S.No. : 05 GH1_ME_D_230519
Thermodynamics

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CLASS TEST 2019-2020

MECHANICAL ENGINEERING

Thermodynamics

Date of Test : 23/05/2019

Answer Key

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)

$$P_0A + W = PA$$

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

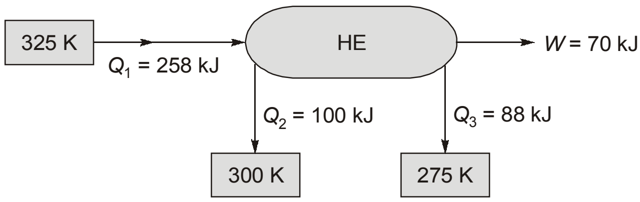
$$P_2 = 100 + \frac{50 \times 9.81 \times 4}{\pi \times 0.1^2 \times 10^3}$$

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

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

$$\Rightarrow \quad T_2 = 372.33 \text{ K or } t_2 = 99.33°\text{C}$$

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

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

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

$$= 0.14 > 0$$

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,

$$W = \int_6^{0.3} P\,dV = \int_6^{0.3} \left(\frac{300}{V}\right) dV$$

$$= 300 \int_6^{0.3} \frac{dV}{V} = 300\,[l\text{n}\,V]$$

$$= 300\, l\text{n}\left(\frac{0.3}{6}\right) = -898.7\text{ kJ}$$

4. (a)

I[st] law of thermodynamics for steady flow through an adiabatic nozzle is given by

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

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

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

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

5. (d)

Given that, $P \,\alpha\, D$

$$\Rightarrow \quad P = KD$$

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

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

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

$$W = \int_1^2 P\,dV = \int_1^2 (KD)\cdot\frac{\pi D^2}{2}\,dD$$

$$= \frac{\pi K}{8}\left[D_1^4 - D_2^4\right] = \frac{600\pi}{8}\,[0.3^4 - 0.25^4]$$

$$= 0.988\text{ kJ} \approx 1\text{ kJ}$$

6. (a)

$$(m_2u_2 - m_1u_1) = (m_2 - m_1)h_0$$

$$\Rightarrow \quad \left(\frac{P_2V}{RT_2}\cdot c_vT_2 - \frac{P_1V}{RT_1}\cdot c_vT_1\right) = \left(\frac{P_2V}{RT_2} - \frac{P_1V}{RT_1}\right)c_pT_0$$

$$\Rightarrow \quad \frac{c_v.V}{R}[P_2 - P_1] = \frac{c_p.T_0V}{R}\left[\frac{P_2}{T_2} - \frac{P_1}{T_1}\right]$$

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

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

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

$$\Rightarrow \quad t_2 = 75.4°\text{C}$$

7. (a)

Using the Claussius-Claperyon's equation:

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

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

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

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

$$10.5 \times t = mc \cdot \Delta t$$
$$= 1500 \times 4.2 \times 30$$
$$\Rightarrow \quad t = 18000 \text{ s}$$
$$= 5 \text{ hrs}$$

11. (b)

Given:

$$V = 0.1 \text{ m}^3$$
$$P = 3.5 \times 10^5 \text{ Pa}$$
$$\text{Output} = 10 \text{ Watt}$$
$$P_{amb} = 1 \times 10^5 \text{ Pa}$$
$$\eta_T = 0.6$$
$$t = ?$$

- Energy available in the compressed air bottle

$$= 3.5 \times 10^5 \times 0.1 = 35000 \text{ J}$$

- Energy at dead state $= 1 \times 10^5 \times 0.1 = 10000$ J

- Net available energy $= 35000 - 10000 = 25000$ 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 10 W output

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

$$= 25 \text{ min}$$

12. (b)

Using the principal of conservation of energy

$$m\,c_p(T_1 - T_f) = mc_p(T_f - T_2)$$

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

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

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

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

$$= T_0 \cdot mc_p \, ln\frac{T_f^2}{T_1 \cdot T_2}$$

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

$$= 2707.36 \text{ kJ}$$

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,

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

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

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

- Maximum possible work/kg of steam

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

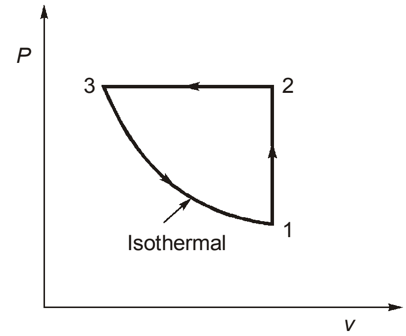
$$= 1850 - 140 = 1710 \text{ kJ}$$

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

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

14. (d)

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



Given that,

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

15. (d)

$$Q - W = \frac{dE}{dt} = \frac{dU}{dt} = \frac{d}{dt}(mu)$$
$$= \frac{d}{dt}(mc_v T)$$
$$= mc_v \cdot \frac{dT}{dt}$$
$$\Rightarrow \quad -1 + 8.165 = 0.5 \times 0.718 \times \frac{dT}{dt}$$
$$\Rightarrow \quad \frac{dT}{dt} = 19.95 \text{ k/s} \approx 20 \text{ k/s}$$

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.

$$\left(\frac{\partial P}{\partial T}\right)_{sat} = \frac{h_{fg} \cdot P}{RT^2}$$
$$\Rightarrow \quad [\ln P]_{P_1}^{P_2} = \frac{h_{fg}}{R}\left[-\frac{1}{T}\right]_{T_1}^{T_2}$$

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

$$\Rightarrow \qquad ln\frac{250}{101.325} = \frac{2257}{\frac{8.314}{18}}\left[\frac{1}{373} - \frac{1}{T_2}\right]$$

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

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

$$t_2 = 127.6°\text{C}$$

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.):

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

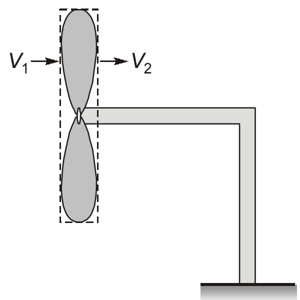
Per unit mass $\rightarrow$

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

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

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

(The maximum possible power output would correspond to a reversible flow process (from IInd 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 →

(i) $V_2 > 0$ i.e. exit velocity of air is always > 0.

(ii) 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:

$$T_1 = 300 \text{ K}$$
$$P_1 = 1000 \text{ kPa}$$
$$T_0 = 300 \text{ K}$$
$$P_2 = 100 \text{ kPa}$$

Mass of air in the tank, $m_1 = \dfrac{P_1V_1}{RT_1} = \dfrac{1000 \times 250}{0.287 \times 300} = 2903.6 \text{kg}$

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

$$\phi_1 - \phi_2 = (u_1 - u_2) + P_0(v_1 - v_2) - T_0(s_1 - s_2)$$

$$= P_0(v_1 - v_0) - T_0(s_1 - s_0) \qquad [\because (u_1 - u_2) = 0,\ (s_2 = s_0), (v_2 = v_0)]$$

$$= P_0\left[\frac{RT_1}{P_1} - \frac{RT_0}{P_0}\right] - T_0\left[c_p l\text{n}\frac{T_1}{T_0} - Rl\text{n}\frac{P_1}{P_0}\right]$$

$$= RT_0\left[\frac{P_0}{P_1} - 1\right] + RT_0 l\text{n}\frac{P_1}{P_0} \qquad [\because\ T_1 = T_0]$$

$$= RT_0\left[\frac{P_0}{P_1} - 1 + l\text{n}\frac{P_1}{P}\right]$$

$$= 0.287 \times 300\left[\frac{100}{1000} - 1 + l\text{n}\frac{1000}{100}\right]$$

$$= 120.76 \text{ kJ/kg}$$

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

$$= 2903.6 \times 120.76$$
$$= 350646.22 \text{ kJ}$$
$$= 350.6 \text{ MJ}$$

19. (c)

Maximum Work,

$$W_{max} = (u_1 - u_2) - T_0(s_1 - s_2)$$

$$= m\, c_v(T_1 - T_2) + mT_0\left(c_v \ln\frac{T_2}{T_1} + R\ln\frac{V_2}{V_1}\right)$$

As we know for adiabatic process,

$$(\Delta S)_{surrouinding} = 0$$
$$(\Delta S)_{universe} = (\Delta S)_{system}$$

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

$$15 = T_0\, m\left(c_v \ln\frac{T_2}{T_1} + R\ln\frac{V_2}{V_1}\right) \qquad \text{....(ii)}$$

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.

$$\text{Mass of 10 m long rod, } m = \rho V = \rho \times \frac{\pi}{4} D^2 \times L$$

$$= 2700 \times \frac{\pi}{4} \times (0.05)^2 \times 10 = 53 \text{ kg/min}$$

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

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 →

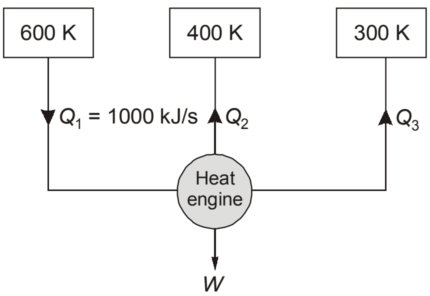
$$q_{in} = \frac{Q_{in}}{\Delta t} = 19596.22 \text{ kJ/min}$$
$$= 326.6 \text{ kJ/sec}$$

Alternate:

$$\dot{m} = \rho A V$$
$$= 2700 \times \frac{\pi}{4} \times (0.05)^2 \times 10$$
$$= 53 \text{ kJ/min}$$
$$Q = \dot{m}c(T_2 - T_1)$$
$$= 19601 \text{ kJ/min}$$
$$= 326.7 \text{ kJ/sec}$$

21. (d)

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



$$Q_1 = Q_2 + Q_3 + W \qquad \text{(As per 1}^{st}\text{ law of thermodynamics)}$$
$$1000 = Q_2 + Q_3 + 50$$
$$\Rightarrow \quad Q_2 + Q_3 = 950 \text{ kJ/s} \qquad ...(i)$$
$$\sum \frac{Q}{T} = 0 \qquad \text{[Claussius inequality] [for reversible process]}$$
$$\Rightarrow \quad \frac{1000}{600} - \frac{Q_2}{400} - \frac{Q_3}{300} = 0$$
$$\Rightarrow \quad 3Q_2 + 4Q_3 = 2000 \qquad ...(ii)$$

Solving equation (*i*) and (*ii*) we get

$$Q_2 = 1800$$
$$Q_3 = -850$$

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

So, net energy absorbed = 1000 + 850

= 1850 kJ/s

Thermal efficiency of the engine

$$\eta = \frac{\text{Net work done}}{\text{Heat absorbed}}$$

$$= \frac{50}{1850} = 2.7\%$$

22. (d)

For isentropic compression of saturated steam,

$$W_{cv} = \int_1^2 -vdp$$

$$= \int_1^2 dh$$

$$= (h_2 - h_1) \qquad [Tds = dh - vdp,$$

$$= 3009.2 - 2675.5 \qquad \text{for isentropic compression } (Tds = 0)$$

$$= 333.7 \text{ kJ/kg} \qquad \therefore\ dh = vdp]$$

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

$$W_{cw} = \int_1^2 -vdp \approx v\cdot(p_2 - p_1)$$

$$= 0.001043 \times (5 - 1) \times 10^5$$

$$= 417.2 \text{ J/kg}$$

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

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: $T_1 = 900$ K

$T_2 = 300$ K

$m = 50$ kg

Final temperature of tank for maximum power production,

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

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

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

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

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

$$= 5772.72 \text{ kJ}$$

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

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

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

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

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

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

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

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

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

26. (d)

We know efficiency of Carnot engine operating between temperature limits T_H and T_L is

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

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

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

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

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

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

27. (b)

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

Initial temperature = $T_1 = 10°C$

Freezing point = $T_f = -5°C$

Final temperature = $T_2 = -10°C$

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

Specific heat below freezing point = c_{p2}

Latent heat = $L = 250$ kJ/kg

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

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

Heat removed above freezing point = $mc_{p1}(T_1 - T_f)$

$$= 500 \times 3.2 \times (10 - (-5)) = 24000 \text{ kJ} = 24 \text{ MJ}$$

Heat removed below freezing point = 156.25 – 24 – 125 = 7.25 MJ

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

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

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

28. (b)

$$W_{max} = (u_1 - u_2) - T_0(s_1 - s_2)$$

$$= c_v(T_1 - T_2) - T_0\left(c_p \ln\frac{T_1}{T_2} - R\ln\frac{P_1}{P_2}\right)$$

$$= 0.716(300 - 600) - 300\left[1.004\ln\frac{300}{600} - 0.288\ln\frac{1}{8}\right]$$

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

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

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

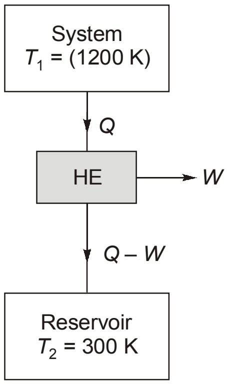
$$\Rightarrow \quad n = 1.5$$

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

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

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

29. (a)



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

$$= 0.05\left[\frac{T^3}{3}\right]_{1200}^{300} = -28.35\times10^6 \text{ J}$$

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

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

$$(\Delta s)_{\text{reservoir}} = \frac{Q_1 - W}{T_{Reservoir}} = \frac{28.35\times10^6 - W}{300} J/k$$

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

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

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

$$\Rightarrow \quad 0 = -33750 + \frac{28.35\times10^6 - W}{300}$$

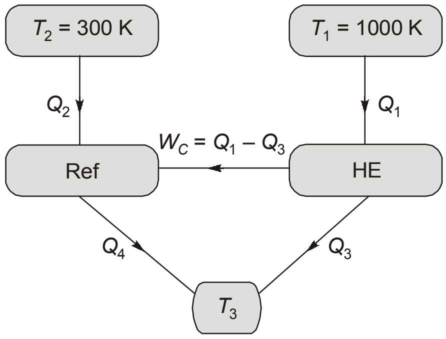
$$\Rightarrow \quad W = 18.225\times10^6 \text{J} = 18.23 \text{ MJ}$$

30. (c)

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

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

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



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

From Equation (i) and (ii)

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

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

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

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

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

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

$$\Rightarrow \quad 13T_3 = 6000$$

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

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