times 0.35 \times (0.698)^{-0.5} \times (0.952 + 0.698)^{0.25} \times (224844720.5)^{-0.25}$$

$$\delta_x = 0.0152\ m.$$

$$Nu_x = 0.508 \times P_r^{0.5} \times (0.952 + P_r)^{-0.25} \times Gr_x^{0.25}$$

$$= 0.508 \times (0.698)^{0.5} \times (0.952 + 0.698)^{-0.25} \times (224844720.5)^{0.25}$$

$$Nu_x = 45.855$$

$$\frac{hx}{K} = 45.855 \rightarrow h = \frac{45.855 \times 0.02826}{0.35}$$

$$h_x = 3.702\ W/m^2\,°C.$$

forced convection.

$$Re_x = \frac{Vx}{\nu} = \frac{6 \times 0.35}{17.95 \times 10^{-6}} = 116991.64$$

$Re_x < 5 \times 10^5 \rightarrow$ Laminar flow.

$$Nu_x = 0.332 \times Re_x^{0.5} \times Pr^{0.333}$$

$$= 0.332 \times (116991.64)^{0.5} \times (0.698)^{0.333}$$

$$Nu_x = 100.744$$

$$Nu_x = \frac{hx}{K} = 100.744 \Rightarrow h = \frac{100.744 \times K}{x}$$

$$h = \frac{100.744 \times 0.02826}{0.35} = 8.134 \ W/m^2 \, ^\circ C$$

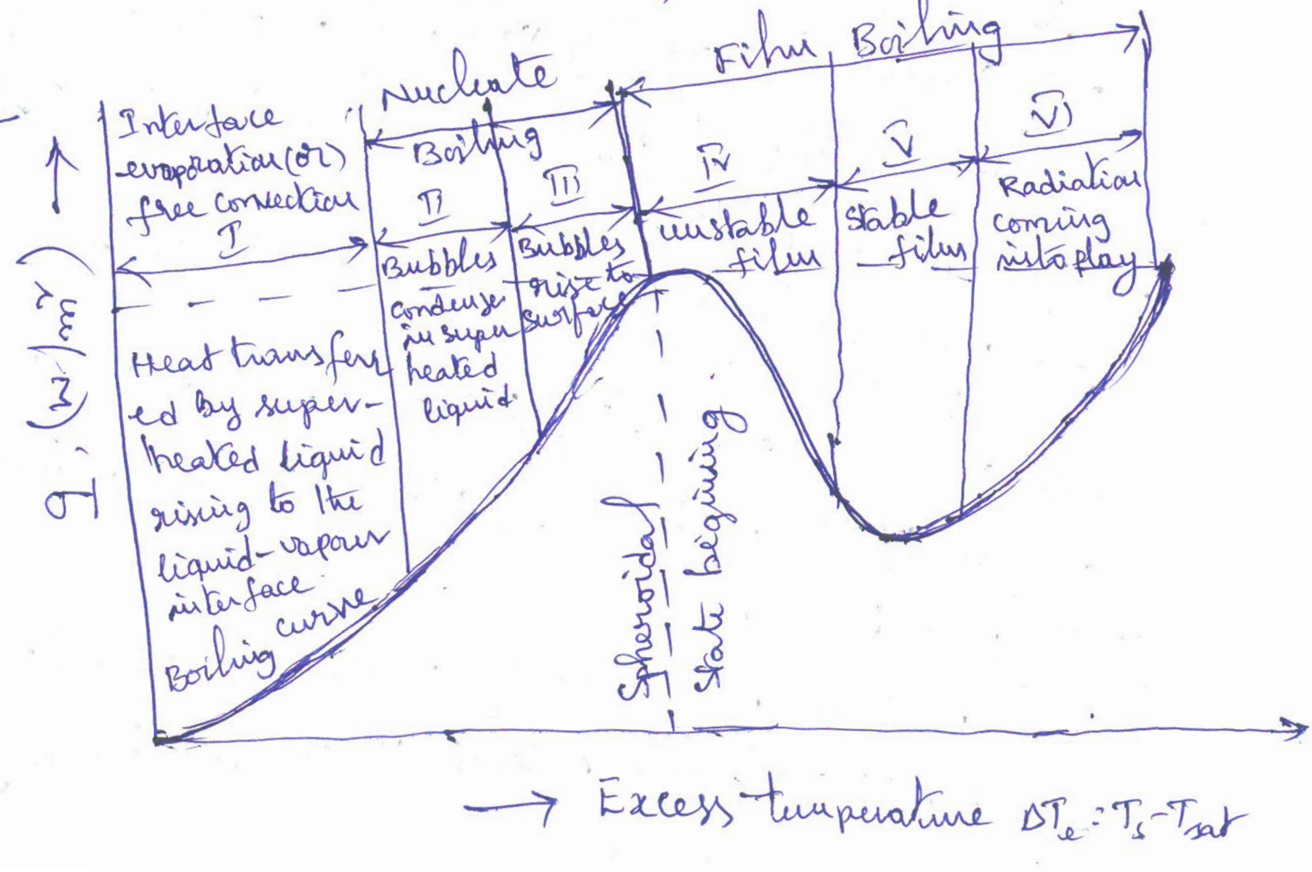
boundary layer thickness.

$$\delta_{hx} = 5x \, Re_x^{-0.5}$$

$$= 5 \times 0.35 \times (116991.64)^{-0.5}$$

$$= 5.116 \times 10^{-3} \ m$$

8.



1. <u>Natural convection (Pre-boiling region)</u>

→ Surface temperature is just slightly above the liquid temperature.

→ No bubbles form

→ Heat transfer occurs by natural convection only.

→ Heat flux increases slowly.

2. <u>Nucleate boiling:-</u>

→ It begins when surface temperature exceeds satura-tion temperature enough to form bubbles.

→ vapour bubbles form at nucleation stage.

→ High heat transfer due to latent heat.

→ Heat flux increases rapidly with temperature difference.

3. <u>Critical heat flux / Burnout point.</u>

→ Maximum heat transfer rate

→ surface is ~~rapidly~~ partially covered by vapour

→ beyond this point, heat transfer deteriorates sharply.

4. <u>Transition Boiling:-</u>

→ unstable regime between nucleate and film boiling.

→ surface alternates between liquid and vapour.

→ Heat flux decreases with increasing temperature

5. <u>Film Boiling</u>

→ surface is completely covered by a stable vapour

→ liquid no longer contacts the surface directly. film

→ Heat transfer occurs mainly by conduction and radiation through vapour.

→ Less efficient than nucleate boiling.

9.

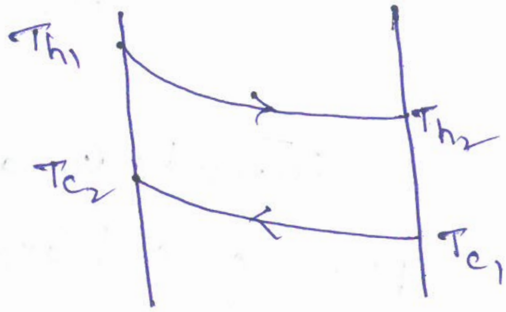
Given Data

$\dot{m}_h = 0.55$ kg/sec.

$C_{ph} = 2.45$ KJ/kg °c.

$T_{h_1} = 115°c$ $T_{c_1} = 15°c$

$T_{h_2} = 40°c$ $T_{c_2} = 75°c$



{Heat loss by the hot fluid} = {Heat gained by the cold fluid}.

$$Q_h = Q_c$$

$$\dot{m}_h c_{ph} (T_{h_1} - T_{h_2}) = \dot{m}_c c_{pc} (T_{c_2} - T_{c_1})$$

$$0.55 \times 2.45 \times (115 - 40) = \dot{m}_c \times 4.18 (75 - 15)$$

$$\boxed{\dot{m}_c = 0.402 \text{ kg/sec}}$$

$$C_h = \dot{m}_h c_{ph} = 0.55 \times 2.45 \times 10^3 = 1347.5 \frac{W}{K} = C_{min}$$

$$C_c = \dot{m}_c c_{pc} = 0.402 \times 4.18 \times 10^3 = 1680.36 \frac{W}{K} = C_{max}.$$

Effectiveness, $\epsilon = \dfrac{C_h (T_{h_1} - T_{h_2})}{C_{min} (T_{h_1} - T_{c_1})}$

$$= \frac{\cancel{1347.5} \times (115 - 40)}{\cancel{1347.5} \times (115 - 15)} = \frac{75}{100} = 0.75$$

$$C = \frac{C_{min}}{C_{max}} = \frac{1347.5}{1680.36} = 0.80$$

From chart NTU = 2.4

$$NTU = \frac{UA}{C_{min}} \Rightarrow 2.4 = \frac{1450 \times A}{1347.5}$$

$$\therefore A = 2.230 \ m^2.$$

10.a Stefan Boltzmann law is defined as the emissive power of a black body is directly proportional to fourth power of absolute temperature.

$$E_b \propto T_a^4 \Rightarrow E_b = \sigma T_a^4.$$

where, E_b: Emissive power of a black body (W/m^2)

σ : Stefan boltzman constant $= 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$

T_a = absolute temperature, K.

→ The emissive power is defined as the total amount of radiation emitted by a body per unit area and time. It is expressed in W/m^2. The emissive power of a black body, according to stefan - Boltzmann is proportional to absolute temperature to the fourth power.

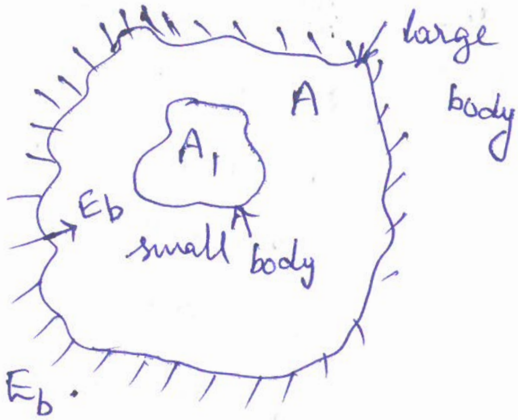
$$E_b = \sigma T^4 \ W/m^2$$

$$E_b = \sigma A T^4 \ W$$

where $\sigma = 5.67 \times 10^{-8} \ W/m^2 K^4$

10.b

Kirchhoff's Law states that at any temperature the ratio of total emissive power E to the total absorptivity α is a constant for all substances which are in thermal equilibrium with their environment.



Let us consider a lage body of surface area A which encloses a small body (1) of surface area A_1. Let the energy fall on the unit surface of the body at the rate E_b.

Of this energy generally, a fraction α, will be absorbed by the small body. This energy absorbed by the small body(1) is $\alpha_1 A_1 E_b$, in which α_1 is the absorptivity of the body. When thermal equilibrium is attained, the energy absorbed by the body (1) must be equal to the energy emitted, say. E_1 per unit surface, $A_1 E_1 = \alpha_1 A_1 E_b$

remove body(1) and replace it by body (2) having absorptivity α_2. The radiative energy impinging on the surface of this body is again E_b. $A_2 E_2 = \alpha_2 A_2 E_b$

$$E_b = \frac{E_1}{\alpha_1} = \frac{E_2}{\alpha_2} = \frac{E}{\alpha} \rightarrow (1)$$

as per definition of emissivity $\epsilon = \frac{E}{E_b} \Rightarrow E_b = \frac{E}{\epsilon} \rightarrow (2)$

equating eq'n (1) & eq'n (2)

$$\epsilon = \alpha.$$

→ Kirchhoff's law also states that the emissivity of a body is equal to its absorptivity when the body remains in thermal equilibrium with its surroundings.

(i) Thermal equilibrium.
(ii) same wavelength (monochromatic condition)
(iii) same temperature
(iv) ~~dol~~ closed system.

11. <u>Given Data</u>

$d_1 = d_2 = 20\ cm \Rightarrow r_1 = r_2 = 10\ cm.$

$L = 2\ m \qquad T_1 = 800 + 273 = 1073\ K$

$\epsilon_1 = 0.3 \qquad T_2 = 300 + 273 = 573\ K.$

$\epsilon_2 = 0.5$

$A = \pi r^2 = \pi \times (0.1)^2 = 0.0314\ m^2$

$L = 2\ m.$

$\frac{r}{L} = \frac{0.1}{2} = 0.05$

$$F_{12} = \frac{1}{2}\left[1 - \frac{1}{\sqrt{1 + \left(\frac{r}{L}\right)^2}}\right] =$$

$$F_{12} = \frac{1}{2}\left[1 - 0.99875\right] = 0.000625$$

$$Q = \frac{\sigma A F_{12}\left[T_1^4 - T_2^4\right]}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1}$$

$\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1 =$

$\frac{1}{0.3} + \frac{1}{0.5} - 1 = 4.333$

$$T_1^4 - T_2^4 = (1073)^4 - (573)^4 = 1.217 \times 10^{12}\ K^4$$

$$Q = \frac{5.67 \times 10^{-8} \times 0.314 \times 0.000625 \times 1.217 \times 10^{12}}{4.333}$$

$Q = 0.31$ watts