

CLASS TEST

S.No. : 07 GH1_ME_220619

Thermodynamics



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CLASS TEST 2019-2020

MECHANICAL ENGINEERING

Date of Test : 22/06/2019

ANSWER KEY > Thermodynamics

1. (d)	7. (a)	13. (c)	19. (c)	25. (d)
2. (c)	8. (d)	14. (d)	20. (b)	26. (d)
3. (c)	9. (b)	15. (d)	21. (d)	27. (b)
4. (a)	10. (c)	16. (d)	22. (d)	28. (b)
5. (d)	11. (b)	17. (d)	23. (b)	29. (a)
6. (a)	12. (b)	18. (a)	24. (a)	30. (c)

Detailed Explanations

1. (d)

$$P_0 A + W = P A$$

$$\Rightarrow P = P_0 + \frac{W}{A}$$

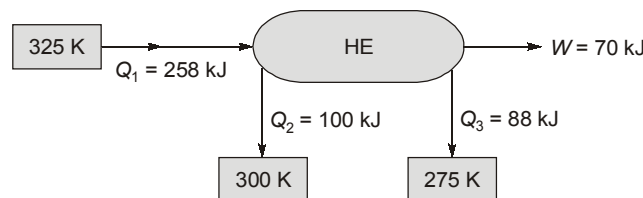
$$P_2 = 100 + \frac{50 \times 9.81 \times 4}{\pi \times 0.1^2 \times 10^3}$$

$$P_2 = 162.45 \text{ kPa}$$

$$\bullet \quad \frac{T_2}{162.45} = \frac{300 + 273}{250} \quad \left(\because \frac{T_2}{T_1} = \frac{P_2}{P_1} \right)$$

$$\Rightarrow T_2 = 372.33 \text{ K or } t_2 = 99.33^\circ\text{C}$$

2. (c)



The first law of thermodynamics

$$\oint dQ = \oint dW = 258 - 100 - 88 = 70 \text{ kJ}$$

Net-work delivered by the engine is 70 kJ. Hence the first law of thermodynamics is satisfied.

2nd law of thermodynamics (in the form of claussius inequality) gives

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

$$\Rightarrow \oint \frac{dQ}{T} = \frac{258}{325} + \frac{-100}{300} + \frac{-88}{275} = 0.14 > 0$$

We find that the claussius inequality is not satisfied.

Hence, the 2nd law of thermodynamics is violated.

3. (c)

$$V_1 = \frac{3}{0.5} = 6 \text{ m}^3$$

$$V_2 = \frac{3}{10} = 0.3 \text{ m}^3$$

From the given relation, the pressure P can be expressed as

$$P = \frac{3.0}{V} \text{ bar} = \frac{300}{V} \text{ kPa}$$

The work done by the system,

$$\begin{aligned}
 W &= \int_6^{0.3} P dV = \int_6^{0.3} \left(\frac{300}{V} \right) dV \\
 &= 300 \int_6^{0.3} \frac{dV}{V} = 300 [\ln V] \\
 &= 300 \ln \left(\frac{0.3}{6} \right) = -898.7 \text{ kJ}
 \end{aligned}$$

4. (a)

1st law of thermodynamics for steady flow through an adiabatic nozzle is given by

$$\left(h_e + \frac{V_e^2}{2} \right) - \left(h_i + \frac{V_i^2}{2} \right) = 0$$

$$\Rightarrow \frac{V_e^2 - V_i^2}{2} = h_i - h_e = c_p (T_i - T_e)$$

$$\Rightarrow \frac{V_e^2 - 10^2}{2} = 1.005 \times 10^3 (200 - 150)$$

$$\Rightarrow V_e = 317.18 \text{ m/s}$$

5. (d)

Given that,

$$P \propto D$$

$$\Rightarrow P = KD$$

$$\Rightarrow K = \frac{P_1}{D_1} = \frac{150}{0.25} = 600 \text{ kPa/m}$$

$$V = \frac{4}{3} \pi R^3 = \frac{\pi D^3}{6}$$

$$\Rightarrow dV = \frac{\pi D^2}{2} dD$$

$$\begin{aligned}
 W &= \int_1^2 P dV = \int_1^2 (KD) \cdot \frac{\pi D^2}{2} dD \\
 &= \frac{\pi K}{8} [D_1^4 - D_2^4] = \frac{600\pi}{8} [0.3^4 - 0.25^4] \\
 &= 0.988 \text{ kJ} \approx 1 \text{ kJ}
 \end{aligned}$$

6. (a)

$$(m_2 u_2 - m_1 u_1) = (m_2 - m_1) h_0$$

$$\Rightarrow \left(\frac{P_2 V}{RT_2} \cdot c_v T_2 - \frac{P_1 V}{RT_1} \cdot c_v T_1 \right) = \left(\frac{P_2 V}{RT_2} - \frac{P_1 V}{RT_1} \right) c_p T_0$$

$$\Rightarrow \frac{c_v \cdot V}{R} [P_2 - P_1] = \frac{c_p \cdot T_0 V}{R} \left[\frac{P_2}{T_2} - \frac{P_1}{T_1} \right]$$

$$\Rightarrow (P_2 - P_1) = \gamma T_0 \left(\frac{P_2}{T_2} - \frac{P_1}{T_1} \right)$$

$$\Rightarrow (1.013 - 0.5) \times 10^5 = 1.4 \times 298 \left(\frac{1.013}{T_2} - \frac{0.5}{298} \right) \times 10^5$$

$$\Rightarrow T_2 = 348.4 \text{ K}$$

$$\Rightarrow t_2 = 75.4^\circ\text{C}$$

7. (a)

Using the Clausius-Claperyon's equation:

$$\left(\frac{dP}{dT}\right) = \frac{h_{fg}}{T_s(v_g - v_f)}$$

$$\Rightarrow 31 = \frac{h_{fg}}{(200 + 273)(0.1275 - 0.001157)}$$

$$\Rightarrow h_{fg} = 1851.1 \text{ kJ/kg}$$

8. (d)

Given:

$$m = 50 \text{ kg}$$

$$T_1 = 227 + 273 = 500 \text{ K}$$

$$T_0 = 300 \text{ K}$$

$$c = 0.5 \text{ kJ/kgK}$$

$$W_{\max} = mc \left[(T_1 - T_0) - T_0 \ln \frac{T_1}{T_0} \right]$$

$$= 50 \times 0.5 \left[(500 - 300) - 300 \ln \frac{500}{300} \right]$$

$$= 1168.8 \text{ kJ}$$

9. (b)

10. (c)

Total heat removed from water = (42 - 4.2) MJ/h

$$= \frac{37.8 \times 1000}{3600} = 10.5 \text{ kJ/s}$$

- This heat removed will decrease the temperature of water

$$10.5 \times t = mc \cdot \Delta t$$

$$= 1500 \times 4.2 \times 30$$

$$\Rightarrow t = 18000 \text{ s}$$

$$= 5 \text{ hrs}$$

11. (b)

Given:

$$V = 0.1 \text{ m}^3$$

$$P = 3.5 \times 10^5 \text{ Pa}$$

$$\text{Output} = 10 \text{ Watt}$$

$$P_{\text{amb}} = 1 \times 10^5 \text{ Pa}$$

$$\eta_T = 0.6$$

$$t = ?$$

- Energy available in the compressed air bottle
 $= 3.5 \times 10^5 \times 0.1 = 35000 \text{ J}$
- Energy at dead state = $1 \times 10^5 \times 0.1 = 10000 \text{ J}$
- Net available energy = $35000 - 10000 = 25000 \text{ J}$
- Energy used/ sec by turbogenerator

$$= \frac{10}{0.6} = \frac{100}{6} = \frac{50}{3} \text{ J}$$

- Time for which the turbogenerator can be operated with 10W output

$$= \frac{25000}{50/3} = 1500 \text{ sec}$$

$$= 25 \text{ min}$$

12. (b)

Using the principal of conservation of energy

$$m c_p (T_1 - T_f) = m c_p (T_f - T_2)$$

$$\Rightarrow T_f = \frac{T_1 + T_2}{2} = \frac{1200 + 600}{2} = 900 \text{ K}$$

Loss of available energy = increase in U.A.E. = $T_0 \cdot \Delta S_{\text{uni}}$.

$$= T_0 (\Delta S_1 + \Delta S_2)$$

$$= T_0 \left[m c_p \ln \frac{T_f}{T_1} + m c_p \ln \frac{T_f}{T_2} \right]$$

$$= T_0 \cdot m c_p \ln \frac{T_f^2}{T_1 \cdot T_2}$$

$$= 300 \times 200 \times 0.3831 \times \ln \frac{900 \times 900}{1200 \times 600}$$

$$= 2707.36 \text{ kJ}$$

13. (c)

Given:

$$Q = 0$$

$$h_1 = 4142 \text{ kJ/kg}$$

$$h_2 = 2500 \text{ kJ/kg}$$

$$\phi_1 = 1700 \text{ kJ/kg}$$

$$\phi_2 = 140 \text{ kJ/kg}$$

$$T_0 = 300 \text{ K}$$

$$\Delta KE = 0$$

$$\Delta PE = 0$$

- Actual work/ kg of steam,

$$Q - W = m (\Delta h + \Delta PE + \Delta KE)$$

$$W_{\text{act}} = -\Delta h = -(h_2 - h_1) = (h_1 - h_2)$$

$$= 4142 - 2500 = 1642 \text{ kJ/kg}$$

- Maximum possible work/kg of steam

$$W_{\text{rev}} = (\phi_1 - \phi_2)$$

$$= 1850 - 140 = 1710 \text{ kJ}$$

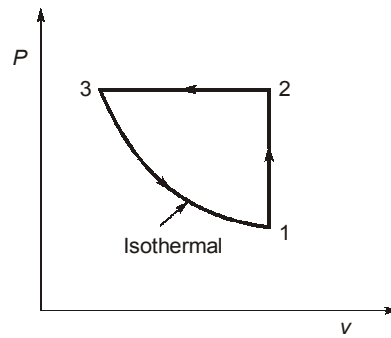
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$$T_0 s_{\text{gen}} = W_{\text{rev}} - W_{\text{act}}$$

$$\Rightarrow s_{\text{gen}} = \frac{W_{\text{rev}} - W_{\text{act}}}{T_0} = \frac{1710 - 1642}{300} = 0.2267 \text{ kJ/kg K}$$

14. (d)

The cycle followed by the ideal gas as shown in figure.



Given that,

$$\begin{aligned}
 T_2 &= 2T_1 \\
 T_3 &= T_1 \\
 (W_{1-2})_{\text{isometric}} &= 0 \\
 (W_{2-3})_{\text{isobaric}} &= P_2 (v_3 - v_2) \quad (P_2 = P_3) \\
 &= R(T_3 - T_2) = R(T_1 - 2T_1) = -RT_1 \\
 (W_{3-1})_{\text{isothermal}} &= \int_3^1 P dv = \int_3^1 RT_3 \frac{dv}{v} \\
 &= RT_3 \ln \frac{v_1}{v_3} = RT_3 \ln \frac{v_2}{v_3} \\
 &= RT_3 \ln \frac{T_2}{T_3} = RT_1 \ln \frac{2T_1}{T_1} = RT_1 \ln 2 \\
 W_{\text{net}} &= W_{1-2} + W_{2-3} + W_{3-1} \\
 &= 0 - RT_1 + RT_1 \ln 2 \\
 &= -0.3069 RT_1
 \end{aligned}$$

15. (d)

$$\begin{aligned}
 Q - W &= \frac{dE}{dt} = \frac{dU}{dt} = \frac{d}{dt}(mu) \\
 &= \frac{d}{dt}(mc_v T) \\
 &= mc_v \cdot \frac{dT}{dt}
 \end{aligned}$$

$$\Rightarrow -1 + 8.165 = 0.5 \times 0.718 \times \frac{dT}{dt}$$

$$\Rightarrow \frac{dT}{dt} = 19.95 \text{ k/s} \approx 20 \text{ k/s}$$

16. (d)

In the absence of any other information regarding V_g and V_f , the Clausius Clapeyron equation may be used to determine the saturation temperature corresponding to the given pressure.

$$\left(\frac{\partial P}{\partial T} \right)_{\text{sat}} = \frac{h_{fg} \cdot P}{RT^2}$$

$$\Rightarrow [\ln P]_{P_1}^{P_2} = \frac{h_{fg}}{R} \left[-\frac{1}{T} \right]_{T_1}^{T_2}$$

$$\Rightarrow \ln\left(\frac{P_2}{P_1}\right) = \frac{h_{fg}}{R} \left[\frac{1}{T_1} - \frac{1}{T_2} \right]$$

$$\Rightarrow \ln \frac{250}{101.325} = \frac{2257}{8.314} \left[\frac{1}{373} - \frac{1}{T_2} \right]$$

$$\Rightarrow 0.903 = 4886.45 \left[\frac{1}{373} - \frac{1}{T_2} \right]$$

$$T_2 = 400.6 \text{ K}$$

$$t_2 = 127.6^\circ\text{C}$$

17. (d)

$$\text{Velocity of air at entry} = \frac{36 \times 1000}{3600}$$

$$= 10 \text{ m/s}$$

Steady flow energy equation (S.F.E.E.):

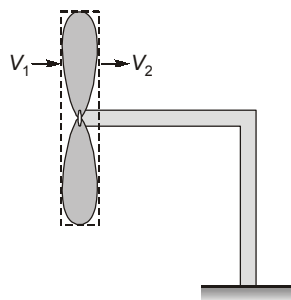
$$\left(h_1 + \frac{V_1^2}{2} + gz_1 \right) m + Q_{cv} = \left(h_2 + \frac{V_2^2}{2} + gz_2 \right) m + W_{cv}$$

$$\text{Per unit mass} \rightarrow W_{cv} = (h_1 - h_2) + \frac{V_1^2 - V_2^2}{2} + g(z_1 - z_2) + Q_{cv}$$

$$\Rightarrow W_{\text{Rev}} = \frac{V_1^2}{2} \quad [\text{For maximum power output } V_2 \approx 0]$$

$$= \frac{1}{2} \times 10^2 = 50 \text{ J/kg}$$

(The maximum possible power output would correspond to a reversible flow process (from IIInd low), through the control volume enclosing the wind blades as shown in figure)



Mass flow rate of air through the control volume,

$$m = \text{Density} \times \text{Area} \times \text{Velocity}$$

$$= \rho AV$$

$$= \frac{P}{RT} \times \frac{\pi}{4} d^2 \times 10$$

$$= \frac{101 \times 10^3}{287 \times 300} \times \frac{\pi}{4} \times 10^2 \times 10$$

$$= 921.3 \text{ kg/s}$$

- Maximum possible power output,

$$W_{\max} = 50 \times 921.3$$

$$= 46065 \text{ Watt} = 46.065 \text{ kW}$$

Comment: Actual power will be lesser than W_{\max} , on two accounts →

- $V_2 > 0$ i.e. exit velocity of air is always > 0 .
- Irreversibilities in the process will also preclude complete conversion of change in K.E. into work.

18. (a)

It is the case of work potential of a fixed mass which is non-flow energy by definition.

Given:

$$T_1 = 300 \text{ K}$$

$$P_1 = 1000 \text{ kPa}$$

$$T_0 = 300 \text{ K}$$

$$P_2 = 100 \text{ kPa}$$

$$\text{Mass of air in the tank, } m_1 = \frac{P_1 V_1}{RT_1} = \frac{1000 \times 250}{0.287 \times 300} = 2903.6 \text{ kg}$$

Exergy content of compressed air per kg = $\phi_1 - \phi_2$

$$\begin{aligned} \phi_1 - \phi_2 &= (u_1 - u_2) + P_0(v_1 - v_2) - T_0(s_1 - s_2) \\ &= P_0(v_1 - v_2) - T_0(s_1 - s_2) \quad [\because (u_1 - u_2) = 0, (s_2 = s_0), (v_2 = v_0)] \\ &= P_0 \left[\frac{RT_1}{P_1} - \frac{RT_0}{P_0} \right] - T_0 \left[c_p \ln \frac{T_1}{T_0} - R \ln \frac{P_1}{P_0} \right] \\ &= RT_0 \left[\frac{P_0}{P_1} - 1 \right] + RT_0 \ln \frac{P_1}{P_0} \quad [\because T_1 = T_0] \\ &= RT_0 \left[\frac{P_0}{P_1} - 1 + \ln \frac{P_1}{P_0} \right] \\ &= 0.287 \times 300 \left[\frac{100}{1000} - 1 + \ln \frac{1000}{100} \right] \\ &= 120.76 \text{ kJ/kg} \end{aligned}$$

Total exergy content of air, $X = m\phi$

$$\begin{aligned} &= 2903.6 \times 120.76 \\ &= 350646.22 \text{ kJ} \\ &= 350.6 \text{ MJ} \end{aligned}$$

19. (c)

Maximum Work,

$$\begin{aligned} W_{\max} &= (u_1 - u_2) - T_0(s_1 - s_2) \\ &= m c_v(T_1 - T_2) + m T_0 \left(c_v \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1} \right) \end{aligned}$$

As we know for adiabatic process,

$$\begin{aligned} (\Delta S)_{\text{surrounding}} &= 0 \\ (\Delta S)_{\text{universe}} &= (\Delta S)_{\text{system}} \end{aligned}$$

Irreversibility, $I = T_0 (\Delta S)_{\text{universe}} = (\Delta S)_{\text{system}}$

$$15 = T_0 m \left(c_v \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1} \right) \quad \dots(ii)$$

Put value from equation (ii) in equation (i),

$$W_{\max} = 2 \times 0.7 (127 - 27) + 15 = 140 + 15 = 155 \text{ kJ}$$

20. (b)

Here 10 m long section of cold rods enters and 10 m long section of hot rods leaves the oven every minute. So we consider 10 m long section of rod as the system.

$$\begin{aligned} \text{Mass of 10 m long rod, } m &= \rho V = \rho \times \frac{\pi}{4} D^2 \times L \\ &= 2700 \times \frac{\pi}{4} \times (0.05)^2 \times 10 = 53 \text{ kg/min} \end{aligned}$$

$$\begin{aligned} Q_{\text{in}} &= mc(T_2 - T_1) \\ &= 53 \times 0.973 (400 - 20) \\ &= 19596.22 \text{ kJ/min} \end{aligned}$$

Now, considering that 10 m long section of rods is heated every minute, the rate of the heat transfer to the rods in the oven becomes →

$$\begin{aligned} q_{\text{in}} &= \frac{Q_{\text{in}}}{\Delta t} = 19596.22 \text{ kJ/min} \\ &= 326.6 \text{ kJ/sec} \end{aligned}$$

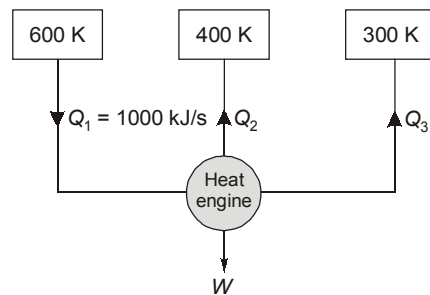
Alternate:

$$\begin{aligned} \dot{m} &= \rho AV \\ &= 2700 \times \frac{\pi}{4} \times (0.05)^2 \times 10 \\ &= 53 \text{ kg/min} \end{aligned}$$

$$\begin{aligned} Q &= \dot{m}c(T_2 - T_1) \\ &= 19601 \text{ kJ/min} \\ &= 326.7 \text{ kJ/sec} \end{aligned}$$

21. (d)

A schematic diagram of a reversible heat engine operating with three thermal reservoir is shown in figure.



$$\begin{aligned} Q_1 &= Q_2 + Q_3 + W && \text{(As per 1st law of thermodynamics)} \\ 1000 &= Q_2 + Q_3 + 50 \\ \Rightarrow Q_2 + Q_3 &= 950 \text{ kJ/s} && \dots(i) \end{aligned}$$

$$\sum \frac{Q}{T} = 0 \quad \text{[Clausius inequality] [for reversible process]}$$

$$\Rightarrow \frac{1000}{600} - \frac{Q_2}{400} - \frac{Q_3}{300} = 0$$

$$\Rightarrow 3Q_2 + 4Q_3 = 2000 \quad \dots(ii)$$

Solving equation (i) and (ii) we get

$$Q_2 = 1800$$

$$Q_3 = -850$$

\Rightarrow Engine rejects 1800 kJ/s to the reservoir at 400 K and absorbs 850 kJ/s from the reservoir at 300 K.

$$\begin{aligned} \text{So, net energy absorbed} &= 1000 + 850 \\ &= 1850 \text{ kJ/s} \end{aligned}$$

Thermal efficiency of the engine

$$\begin{aligned} \eta &= \frac{\text{Net work done}}{\text{Heat absorbed}} \\ &= \frac{50}{1850} = 2.7\% \end{aligned}$$

22. (d)

For isentropic compression of saturated steam,

$$\begin{aligned} W_{cv} &= \int_1^2 -v dp \\ &= \int_1^2 dh \\ &= (h_2 - h_1) \quad [Tds = dh - vdp, \\ &= 3009.2 - 2675.5 \quad \text{for isentropic compression } (Tds = 0) \\ &= 333.7 \text{ kJ/kg} \quad \therefore dh = vdp] \end{aligned}$$

In case of compression of water, the specific volume can be taken as constant.

$$\begin{aligned} W_{cw} &= \int_1^2 -v dp \approx v \cdot (p_2 - p_1) \\ &= 0.001043 \times (5 - 1) \times 10^5 \\ &= 417.2 \text{ J/kg} \end{aligned}$$

$$\text{Ratio of workdone} = \frac{W_{cv}}{W_{cw}} = \frac{333.7 \times 10^3}{417.2} = 799.85 \approx 800$$

23. (b)

Maximum efficiency for heat engine,

$$\eta_{\max} = 1 - \frac{T_2}{T_1} = 1 - \frac{300}{400} = \frac{1}{4}$$

Now,
$$\eta_{\max} = \frac{W}{Q_{\min}}$$

$$Q_{\min} = \frac{1}{(1/4)}$$

$$Q_{\min} = 4 \text{ kJ/s}$$

Now minimum area required for the collector plate,

$$A_{\min} = \frac{\text{Net heat absorbing rate}}{\text{heat absorbing rate per unit area}}$$

$$= \frac{4}{2} = 2 \text{ m}^2$$

24. (a)

Given:

$$T_1 = 900 \text{ K}$$

$$T_2 = 300 \text{ K}$$

$$m = 50 \text{ kg}$$

Final temperature of tank for maximum power production,

$$T_f = \sqrt{T_1 T_2} = \sqrt{900 \times 300} = 519.6 \text{ K}$$

$$W_{\max} = Q_{\text{source}} - Q_{\text{sink}}$$

$$= mc_v(T_1 - T_f) - mc_v(T_f - T_2)$$

$$= mc_v [T_1 + T_2 - 2T_f]$$

$$= 50 \times 0.718 [900 + 300 - 2 \times 519.6]$$

$$= 5772.72 \text{ kJ}$$

25. (d)

The iron block will cool to 285 K from 500 K while the lake temperature remains constant at 285 K.

The entropy change of iron block

$$(\Delta s)_{\text{iron}} = m(s_2 - s_1)$$

$$= mc_v \ln \frac{T_2}{T_1} = 100 \times 0.45 \times \ln \frac{285}{500}$$

$$= -25.29 \text{ kJ/K}$$

The temperature of the lake water remains constant during this process at 285 K and heat is transferred from iron block to lake water. So entropy change of lake

$$(\Delta s)_{\text{lake}} = \frac{Q}{T} = \frac{mc_v(T_2 - T_1)}{T_{\text{lake}}}$$

$$= \frac{100 \times 0.45 \times (500 - 285)}{285} = 33.95 \text{ kJ/K}$$

$$\text{Entropy generated, } (\Delta s)_{\text{gen}} = (\Delta s)_{\text{iron}} + (\Delta s)_{\text{lake}}$$

$$= -25.29 + 33.95 = 8.65 \text{ kJ/K}$$

26. (d)We know efficiency of Carnot engine operating between temperature limits T_H and T_L is

$$\eta = 1 - \frac{T_L}{T_H}$$

$$\therefore 2 \left(1 - \frac{T_L}{T_H} \right) = 1 - \frac{T_L}{T_H'}$$

$$\Rightarrow 2 - \frac{2T_L}{T_H} = 1 - \frac{T_L}{T_H'}$$

$$\Rightarrow 1 = T_L \left(\frac{2}{T_H} - \frac{1}{T_H'} \right)$$

$$\Rightarrow \frac{1}{T_H'} = \frac{2}{T_H} - \frac{1}{T_H'}$$

$$\therefore \text{On solving, } T_H' = \frac{T_L T_H}{2T_L - T_H}$$

27. (b)

$$m = 500 \text{ kg}$$

$$\text{Initial temperature} = T_1 = 10^\circ\text{C}$$

$$\text{Freezing point} = T_f = -5^\circ\text{C}$$

$$\text{Final temperature} = T_2 = -10^\circ\text{C}$$

$$\text{Specific heat above freezing point} = c_{p1} = 3.2 \text{ kJ/kgK}$$

$$\text{Specific heat below freezing point} = c_{p2}$$

$$\text{Latent heat} = L = 250 \text{ kJ/kg}$$

$$\text{Heat removed as latent heat} = mL = 1,25,000 \text{ kJ} = 125 \text{ MJ}$$

$$\Rightarrow \text{Total heat removed} = \frac{mL}{0.8} = \frac{125}{0.8} \text{ MJ} = 156.25 \text{ MJ}$$

$$\begin{aligned} \text{Heat removed above freezing point} &= mc_{p1}(T_1 - T_f) \\ &= 500 \times 3.2 \times (10 - (-5)) = 24000 \text{ kJ} = 24 \text{ MJ} \end{aligned}$$

$$\text{Heat removed below freezing point} = 156.25 - 24 - 125 = 7.25 \text{ MJ}$$

$$\Rightarrow mc_{p2}(T_f - T_2) = 7.25 \times 1000$$

$$\Rightarrow 500 \times c_{p2} \times (-5 - (-10)) = 7.25 \times 1000$$

$$\Rightarrow c_{p2} = 2.9 \text{ kJ/kgK}$$

28. (b)

$$\begin{aligned} W_{max} &= (u_1 - u_2) - T_0(s_1 - s_2) \\ &= c_v(T_1 - T_2) - T_0 \left(c_p \ln \frac{T_1}{T_2} - R \ln \frac{P_1}{P_2} \right) \\ &= 0.716(300 - 600) - 300 \left[1.004 \ln \frac{300}{600} - 0.288 \ln \frac{1}{8} \right] \\ &= -185.687 \text{ kJ/kg} \end{aligned}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}}$$

$$\Rightarrow \frac{n-1}{n} = \frac{\ln \left(\frac{T_2}{T_1} \right)}{\ln \left(\frac{P_2}{P_1} \right)} = \frac{\ln 2}{\ln 8} = 0.333$$

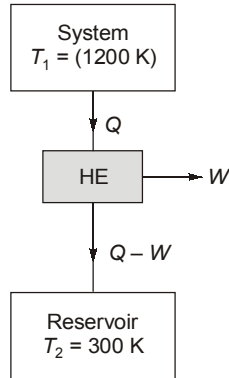
$$\Rightarrow n = 1.5$$

$$W_{actual} = \frac{mR(T_1 - T_2)}{n-1} = \frac{1 \times 0.288(300 - 600)}{1.5 - 1} = -172.8 \text{ kJ/kg}$$

$$\text{Irreversibility, } I = W_{max} - W_{actual}$$

$$= 185.687 - 172.8 = 12.88 \text{ kJ/kg}$$

29. (a)



$$\text{Heat removed from the system, } Q_1 = \int_{T_1}^{T_2} C_v dT = \int_{1200}^{300} (0.05T^2) dT$$

$$= 0.05 \left[\frac{T^3}{3} \right]_{1200}^{300} = -28.35 \times 10^6 \text{ J}$$

$$(\Delta s)_{\text{system}} = \int_{1200}^{300} \frac{C_v \cdot dT}{T} = \int_{1200}^{300} (0.05 \times T^2) \frac{dT}{T}$$

$$= 0.05 \int_{1200}^{300} T dT = 0.05 \left[\frac{T^2}{2} \right]_{1200}^{300} = -33750 \text{ J/K}$$

$$(\Delta s)_{\text{reservoir}} = \frac{Q_1 - W}{T_{\text{Reservoir}}} = \frac{28.35 \times 10^6 - W}{300} \text{ J/K}$$

$$(\Delta s)_{\text{working fluid in HE}} = 0$$

$$(\Delta s)_{\text{universe}} = (\Delta s)_{\text{system}} + (\Delta s)_{\text{reservoir}}$$

$$\text{For maximum work, } (\Delta s)_{\text{universe}} = 0$$

$$\Rightarrow 0 = -33750 + \frac{28.35 \times 10^6 - W}{300}$$

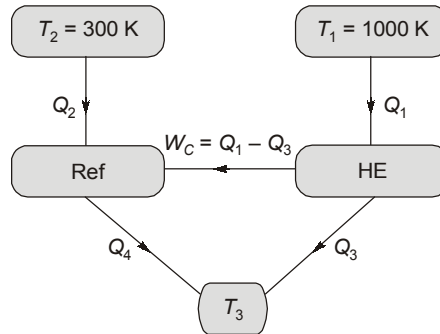
$$\Rightarrow W = 18.225 \times 10^6 \text{ J} = 18.23 \text{ MJ}$$

30. (c)

$$\eta_{\text{Carnot engine}} = \frac{Q_1 - Q_3}{Q_1} = \frac{T_1 - T_3}{T_1} = \frac{W_c}{Q_1}$$

$$\Rightarrow W_c = Q_1 \left(\frac{T_1 - T_3}{T_1} \right) \quad \dots(i)$$

$$(\text{COP})_{\text{Carnot Ref.}} = \frac{Q_2}{Q_4 - Q_2} = \frac{T_2}{T_3 - T_2} = \frac{Q_2}{W_c}$$



$$\Rightarrow W_c = Q_2 \left(\frac{T_3 - T_2}{T_2} \right) \quad \dots(ii)$$

From Equation (i) and (ii)

$$Q_1 \left(\frac{T_1 - T_3}{T_1} \right) = Q_2 \left(\frac{T_3 - T_2}{T_2} \right)$$

$$\Rightarrow \frac{T_1 - T_3}{T_1} = \frac{T_3 - T_2}{T_2} \quad (\because Q_1 = Q_2)$$

$$\Rightarrow \frac{T_1}{T_2} = \frac{T_1 - T_3}{T_3 - T_2}$$

$$\Rightarrow \frac{1000}{300} = \frac{1000 - T_3}{T_3 - 300}$$

$$\Rightarrow (T_3 - 300)10 = (1000 - T_3)3$$

$$\Rightarrow 10T_3 - 3000 = 3000 - 3T_3$$

$$\Rightarrow 13T_3 = 6000$$

$$\Rightarrow T_3 = \frac{6000}{13} = 461.5 \text{ K}$$

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