

# CLASS TEST

S.No. : 10 GH1\_ME\_EGH\_010719

Thermodynamics



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# CLASS TEST 2019-2020

## MECHANICAL ENGINEERING

Date of Test : 01/07/2019

### ANSWER KEY > Thermodynamics

- |        |         |         |         |         |
|--------|---------|---------|---------|---------|
| 1. (d) | 7. (a)  | 13. (c) | 19. (c) | 25. (d) |
| 2. (c) | 8. (d)  | 14. (d) | 20. (b) | 26. (d) |
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| 4. (a) | 10. (c) | 16. (d) | 22. (d) | 28. (b) |
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| 6. (a) | 12. (b) | 18. (a) | 24. (a) | 30. (c) |

### Detailed Explanations

1. (d)

$$P_0 A + W = P A$$

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

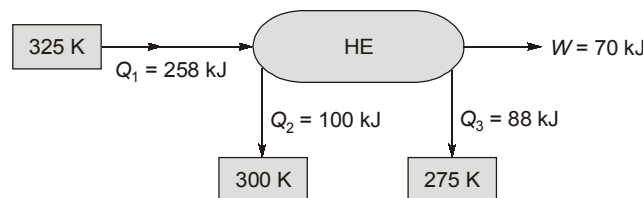
$$P_2 = 100 + \frac{50 \times 9.81 \times 4}{\pi \times 0.1^2 \times 10^3}$$

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

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

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

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.

2<sup>nd</sup> 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 2<sup>nd</sup> 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)

1<sup>st</sup> 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

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

$$= 1750 - 140 = 1710 \text{ kJ}$$

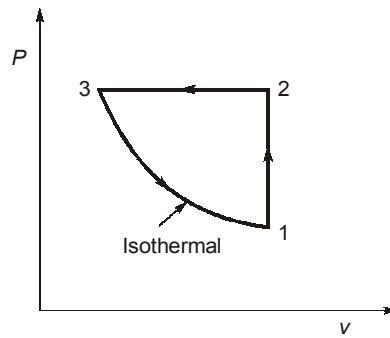
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$$T_0 s_{\text{gen}} = W_{\text{rev}} - W_{\text{act}}$$

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

## 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.):

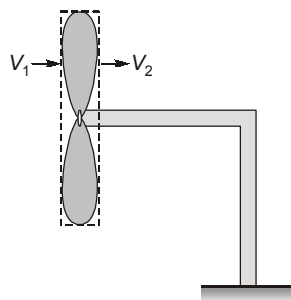
$$\left( h_1 + \frac{V_1^2}{2} + gz_1 \right) m + Q_{cv} = \left( h_2 + \frac{V_2^2}{2} + gz_2 \right) m + W_{cv}$$

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

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

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

(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,

$$\begin{aligned} W_{\max} &= 50 \times 921.3 \\ &= 46065 \text{ Watt} = 46.065 \text{ kW} \end{aligned}$$

**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:

$$\begin{aligned} T_1 &= 300 \text{ K} \\ P_1 &= 1000 \text{ kPa} \\ T_0 &= 300 \text{ K} \\ P_2 &= 100 \text{ kPa} \end{aligned}$$

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

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 →

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

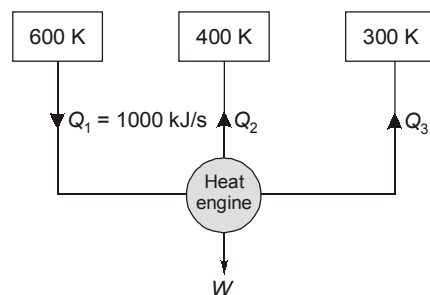
Alternate:

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

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

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,

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

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)

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

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

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

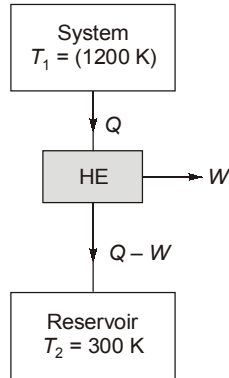
$$\Rightarrow n = 1.5$$

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

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

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

29. (a)



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

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

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

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

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

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

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

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

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

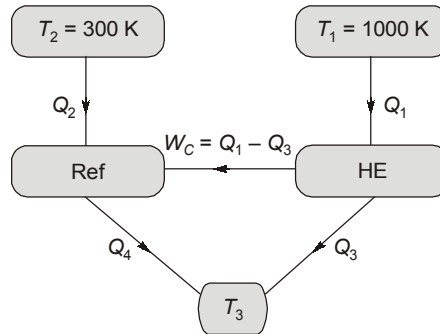
$$\Rightarrow W = 18.225 \times 10^6 \text{ J} = 18.23 \text{ MJ}$$

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)

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

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

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

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

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

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

$$\Rightarrow 13T_3 = 6000$$

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

