Time of day	9	10	11	12	1	2	3
t (hrs)	0	1	2	3	4	5	6
T °C	25	35	42.32	45	42.32	35	25

The maximum flux is at 12 noon:

$$\mathbf{Q_{max}} = \frac{(45 - 20) \times 400}{2.8449} = \mathbf{3515\ W}$$

$$\mathbf{Q_{min}} = \frac{(25 - 20) \times 400}{2.8449} = \mathbf{703\ W}$$

Average: using arithmetic average of temperatures at middle of each interval

Average temperature = 37.44°C

Average flux $= \dfrac{(37.44 - 20)}{2.8449} \times 400 = \mathbf{2452\ W}$

Calculating the average temperature by integration:

The angle $\theta = \left(\dfrac{2\pi}{12} t\right)$ varies from $0 - \pi$, by letting $\theta = \left(\dfrac{2\pi}{12} t\right)$ and t taking values from 0-6

Average excess over 25°C $= \dfrac{20}{\pi} \displaystyle\int_0^{\pi} \sin \theta \, d\theta = \dfrac{20}{\pi} \times 2 = \dfrac{40}{\pi} = 12.732$

Average temperature = 37.732

Average flux $= \dfrac{(37.732 - 20)\ 400}{2.8449} = \mathbf{2493.16\ W/m^2}$.

OBJECTIVE QUESTIONS

Choose the Correct Answer

2.1 In a slab under steady conduction if the thermal conductivity increases along the thickness, the temperatures gradient along the direction will become

(*a*) Steeper (*b*) flatter

(*c*) will depend upon the heat flow (*d*) will remain constant.

2.2 In steady state heat conduction in the x direction, the sectional area increases along the flow direction. Then the temperature gradient in the x direction will

(*a*) Remain constant (*b*) will become flatter

(*c*) will become steeper (*d*) either b or c depending on the heat flow rate.

2.3 In steady state conduction with variable thermal conductivity if the conductivity decreases along the flow direction, then the temperature gradient along the flow direction will become

(*a*) steeper (*b*) flatter

(*c*) remain constant (*d*) either of the three depending on heat flow rate

2.4 In steady state conduction with thermal conductivity given by $k = k_o (1 + \beta T)$ where β, is +ve, a slab of given thickness and given temperature drop will conduct

(*a*) more heat at lower temperature levels

(*b*) more heat at higher temperature levels

(*c*) will be the same as flow depends on the temperature drop

(*d*) will be the same as flow depends on the thickness only.

2.5 Choose the correct statement or statements

(*a*) the thermal conductivity of gases decreases with temperature

(*b*) the thermal conductivity of insulating solids increase with temperature

(*c*) The thermal conductivity of good electrical conductors or generally low

(*d*) The thermal conductivity variation is of low percentage in gases as compared to solids.

Answers to objective questions: **(1) b, (2) b, (3) a, (4) b, (5) b.**

EXERCISE PROBLEMS

2.1 A furnace operating at 900°C is to be insulated. The outside is to be exposed to air at 30°C with h = 15 W/m^{2}K. The convection coefficient on the inside (including radiation) is 85 W/m^{2}K. The maximum space available is 0.25 m. The heat loss should not exceed 300 W/m^2. Determine the thermal conductivity of the material to be chosen for the insulation.

2.2 A composite wall is to be used to insulate a freezer chamber at – 35°C. Two insulating materials are to be used with conductivities of 0.04 W/mK and 0.1 W/mK. If the outside surface temperature of the inner layer (0.04 W/mK) should not go below zero and if the exposed surface temperature should not go below (the expected wet bulb temperature) 22°C determine the insulation thicknesses. The heat gain is to be limited to 10 W/m^2. Also estimate the value of convection coefficient at such a situation. Outside is at 25°C. (0.14 m, 0.22 m, 3.33 W/m^{2}K).

2.3 A composite wall consists of 20 mm thick steel plate backed by insulation brick (k = 0.39 W/mK) of 50 cm thickness and overlaid by mineral wool of 20 cm thickness (k = 0.05 W/mK) and 70 cm layer of brick of (k = 0.39 W/mK). The inside is exposed to convection at 650°C with h = 65 W/m^{2}K. The outside is exposed to air at 35°C with a convection coefficient of 15 W/m^{2}K. Determine the heat loss per unit area, interface temperatures and temperature gradients in each materials.

2.4 A solar collector receives 880 W/m^2. Its surface temperature is 60°C. The back side is to be insulated so that back losses are limited to 15%. Insulating material with a thermal conductivity of 0.05 W/mK is available. The atmospheric temperature is 30°C and the convection coefficient on the back side is 5 W/m^{2}K. Determine the insulation thickness.

2.5 A composite plate is made up of stainless steel sheet of 25 mm thickness backed by 30 mm carbon steel plate. The thermal conductivities are 19.1 W/mK and 39.2 W/mK. A contact resistance of 5.28×10^{-4} m^2°C/W exists between the sheets. If the total temperature drop in the composite wall is 18°C, determine the heat flow. If convection on the stainless steel side is from fluid at 160°C with h = 45 W/m^{2}K find the surface temperatures of the plates. If the outside is exposed to air at 35°C, determine the convection coefficient on the outside.

2.6 A membrane type electrical heater of 20,000 W/m^2 capacity is sandwiched between an insulation of 25 mm thickness with thermal conductivity of 0.029 W/mK and a metal plate with k = 12.6 W/mK of thickness 15 mm. The convection coefficient is 150 W/m^{2}K. The surroundings are at 5°C. Determine the surface temperature of the heater and the flow on either side.

2.7 A composite wall is made of two layers of 0.3 m and 0.15 m thickness with surfaces held at 600°C and 20°C respectively. If the conductivities are 20 and 50 W/mK, determine the heat conducted. In order to restrict the heat loss to 5 kW/m^2 another layer of 0.15 m thickness is proposed. Determine the thermal conductivity of the material required (32.22 kW, 1.53 W/mK).

This is equal to l^2R. Therefore **l = 42.7 amps**

Heat generation rate $\mathbf{q} = 29.03/\text{V} = 29.03/\pi \times r^2 \times 1$ (V-Volume)

$= \mathbf{9.24 \times 10^6\ W/m^3}$

$$T_o - T_w = qR^2/4k = 0.0065°\text{C} \ (R - \text{radius here})$$

When radius is small, the whole wire is at near uniform temperature.

OBJECTIVE QUESTIONS

Choose the Correct Statement or Statements

(*i*) In a slab generating heat uniformly and at steady state convecting equally on both sides, the temperature gradient will

(*a*) flatten out as the distance from the centre increases

(*b*) become steeper as the distance from the centre increases

(*c*) will remain constant

(*d*) can be any of (*a, b*) or (*c*) depending the heat generation rate.

(*ii*) For the same linear size (*i.e. L, r*) and heat generation rate, the temperature drop from centre to surface is highest in

(*a*) spherical shape (*b*) plate shape

(*c*) cylindrical shape (*d*) rod of square section.

(*iii*) The temperature drop in a heat generating solid under steady state conduction depends to a greater extent on

(*a*) linear dimension (*b*) thermal conductivity

(*c*) heat generation rate (*d*) convection coefficient at the surface.

(*iv*) The most effective way to reduce the temperature drop in a heat generating solid is to

(*a*) reduce the linear dimension

(*b*) reduce the thermal conductivity

(*c*) reduce the convection coefficient on the surface

(*d*) reduce the heat generation rate.

(*v*) The thermal gradient in a heat generating cylinder under steady conduction, at half the radius location will be

(*a*) One half of that at surface (*b*) One fourth of that at surface

(*c*) Twice that at surface (*d*) Four times that at surface.

(*vi*) In a sphere under steady state conduction with uniform heat generation, the temperature gradient at half the radius location will be

(*a*) one half of that at the surface (*b*) one fourth of that at the surface

(*c*) one eight of that at the surface (*d*) 2 times of that at the surface.

Answers: (i) b, (ii) b, (iii) a, (iv) a, (v) a, (vi) a.

EXERCISE PROBLEMS

3.1 An exothermic reaction in a slab of material generates heat uniformly at a rate of 2×10^6 W/m^3. The material has a thermal conductivity of 6.5 W/mK and the thickness is 80 mm. The slab is

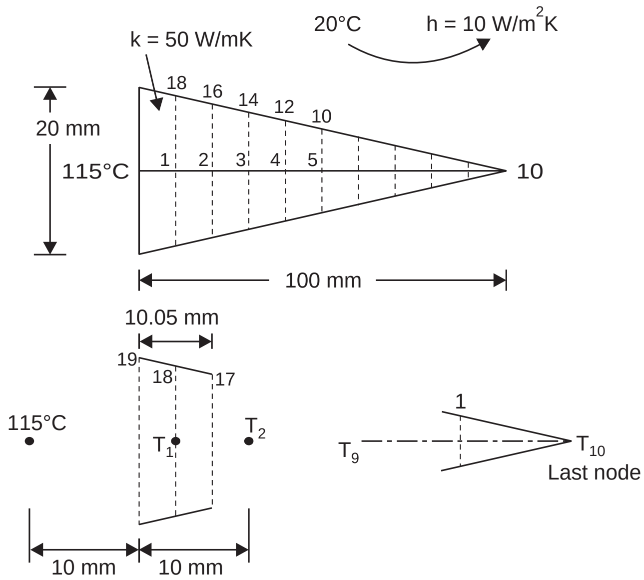

Fig. P. 4.37. Model of nodes.

Similarly for other elements

$$85\ T_1 - 160.201\ T_2 + 75\ T_3 + 4.02 = 0$$
$$75\ T_2 - 140.201\ T_3 + 65\ T_4 + 4.02 = 0$$
$$65\ T_3 - 120.201\ T_4 + 55\ T_5 + 4.02 = 0$$
$$55\ T_4 - 100.201\ T_5 + 45\ T_6 + 4.02 = 0$$
$$45\ T_5 - 80.201\ T_6 + 35\ T_7 + 4.02 = 0$$
$$35\ T_6 - 60.201\ T_7 + 25\ T_8 + 4.02 = 0$$
$$25\ T_7 - 40.201\ T_8 + 15\ T_9 + 4.02 = 0$$
$$15\ T_8 - 20.201\ T_9 + 5\ T_{10} + 4.02 = 0$$
$$5\ T_9 - 5.1005\ T_{10} + 2.01 = 0$$

For the last node

$$(T_9 - T_{10})/((0.01)/(50 \times 0.001)) + 10 \times 0.01005\ (20 - T_{10}) = 0$$

This reduces to the last equation above.

These equations can be solved for temperature distribution using matrix inversion or other such methods.

OBJECTIVE QUESTIONS

Choose the correct statement

1. In a long fin if the thermal conductivity is increased with other parameters maintained constant.

(*a*) The temperature will drop at a faster rate along the length

(*b*) The temperature will drop at a lower rate along the length (*c*) The temperature gradient is not strongly influenced by the conductivity

(*d*) The temperature gradient is dependent on the heat flow only.

2. In a long fin if the convection coefficient is increased with other parameters maintained constant.

(*a*) The temperature drop along the length is not strongly influenced by the convection coefficient.

(*b*) The temperature gradient depends only on heat flow rate.

(*c*) The temperature drop will be faster along the length.

(*d*) The temperature drop along the length will be at a lower rate.

3. In a long fin if the parameter $m = \sqrt{(hP/kA)}$ increases, other parameters being maintained constant then.

(*a*) The temperature drop along the length will be at a lower rate

(*b*) The temperature drop along the length will be steeper

(*c*) The parameter m influences the heat flow only

(*d*) The temperature profile will remain the same.

4. For a given sectional area of fin if the circumference is increased by adopting different geometric shape, then

(*a*) The temperature variation along the fin length will be steeper.

(*b*) The temperature variation along the fin length will be featter

(*c*) The circumference length does not affect the temperature change

(*d*) The circumference will only influence the heat convected.

5. In a given fin configuration increase in conductivity will

(*a*) Decrease the total heat flow

(*b*) Will affect only the temperature gradient

(*c*) Increase the total heat flow

(*d*) Heat flow is influenced only by the base temperature and sectional area.

6. An increase in convection coefficient over a fin will

(*a*) increase effectiveness (*b*) decrease effectiveness

(*c*) does not influence effectiveness (*d*) influences only the fin efficiency

7. In the case of fins it is desirable to have

(*a*) area of section maintained constant along the length

(*b*) area of section reduced along the length

(*c*) area of section increased along the length

(*d*) better to vary the convection coefficient than the area.

8. Fin effectiveness will be increased more by

(*a*) having a higher value of convection coefficient

(*b*) higher sectional area

(*c*) higher thermal conductivity

(*d*) longer circumference.

9. If a square section fin is split longitudinally and used as two fins

(*a*) The total heat flow will decrease

(*b*) The total heat flow will increase

(*c*) The toal heat flow will remain constant

(*d*) Heat flow may increase or decrease depending on the material used.

10. For a given volume of material for use in a pin fin
(*a*) longer the fin, better the total neat flow
(*b*) shorter the fin, better the heat flow
(*c*) As the volume is constant, the heat flow will not change
(*d*) As length is increased heat flow will increase and after some length will decrease.

Choose the correct statement or statements for the following questions

11. (*a*) If the convection coefficients is low, it is not desirable to use a fin
(*b*) If the conductivity is large, a longer fin will be more effective
(*c*) Plate fins of smaller thickness is better in the point of view of heat dissipation.
(*d*) Finned surface is desirable under conditions of boiling.

12. (*a*) Aluminium fins are better because the material is light
(*b*) A constant area fin provides the best (heat flow/weight) ratio.
(*c*) On rare occasions the heat flow may be reduced by the addition of fins.
(*d*) If conductivity is high a short fin will be a good proportion.

13. (*a*) A constant temperature gradient along the length of a constant area fin is not possible
(*b*) The temperature gradient, in circular section fin dissipating heat will increase along the length.
(c) Longitudinal fins are less effective compared to annular fins.
(*d*) Fins at close pitch will give a high heat dissipation rate.

14. (*a*) An aluminium fin will be cooler at a given distance compared to a copper fin of identical section and other parameters.
(*b*) An aluminium fin will be hotter at a given distance compared to a copper fin of identical section and other parameters.
(*c*) An aluminium fin of same configuration will dessipate more heat compared to copper fin.
(*d*) A aluminium fin of same configuration will dessipate less heat compared to copper fin.

Answers

1. (*b*)	**2.** (*c*)	**3.** (*b*)	**4.** (*a*)	**5.** (*c*)
6. (*a*)	**7.** (*b*)	**8.** (*d*)	**9.** (*b*)	**10.** (*d*)
11. (*c*)	**12.** (*a, d*)	**13.** (*a*), (*b*) (*d*)	**14.** (*b*), (*d*).	

EXERCISE PROBLEMS

4.1 A copper rod extends from a surface at 300°C. The diameter is 12 mm and length is 9 cm. The rod is exposed to air at 30°C with convection coefficient of 35 W/m^2 K. Assuming end is insulated determine the tip temperature. k = 340 W/mK. If an aluminium fin of the same diameter is used, what should be the length of the fin, if the tip temperature is to be the same as the copper fin. Assume k = 210 W/mK.

4.2 A surface is at 200°C. Pin fins of diameter 6 mm and length 12 mm are used at 12 mm spacing between centres. The surroundings are at 20°C. The convection coefficient is 30 W/m^{2}K. The conductivity of the material is 131 W/m K. Determine the increase in heat loss from the surface. Another proposal is to use fins of half the length at the same spacing, but the diameter increased to 8 mm. Compare the heat dissipation for this proposal, workout the heat dissipation/unit volume of fin.

The solution is given as a tabulation. The temperature at any time intervals are the mean of the adjacent temperature at the previous level for nodes 2, 3, and 4, and for T_5 it is equal to the temperature at the previous interval at T_4.

Time, end of minute	T_1	T_2	T_3	T_4	T_5
0	20	80	80	80	80
5	20	50	80	80	80
10	20	50	65	80	80
15	20	42.5	65	72.5	80
20	20	42.5	57.5	72.5	72.5
25	20	38.75	57.5	65	72.5
30	20	38.75	51.875	65	65
35	20	35.94	51.875	58.43	65

At 30 min the nodal temperatures are 20, 37.35, 51.9, 61.72 and 65°C (at nodes 2 and 4, mean value is taken).

OBJECTIVE QUESTIONS

6.1 Choose the correct statement
(*a*) Transient conduction means very little heat transfer
(*b*) Transient conduction means conduction when the temperature at a point varies with time
(*c*) Transient conduction means heat transfer for a short time
(*d*) Transient conduction means heat transfer with very small temperature difference.

6.2 Choose the correct statement
Lumped parameter model can be used when
(*a*) the thickness is small
(*b*) when the conductivity is high
(*c*) when the convective heat transfer coefficient is low
(*d*) when conditions (*a*), (*b*) and (*c*) are true

6.3 Choose the correct statement
In the lumped parameter model, the temperature variation is
(*a*) linear with time (*b*) sinusoidal with time
(*c*) exponential with time (*d*) cubic with time.

6.4 Choose the correct statement
The response time of a thermocouple is the time taken for the temperature change to be
(*a*) 0.5 of original temperature difference
(*b*) 1/1.414 of original temperature difference
(*c*) 1/*e* of original temperature difference
(*d*) 99% of the original temperature difference.

6.5 Choose the correct statement
To make a thermocouple to respond quickly
(*a*) the wire diameter should be large
(*b*) convective heat transfer coefficient should be high

(*c*) density should be very small

(*d*) specific heat should be high.

6.6 Choose the correct statement

Semi infinite model can be adopted when

(*a*) thickness of the solid is very large (*b*) heat diffusion is very slow

(*c*) short time period (*d*) all of these.

6.7 The temperature distributions in a semi infinite solid with time are shown in Fig. 6.7 (*a*), (*b*), (*c*) and (*d*) match these with the statements and figures

(1) sudden surface temperature change (2) cooling

(3) convection boundary (4) constant heat flux.

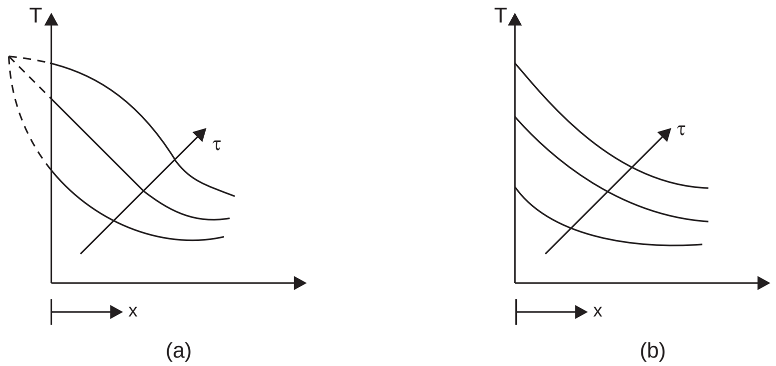

Fig. E. 6.7 (a, b)

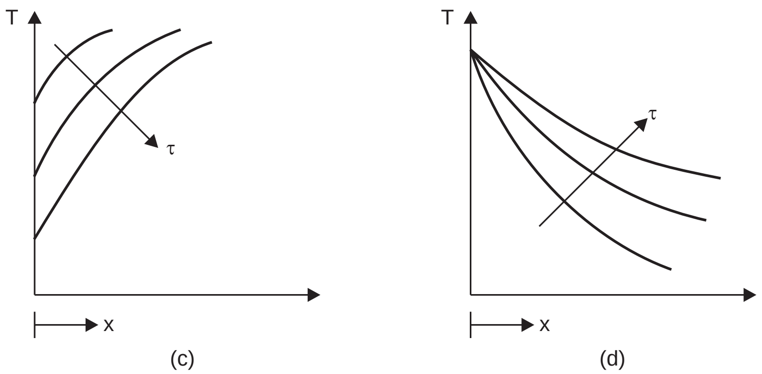

Fig. E. 6.7 (c, d)

6.8 Choose the correct statement

Heating or Cooling of a road surface can be analysed using

(*a*) lumped parameter model (*b*) Infinite slab model

(*c*) Semi infinite slab model (*d*) none of these.

6.9 Match the figures and the statements under transient conditions.

(1) cooling (2) heating

(3) steady state (4) heat generation.

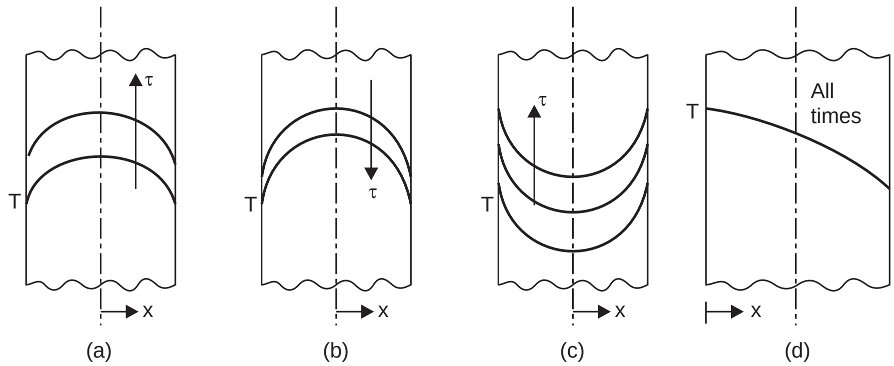

Fig. E. 6.9 (a, b, c, d)

EXERCISE PROBLEMS

6.1 For the materials with the following values of conductivity and a convective heat transfer coefficient of 60 W/m^{2}K, determine the minimum diameter for cylindrical shape for which lumped parameter model can be applied

(*a*) Aluminium k = 204.2 W/mK (*b*) Silumin with k = 136.8 W/mK
(*c*) Steel k = 43.3 W/mK (*d*) Nickel steel with k = 19.1 W/mK
(*e*) Inwar with k = 10.7 W/mK.

6.2 In the problem 6.1 determine the diameter if spherical shape is used.

6.3 In the problem 6.2 determine the thickness if flat slab shape is used.

6.4 Determine the maximum value of convective heat transfer coefficient for the following materials of spherical shape of diameter 0.05 m for the application of lumped parameter model

(*a*) k = 204.2 W/mK (*b*) k = 136.8 W/mK
(*c*) k = 43.3 W/mK, and (*d*) k = 107 W/mK.

6.5 Determine the time constant for the following materials if the wire is of 1 mm dia and exposed to convection at 50 W/m^{2}K. The property values are:

Material	*density, kg/m^3*	*Specific heat, J/kgK*	*Thermal conductivity W/mK*
a	2700	896	204.2
b	2660	867	136.8
c	8196	461	10.4
d	8954	381	386
e	8922	394	24.9
f	19350	134	162.7
g	10525	235	407

6.6 Pellets of 3 mm × 10 mm × 8 mm size are to be cooled from 25°C to –90°C in atmosphere at – 176°C with a convection coefficient of 45 W/m^{2}K. The material properties are density = 10525 kg/m^3, specific heat = 235 J/kg/K, Thermal conductivity = 407 W/mK. Determine the time required.

6.7 Plate glass 5 mm thick at 200°C is to be cooled from both sides using air at 40°C. If surface cracks are to be avoided, determine the maximum value of convective heat transfer coefficient. Material properties are density = 2500 kg/m^3, specific heat 670 J/kgK. Thermal conductivity 0.744 W/mk. Also determine the time required in this case to cool the plate to 80°C.

$$\frac{3}{2}\, k\,(T_w - T_\infty)\,\frac{1}{\delta} = h_x\,(T_w - T_\infty)$$

$$\therefore \qquad \frac{\mathbf{h_x x}}{\mathbf{k}} = \frac{3}{2}\,\frac{(Re_x\ Pr)^{0.5}}{2.191} = \mathbf{0.685\ (Re_x\ Pr)^{0.5}}$$

Compare with 0.565 $(Re_x\, Pr)^{0.5}$ correlation for liquid metals for $Pr < 0.05$ and $Re_x < 5 \times 10^5$.

OBJECTIVE QUESTIONS

Choose the correct statement

7.1 The convective heat transfer coefficient in laminar flow over a flat plate
(*a*) increases if a lighter fluid is used
(*b*) increases if a higher viscosity fluid is used
(*c*) increases if higher velocities are used
(*d*) increases with distance.

7.2 In the boundary layer over a flat plate in laminar flow the velocity is
(*a*) zero at the boundary layer thickness.
(*b*) slowly decreases from the free stream to the solid surface
(*c*) slowly increases from the free stream to the wall
(*d*) only temperature in the boundary layer will be different from that of free stream.

7.3 As viscosity of fluid increases the boundary layer thickness
(*a*) will increase (*b*) will decrease
(*c*) will not change
(*d*) will increase at medium values and then will decrease.

7.4 The temperature gradient in the fluid flowing over a flat plate
(*a*) will be zero at the surface (*b*) will be positive at the surface
(*c*) will be very steep at the surface (*d*) will be zero at the top of the boundary layer.

7.5 The ratio of thermal to hydrodynamic boundary layer thickness varies as
(*a*) root of Reynolds number (*b*) root Nusselt number
(*c*) root of Prandtl number (*d*) one third power of Prandtl number.

7.6 In liquid metal flow over a flat plate ($T_s > T_\infty$)
(*a*) The hydrodynamic boundary layer will be very thick and thermal boundary layer will be very thick.
(*b*) The hydrodynamic boundary layer will be very thin and thermal boundary layer will also be thin
(*c*) The two will be more or less equal
(*d*) The thermal boundary layer will be thick and hydrodynamic boundary layer will be thin.

7.7 In forced convection molecular diffusion causes
(*a*) momentum flow in turbulent region
(*b*) momentum flow in the laminar region
(*c*) Heat flow in the turbulent region
(*d*) diffusion has no part in energy transfer.

7.8 Heat transfer rate
(*a*) will be higher in turbulent flow
(*b*) will be lower in turbulent flow
(*c*) will depend only on the fluid
(*d*) will depend only on viscosity.

7.9 Nusselt number is
(*a*) ratio of viscous to inertia forces
(*b*) dimensionless heat transfer coefficient
(*c*) ratio of conduction to convection resistance
(*d*) signifies the velocity gradient at the surface.

7.10 Reynolds number is
(*a*) ratio of conduction to convection resistance
(*b*) ratio of buoyant to inertia forces
(*c*) ratio of viscous to inertia forces
(*d*) ratio of heat conducted to the heat capacity.

7.11 Prandtl number is
(*a*) ratio of buoyant force to inertia force
(*b*) ratio of conduction to convection resistance
(*c*) signifies the temperature gradient at the surface
(*d*) ratio of Molecular momentum diffusivity to thermal diffusivity.

7.12 The Stanton number is
(*a*) the dimensionless temperature gradient at the surface in convection
(*b*) Mass diffused to heat diffused
(*c*) dimensionless convection coefficient
(*d*) wall heat transfer/heat transfer by convection.

EXERCISE PROBLEMS

7.1 Nitrogen at 1 atm and – 20°C flows over a flat plate at 20° at a free stream velocity of 15 m/s. Determine the boundary layer thickness, (both hydrodynamic and thermal) coefficient of drag and local convection heat transfer coefficient at a distance of 0.4 m from the leading edge.

7.2 Air at 10 atm and 25°C flows with free stream velocity of 6 m/s over a flat plate at 75°C. Determine the heat flux at 0.05 m intervals upto a distance where the Reynolds number is 5×10^5.

7.3 A van with a roof length of 3.6 m travels in air at 30°C. Determine the speed of travel at which the flow over the roof will turn just turbulent.

7.4 Air flows parallel to the sides of a house at – 20°C with a speed of 12 km/hr. The size of the surface is 4 m × 3 m, the flow being along the 4 m side. The wall surface is at 20°C. Determine the heat loss to air from the wall.

7.5 Compare the boundary layer thicknesses at 0.4 m for the flow of (*i*) air and (*ii*) water, with a free stream velocity of 1 m/s. The film temperature is 40°C.

7.6 Compare the value of local heat transfer coefficient at 0.2 m for flow of (*i*) water (*ii*) engine oil at a film temperature of 40°C, with a free stream velocity of 1.5 m/s.

7.7 Compare the value of local convective heat transfer coefficient for water flow over a flat plate at a film temperature of 40°C at $Re = 5 \times 10^5$ assuming the flow to be (*i*) laminar (*ii*) turbulent

7.8 Assuming $u/u_\infty = y/\delta$, derive an expression for the y component of velocity in the boundary layer. Use the continuity equation and $\delta = 3.64\, x/\sqrt{Re_x}$.

If the other correlation is used, with properties at T_∞

$$Re = 3.475 \times 0.02/1.006 \times 10^{-6} = 69085$$

$$C = 0.27,\ m = 0.63$$

$$Nu = C\ .\ Re^m\ Pr^{0.36}\left(\frac{Pr_\infty}{Pr_w}\right)^{0.25}$$

$$= \mathbf{752.38} \quad \therefore \quad \mathbf{h_{10} = 22489\ W/m^2K}$$

h_6 = 22140 W/m²K (about 18% more than the other correlation). For water flow this may be better

Problem 8.30: *Hot air is used to heat up rocks in a container 1 m dia and 2 m long. The rocks are approximately spherical with a diameter of 30 mm. The bed has void space of 42%. The rock is at 20°C. The air is at 80°C and flows in the axial direction at a flow rate of 1 kg/s. Calculate the value of convection coefficient.*

Solution: The case is heat transfer from gas to fillings (as compared to wall to the gas discussed in problem no. 8.22)

$$\text{Reynolds} = \frac{D\,U_{BS}}{\nu(1-\varepsilon)}$$

$$D = 6\ \text{V/surface area} = 6 \times \frac{4}{3}\pi r^3/4\pi r^2 = 2r = D = 0.03\ \text{m}$$

U_{BS} = superficial velocity based on the area of empty container

$$= 1 \times \text{sp vol}/(\pi \times 1^2/4) = 4/\pi = 1.273\ \text{m/s}$$

at 80°C, 1 atm, sp. vol. $= 1\ \text{m}^3/\text{kg}$

The property values at 100/2 = 50°C, $\nu = 17.95 \times 10^{-6}$ m²/s, $Pr = 0.698$

$$k = 0.02826\ \text{W/mK}$$

$$Re = 0.03 \times 1.273/17.95 \times 10^{-6} = 2128$$

$$\frac{h.D}{k} = \frac{1-\varepsilon}{\varepsilon}\,[0.5\,Re^{0.5} + 0.2\,Re^{0.67}]\,Pr^{1/3}$$

$$= \frac{0.58}{0.42}\,[0.5\,(2128)^{0.5} + 0.2\,(2128)^{0.67}]\,(0.698)^{0.333} = 69.83$$

$$\therefore \quad \mathbf{h = 65.78\ W/m^2K}$$

OBJECTIVE QUESTIONS

Choose the correct statement

8.1 In flow over a flat plate the convection coefficient
(*a*) Always increases along the flow
(*b*) Decreases, increases and decreases
(*c*) Increases upto critical Reynolds number and then decreases
(*d*) Decreases upto critical Reynolds number and then increases.

8.2 In laminar flow over a flat plate,

(*a*) The thermal boundary layer and hydrodynamic boundary layers are of equal thickness

(*b*) The thermal boundary layer is thicker if the Prandtl number is greater than one

(*c*) The thermal boundary layer is thicker if the Prandtl number is less than one

(*d*) The thermal boundary layer is always thinner in the laminar region.

8.3 The friction factor in the laminar region is proportional to

(*a*) $Re^{0.5}$ (*b*) $Re^{0.2}$ (*c*) $Re^{-0.2}$ (*d*) $Re^{-0.5}$.

8.4 The boundary layer thickness in laminar flow is proportional to

(*a*) $Re^{0.2}$ (*b*) $Re^{0.5}$ (*c*) $Re^{-0.5}$ (*d*) $Re^{-0.2}$.

8.5 In laminar flow over a flat plate the convection coefficient is proportional to

(*a*) $x^{-0.5}$ (*b*) $x^{0.5}$ (*c*) $x^{-0.2}$ (*d*) x.

8.6 The boundary layer thickness in laminar flow over a flat plate, is proportional to

(*a*) x (*b*) $x^{0.5}$ (*c*) $x^{-0.5}$ (*d*) x^{-1}.

8.7 (*a*) higher the value of kinematic viscosity thinner will be the boundary layer

(*b*) Higher the Prandtl number lower will be the thickness of thermal boundary layer.

(*c*) The convective heat transfer coefficient will be lower in turbulent flow as compared to laminar flow

(*d*) The boundary layer will thicken as the free stream velocity increases.

8.8 In flow across a cylinder, the local Nusselt number will be highest at

(*a*) 90° from the stagnation point

(*b*) At the stagnation point

(*c*) At 80°C from stagnation point

(*d*) At 135°C from stagnation point.

8.9 In banks of tubes heat transfer will be highest

(*a*) In linear arrangement with square pitch

(*b*) Linear arrangement with lower longitudinal pitch

(*c*) Staggered arrangement with equal pitch

(*d*) Staggered arrangement with lower longitudinal pitch.

EXCERCISE PROBLEMS

8.1 Nitrogen at 30°C flows over a plate maintained at 70°C with a free stream velocity of 10 m/s.

(*a*) Determine the local and average values of convective heat transfer coefficient

(*b*) Also calculate the values of the boundary layer thickness (velocity, thermal) and momentum and displacement thicknesses at these locations.

(*c*) Determine also the location at which the flow turns turbulent, considering $Re_{cr} = 5 \times 10^5$.

8.2 Air at 20°C was heated by flow over a flat plate at 100°C, the flow velocity being 16 m/s. The plate is 1 m wide and 1.2 m long. Due to deterioration of performance of the fan and the heating medium, the plate temperature is reduced to 80°C while the flow velocity is reduced to 10 m/s. Determine the percentage reduction in heat flow.

8.3 It is desired to predict the performance of heat transfer in an equipment using liquid ammonia at a film temperature of – 30°C upto a Reynolds number of 10^5, using heat transfer studies on similar flat surface, with air as the test fluid. The maximum velocity of air is 10 m/s and the film temperature is 40°C. Determine the length of the plate to be used for the experiment.

$$D_h = \frac{4.a^2}{4a} = a,\ u = 0.06 \times \frac{1}{1.128} \times \frac{1}{a^2} = 27.28 \text{ m/s}$$

$$Re = 27.28 \times 0.0443/16.96 \times 10^{-6} = 71284, \text{ Turbulent}$$

$$\therefore \quad Nu = 0.023\ Re^{0.8}\ Pr^{0.4} = 155.7,\ \mathbf{h = 96.8\ W/m^2\ K}$$

This comparison is for the same area and mass flow and so the velocity in the square section is the same. Use of non-circular section is not desirable in heat transfer or for construction purposes, but may be dictated by other considerations.

OBJECTIVE QUESTIONS

9.1 Choose the correct Statement in flow through pipes:
(*a*) In laminar flow, the exit Nusselt number in the fully developed condition is lower than at entry.
(*b*) In laminar flow, the exit Nusselt number in the fully developed condition is higher than at entry.
(*c*) In laminar flow, the Nusselt number remains constant.
(*d*) In laminar flow the Nusselt at constant wall temperature is higher as compared to Nusselt at constant heat flux.

9.2 In flow through pipes for the same Reynolds number,
(*a*) The thermal entry length is longer for low Prandtl number fluids
(*b*) The thermal entry length is longer for high Prandtl number fluids
(*c*) Prandtl number does not influence the thermal entry length.
(*d*) The thermal entry length effect is more pronounced only in turbulent flow.

9.3 (*a*) Flow of air can be considered as hydrodynamic layer fully developed and thermal layer developing
(*b*) Flow of oils can be considered as *HFD* and thermal layer developing
(*c*) Flow of liquid metals can be considered as Hydrodynamic layer fully developed and thermal layer developing
(*d*) Flow of water can be considered as hydrodynamic layer fully developed and thermal layer developing.

9.4 In pipe flow, the average convection coefficient
(*a*) will be higher in rough pipes
(*b*) will be higher in smooth pipes
(*c*) Roughness affects only pressure drop and not the convection coefficient
(*d*) Only Reynolds and Prandtl numbers influence the convection coefficient and not the roughness.

9.5 In pipe flow:
(*a*) for constant heat flux, the initial length is more effective compared to the end length
(*b*) for constant wall temperature the initial length are less effective compared to the end lengths
(*c*) In fully developed flow and constant wall temperature, the effectiveness increases with length
(*d*) In fully developed flow and constant heat flux, the effectiveness decreases with length.

9.6 (*a*) In smooth pipes a laminar flow remains laminar all through the length
(*b*) In smooth pipes a laminar flow turns turbulent after a certain length
(*c*) The temperature profile in fully developed layer remains the same
(*d*) The velocity profile in a pipe flow is established at the entry.

Answers

1. (*a*) **2.** (*b*) **3.** (*c*) **4.** (*a*) **5.** (*a*) **6.** (*a*).

EXERCISE PROBLEMS

9.1 Show that $(1.2 \log Re - 1.64)^{-2} = 4\,(1.58 \ln Re - 3.28)^{-2}$

9.2 Show that

$$\sqrt{2/f} = 2.46 \ln (Re \,.\, \sqrt{f/2} + 0.292) \text{ and } \sqrt{1/4\,f} = 2 \log [Re \sqrt{4\,f}\,] - 0.8.$$

9.3 For air flow at constant wall temperature of 100°C and bulk mean temperature of 40°C through a 4 cm ID pipe, determine the value of average convection coefficients for a length of 1 m if the entrance velocity is (*i*) 0.6 m/s, (*ii*) 0.8 m/s, (*iii*) 10 m/s.

9.4 For air flow at a constant wall temperature of 100°C and average bulk temperature of 40°C through a 4 cm ID pipe, determine the value of average convection coefficient for an inlet velocity of 0.8 m/s if the pipe length is (*i*) 1 m, (*ii*) 3 m, (*iii*) 10 m.

9.5 Air is to be heated at a rate of 5 kg/hr through a 40 mm ID pipe from 20°C to 60°C, the pipe wall being maintained at 100°C by condensing steam. Determine the length required.

9.6 5m length of 50 mm dia pipe has its wall maintained at 100°C. Air at 20°C enters the pipe. If the exit temperature of air is to be 60°C, determine the air flow rate.

9.7 Air at 20°C is to be heated to 40°C using constant heat flux over a pipe of 40 mm ID at a flow rate of 5 kg/hr. Determine the pipe length required and also the average pipe wall temperature. The heat flux is 500 W/m^2.

9.8 100 kg of water per hour is to be heated by flow through a 2.5 cm ID pipe from 20°C to 60°C. The pipe wall is at 100°C. Determine the length of pipe required. Also determine the mean temperature at half this length.

9.9 Water is to be heated from 20°C at a rate of 500 kg/hr by flow through a pipe of 25 mm ID with a wall temperature of 100°C. Determine the length required. Also determine the temperature at half this length.

9.10 Water flows at a rate of 500 kg/hr through a pipe uniformly heated. It is heated from 20°C to 60°C through a length of 5.6 m. The pipe diameter is 25 mm. Determine the average pipe temperature.

9.11 Water flows at a rate of 500 kg/hr through a 40 mm dia pipe with uniform wall heat flux and is heated from 20°C to 40°C over a length of 8 m. Determine the wall temperature at the exit.

9.12 Engine oil is cooled from 120°C by flow through a tube of 5 mm ID, with uniform wall temperature of 40°C at a rate of 0.08 kg/s. Estimate the temperature of the oil at the outlet for lengths of 1 m, 5 m and 10 m.

9.13 Furnace oil is to be heated from 30°C to 70°C for proper atomisation. Steam is used at 110°C for the heating. If the flow rate through a 15 mm ID pipe is 40 kg/hr, determine the length of pipe required. (use the property values of engine oil for the estimate).

9.14 Liquid ammonia flows in a duct of diameter 2 cm. The average bulk temperature is 20°C. The duct wall is at 50°C. If fully developed laminar flow prevails, determine the heat transfer per m length.

9.15 Liquid refrigerant *R*12 ($CCl_2\,F_2$) flows through a 4 mm dia tube at 30°C, the Reynolds number being 1000. Calculate the length necessary to cool the fluid to 20°C. The wall temperature is 10°C.

9.16 Air at 14 atm pressure flows through a 75 mm ID pipe at a rate of 0.55 kg/s, the duct wall being at 20°C. The average air temperature at inlet is 60°C. The duct is 6 m long. Estimate the temperature of air as it leaves, the duct.

OBJECTIVE QUESTIONS

Choose the correct Statement in the following cases.

10.1 (*a*) Buoyant forces and inertia forces only influence free convection heat transfer.

(*b*) Viscous and buoyant forces only influence free convection heat transfer.

(*c*) Viscous and inertia forces only influence free convection heat transfer.

(*d*) Viscous, inertia and buoyant forces influence the heat transfer in free convection.

10.2 The heat transfer rate in free convection in the laminar region depends on

(*a*) ΔT (*b*) $\Delta T^{1.25}$ (*c*) $\Delta T^{1.33}$ (*d*) $\Delta T^{0.25}$.

10.3 The heat transfer rate in free convection in the turbulant region depends on

(*a*) $\Delta T^{1.33}$ (*b*) ΔT (*c*) $\Delta T^{0.33}$ (*d*) $\Delta T^{1.25}$.

10.4 The convection coefficient in free convection over a vertical plate in the laminar region depends on

(*a*) $L^{-0.25}$ (*b*) $L^{-1.25}$ (*c*) $L^{-0.33}$ (*d*) $L^{+0.25}$.

10.5 The convection coefficient in the case of a vertical plane in free convection in turbulent region depends on

(*a*) $L^{-0.25}$ (*b*) $L^{0.25}$ (*c*) $L^{0.0}$ (*d*) $L^{0.33}$.

10.6 When some flow velocity is superimposed on free convection, the predominance of either is determined by

(*a*) $Gr >> Re^2$ means forced convection

(*b*) $Gr \approx Re^2$ means none of the two

(*c*) $Gr << Re^2$ means free convection

(*d*) $Gr = Re$ means purely free convection.

10.7 In free convection, the slope of the curve *Nu vs Gr Pr*

(*a*) Increases with increasing *Gr Pr*

(*b*) Decreases with increasing *Gr Pr*

(*c*) Increases and then decreases with increasing *Gr Pr*

(*d*) Decreases and then increases with increasing *Gr Pr*.

Answers

1. (*d*) **2.** (*b*) **3.** (*a*) **4.** (*a*) **5.** (*c*) **6.** (*b*)
7. (*a*).

Chapter 10

EXERCISE PROBLEMS

10.1 A large chemical process tank is in the form of a cylinder of 2 m dia and 4.5 m high. The surface temperature is 80°C and the surrounding air is at 40°C. Determine the rate of heat loss over the curved surface under these conditions.

10.2 100 m^3 of chemical at 80°C is to be stored in a process plant. Examine the heat loss by free convection from the following shapes. (*i*) cubical (*ii*) vertical cylinder of $D : L = 1 : 3$ (*iii*) horizontal cylinder of the same length to diameter ratio (*iv*) sphere. The surrounding is at 20°C. In the case of cylinder neglect the end losses and for the cubical shape from the top and bottom.

10.3 A cylindrical tank of 1 m dia and 2 m height has its surface maintained at 120°C. It contains water at 20°C. Determine the free convection heat transfer coefficient at the surface.

Problem 11.33: *Determine the time needed to freeze (frost bite) a layer of 1mm thickness of skin exposed to wind at –20°C with a convection coefficient of 50 W/m² K. Assume properties of water and the temp. of the skin as 35°C to start with. The convection coefficient at the interface is 25 W/m² K.*

Solution: Eqn. (11.44) is applicable.

$$\tau^* = \left(\frac{1}{H^*T^*}\right)^2 \ln\left[\frac{1-H^*T^*}{1-H^*T^*(1+x^*)}\right] - \frac{x^*}{H^*T^*}$$

$$x^* = x \times h_\infty/k_s = 0.001 \times 50/2.22 = 0.02252252$$

$$H^* = \frac{h_1}{h_\infty} = \frac{25}{50} = 0.5$$

$$T^* = \frac{T_L - T_{fr}}{T_{fr} - T_\infty} = \frac{35}{20} = 1.75$$

$$\tau^* = \frac{h_\infty^2\,(T_{fr} - T_\infty)}{k_s\,\rho_s\,h_{sf}}\,\tau = 7.33623 \times 10^{-5}\,\tau \qquad \text{...(A)}$$

Substituting

$$\tau^* = \left(\frac{1}{0.5\times1.75}\right)^2 \ln\left[\frac{1-0.5\times1.75}{1-0.5\times1.75(1+0.02252)}\right] - \frac{0.02252}{0.5\times1.75} \qquad \text{...(B)}$$

$$= 0.19835$$

Using (A) and (B), $\therefore$ τ = **2704s = 45 min.**

Frost bite may start after 45 min.

OBJECTIVE QUESTIONS

Choose the correct statement in each of the following sets:

11.1 With increase in excess temperature the heat flux in boiling

(*a*) increases continuously

(*b*) decreases and then increases

(*c*) increases then decreases and again increases

(*d*) decreases then increases and again decreases.

11.2 The heat flux in nucleate pool boiling is proportional to (where h_{fg} is enthalphy of evaporation)

(*a*) h_{fg} (*b*) $1/h_{fg}$ (*c*) f_{fg}^2 (*d*) $1/h_{fg}^2$.

11.3 The heat flux in nucleate pool boiling is proportional to (where σ is surface tension)

(*a*) σ (*b*) $\sigma^{0.5}$ (*c*) $\sigma^{-0.5}$ (*d*) σ^2.

11.4 The critical heat flux in nucleate pool boiling is proportional to (where ρ_v is the density of vapour)

(*a*) ρ_v (*b*) $\rho_v^{\,2}$ (*c*) $\rho_v^{\,0.5}$ (*d*) $\rho_v^{\,1/3}$.

11.5 The critical heat flux in nucleate pool boiling is proportional to (where h_{fg} is the enthalphy of evaporation)

(*a*) h_{fg} (*b*) $h_{fg}^{0.5}$ (*c*) h_{fg}^{2} (*d*) $h_{fg}^{1/3}$.

11.6 The critical heat flux in nucleate pool boiling is proportional to (where σ is the surface tension)

(*a*) σ (*b*) $\sigma^{0.5}$ (*c*) $\sigma^{1/3}$ (*d*) $\sigma^{1/4}$.

11.7 The critical heat flux in nucleate pool boiling is proportional to (where ρ_f is the density of liquid)

(*a*) ρ_l^{2} (*b*) $\rho_l^{0.25}$ (*c*) $\rho_l^{0.5}$ (*d*) $\rho_l^{1/3}$.

11.8 In nucleate pool boiling the heat flux depends on

(*a*) only the material of the surface

(*b*) material and roughness of the surface

(*c*) independent of surface

(*d*) fluid and material and surface roughness.

11.9 In nucleate pool boiling the heat flux is proportional to (ΔT is the excess temperature)

(*a*) ΔT^3 (*b*) ΔT (*c*) ΔT^2 (*d*) $\Delta T^{0.5}$.

11.10 In nucleate pool boiling the heat flux for boiling of water is proportional to (μ_1) is the viscosity of liquid)

(*a*) μ_1^{-2} (*b*) μ_1 (*c*) $\mu_1^{0.5}$ (*d*) μ_1^{2}.

11.11 In nucleate pool boiling of liquids other tahn water the heat flux varies as (when μ_1 is the viscosity of liquid)

(*a*) $\mu_1^{5.1}$ (*b*) $\mu_1^{-4.1}$ (*c*) μ_1^{2} (*d*) μ_1^{-2}.

11.12 In nucleate film boiling of water the heat flux varies as (where k is the vapur thermal conductivity)

(*a*) $k^{0.33}$ (*b*) $k^{0.75}$ (*c*) k^2 (*d*) $k^{5.1}$.

11.13 In nucleate pool boiling of liquids other than water the heat flux varies as

(*a*) $Pr^{-5.1}$ (*b*) $Pr^{3.1}$ (*c*) Pr^3 (*d*) $Pr^{0.5}$.

11.14 In nucleate pool boiling the convective heat transfer coefficient varies as (where ΔT is excess temperature)

(*a*) ΔT^2 (*b*) ΔT^3 (*c*) $\Delta T^{2.5}$ (*d*) $\Delta T^{0.5}$.

11.15 In film boiling the properties that contribute to the value of convection coefficient are

(*a*) h_{fg} μ_1 . ρ_1 and ΔT

(*b*) h_{fg} μ_v, k_v and ρ_1

(*c*) h_{fg}, k_v, μ_1 and ΔT

(*d*) h_{fg}, k_1, μ_v and ΔT.

11.16 The heat flux in nucleate pool boiling will be higher for

(*a*) horizontal plane (*b*) vertical plane

(*c*) horizontal cylinder (*d*) independent of location.

11.17 In condensing under same conditions, the convection coefficient will be lowest for

(*a*) vertical palte (*b*) vertical pipe

(*c*) horizontal pipe (*d*) row of vertical pipes.

11.18 In condensation over a vertical surface, the value of convection coefficient varies as (k–conductivity of liquid)

(*a*) k^3 (*b*) $k^{0.75}$ (*c*) $k^{0.25}$ (*d*) $k^{0.33}$.

11.19 The heat transfer rate in laminar film condensation varies as (where $\Delta T = T_g - T_w$)

(*a*) ΔT (*b*) $\Delta T^{0.75}$ (*c*) $\Delta T^{0.25}$ (*d*) $\Delta T^{-0.25}$.

11.20 The convective heat transfer coefficient in laminar film condensation varies as (ρ-density of liquid)

(*a*) ρ (*b*) $\rho^{0.5}$ (*c*) $\rho^{-0.5}$ (*d*) ρ^2.

11.21 In laminar film condensation, the average convection coefficient varies as (where μ is the dynamic viscosity of liquid).

(*a*) μ^{-1} (*b*) $\mu^{-0.5}$ (*c*) $\mu^{0.25}$ (*d*) $\mu^{-0.25}$.

11.22 In laminar film condensation the convection coefficient varies as (where L is the height of plate)

(*a*) L^{-1} (*b*) $L^{-0.5}$ (*c*) L (*d*) $L^{-0.25}$.

11.23 In laminar film condensation the convection coefficient varies as (h_{fg} is the enthalpy of evaporation).

(*a*) h_{fg} (*b*) $h_{fg}^{0.5}$ (*c*) $h_{fg}^{1/3}$ (*d*) $h_{fg}^{0.25}$.

EXERCISE PROBLEMS

11.1 Determine the maximum heat flux and the heat flux at an excess temperature of 8°C for water at pressure corresponding to (*i*) 50°C (*ii*) 100°C (*iii*) 180°C (*iv*) 310°C. In all cases assume a surface coefficient of 0.013 and pool boiling in the nucleate regime. Comment on the results.

11.2 Determine for the cases in 11.1 the minimum heat flux in the film boiling regime.

11.3 Determine the heat flux in boiling of water at a pressure corresponding to a saturation temperature of 310°C under film boiling regime if the excess temperature is (*i*) 1000°C (*ii*) 2000°C. Assume boiling to take place over a flat surface.

11.4 Smoke tubes of 6.25 cm *OD* are used in a boiler. Steam is generated at 170°C. The tube surface is at 178°C. There are 100 tubes of length 3 m each. Estimate the rate of possible steam production at saturated conditions. Assume pool boiling conditions and $C_{sf} = 0.013$.

11.5 Ammonia liquid evaporates in a flooded type of evaporator at – 10°C over tube surfaces immersed in the liquid. Brine at 0°C is circulated through the inside of the tubes and the tube surface is maintained at 0°C. The tube outside dia is 25 mm. 40 tubes of 1 m length are used. Determine the evaporation rate of ammonia. Assume $\sigma = 28 \times 10^{-3}$ N/m, $h_{fg} = 1296.5$ kJ/kg. $C_{sf} = 0.013$.

11.6 Boiling heat flux with water over a surface is measured under certain conditions. It is desired to estimate the heat flux for boiling of water at a higher pressure at which $\mu_2 = 0.8\,\mu_1$, $h_{fg2} = 0.8\,h_{fg1}$, $\sigma_2 = 0.6\,\sigma_1$, $P_{r2} = 0.6\,P_{r1}$. There is no significant change in density and specific heat and excess temperature. Determine the % change in the heat flux.

11.7 The maximum heat flux for boiling a liquid was measured under certain conditions. Estimate the critical heat flux for boiling under similar conditions but at a different saturation temperature. The following are the significant changes in property value $\sigma_2 = 0.7\,\sigma_1$, $h_{fg2} = 0.9\,h_{fg1}$, $\rho_{v1} = 2\rho_{v2}$.

11.8 An electrical heater rod of 10 mm dia is immersed in water at atmospheric pressure. The surface temperature reached is 600°C. If the emissivity of the surface is 0.5, estimate the electrical power input.

11.9 Estimate the convection coefficient for steam at 40°C saturation conditions condensing on a vertical surface maintained at 30°C. The plate is 1.5 m high. Also find the film thickness at 1 m and 1.5 m from the top edge.

11.10 Determine the value of convection coefficient for steam at 40°C saturation conditions condensing on a flat surface maintained at 30°C. If the surface is inclined at 4° to the vertical. The plate is 1.5 m high.

11.11 Determine the value of convection coefficient for condensing steam at 40°C saturation conditions over the outside surface of a vertical tube of 6.25 cm *OD* maintained at 30°C. The tube is 1.5 m high. Also determine the film thickness at 1 m and 1.5 m from top.

11.12 Determine the value of convection coefficient for condensing of steam over the outside surface of horizontal tubes of 6.25 cm *OD* with surface temperature maintained at 30°C. Steam temperature is 40°C. Compare the value with that of a vertical surface of 62.5 cm height.

Check: The heat flow has to be doubled. Also *UA* is the same and so LMTD has to be doubled.

$$\text{Old value of LMTD} = \frac{(110-20)-(110-75)}{\ln \dfrac{110-20}{110-75}} = 58.23°\text{C}$$

$$\text{New value of LMTD} = \frac{(166.12-20)-(166.12-75)}{\ln \dfrac{166.12-20}{166.12-75}} = 116.46°\text{C}$$

so checks.

Note: As the temperature increases the condensing pressure also increases. In this case the pressure increases from about 1.45 to about 7.2 bar. So the tubes may not withstand this pressure.

Problem 12.27: *In an existing heat exchanger of counter flow type dry air is cooled from 70°C to 35°C at a rate of 1.2 kg/s using cold air at 15°C at a rate of 1.5 kg/s. It is desired to cool this stream by another 10°C by increasing the area with the same inlet conditions. Calculate the percentage increase in area.*

Solution: This problem can be worked by LMTD or NTU method. The main assumption is that U remains unchanged and C_{min}/C_{max} are known. Entering the chart NTU can be determined. The ratio of NTU values is the same as ratio of areas as U and C_{min} are the same.

Under the first operating conditions

$$\varepsilon = \frac{70-35}{70-15} = \frac{35}{55} = \mathbf{0.636}, \quad C_{min}/C_{max} = 1.2/1.5 = 0.8$$

From chart **NTU = 1.5**

Under the altered conditions

$$\varepsilon = \frac{70-25}{70-15} = \frac{45}{55} = \mathbf{0.8182}$$

corresponding **NTU = 3.21**

∴ Area increase = 114%.

Note: (*i*) As all the four temperatures can be worked out these values can be checked using LMTD method

(*ii*) equations can be used to determine NTU, instead of using chart.

As $$N = \frac{1}{C-1} \ln \frac{\varepsilon-1}{C\varepsilon-1}$$

These methods may be tried.

OBJECTIVE QUESTIONS

Choose the correct statement.

12.1 The overall heat transfer conefficient is the

(*a*) sum of all resistances (*b*) sum of all conductances

(*c*) sum of the convection coefficients (*d*) resistance due to the wall material.

12.2 The range of value of overall heat transfer coefficients fall in the following increasing order

(*a*) boiling or condensation to liquid, liquid to gas, liquid to liquid, gas to gas.

(*b*) liquid to liquid, gas to gas, boiling or condensation to liquid, liquid to gas

(*c*) gas to gas, liquid to gas, liquid to liquid, Boiling or condensation to liquid

(*d*) boiling or condensation to liquid, Liquid to gas, gas to gas liquid to liquid.

12.3 The decreasing order of effectiveness for a given situation among types of heat exchangers is

(*a*) parallel flow, cross flow, shell and tube, counter flow

(*b*) cross flow, counter flow, shell and tube, parallel flow

(*c*) counter flow, shell and tube, cross flow, parallel flow

(*d*) counter flow, cross flow, shell and tube, parallel flow.

12.4 When one of the fluid is condensing the best flow arrangement is

(*a*) counter flow (*b*) parallel flow

(*c*) cross flow (*d*) all are equal.

12.5 Thermodynamically the type which leads to lower loss in availability is

(*a*) parallel flow (*b*) counter flow

(*c*) cross flow (*d*) shell and tube.

12.6 The Net Transfer Unit is (NTU)

(*a*) $U.C_{min}/A$ (*b*) UA/C_{min}

(*c*) AC_{min} (*d*) U/AC_{min}.

12.7 Effectiveness of a heat exchanger is

(*a*) actual heat transfer/heat content of hot fluid

(*b*) actual heat transfer/heat content of cold fluid

(*c*) actual heat transfer/heat content of higher heat capacity fluid

(*d*) actual heat transfer/heat transfer when minimum heat capacity fluid goes through the maximum temperature difference in the exchanger.

12.8 Cross flow exchangers are popularly used for heat transfer

(*a*) liquid and liquid (*b*) liquid and evaporating fluid

(*c*) condensing fluid and liquid (*d*) gas and gas or liquid and gas.

12.9 The minimum heat transfer area for a given situation is for

(*a*) parallel flow (*b*) counter flow

(*c*) cross flow (*d*) shell and tube.

12.10 Effectiveness is generally represented by (with in usual notations)

(*a*) $\dfrac{C_h}{C_{min}} \dfrac{T_{h1} - T_{h2}}{T_{c2} - T_{c1}}$ (*b*) $\dfrac{C_c}{C_{min}} \dfrac{T_{c2} - T_{c1}}{T_{h1} - T_{h2}}$

(*c*) $\dfrac{C_h}{C_{min}} \dfrac{T_{h1} - T_{h2}}{T_{h1} - T_{c1}}$ (*d*) $\dfrac{C_c}{C_{min}} \dfrac{T_{h1} - T_{c2}}{T_{h2} - T_{c1}}$.

12.11 The flow direction is immaterial in the case of heat exchange from

(*a*) Wet or saturated steam to water (*b*) Water to gas

(*c*) Oil to water (*d*) Oil to gas.

Answers

1. (*b*)	**2.** (*c*)	**3.** (*c*)	**4.** (*d*)	**5.** (*b*)	**6.** (*b*)
7. (*d*)	**8.** (*d*)	**9.** (*b*)	**10.** (*c*)	**11.** (*a*).	

(i) Direct to row 1 = 0.65 **(ii) Direct to row 2 = 0.2**

(iii) Total to row 1 = 0.7 **(iv) Total to row 2 = 0.28**

(v) Total to 1 and 2 = 0.98

The heat picked up by first row will be more than double that picked up by row 2.

Problem 13.42: *Determine the shape factor values between* ***two short coaxial cylinders*** *of diameters 0.5 m and 1 m of length 1 m and also between the cylinder to each end anuular surface.*

Solution: The outer cylinder is designated as 2 and the inner as 1 and ends as 3 and 3′.

Here $r_2 = 0.5$ m, $r_1 = 0.25$ m $L = 1$ m

The parameters are:

$$r_1/r_2 = 0.5 \qquad L/R_2 = 1/0.5 = 2$$

Reading from chart in data book

$\therefore$ F_{2-1} (outer to inner) = 0.44, $F_{2-2} = 0.32$

$$A_2F_{2-1} = A_1F_{1-2} \qquad \therefore \quad F_{1-2} = 0.44 \times \frac{A_2}{A_1} = 0.44 \times 2 = 0.88$$

$$\therefore \qquad F_{1-3'} = F_{1-3} = 0.12/2 = 0.06$$

$$F_{2-3} = F_{2-3'} = (1 - 0.44 - 0.32)/2 = 0.12$$

$$A_1F_{1-3} = A_3F_{3-1} \qquad \therefore \quad F_{3-1} = \frac{A_1}{A_3} \times 0.06$$

$$F_{3'-1} = 0.06 \times \pi \times 0.5 \times 1 \times 4\, \frac{1}{\pi\,(1^2 - 0.5^2)} = 0.16$$

$$\mathbf{F_{3'-1} = F_{3-1} = 0.16}$$

$$\mathbf{F_{3-2}} = \frac{A_2}{A_3} = 0.12 = \frac{\pi \times 0.51 \times 4}{\pi\,(1^2 - 0.5^2)} = 0.64$$

$$\mathbf{F_{3-2} = 0.64}$$

$$\therefore \qquad \mathbf{F_{3'-3}} = 1 - 0.16 - 0.64 = \mathbf{0.2}$$

This is the shape factor between annular disks placed coaxially opposite each other. (refer P. 13.20 also).

OBJECTIVE QUESTIONS

Choose the correct statement in all cases:

13.1 The monochromatic emissive power of a black body with increasing wavelength.

(*a*) decreases (*b*) increases

(*c*) decreases, reaches a minimum and then increases

(*d*) Increases, reaches a maximum and then decreases.

13.2 A gray surface is one for which

(*a*) reflectivity equals emissivity (*b*) emissivity equals transmissivity

(*c*) emissivity is constant (*d*) Absorptivity equals reflectivity.

13.3 As the source temperature increases the wavelength at which the monochromatic emissive power is maximum

(*a*) decreases continuously (*b*) decreases and then increases
(*c*) lncreases continuously (*d*) increases and then decreases.

13.4 The directional emissivity for metallic surfaces is

(*a*) constant all over the angles from normal
(*b*) More near the normal and less near the tengential direction
(*c*) More near tangential direction compared to normal direction
(*d*) The distribution is affected more by temperature than by direction.

13.5 For non metallic insulating materials directional emissivity

(*a*) is constant all over the angles
(*b*) more at near normal directions than at tangential direction
(*c*) Less at near normal directions compared to tengential directions
(*d*) Can be as case *b* or *c* depending on surface preparation.

13.6 Selective surfaces

(*a*) do not follow Kirchhoff's law (*b*) absorb only at definite wavelengths
(*c*) emit only at definite wave bands (*d*) all of these.

13.7 Glasses are

(*a*) opaque for high temperature radiation (*b*) opaque for low temperature radiation
(*c*) Transparent at short wavelengths (*d*) Transparent at long wavelengths
(*e*) opaque for low temperature radiation Transparent at long wavelengths.

13.8 For solar collectors the required surface characteristics combination is

(*a*) high emissivity and low absorptivity (*b*) high emissivity and high reflectivity
(*c*) high reflectivity and high absorptivity (*d*) low emissivity and high absorptivity.

13.9 Emissivity of gas body of a given composition depends on

(*a*) shape and temperature (*b*) partial pressure and shape
(*c*) partial pressure and temperature (*d*) All of these.

13.10 For a given shape, partial pressure and temperature the emissivity of

(*a*) O_2 is higher than that of N_2 (*b*) N_2 is higher than that of N_2
(*c*) O_2 is higher than that of CO_2 (*d*) CO_2 is higher than that of O_2.

13.11 The combination which will give the highest gas emissivity is

(*a*) low partial pressure, higher temperature and larger thickness
(*b*) higher partial pressure, higher temperature and larger thickness
(*c*) higher partial pressure, lower temperature and larger thickness
(*d*) lower partial pressure, lower temperature and larger thickness.

13.12 The value of shape factor will be highest when

(*a*) the surfaces are farther apart (*b*) the surfaces are closer
(*c*) the surfaces are smaller and closer (*d*) the surfaces are larger and closer.

13.13 A radiation shield should have

(*a*) high emissivity (*b*) high absorptivity
(*c*) high reflectivity (*d*) high emissive power.

13.14 Choose the correct statement or statements

(*a*) Highly reflecting surface is suitable for solar heat collection through flat plates.
(*b*) The emissivity of smooth surface is higher compared to a rough surface of the same material

(*c*) For a given gas body, the emissivity will decrease with increase in temperature.

(*d*) Snow has high emissivity.

13.15 Choose the correct statement or statements

(*a*) The shape factor of samll enclosed body with respect to the enclosing surface is zero

(*b*) The shape factor of small enclosed body with respect to the enclosing surface is unity

(*c*) A small opening from a large enclosure at constant temperature will provide black body radiation.

(*d*) Black paint is an example of block body.

13.16 The reciprocity theorem states

(*a*) $F_{1-2} = F_{2-1}$ (*b*) $A_1 F_{1-2} = A_2 F_{2-1}$

(*c*) $A_2 F_{1-2} = A_1 F_{2-1}$ (*d*) $\varepsilon_1 F_{1-2} = \varepsilon_2 F_{2-1}$.

13.17 Choose the correct statement or statements

(*a*) $F_{1-2,3} = F_{1-2} + F_{1-3}$ (*b*) $A_1 F_{1-2,3} = A_2 F_{2-1} + A_3 F_{3-1}$

(*c*) $F_{1,2-3} = F_{1-3} + F_{2-3}$ (*d*) $A_{1,2} F_{1,2-3,4} = A_1 F_{1,2-3,4} + A_2 F_{1,2-3,4}$.

13.18 Choose the correct statement or statements

(*a*) Radiosity is another name for emisive power

(*b*) Radiation intensity is the flux per unit area

(*c*) Radiation intensity is the radiant energy per unit solid angle

(*d*) Irradiation is the total radiant energy incident on a surface.

13.19 Choose the correct statement or statements

(*a*) Convex surface have positive value for shape factor with themselves

(*b*) Concave surface have positive value for shape factor with themselves

(*c*) Flat surfaces have positive value for shape factor with themselves

(*d*) Irregular surfaces have possitive value for shape factor with themselves.

13.20 If $A_1 = 4$ and $A_2 = 2$ and $F_{1-2} = 0.2$ then

(*a*) $F_{2-1} = 0.2$ (*b*) $F_{2-1} = 0.8$ (*c*) $F_{2-1} = 0.4$ (*d*) $F_{2-1} = 0.1$.

Answers

1. (*d*)	**2.** (*c*)	**3.** (*a*)	**4.** (*c*)	**5.** (*b*)	**6.** (*d*)
7. (*c*)	**8.** (*d*)	**9.** (*d*)	**10.** (*d*)	**11.** (*c*)	**12.** (*d*)
13. (*c*)	**14.** (*c*), (*d*)	**15.** (*b*), (*c*)	**16.** (*b*)	**17.** (*a*), (*b*)	**18.** (*c*), (*d*)
19. (*b*), (*d*)	**20.** (*c*).				

EXERCISE PROBLEMS

13.1 Determine the wavelength at which monochromatic emissive power is maximum for the following surface temperatures. Also determine the value of the monochromatic emissive power at these wavelengths.

(*i*) 600 K (*ii*) 2000 K and (*iii*) 5500 K.

13.2 Using Plancks equation derive the Stefan-Boltzmann equation for emissive power of a black surface.

13.3 Determine the fraction of radiant energy emitted up to the wavelength at which monochromatic emissive power is maximum for the following surface temperatures.

(*i*) 600 K (*ii*) 2000 K (*iii*) 5000 K.

FILL IN THE BLANKS

1. Thermal conductivity of materials (k) generally varies with ____________ . (Temperature)
2. With increase in temperature thermal conductivity of insulators will ____________ . (increase)
3. With increase in temperature thermal conductivity of good conductors will ____________. (decrease)
4. With increase in temperature thermal conductivity of many liquids will ____________ . (decrease)
5. With increase in temperature thermal conductivity of water and glycerine will ____________ . (increase)
6. With increase in temperature thermal conductivity of gases in general will ____________ . (increase)
7. Heat conduction in insulators is mainly by ____________ . (lattice vibration)
8. Heat conduction in good conductors is largely by ____________ . (free electron flow)
9. In the SI system, the unit for thermal conductivity is ____________ . (W/mK)
10. The unit for thermal resistance in the SI system is ____________ . (K/W)
11. The unit for convective heat transfer coefficient in the SI system is ____________ . (W/m^{2}K)
12. Convection resistance over a given surface area A is ____________ . (1/hA)
13. Conduction resistance due to a plane wall of thickness L of material with thermal conductivity k and area A is ____________ . (L/kA)
14. For a given amount of heat conducted, higher the value of thermal conductivity ____________ will be the temperature difference. (lower)
15. If heat flow across a plane in a given slab should increase the temperature gradient at the plane should ____________ . (increase)
16. For a given material and temperature drop, if heat conducted is to be reduced the thickness should be ____________ . (increased)
17. In steady conduction for a material whose thermal conductivity increases with increase in temperature, the temperature gradient at the high temperature side will be ____________ . (lower)
18. In steady conduction for a material whose thermal conductivity decreases with increase in temperature, the temperature gradient at the low temperature side will be ____________ . (lower)
19. The temperature profile in a plane wall under steady conduction will be a straight line if thermal conductivity is ____________ . (constant)
20. In the case of a hollow cylinder, the temperature profile along the radius will be ____________ . (logarithmic)

21. In the case of a hollow sphere, the temperature profile along the radius will be a ____________ . (2nd degree curve)

22. When conductivity varies linearly with temperature the conductivity at the ____________ can be used in the calculation of heat flow using the general equations. (mean temperature)

23. In radial heat conduction in a hollow sphere/cylinder, the temperature gradient at the outer surface will be ____________ compared to the gradient at the inner surface. (lower)

24. The pure metal whose thermal conductivity is highest at atmospheric temperatures is ____________. (Silver)

25. For super insulation, ____________ form will be suitable. (powder)

26. Thermal diffusivity of a material is indicative of ____________ ____________ under transient conditions. (heat penetration)

27. When multilayers of insulation is used over a sphere, for a given volume, the material with higher thermal conductivity should be applied ____________ the surface. (nearer)

28. In a conducting slab with uniform heat generation the temperature variation along the thickness is ____________ . (parabolic)

29. In a heat conducting slab of given material, with uniform heat generation the difference in temperature between the center plane and the surface is directly proportional to ____________ and ____________ . (square of thickness, heat generation rate)

30. In a heat conducting slab of given thickness, with uniform heat generation the difference in temperature between the center plane and surface is ____________ proportional to the thermal conductivity of the material. (inversely)

31. In a heat conducting sphere with uniform heat generation the difference in temperature between the center and surface is directly proportional to ____________ and ____________ and inversely proportional to ____________ . (heat generation rate, square of outer radius, conductivity)

32. In heat generation, surface convection also controls the ____________ temperature. (center)

33. For a given heat flow, a fin of rectangular section will require ____________ volume as compared to a fin of triangular section with the same base thickness. (more)

34. With the same cross section two fins each of length L will dissipate ____________ heat compared to a single fin of length $2L$. (more)

35. To reduce error in temperature measurement of flowing fluids, the thermometer well length should be ____________ . (longer)

36. Fins may be modeled as ____________ ____________ system. (conduction-convection)

37. For given fin volume as the length of the fin is decreased the heat flow will ____________ and then ____________ (increase, decrease)

38. The ratio of heat flow by fin to the heat flow on the bare base areas is called ____________ of the fin. (effectiveness)

39. Fin effectiveness is generally ____________ than one. (greater)

40. For a given volume tapering fin will dissipate ____________ heat as compared to constant area fin. (more)

41. Along the length of a constant area fin the temperature gradient ____________ . (increases)

42. In fins the temperature gradient is highest at the ____________ . (tip)

43. For a given fin configuration the heat flow is proportional to ____________ power of h and k. (0.5)

44. In electronic components Gold is used to improve fin efficiency by reducing ____________ resistance. (contact)

45. In transient conduction lumped capacity model can be used if ____________ . (Bi < 0.1)

46. For lumped parameter model the surface resistance should be ____________ compared to the internal resistance. (higher)

47. For lumped parameter model volume/Area ratio should be ____________ . (small)

48. For lumped parameter model heat capacity of the piece should be ____________ . (low)

49. For a given thermocouple if the response time should be shortened then ____________ should be increased. (convection coefficient)

50. For lumped parameter model to be used the temperature gradient within the body should be ____________ . (very small)

51. In transient conduction for the use of semi infinite solid model, the heat penetration depth should be ____________ over the period considered. (small)

52. For the adoption of semi infinite solid model, the temperature at a depth should not have ____________ in the time considered. (increased)

53. A thick concrete slab exposed to flames on one side can be analysed using ____________ model. (semi infinite solid)

54. For the same characteristic dimension, the shape of the object for shorter heating time is ____________ . (sphere)

55. When Schmidt method is used for temperature calculations in transient conduction the choice of nodal thickness x and time interval $\Delta\tau$ should satisfy the condition. ($\Delta x^2/\alpha\Delta\tau$)= 2

56. In transient conduction, increasing and maintaining a surface at a temperature is equivalent to Biot number being equal to ____________ . (infinite)

57. The electrical analogue element for the product of mass and specific heat is ____________. (condenser)

58. In convection, temperature and velocity gradients vary only in the ____________ . (boundary layer)

59. Along the thickness in the boundary layer velocity and temperature gradients ____________ . (decrease)

60. The thickness of the hydrodynamic boundary layer is defined as the distance from the surface at which velocity ____________ is nearly zero. (gradient)

61. In laminar flow, the average convection coefficient along the length will ____________ . (decrease)

62. In laminar flow the velocity at a location with respect to time is ____________ . (constant)

63. In turbulent flow the velocity at a point varies randomly about a ____________ velocity. (mean)

64. In laminar flow momentum and heat transfer is mainly at the ____________ level. (molecular)

65. In laminar flow there is no ____________ mixing between layers. (macroscopic)

66. In turbulent flow momentum and heat transfer is due to ____________ mixing between layers. (macroscopic)

67. If thermal deffusivity equals momentum diffusivity, then the ratio of thermal and velocity boundary layer thickness will be equal to ____________ . (one)

68. The ratio of momentum diffusivity to thermal diffusivity is called ____________ number. (Prandtl)

69. Flow transition is generally judged by ____________ number. (Reynolds)

70. The thickness of hydrodynamic boundary layer at distance x in laminar flow over a plate is ____________ . $\left(\dfrac{5x}{Re^{0.5}}\right)$

71. The thickness of hydrodynamic boundary layer in flow over plate in turbulent flow is proportional to ____________ . $(Re_x^{-0.2})$

72. In liquid metal flow over a flate, thermal boundary layer will be ____________ than hydrodynamic boundary layer. (thicker)

73. In viscous oil flow thermal boundary layer will be ____________ than hydrodynamic boundary layer. (thinner)

74. In laminar flow over flat plates the convection coefficient will be proportional to the distance raised to the power of ____________ . (– 0.5)

75. In turbulent flow over flat plate the convection coefficient will be proportional to the distance raised to the power ____________ . (– 0.2)

76. In flow over a flat plate the temperature and velocity gradients above the boundary layer is ____________ . (zero)

77. In the case of flow over flat plate the Reynolds number along the length will ____________ continuously. (increase)

78. The value of transition Reynolds number in the case of flow over flat plate is ____________. (5×10^5)

79. Reynolds number expressed in terms of mass flux G in pipe flow is ____________ . $\left(\dfrac{4Gd}{\mu}\right)$

80. In pipe flow the analogy method of convection analysis relates ____________ number to friction factor. (Stanton)

81. In flow over a bank of tubes effective way to increase heat transfer rate is to ____________ the pitch along the flow direction. (reduce)

82. In flow over spheres, and cylinders the characteristic length used in the calculation of dimensionless number is ____________ . (diameter)

83. Hydraulic mean diameter is defined as ____________ . $(4A/P)$

84. In flow through non circular sections ____________ replaces diameter. (Hydraulic mean diameter)

85. In flow through pipes the type of flow is decided by the conditions at ____________ . (entry)

86. In fully developed laminar flow through pipes the convection coefficient is ____________. (constant)

87. In pipe flow, convection coefficient at entrance region will be ____________ compared to the fully developed region. (higher)

88. In pipe flow under constant wall heat flux conditions the convection coefficient will be ____________ as compared to constant wall temperature condition. (higher)

89. In fully developed flow in a pipe under constant heat flux condition the temperature difference between the wall and the fluid will be ____________ . (constant)

90. In turbulent flow in rough pipes the Stanton number is related to ____________ . (friction factor)

91. In the case of ____________ the flow in pipes can be considered as slug flow. (liquid metals)

92. As compared to forced convection the additional force encountered in free convection analysis is ____________ . (buoyant force)

93. At constant pressure the value of coefficient of cubical expansion for gases is ____________. ($1/T(K)$)

94. The velocity in the case of free convection boundary layer is zero at ____________ . (wall and boundary layer thickness)

95. The velocity variation in the natural convection boundary layer can be expressed by ____________ order equation. (third)

96. The temperature variation in free convection in boundary layer can be expressed by ____________ order equation. (second)

97. The dimensionless number which replaces the Reynolds number in the case of free convection is ____________ . (Grashof number)

98. The average value of convection coefficient upto length L in free convection is ____________ . $\left(\frac{4}{3}h_L\right)$

99. Reyleigh number is the product of ____________ Number and ____________ number. (Grashof, Prandtl)

100. In free convection the average value of h will be ____________ for short vertical plate as compared to a longer vertical plate. (higher)

101. Graetz number is defined as the product of ____________ .(Reynolds, Prandtl and D/L)

102. Peclet number is the product of ____________ number and ____________ number. (Reynolds, Prandtl)

103. In cooling of unattended equipments ____________ convection is more suitable. (free)

104. In some cases where both free convection and forced convection may contribute to heat transfer, the criterion for the determination of predominance of either is the value of ____________ . (Gr/Re^2)

105. In boiling excess temperature is the difference between ____________ and ____________ temperatures. (surface, saturation)

106. In film boiling main mode of heat transfer is ____________ . (radiation)

107. In boiling surface tension is an important parameter due to ____________ . (bubble wettability)

108. In nucleate boiling at higher heat flux levels convection coefficient is proportional to the ____________ power of excess temperature. (third)

109. In boiling the excess temperature at which maximum heat flux occurs is about ____________ . (15°C)

110. The shape of the heating surface ____________ affect boiling heat transfer. (does not)

111. The maximum heat flux in boiling of a fluid varies with the pressure ratio ____________. ($P/P_{critical}$)

112. In flow boiling h is maximum at ____________ flow. (annular)

113. Maximum heat flux without damage can be sustained only in ____________ boiling. (nucleate)

114. Minimum heat flux occurs in stable ____________ boiling. (film)

115. In film boiling a ____________ exists between surface and liquid. (vapour film)

116. Flow boiling is encountered in ____________ water tubes. (Boiler)

117. In film boiling excess temperature will be ____________ . (high)

118. The important parameter which controls heat flux in boiling is ____________ . (excess temperature)

119. Temperature variation is assumed ____________ in condensate film. (linear)

120. Velocity in condensate film varies along the film thickness as ____________ of thickness. (second order)

121. Average value of convection coefficient in condensation up to distance L is ____________. $\{(4/3)h_L\}$

122. In film wise condensation the value of h will be ____________ compared to dropwise condensation. (lower)

123. The surface should be ____________ for dropwise condensation. (non wetting)

124. As the vapour is in direct contact with more cooler surface the convection coefficient is ____________ in dropwise condensation. (higher)

125. The additional force encountered in condensation boundary layer analysis is ____________. (gravity force)

126. In condensation 'h' depends on the ____________ power of conductivity. (0.75)

127. In condensation 'h' depends on the ____________ power of density. (0.5)

128. In condensation 'h' depends on the ____________ power of latent heat. (0.25)

129. Condensation Reynolds number is defined in terms of mass flow G per unit width as ____________ . ($4G/\mu$)

130. In condensation, convection coefficient over a single tube is ____________ compared to condensation over a row of tubes. (higher)

131. Critical film Reynolds number in condensation is ____________ . (1800)

132. In freezing the conduction resistance is due to ____________ . (ice layer)

133. In the regenerator of a gas turbine the ____________ will be nearly equal. (heat capacities)

134. The value U_o will be ____________ compared to value U_i in heat exchangers. (lower)

135. The product U_oA_o will equal ____________ . (U_iA_i)

136. During the life of heat exchanger the performance will deteriorate due to ____________. (fouling)

137. In a shell and tube arrangement, the fluid that can be said to be mixed is the ____________ side fluid. (shell side)

138. In a shell and tube arrangement, the fluid that can be said to be unmixed is the ____________ side fluid. (tube side)

139. A heat exchanger in which superheated fluid is cooled, condensed and undercooled, using a cold fluid, the location at which minimum temperature difference occurs is called ____________ . (pinch point)

140. NTU is defined as ____________ . (UA/C_{min})

141. Capacity ratio when cold fluid is having lower heat capacity is defined in terms of terminal temperatures as ____________ . $(T_{h1} - T_{h2})/(T_{c2} - T_{c1})$

142. The three main flow arrangement in heat exchangers are ____________ flow. (Parallel, Counter, Cross)

143. Compact heat exchangers use ____________ tube bundles. (finned)

144. Thermodynamically the flow direction that will give minimum loss of available energy is ____________ . (counter flow)

145. The flow direction does not affect the performance in the case of ____________ and ____________ . (condensers, evaporators)

146. Fouling resistance is due to ____________ of the heating surface during operation. (deterioration)

147. Shell and tube arrangement is generally adopted because single tube type will be ____________. (too long)

148. The heat capacity of the fluid stream is the product of ____________ and ____________ . (mass flow rate, specific heat)

149. If heat capacities are equal in a counter flow exchanger the slope of the hot and cold fluid temperature lines at any point will be ____________ . (the same)

150. If heat capacities are equal in a parallel flow exchanger the slop of the temperature lines at any point of flow will be ____________ but ____________ . (equal, of opposite sign)

151. LMTD method of analysis is suitable when ____________ ____________ are known. (all four temperatures)

152. When inlet flow rates and temperatures for a heat exchanger are specified the easier method of analysis ____________ . (NTU method)

153. For the performance evaluation over the whole operating range of a heat exchanger ____________ ____________ method is more suitable. (effectiveness-NTU)

154. When heat capacity ratio is zero, effectiveness is equal to ____________ . ($1-e^{-NTU}$)

155. For a condenser/evaporator the effectiveness is ____________ . ($1 - e^{-NTU}$)

156. If heat capacities are equal for the counter flow type the effectiveness is ____________ . (N/(N + 1) + 1)

157. If heat capacities are equal for parallel flow type the effectiveness is ____________ . $(1 - e^{-2N})/2$

158. Effectiveness of a heat exchanger is the ratio of ____________ and ____________ . (actual heat flow/max possible heat flow)

159. For a given exchanger if the heat capacity ratio (C_{min}/C_{max}) increases the effectiveness will ____________ . (decrease)

160. When effectiveness increases the total heat flow ____________ increase. (need not)

161. Storage type heat exchanger is also called ____________ heat exchanger. (regenerative)

162. Air preheaters in large thermal plants use ____________ of heat exchangers. (regenerative type)

163. The overall heat transfer coefficient will generally be minimum in the case of ____________ exchangers. (gas to gas)

164. In a condenser the controlling resistance will be on the ____________ side. (cold/fluid)

165. In an evaporator the controlling resistance will be on the ____________ side. (hot fluid)

166. In a gas to liquid heat exchangers the controlling resistance will be on the ____________ side. (gas)

167. In the various flow arrangements the one that may require largest area will be ____________ . (parallel flow)

168. The wave length range of thermal radiation is ____________ . (1 to 100 μm)

169. The wave length range for visual radiation is ____________ . (0.3 to 0.7 μm)

170. For a black body ____________ is maximum. (emissive power)

171. The radiant energy emitted per unit area and unit wave length called ____________ . (monochromatic emissive power)

172. The equality of emissivity and absorptivity is postulated by ____________ law. (Kirchhoff)

173. The statement that "the product of the temperature and the wavelength at which the monochromatic emissive power is maximum is a constant" is due to ____________ law. (Wien's displacement)

174. At any temperature as wavelength increases the monochromatic emissive power __________. (increases and then decrease)

175. The ratio of emissive power of a body to the emissive power of a black body is defined as ____________ . (emissivity)

176. Radiation from a small opening from an isothermal enclosure can be considered as ____________. (black)

177. The relationship between emissive power E and intensity I is ____________ . ($E = \Pi I$)

178. The radiant energy per unit solid angle in a direction is known as ____________ of radiation. (intensity)

179. The emissivity is constant in the case of a ____________ (gray surface)

180. Gases are generally ____________ radiators. (band)

181. Suns radiation is mostly at ____________ wavelengths. (short, 0-4 μm)

182. Radiation at atmospheric temperature is at ____________ wave lengths. (longer)

183. Glasses generally transmit ____________ wavelength radiation. (short)

184. Green house effect is due to ____________ short wavelength radiation and ____________ long wavelength radiation. (transmitting, cutting off)

185. For real surfaces, the monochromatic emissive power does not vary in a ____________ . (regular pattern)

186. The sum of emissivity, and reflectivity will be equal to ____________ in the case of opaque surfaces. (one)

187. For an opaque surface high reflectivity means ____________ emissivity. (low)

188. For selective surface the emissivity is dependent on ____________ and ____________ of radiation. (temperature, wavelength)

189. Solar collector surfaces should have high absorptivity for ____________ wavelength radiation and low emissivity at ____________ temperatures. (short, low)

190. In the case of solids/liquids radiation is a ____________ phenomenon. (surface)

191. CO_2 and water vapour are ____________ radiators. (band)

192. In the case of gases radiation is a ____________ phenomenon. (volume)

193. Diatomic gases are ____________ for radiation. (transparent)

194. The emissivity of a gas body depend on ____________, ____________, ____________ .
(pressure, characteristic length and temperature)

195. Beers law states that transmissivity of a gas body of length L with transmission coefficient a is ____________ $(1- e^{aL})$

196. Most of the real surfaces have emissivity ____________ with angle from normal.
(varying)

197. Insulating materials have ____________ emissivity at angles near horizontal. (low)

198. Conducting materials have high emissivity at angles ____________ horizontal. (near)

199. The total radiant energy leaving a gray surface is known as ____________ .
(Radiosity)

200. The total radiant energy incident on a gray surface is known as ____________ .
(irradiation)

201. Radiosity include emissive power and ____________ . (reflected radiation)

202. Irradiation includes radiation from other surfaces and ____________ .
(reflected radiation by them)

203. The fraction of radiation emanating from surface 1 incident on surface 2 is called ____________ . (shape factor $F_{1\text{-}2}$)

204. Shape factor will ____________ when surfaces are moved closer. (increase)

205. Shape factor will ____________ if the areas of the participating planes increase.
(increase)

206. Shape factor is ____________ of surface properties. (independent)

207. Shape factor of body with respect to a fully enclosing body is ____________ . (one)

208. Concave surfaces will have a shape factor with ____________ . (themselves)

209. The shape factor of a hemisphere to itself is ____________ . (0.5)

210. Shape factor of a hemispherical surface to its base is ____________ . (0.5)

211. Shape factor of the base of a cone to the curved surface is ____________ . (one)

212. If n radiation shields of equal emissivity as the parallel large planes are used the heat flow will be reduced ____________ times. $(1/n + 1)$

213. Radiation shield should have ____________ reflectivity. (high)

214. Surface resistance is due to the ____________ of the surface. (emissivity)

215. Space resistance between two surfaces is due to the ____________ . (shape factor)

216. Reciprocity theorem for shape factor is ____________ . $(A_1F_{1-2} = A_2F_{2-1})$

217. Well insulated surfaces enclosing surfaces exchanging heat by radiation are called ____________. (Non absorbing reradiating surfaces)

218. Reradiating enclosure ____________ the effective shape factor. (improves)

219. Mass transfer is due to ____________ gradient. (concentration)

220. The two types of mass transfer are ____________ and ____________ . (diffusion, convective)

221. Mass transfer at molecular level can be likened to heat ____________ . (conduction)

222. The unit of mass diffusivity is ____________ . (m^2/s)

223. The ratio of mass diffusivity to momentum diffusivity is called ____________ . (Schmidt number)

224. The two types of molecular diffusion are ____________ and ____________ . (equimolal counter diffusion, Diffusion into a stationary medium)

225. For the same concentration gradient, diffusion, into a stationary component will give ____________ rate. (larger)

226. Use of kg mole in place of kg is more convenient mass transfer because of ____________. (diffusion as molecules)

227. If $D_{ba} <> D_{ab}$ then spontaneous ____________ build up will result. (pressure)

228. The unit of mass transfer coefficient h_m is ____________. (m/s)

229. Sherwood number is given by ____________. ($h_m x/D$)

230. By similarity h/h_d is proportional to ____________ . ($Le^{2/3}$)

231. Transient mass diffusion problems can be solved similar to ____________ . (Transient conduction problems)

SHORT PROBLEMS

1. Hot air at 80°C flows over a surface of area 0.2 m^2 at 60°C, the convection coefficient being 25 W/m^2K. The heat flow is ____________ . (100 W)
2. The surface temperatures of a slab conducting heat under steady conditions are 80°C and 60°C. The thermal conductivity of the material of the slab is 25 W/mK. The heat flow rate is 2500 W/m^2. The thickness of the slab is ____________ . (0.2 m)
3. A slab 0.2 m thick of thermal conductivity 25 W/mK conducting heat under steady conditions at the rate of 2500 W/m^2 has the hotter surface at 100°C. The temperature of the other surface is ____________ . (80°C)
4. A slab of 0.2 m thickness has its surfaces at 120°C and 100°C. The heat conducted at steady conditions is 250 W/m^2. The conductivity of the material is ____________ . (2.5 W/mK)
5. A slab conducts heat at a steady rate of 2500 W/m^2. The thermal conductivity of the material is 25 W/mK. The temperature gradient in the slab is ____________ . (– 100°C/m)
6. The temperature gradient in a slab at steady conduction is – 1000°C/m. The slab conducts heat at 250 W/m^2. The conductivity of the material is ____________ . (0.25 W/mK)
7. A slab conducts heat at 2500 W/m^2 under steady conditions. The conductivity of the material is 20 W/mK. If the thickness is reduced to half the value, maintaining the heat flow rate, the temperature gradient will be ____________ . (– 125°C/m)
8. In a composite slab of two layers the temperature gradient in the first layer of thermal conductivity 50 W/mK is – 50°C/m. If the conductivity of the material of the second layer is 25 W/mK the temperature gradient in the second layer will be ____________ . (– 100°C/m)
9. In a composite slab consisting of two layers of equal thickness the temperature drop in the first layer is 40°C. If the conductivity of the material of the second layer is 1/4th of that of the first layer the temperature drop in this layer will be ____________ . (160°C)
10. In a composite slab made of two layers of equal thickness the total temperature drop is 100°C. The conductivity of the first layer material is 1/4th of the conductivity of the second layer material. The temperature drop in the first layer will be ____________. (80°C)
11. A hollow cylindrical insulation of *ID* 0.2 m and *OD* 0.4 m conducts heat radially. If another layer of insulation of the same material of thickness of 0.4 m is added to the heat flow will be changed by the ratio ____________ . (0.5)
12. A hollow spherical insulation of 0.2 m *ID* and 0.4 m *OD* conducts heat under steady conditions. If another layer of insulation of the same material of thickness of 0.4 m is added the heat flow will be reduced to ____________ of the original value. (2/3)
13. A hollow spherical insulation of *ID* 0.2 m and *OD* 0.4 m conducts heat at steady conditions radially. The thickness of additional insulation of the same material needed to reduce the heat flow to 75% of the original value is ____________ . (0.2 m)
14. To reduce the heat flow through a hollow cylinder to 1/*n*th the value of the original flow the new value of the ratio of the radii should be the ____________ power of the original radii ratio. (*n*th)

15. In a hollow spherical insulation of radii r_i and r_o in order to reduce heat flow by fraction c of the original flow additional insulation up to radius r_{o2} was added. Then the relation between the new and old radii is ____________ . $\{1 - (r_o/r_i)\} = c\{1 - (r_{o2}/r_i)\}$

16. One end of two long rods of same radius of material A and B are in a furnace. The temperature at 10 cm from the furnace in rod A was found equal to the temperature at 20 cm in rod B. The conductivity of material A was 10 W/mK. The conductivity of material B will be ____________ . (40 W/mK)

17. Two long cylindrical rods A and B of the same material but of different diameters have one of their ends placed in a furnace. The temperature measured at 10 cm from the furnace in rod A was found equal to the temperature at 20 cm in rod B. The ratio of the diameters of the larger to the smaller is ____________ . (4)

18. Two long rods of the same material of diameters 4 cm and 1 cm have one of their ends placed in a furnace. The heat loss from the 4 cm diameter rod will be ____________ times the heat loss from the 1 cm diameter rod. (8 times)

19. A long rod has one of its ends in a furnace and has reached steady conditions. Suddenly a fan is switched on and the convection coefficient over the surface increases four fold. Under steady conditions the heat loss will increase by ____________ %. (100%)

20. A long rod has one of its end in a furnace and has reached steady conditions. The temperature at 16 cm from the end was measured as T°C. Suddenly a fan is switched on and the convection coefficient over the surface increases four fold. Under steady conditions the location at which the temperature will equal T°C will be at ____________ from the end. (8 cm)

21. A long rod of diameter d m has one of its ends in a furnace and has reached steady conditions. The temperature at 10 cm from the end was measured as T°C. If a rod of 4d m diameter is in a similar situation the location at which the temperature will equal T°C will be at ____________ from the end. (20 cm)

22. In a heat treatment process a small component of good thermal conductivity is to be cooled. For the same volume if the surface area is doubled the cooling time will be reduced to ____________ the original time. (half)

23. Two sets of spherical pieces are to be cooled in batch process. The diameter of one set is 20 mm and that of the other set is 10 mm. The batch time for the 20 mm shots was 8 min. If other conditions are the same then the batch time for the 10 mm shots will be ____________ . (4 min)

24. Steel shots of heat capacity 1000 J/K are cooled in a bath, the batch time being 6 min. If similar sized shots of a different material with heat capacity of 1500 J/K are to be cooled under similar conditions the batch time will be ____________ . (9 minutes)

25. A thermocouple of volume 1.5×10^{-8} m^3 and area of 9×10^{-6} m^2 with a specific heat of 500 J/kg K and density of 8000 kg/m^3 is exposed to convection at 667 W/m^{2}K. The time constant is ____________ . (10s)

26. A slab 16 cm thick generating heat at the rate of 5 MW/m^3 when exposed on both sides to convection has its center temperature 60°C above the surface temperature. If a long cylinder of 8 cm diameter generating heat at the same rate is exposed to convection under similar conditions its center temperature will be ____________ above the surface temperature. (30°C)

27. The center to surface temperature difference in a heat generating cylindrical rod of 8 cm dia was 30°C. Under similar conditions the center to surface temperature difference in the case of a sphere of 8 cm dia will be ____________ . (20°C)

28. In a slab 0.2 m thick with a surface temperature of 200°C on both surfaces heat is generated at a rate of 10^6 W/m^3. The conductivity of the material is 50 W/mK. The center temperature will be ____________ . (300°C)

29. In a long solid cylinder the heat generation rate is 10^6 J/m^3. The conductivity is 50W/mK. The surface temperature is 250°C. The center temperature is 300°C. The radius of the cylinder is ____________ . (0.1 m)

30. In a solid sphere of 0.2 m dia, heat is generated at the rate of 1.2×10^6 W/m^3. The center temperature is 300°C. Conductivity is 50 W/mK. The surface temperature is ____________.

(260°C)

31. In a heat generating slab of 0.1 m half thickness the center to surface temperature difference was 100°C. If the half thickness is increased to 0.15 m, the temperature difference will be ____________ . (225°C)

32. A cylindrical rod of 0.1 m radius generating heat has its radius increased to 0.2 m. The center to surface temperature difference is ____________ times the original value.

(4 times)

33. A thermocouple has a time constant of 24 seconds, under a certain calibration conditions to improve performance, the convection coefficient is doubled and the surface area is also increased to 1.2 times the value keeping the volume unchanged. The new time constant will be ____________ . (10 seconds)

34. Inside of a slab under transient conduction three planes 1, 2 and 3 are located at distance of 2 cm intervals. The thermal diffusivity of the material was 1×10^{-6} m^2/s. The temperatures at node 1 and 3 at a point of time was 300 and 200°C. After an interval of ____________ seconds temperature at node-2 will reach 250°C. (200 sec)

35. Under steady two dimensional conduction the temperatures at nodes $(m + 1, n)$, (m, n), $(m, n + 1)$, $(m, n - 1)$ are respectively 600, 400, 350 and 325. The modes are equal spaced. The temperature at the node $(m - 1, n)$ *i.e.*, $T_{m-1,\, n}$ is ____________ . (325°C)

36. In a flow over a flat plate at a distance of 0.12 m, the Reynolds number is 14,400. The hydro dynamic boundary layer thickness is ____________ (5 mm)

37. The boundary layer thickness at a point in flow over a plate, is 8 mm. The Reynolds number is 25600. The distance from the leading edge is ____________ . (0.256 m)

38. The Reynolds number in air flow over a flat plate at 8 m/s was 25000. The kinematic viscosity was 64×10^{-6} m^2/s. The distance from the leading edge is ____________ .

(0.2 m)

39. In a flow over a flat plate the distance from the leading edge for the flow to become turbulent is ____________ . The free stream velocity is 20 m/s. Kinematic viscosity is 50×10^{-6} m^2/s. (1.25 m)

40. In a flow over a flat plate the Reynolds number is 25600 and the Prandtl number is 0.834. The average Nusselt number is ____________ . (100)

41. The Nusselt number is 100. The location from leading edge is 0.5 m. $k = 0.025$ W/mK. Convection coefficient is ____________ . (5 W/m^{2}K)

42. The temperature gradient at the wall in flow over a flat plate is – 4000°C/m. Conductivity is 0.025W/mK. Plate temperature is 80°C. Air temperature is 60°C. Convection coefficient is ____________ . (5W/m^{2}K)

43. In flow over a flat plate Reynolds number at a location is 25600. The average friction coefficient is ____________ . (8.3125×10^{-3})

44. In flow over a flat plate, in the laminar region, velocity boundary layer thickness is 0.009 m. $Pr = 0.729$. Thermal boundary layer thickness is ____________ . (10 mm)

45. When cubic velocity profile is assumed the hydro dynamic boundary layer thickness in flow over a flat plate is given by ____________ . ($4.64\, x/Re^{0.5}$)

46. In flow through a pipe the Reynolds number is 1600. The friction factor is ____________. (0.04)

47. In laminar flow through a pipe the friction factor is 0.032. The Reynolds number is ____________. (2000)

48. In fully developed laminar flow of water through a pipe of 0.15 m diameter with uniform wall temperature the thermal conductivity at the condition was 0.655 W/mK. The average convection coefficient is ____________ . (16 W/m^{2}K)

49. Water flows at the rate of 0.08 kg/m^{2}s through a 0.1 m diameter pipe the viscosity being 356×10^{-6} kg/ms. The Reynolds number is ____________ . (2861)

50. In fully developed laminar flow of water through a 0.15 m diameter pipe under constant heat flux conditions the thermal conductivity at the bulk mean temperature was 0.6874 W/mK. The value of convection coefficient is ____________ . (20 W/m^{2}K)

51. An equilateral triangular duct of side 0.1 m has air flowing through it. The hydraulic mean diameter is ____________ . (0.0577 m)

52. The hydraulic mean diameter of a rectangular duct of 0.12 × 0.1 m sides is ____________. (0.109 m)

53. In a convection situation both forced and free convections appear to contribute equally. The Reynolds number is 4000. The range of value of Grashof number is ____________ . (16×10^6)

54. In a flow the convection coefficient has a value of 2600 W/m^{2}K. The thermal conductivity of the material is 0.64 W/mK. The temperature difference is 40°C. The value of temperature gradient at the interface is ____________ . (– 162500°C/m)

55. In a flow across a tube bundle the tube *OD* is 0.75 m. The tube arrangement is staggered with a pitch of 0.15 m normal to the flow and 0.1 m pitch along the flow. The entrance velocity is 10 m/s. The maximum velocity is ____________ . (20m/s)

56. In a heat exchanger the terminal temperatures of the hot fluid are 150 and 80°C. For the cold fluid the terminal temperatures are 30 and 100°C. The flow arrangement is ____________ and the value of LMTD is ____________ . (counter flow, 70°C)

57. A clean heat exchanger under test gave a *U* value of 2000 W/m^{2}K. After one year of operation the value of *U* was determined as 1600 W/m^{2}K. The fouling resistance is ____________ . (1.25×10^{-4} m^2 K/W)

58. The inlet and outlet temperatures of the hot and cold fluids are 200, 40 and 180 and 100°C. The value of the LMTD for (*i*) counter flow and (*ii*) Parallel flow are ____________. (118.88, 115.42)

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59. In a heat exchanger the hot fluid inlet and outlet temperatures are 200 and 180°C. For the cold fluid the terminal temperatures are 40 and 100°C. The capacity ratio is ____________ . (0.3333)

60. For a parallel flow heat exchanger the capacity ratio is 1.0 and the NTU value is 2.0. The effectiveness is ____________ . (0.491)

61. For a counter flow heat exchanger the capacity ratio is 1.0 and NTU is 2.0. The effectiveness is ____________ . (0.66666)

62. For a condenser the value of NTU is 1.5. The effectiveness is ____________ . (0.777)

63. For a condenser the effectiveness was found as 0.61. The value of NTU is ____________ . (0.942)

64. For a counter flow heat exchanger with equal heat capacities the effectiveness was found as 0.6. The value of NTU is ____________ . (1.5)

65. For an evaporator the effectiveness was 0.5. The value of NTU is ____________ . (0.693)

66. A heat exchanger with 10 m^2 heat transfer area has an overall heat transfer coefficient of 600 W/m^2 K. The minimum heat capacity of the flow is 2100 W/K. The value of NTU is ____________ . (2.86)

67. In an economiser of a large steam generator pressurised water flows at a rate of 20 kg/s. The water temperature increases from 40°C to 160°C. The flue gas temperature drops from 360°C to 190°C. The heat capacity of the gas flow is ____________ . (58984 W/K)

68. In an economiser water gets heated by 120°C while flue gases are cooled by 170°C. The capacity ratio is ____________ . If the heat capacity of the gases is 58984 W/K the heat capacity of water is ____________ . (0.706, 83561 W/K)

69. In a heat exchanger the LMTD was 26.2°C under certain flow conditions. The heat transfer rate was 11000 W. Due to changes in surrounding conditions the inlet temperature alone had changed and the value of LMTD was found as 22.3°C. The heat flow rate at this conditions will be ____________ . (9363 W)

70. In an evaporator due to a change in the heat capacity of the hot fluid the effectiveness increased from 0.6 to 0.75. The overall heat transfer coefficient decreased by 20%. The percentage change in the heat capacity is ____________ . (– 17.4%)

71. In a counter flow heat exchanger with equal heat capacities the flow rate changed equally on both sides of flow. This changed the effectiveness from 0.6 to 0.75. If there was no change in the value of overall heat transfer coefficient the percentage change in the flow rates is ____________ . (– 33.3%)

72. In a counter flow heat exchanger with equal heat capacities the effectiveness was 0.75. If both the flow rates were doubled and if this increased the overall heat transfer coefficient by 20% the new effectiveness will be ____________ . (0.375)

73. In the case of parallel flow heat exchangers with equal heat capacities the limiting value of effectiveness is ____________ . (0.5)

74. In a parallel flow heat exchanger the value of NTU is 2.0. The capacity ratio is 0.5. The value of effectiveness is ____________ . (0.633)

75. In a parallel flow heat exchanger the heat capacities are equal. The hot and cold fluid inlet temperatures are 200°C and 100°C. The limiting value of the exit temperature is ____________ . (150°C)

76. In a counter flow heat exchanger with equal heat capacities the inlet temperatures are 100°C and 30°C. The hot fluid exit temperatures was 50°C. The cold fluid exit temperature will be ____________ . (80°C)

77. In a parallel flow heat exchanger the heat capacity of the hot fluid was 0.5 of the cold fluid heat capacity. The entry temperatures are 200°C and 50°C. If the cold fluid leaves at 100°C then the hot fluid will leave at ____________ . (100°C)

78. In a counter flow heat exchanger the hot fluid enters at 200°C and leaves at 100°C. The cold fluid enters at 50°C and leaves at 200°C. The capacity ratio is ____________ . (0.66667)

79. In a counter flow heat exchanger the cold fluid enters at 50°C and leaves at 100°C. The capacity ratio is 0.3333. If the hot fluid enters at 200°C and if the hot fluid has the minimum heat capacity it will leave at ____________ . (50°C)

80. The emissive power of a surface is 49000 W/m^2. The intensity of radiation of that surface will be ____________ . (15597 W/str)

81. A black surface is at 1000 K. The fraction of radiation upto a wave length of 5 m will be ____________ . (0.6337) Note : refer table.

82. The fraction of radiation emitted by a black surface upto a wave length of 10 m was 0.6337. The temperature of the surface will be ____________ .(500 K) Note : Refer table

83. If the fraction of radiation emitted by a black surface in the wave band 0 to 4 m was 0.8563 then the surface temperature will be _________ . (2000 K)

84. At a temperature of 1000 K the monochromatic emissive power will be maximum at the wave length ____________ . (2.8976 μ m)

85. The maximum monochromatic emissive power of a surface was found to occur at a wave length of 2 μ m. The surface temperature should be ____________ . (1448.2 K)

86. When the surface temperature was increased from 500 K to 1000 K the wave length at which the monochromatic emissive power is maximum will shift from _________ μ m to _________ μ m. (5.7952, 2.8976)

87. The shape factor from a completely enclosing surface whose area is 8 m^2 to the enclosed surface whose area is 4 m^2 is ____________ . (0.5)

88. In a cylindrical furnace the shape factor from the base to the top is 0.31. The shape factor from the top to the curved surface will be ____________ . (0.69)

89. The diameter and the height of a cylindrical furnace are both 2.0 m. The shape factor from the base to the top is 0.18. The shape factor from the curved surface to itself will be _____ . (0.59)

90. The shape factor from the hemispherical surface to half the area of the enclosing base surface is ____________ . (0.25)

91. For a right circular cone of slant length equal to the base diameter the shape factor to itself is ____________ . (0.5)

92. Two long concentric cylinders are of 0.1 m and 0.2 m diameter. The shape factor from the outer to the inner cylinder and to itself are ____________ . (0.5, 0.5)

93. A spherical vessel of 1.2 m diameter encloses another concentric spherical vessel of diameter 1.0 m storing cryogenic liquid. The shape factor of the outer vessel to the inner vessel and to itself are ____________ . (0.6944, 0.3056)

94. Two large planes both having an emissivity of 0.5 are parallel to each other. The resistance for radiation heat exchange between them based on 1 m^2 area is ____________ .

(3.0 K/W)

95. A radiation shield with emissivity of 0.05 on both sides is placed between two large black parallel black planes. The thermal resistance is ____________ . (40 K/W)

96. The shape factor from a surface of 1 m^2 area at 1000 K to another surface is 0.2. The energy radiated by this surface reaching the other surface is ____________ . (11340 W)

97. The emissive power of a surface is 3543.75 W/m^2. The radiosity of the surface is 1451.52 W/m^2. If the emissivity of the surface was 0.5 then the heat flow out of the surface is ____________ . (2092.23 W)

98. The radiosity of surfaces 1 and 2 are 3543.75 and 1451.52 W/m^2. The shape factor F_{1-2} is 0.5 and the area of the surface 1 is 2.0 m^2. The heat transfer between the surfaces is ____________ . (2092.23 W)

99. The volume fraction of N_2 and O_2 at surfaces 0.1 m apart are 10% and 90% and 90% and 10% respectively. The diffusion coefficient is 20.6×10^{-6} m^2/s. If the total pressure is 1 atm and temperature is 300 K then the diffusion rate of Oxygen and Nitrogen are ____________ . (2.11×10^{-10} kg/m^2s, 1.85×10^{-10} kg/m^2s)

100. In a flow involving both heat and mass transfer the convection coefficient was 20 W/m^2K. Lewis number is 0.85. c_p = 1005 J/kgK. Density is 1.2 kg/m^3. The value of mass transfer coefficient is ____________ . (0.0185 m/s)

STATE TRUE OR FALSE

1. Convection coefficient is a material property. (False)
2. Thermal conductivity is a material property. (True)
3. In good conductors lattice vibration contributes more for heat conduction. (False)
4. Thermal conductivity of water decreases with increase in temperature. (False)
5. For the same amount of heat conduction through a slab, as thickness increases the temperature gradient should increase. (False)
6. Fins for the same flow should be longer if the thermal conductivity of the material is increased. (False)
7. For identical fins of different materials the tip to base temperature difference will be lower if the thermal conductivity is lower. (False)
8. In a hollow cylinder, the temperature variation with radius will be linear. (False)
9. The temperatures gradient at the inner surface will be steeper compared to that at the outer surface in radial heat conduction in a hollow cylinder. (True)
10. Fins are more useful with liquids than with gases. (False)
11. Fins effectiveness is generally greater than one. (True)
12. In three dimensional steady state conduction with uniformly spaced nodes the temperature at a node will be one sixth of the sum of the adjacent nodal temperatures. (True)
13. Lumped capacity model can be used in the analysis of transient heat conduction if Biot number is greater than one. (False, should be less than 0.1)
14. Lumped parameter model can be used if the internal conduction resistance is high compared to the surface convection resistance. (False, should be low)
15. To reduce the time constant of a thermocouple, the convection coefficient over its surface should be reduced. (False)
16. To reduce the time constant of a thermocouple its characteristic linear dimension (V/A) should be reduced. (True)
17. A solid of poor conductivity exposed for a short period to surface convection can be analysed as semi infinite solid. (True)
18. A slab will cool the fastest compared to a long cylinder or sphere of the same characteristic dimensions when exposed to the same convection conditions. (False)
19. Higher the value of Biot number slower will be the cooling of a solid. (True)
20. For transient conduction analysis of smaller objects product solution is used. (True)
21. In a slab conducting heat the surface temperatures are 200 and 100°C. The mid plane temperature will be 150°C if k is constant. (True)
22. In a slab of material of variable thermal conductivity, with conductivity increasing with temperature, the surface temperatures are 200°C and 100°C. The mid plane temperature will be greater than 150°C. (False)
23. In a slab material of variable conductivity with conductivity decreasing with temperature the surface temperatures are 200°C and 100°C. The mid plane temperature will be higher than 150°C. (True)
24. In a hollow cylinder with radial conduction the mid plane temperature will be lower than the mean of surface temperatures. (True)
25. In a hollow sphere with radial conduction, the mid plane temperature will be higher than the mean of surface temperatures. (False)

26. With convection on the surface any amount of additional insulation cannot reduce the heat flow through a hollow spherical insulation of the same material to half the original flow rate. (True)

27. In the case of small hollow cylinders or spheres, with outside convection the thermal resistance may decrease by the addition of insulation. (True)

28. Small electronic components may be kept cooler by encasing it in glass like material. (True)

29. If Prandtl number is greater than one, the thermal boundary layer will be thicker compared to hydrodynamic boundary layer. (False)

30. Liquid metal flow in pipes can be approximated to slug flow. (True)

31. The local value of convection coefficient in laminar flow over a flat place will decrease along the length. (True)

32. In flow over a flat plate over length L the , average convection coefficient will be equal to (4/3) h_L. (False)

33. Other conditions remaining the same as viscosity increases the boundary layer thickness will decrease. (False)

34. Momentum and displacement thickness will be more compared to boundary layer thickness. (False)

35. In laminar flow Nusselt is a function of $Re^{0.8}$. (False)

36. In turbulent flow the velocity at point varies about an average value. (True)

37. In turbulent flow in pipes Nusselt is proportional to $\mathrm{Re}^{0.8}$. (True)

38. In fully developed flow through a pipe, under laminar flow conditions, average Nussel number is constant. (True)

39. The hydraulic mean diameter for an annulus is $D_{o2} - D_{12}$. (False)

40. In flow-through tube banks of tubes closer pitch will lead to higher values of h. (True)

41. In free convection, Rayleigh number is similar to Paclet number in forced convection. (True)

42. Gravity force rather than buoyant force plays a more important role in free convection. (False)

43. Grashof number is the ratio between buoyant force and viscous force. (False)

44. Reynolds number is the ratio between viscous force and buoyant force. (False)

45. The value of convection coefficient for the same flow velocity will be lower in the case of water as compared to air. (False)

46. Lower values of kinematic viscosity will lead to higher value of h both in free and forced convection. (True)

47. In pipe flow for similar velocity conditions water will have a higher convection coefficient compared to liquid metal. (False)

48. In cases where both modes of convection may contribute the ratio Gr/Re^2 is a measure of the importance of either mode. (True)

49. As the excess temperature increases, the sustainable heat flux will continuously increase in boiling. (False)

50. The excess temperature range for maximum flux in nucleate pool boiling is about 200°C. (False)

51. In stable film boiling as excess temperature increases sustainable heat flux will increase. (True)

52. In flow boiling mist flow will sustain higher heat flux. (False)

53. In condensation film, linear temperature profile is generally assumed. (True)

54. Dropwise condensation is not sustainable over long periods. (True)

55. Counter flow is always preferable in heat exchanger design. (True)

56. For the same terminal temperatures, LMTD-parallel flow will be higher compared to LMTD-counter flow. (False)

57. NTU method is preferred for the analysis of the complete performance of heat exchangers. (True)

58. For the same NTU, as the capacity ratio increases the effectiveness will decrease. (True)

59. For a given exchanger as the capacity ratio increases the final temperatures will increase. (False)

60. As the capacity ratio in a given exchanger increases, the heat flow will increase. (True)

61. When heat capacities of both fluids are equal, the temperature difference will be constant for parallel flow arrangement. (False)

62. For condensers/evaporators, the flow direction does not affect the heat flow. (True)

63. Capacity ratio is taken as zero for condensers and evaporators. (True)

64. Opaque Gray surfaces have constant reflectivity. (True)

65. Directional emissivity for metals will be lowest at the normal direction. (False)

66. Glasses generally transmit low frequency radiation. (False)

67. Copper dioxide coating can produce selective surface. (True)

68. As temperature increases, the wavelength at which maximum monochromatic emissive power occurs increases. (False)

69. Kirchhoff law states that reflectivity equals absorptivity. (False)

70. As temperature difference increases, radiation resistance will increase. (False)

71. As temperature increases, h_r will increase. (True)

72. Convex surfaces will have shape factor with themselves. (False)

73. Between two surfaces if $F_{1-2} > F_{2-1}$ then $A_1 > A_2$. (False)

74. Shape factor with enclosing surfaces will be one. (True)

75. Gases are truly gray radiators. (False)

76. Radidation from a gas body is a volume phenomenon. (True)

77. Emissivity of a gas body depends on the partial pressure, thickness and temperature. (True)

78. Gases are band radiators. (True)

79. Snow is a very good reflector. (False)

80. Lewis number is used to predict mass transfer rates using heat transfer rates at similar conditions. (True)

81. Schmidt number replaces Nusselt number in convective mass transfer studies. (False)

82. In mass transfer studies the function of Sherwood number is similar to Prandtl number in heat transfer studies. (False)