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ESE- 2020 (Prelims) - Offline Test Series Test - 1

MECHANICAL ENGINEERING

SUBJECT: Thermodynamics and Heat Transfer, Renewable Sources of Energy — SOLUTIONS

01. Ans: (b)

Sol: In isothermal process, Q = W

Hence, there is no degradation of energy in isothermal process as 100% heat is converted to work.

02. Ans: (c)

Sol: Generalised heat conduction equation for 1-D, steady state without heat generation:

$$\frac{1}{r^n}\frac{\partial}{\partial r}\left(r^n\frac{\partial T}{\partial r}\right) = 0$$

for spherical coordinate, n = 2

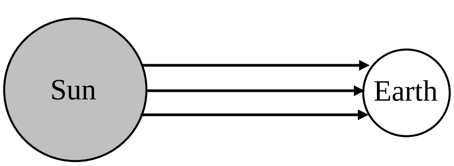
$$\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{dT}{dr}\right) = 0$$

Note: For Cartesian co-ordinate, n = 0

For cylindrical co-ordinate, n = 1

03. Ans: (d)

Sol:



$$Q_E = G_{sc} \times \pi R_{earth}^2$$

$$= 1367 \times \pi(6371 \times 10^3)^2$$

$$= 1.74\times10^{17}\ W$$

04. Ans: (b)

Sol: Reversible process is an ideal process which consumes least and deliver the most work. Reversible process is that process which can be reversed without leaving any trace on system or surrounding.

05. Ans: (c)

Sol:

- *Flow through tubes,*

  Nu = f [(Re), (Pr)]

  For fully developed flow

  $$Re = \frac{\rho VD}{\mu} \rightarrow \text{constant along the length}$$

  $$Pr = \frac{\mu C_p}{k} \rightarrow \text{constant}$$

- *Turbulent flow over flat plate.*

  $Nu_x \propto Re_x^{0.8} Pr^{0.4}$

  $Nu_x \propto Re_x^{0.8}$

  [$\because$ Pr is property of fluid and it is constant]

  $$\frac{hx}{k} \propto \left(\frac{\rho V x}{\mu}\right)^{0.8}$$

  $h \propto x^{-0.2}$

  as $x\uparrow \Rightarrow h\downarrow$

06. Ans: (d)

Sol: The indirect methods of solar energy utilization are wind energy, biomass energy and wave energy.

07. Ans: (c)

Sol: From first law of thermodynamics, Q – W = ΔU. If heat is added and the value of Q – W becomes negative (magnitude of work done by system is greater than magnitude of heat supplied) then ΔU < 0.

$\Rightarrow$Temperature decreases.

08. Ans: (a)

Sol: $\dot{m}_w = 1.2\,kg/s,\ \ C_{pw} = 4.2\,kJ/kgK$

$\dot{m}_a = 2.5\,kg/s;\ \ C_{pa} = 1\,kJ/kgK$

$T_{hi} = 90^o C,\ \ \ \ T_{ci} = 8^o C$

$(\dot{m}_w.C_{pw}) = 1.2\times 4.2 = 5.04$ kW/K

$\dot{m}_a.C_{pa} = 2.5 \times 1 = 2.5$ kW/K

$C_{min} = 2.5$ kW/K

$C_{max} = 5.04$ kW/K

Maximum rate of heat transfer

$= C_{min}(T_{hi} - T_{ci})$

$= 2.5(90 - 8)$

$= 2.5 \times 82 = 205.0$ kW

09. Ans: (A)

Sol: Surfaces should face equator to get maximum insolation.

10. Ans: (b)

Sol:

- There is decrease in volume during melting of ice slab at 273 K. Therefore, negative work is done by ice-water system on the atmosphere or positive work is done on the ice-water system by the atmosphere.
- There is increase in internal energy due to heat absorbed by ice.

11. Ans: (a)

Sol:

- Let the temperature of the surroundings be T_∞. From the Stefan-Boltzmann law, the energy of thermal radiation emitted per unit time by a blackbody of surface area A is given by $E = \sigma A T^4$

  Here, σ is Stephen's constant. Also, the energy absorbed per unit time by the body is given by $E = \varepsilon\sigma A\, T_\infty^4$

As the two spheres have equal radii and temperatures, their rate of absorption and emission will be equal in the beginning.

- *Energy balance:*

  Net radiative heat transfer by sphere = Rate of change of internal energy of sphere.

$$\varepsilon\sigma\left(T_S^4 - T_\infty^4\right) = -mc\frac{dT}{dt}$$

$$\frac{dT}{dt} \propto \frac{1}{m}$$

$\because$ Masses of both the spheres are different, (since, one is solid sphere and other is hollow sphere with same material and radii) initial rate of cooling will be different. So, statement (3) is incorrect.

- As cooling rates are different therefore, temperature at any instant will be different. So statement (4) is incorrect.

12. Ans: (c)

Sol: The collection efficiency of a flat plate collector can be improved by both the methods given.

13. Ans: (b)

Sol: Critical point $\rightarrow$ Properties of saturated liquid and saturated vapor are same.

Sublimation $\rightarrow$ On heating solid changes to vapour state

Triple point $\rightarrow$ (Solid + liquid + vapour) coexist.

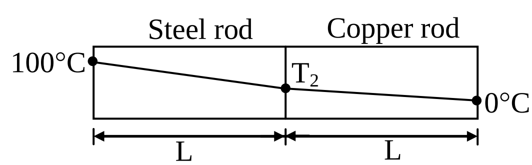
Melting $\rightarrow$ Phase change from solid to liquid.

14. Ans: (b)

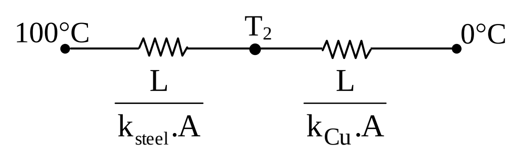
Sol: At higher temperature heat losses increase. The efficiency of various types of collector decreases with increasing temperature.

15. Ans: (a)

Sol:



Thermal circuit:



$$\text{Heat transfer rate} = \frac{100-0}{\frac{L}{k_{steel}.A}+\frac{L}{k_{Cu}.A}}$$

$$= \frac{T_2 - 0}{\frac{L}{k_{Cu}.A}}$$

$$T_2 = \frac{100}{\frac{360}{45}+1} = \frac{100}{8+1}$$

$$T_2 = \frac{100}{9} = 11.11°C$$

16. Ans: (c)

Sol: $\eta_{actual} = \frac{W}{Q_1} = \frac{400}{600} = 0.6667$

$$\eta_{Carnot} = \frac{T_1 - T_2}{T_1} = \frac{1500-300}{1500} = 0.8$$

$$\eta_{2ndlaw} = \frac{\eta_{act}}{\eta_{Carnot}} = \frac{0.6667}{0.8}$$

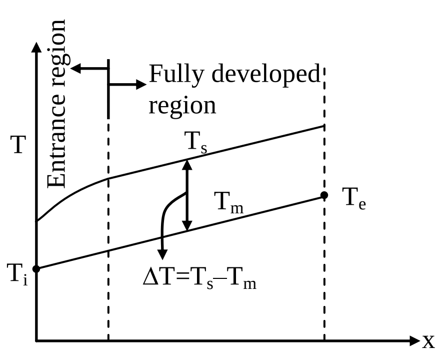
$$= 0.8334 = 83.34\%$$

17. Ans: (d)

Sol: Paraboloid dish collector gives maximum efficiency out of the given collectors.

18. Ans: (b)

Sol: For fully developed flow, Nusselt number and heat transfer coefficient remain constant along the length of tube. As heat flux is also constant, the difference between wall temperature and bulk mean temperature of the fluid remains constant at each section.



$$\text{Nusselt No. } (Nu) = \frac{hD}{k}$$

$$60 = \frac{h \times 0.1}{0.025}$$

$$\frac{60 \times 0.025}{0.1} = h$$

$h = 15$ W/m^2.K

Heat transfer rate = $hA\Delta T$

$= 15 \times \pi DL \times 50$

$= 15 \times \pi \times 0.1 \times 7 \times 50$

$= 15 \times \frac{22}{7} \times 0.1 \times 7 \times 50$

$= 15 \times 110$

$= 1650$ W

19. Ans: (a)

Sol:

- Control volume system is also called open system. It can have moving or fixed boundary.
- Pressure reaches the value of absolute zero when molecular momentum of system becomes zero.

20. Ans: (b)

21. Ans: (c)

Sol: Nucleate boiling is of most importance in boiling heat transfer. Film boiling is always to be avoided. Nucleate boiling involves two separate processes – the formation of bubbles (nucleation) and the subsequent growth and motion of these bubbles.

Two conditions are required to be fulfilled for bubbles to form:

1. The liquid at the heating surface must be superheated.
2. There must be dissolved gases present to form the nuclei of bubbles.

22. Ans: (c)

Sol: Flow through partially open valve is throttling process, where

$$h_1 = h_2$$

$$u_1 + p_1v_1 = u_2 + p_2v_2$$

$p_1 = 20$ bar,

$p_2 = 5$ bar

$v_1 = 0.5$ kg/m^3,

$v_2 = 2$ kg/m^3

$u_1 + 20 \times 100 \times 0.5 = u_2 + 5 \times 100 \times 2$

$\therefore\ u_2 - u_1 = 0$

23. Ans: (b)

Sol: $A_1 = 1$ m^2,

$A_2 = 4$ m^2 ,

$F_{1\text{-}2} = 0.4$

Using reciprocity theorem:

$$A_1F_{1\text{-}2} = A_2F_{2\text{-}1}$$

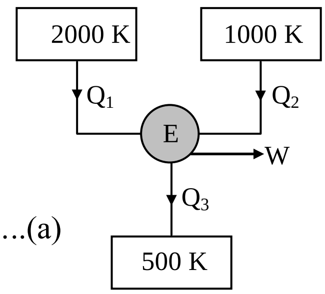
$1 \times 0.4 = 4 \times F_{2\text{-}1}$

$$F_{2-1} = \frac{0.4}{4} = 0.1$$

24. Ans: (b)

25. Ans: (c)

Sol: W = 100 kW



$$Q_3 = \frac{3000}{60} = 50\text{kW}$$

$Q_1 + Q_2 = Q_3 + W$

$Q_1 + Q_2 = 150$……….(a)

$$\oint \frac{dQ}{T} = 0$$

$$\frac{-Q_1}{2000} - \frac{Q_2}{1000} + \frac{Q_3}{500} = 0$$

$Q_1+2Q_2 = 4Q_3 = 200$……….(b)

From equations (a) and (b)

$Q_1 = Q_{2000} = 100$ kW

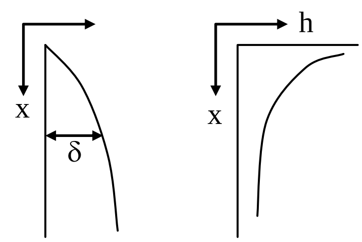
$Q_2 = Q_{1000} = 50$ kW

$$\frac{Q_{2000}}{Q_{1000}} = 3$$

26. Ans: (a)

27. Ans: (a)

Sol:



$$\delta \propto (x)^{1/4}$$

$$h \propto \frac{1}{(x)^{1/4}}$$

$$h \propto \frac{1}{\delta}$$

28. Ans: (a)

Sol: $\eta = \dfrac{W}{Q_{in}} = \dfrac{\text{area of cycle}(abcd)}{\text{area under bc}}$

$$= \frac{(2T_1 - T_1)(S_2 - S_1) + \frac{1}{2}(3T_1 - 2T_1)(S_2 - S_1)}{(2T_1)(S_2 - S_1) + \frac{1}{2}(3T_1 - 2T_1)(S_2 - S_1)}$$

$$= \frac{\frac{3}{2}T_1}{\frac{5}{2}T_1} = \frac{3}{5}$$

29. Ans: (d)

30. Ans: (d)

Sol:

Black body	-	$\rho = \tau = 0$
Gray body	-	Emissivity is constant
Opaque body	-	$\alpha + \rho = 1$
Specular body	-	Reflection is angle dependent

31. Ans: (c)

Sol: Given:

$W_A = 2W_B$

$Q_1 - Q_2 = 2(Q_2 - Q_3)$

$$\frac{Q_1}{Q_2} - 1 = 2\left(1 - \frac{Q_3}{Q_2}\right) \quad \text{------------(1)}$$

Second Law:

$$\frac{Q_1}{T_1} = \frac{Q_2}{T_2}$$

$$\frac{Q_2}{T_2} = \frac{Q_3}{T_3}$$

From equation (1)

$$\frac{T_1}{T_2} - 1 = 2\left(1 - \frac{T_3}{T_2}\right)$$

$$\frac{T_1 - T_2}{T_2} = \frac{2(T_2 - T_3)}{T_2}$$

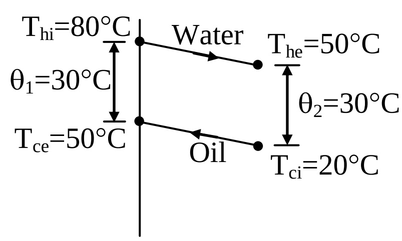
$3T_2 = T_1 + 2T_3$

$$\Rightarrow T_2 = \frac{T_1 + 2T_3}{3}$$

32. Ans: (b)

33. Ans: (b)

Sol:



For water, $C_w = \dot{m}_w . C_{p_w}$

$$= \rho A v \times C_{p_w} = 1000 \times \left(\frac{0.02}{60}\right) \times 4$$

$$C_w = \frac{80}{60} \text{ kW/K}$$

For oil, $C_o = \dot{m}_o . C_{p_o}$

$$= \rho A v \times C_{p_w}$$

$$= 800 \times \left(\frac{0.05}{60}\right) \times 2$$

$$C_o = \frac{80}{60} \text{ kW/K}$$

When, $C_{min} = C_{max} \Rightarrow C = \frac{C_{min}}{C_{max}} = 1$ (every where the temperature difference will be same)

LMTD $= \theta_1 = \theta_2 = 30°C$

$\Rightarrow T_{ce} = T_{hi} - LMTD = 80 - 30$

$\Rightarrow T_{ce} = 50°C$

34. Ans: (c)

Sol:

- Since, process is internally reversible and adiabatic so change in entropy of the gas must be zero.
- If the process is isothermal the enthalpy of the gas is necessarily zero since enthalpy for an ideal gas is function of temperature only.

35. Ans: (b)

Sol: $F_{1-2} = 1$ (from the geometry)

Using reciprocity theorem:

$$A_1F_{1-2} = A_2F_{2-1}$$

$$\pi R^2 \times 1 = \left(\frac{4\pi R^2}{2}\right) \times F_{2-1}$$

$$F_{2-1} = \frac{1}{2} = 0.5$$

Using summation rule:

$$F_{2-1} + F_{2-2} = 1$$

$$F_{2-2} = 1 - 0.5 = 0.5$$

36. Ans: (b)

37. Ans: (a)

Sol: $$(COP)_{max} = \frac{(-7+273)}{(273+25)-(273-7)} = 8.31$$

Minimum power required

$$= \frac{80/60}{8.31} = 0.16kW$$

Irreversibility

= Actual power – Minimum power

= 0.5 – 0.16 = 0.34 kW

38. Ans: (a)

Sol: Due to light weight, the oxygen fuel cells are mostly used for the spacecrafts.

39. Ans: (b)

Sol: Heat transfer coefficient for turbulent free convection is independent of x

Average heat transfer coefficient

$$(\bar{h}) = \frac{1}{L}\int_0^L h_x \, dx$$

$$= \frac{h_x}{L} \times L$$

$$\bar{h} = h_x$$

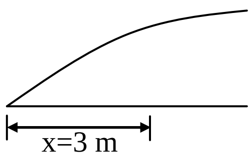
40. Ans: (d)

Sol: For reversible processes temperature and pressure differences should be infinitesimal.

41. Ans: (b)

42. Ans: (c)

Sol:



Dimensionless temperature gradient at the wall = 1000

Nu = 1000

$$\frac{h\times x}{k}=1000$$

$$\frac{h\times 3}{0.024}=1000$$

$$h=\frac{1000\times 0.024}{3} = 8\ \text{W/m}^2.\text{K}$$

43. Ans: (b)

Sol: By applying steady flow energy equation per unit mass flow rate at start and end of compressor

$$h_1 + q = h_2 + w$$

$$\Rightarrow 100 - 60 = 200 + w$$

$$w = -160$$

Power required = 2×160 = 320 kW

44. Ans: (b)

Sol: The bio methane is produced by the anaerobic oxidation of biomass.

45. Ans: (c)

Sol: For constant heat flux condition :

Nu = 4.36 (only for laminar flow)

Nu = $0.023Re^{0.8}Pr^{n}$ (turbulent flow)

$$\frac{L_{e,h}}{D}=0.05\,Re_D$$

$$\frac{L_{e,t}}{D}=0.05\,Re_D\,.Pr$$

$$\frac{L_{e,t}}{L_{e,h}}=Pr$$

If Pr > 1

(thermal entrance length) > (Hydrodynamic entrance length)

If Pr < 1

Thermal entrance length < Hydrodynamic entrance length

46. Ans: (b)

Sol: In isochoric process work done is zero therefore whole heat received will be converted to the internal energy.

47. Ans: (c)

Sol: $\in\ =\ \eta\times\frac{A_s}{A_c}$

$$\frac{\in}{\eta}=\frac{A_s}{A_c}\ =\ \frac{PL}{A_c}$$

Effectiveness of the fin, $(\in)=\sqrt{\frac{Pk}{hA}}$

$$\in\propto\frac{1}{\sqrt{h}}$$

As *h* decreases, effectiveness (∈) increases. Fins will be more effective when it will be put in lower heat transfer coefficient environment.

48. Ans: (c)

Sol: The bio diesel is produced by the distillation of the vegetable oil.

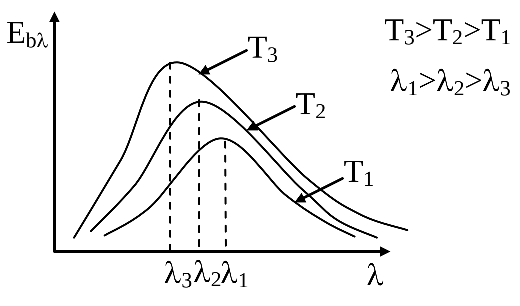
49. Ans: (c)

Sol:

- It violates energy conservation hence violates 1st law of thermodynamic.
- It satisfies Kelvin Plank's statement of second law of thermodynamics.

50. Ans: (b)

Sol:



51. Ans: (d)

52. Ans: (a)

Sol: For the expression ∫pdv to represent the work, the system is closed one and process takes place in non flow system.

53. Ans: (d)

Sol: The following facts affect the distribution of wind energy.

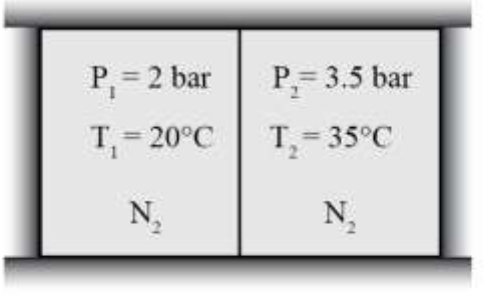
- Mountain chains
- The hills, trees and buildings
- Frictional effect of the surface

54. Ans: (d)

Sol: Rough surfaces give diffused reflections, not specular reflection. Generally most of the engineering materials have rough surfaces.

55. Ans: (d)

Sol:



Non flow process

dQ = 0 (Insulated)

dW = 0 (Diffusion / rigid container)

∴ dQ – dW = dU

∴ dU = 0

U = constant

Thus, internal energy of nitrogen will be conserved.

56. Ans: (b)

Sol: Heat generated = 180 W/cm^3

$$\text{Heatflux} = \frac{180\,W \times \frac{\pi}{4} d^2 \times L}{\pi d L}$$

$$= 180 \times \frac{d}{4}$$

$$= 180 \times \frac{0.3}{4}$$

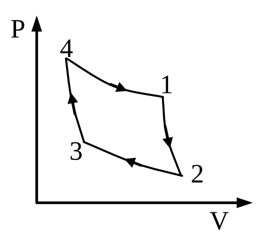
$$= \frac{54}{4} = 13.5\ \text{W/cm}^2$$

57. Ans: (a)

Sol: Wind energy is harnessed as mechanical energy with the help of a wind mill or turbine.

58. Ans: (b)

Sol:



During adiabatic expansion process (1-2) we can write

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$\frac{T_2}{T_1} = \left(\frac{1}{32}\right)^{\frac{7}{5}-1} = \left(\frac{1}{2^5}\right)^{\frac{2}{5}} \quad \left[\because \gamma = \frac{7}{5} \text{ for diatomic gas}\right]$$

$$T_2 = \frac{1}{4} T_1$$

$$\eta = 1 - \frac{T_2}{T_1} = \frac{3}{4} = 0.75$$

59. Ans: (d)

Sol: For 1-D, steady state heat conduction equation without heat generation

$$\frac{\partial^2 T}{\partial x^2} = 0$$

Integrate with respect to x $\quad \frac{\partial T}{\partial x} = C_1$

Again integrate with respect to x

$$T = C_1 x + C_2 \text{ ----------(1)}$$

At x = 0, T = 40°C

$40 = 0 + C_2$

$C_2 = 40$

At x = 0.15 m, T = 28°C

$28 = 0.15C_1 + 40$

$$C_1 = \frac{-12}{0.15} = -80$$

$T(x) = C_1 x + C_2$

$T(x) = -80x + 40$

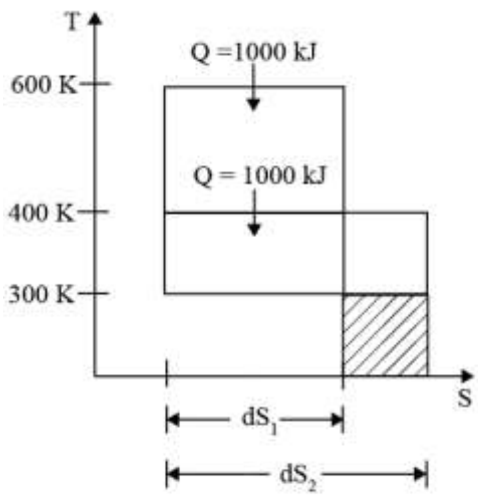
60. Ans: (d)

Sol: The followings are the drawbacks of wind energy:

- Unreliability or non steadiness.
- Output voltage and frequency fluctuations
- Effect on bird life.

61. Ans: (b)

Sol:



Loss of available energy = T_0 ($dS_2 - dS_1$)

$$= T_0\left(\frac{Q}{T_2} - \frac{Q}{T_1}\right)$$

$$= 300\left(\frac{1000}{400} - \frac{1000}{600}\right)$$

= 300[2.5 − 1.667]

= 250 kJ

62. Ans: (d)

Sol: Generally thermal conductivity of liquid is independent of pressure except critical pressure.

For liquids:

As temperature increases → Thermal conductivity decreases

For gas:

$k \alpha \sqrt{T}$ as per kinetic theory of gas

As Temperature decreases → Thermal conductivity increases.

63. Ans: (c)

Sol: Spontaneous processes are always irreversible.

64. Ans: (a)

Sol: The heat transfer coefficient decreases sharply from the presence of this non-condensable gas. The non condensable gas like air not only blankets the cooling surface but also offers a high thermal resistance.

65. Ans: (d)

66. Ans: (b)

Sol:

- μ = Joule – Thomson coefficient $= \left(\frac{\partial T}{\partial p}\right)_h$

  During throttling, pressure always decreases. Hence, for cooling $\partial T < 0$.

  Hence, Joule-Thomson coefficient is positive.
- During throttling process enthalpy remains constant.

67. Ans: (d)

Sol: Nusselt number can not be less than unity.

$$\text{Nusselt number} = \frac{\text{convective heat transfer}}{\text{pure conductive heat transfer}}$$

$$= \frac{\text{pure conductive heat transfer} + \text{heat transfer due to advection}}{\text{pure conductive heat transfer}}$$

If heat transfer rate due to advection is zero, then that means there is no macroscopic bulk displacement of the fluid. In this case, heat transfer in fluid is by conduction only (If radiation effect is neglected).

So, the minimum value of Nusselt number is one.

68. Ans: (a)

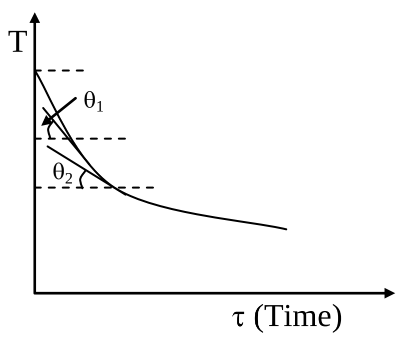
69. Ans: (a)

Sol: When density of atmospheric air becomes equal to density of helium inside balloon, then balloon starts floating in air.

70. Ans: (c)

71. Ans: (d)

Sol:



For unsteady state

$$\frac{T - T_\infty}{T_i - T_\infty} = e^{-\left(\frac{hA}{\rho V C_p}\times\tau\right)}$$

$$\theta_1 > \theta_2$$

$$\left(\frac{dT}{d\tau}\right)_1 > \left(\frac{dT}{d\tau}\right)_2$$

$$\left(\frac{65-60}{5}\right) > \left(\frac{60-55}{d\tau}\right)$$

$$\frac{1}{5} > \frac{1}{d\tau}$$

$$d\tau > 5 \text{ min}$$

It will take more than 5 minutes for cooling the same temperature difference.

72. Ans: (b)

73. Ans: (c)

Sol: All reversible processes are quasi static, but all quasi static processes are not reversible.

74. Ans: (d)

75. Ans: (c)

Sol:

- Temperature profile with heat generation for different geometries.

  For slab, $T = -\frac{\dot{q}}{k}\frac{x^2}{2} + c_1 x + c_2$

  For cylinder, $T = -\frac{\dot{q}}{k}\frac{r^2}{4} + c_2$

  For sphere, $T = -\frac{\dot{q}}{k}\frac{r^2}{6} + c_2$

- For parabolic temperature profile, thermal conductivity of material should be constant.