Darbhanga College of Engineering

Department of Mechanical Engineering
Mechanical Engineering

Question Bank

1. In order to achieve Thermodynamic equilibrium what is the condition for temperature and pressure?
   (a) Temp uniform and pressure steady
   (b) Temp. steady and pressure uniform
   (c) Temp. steady and pressure steady
   (d) Temp uniform and pressure uniform

   Ans. (a)
2. For single component three phase system what is the minimum no of properties required to define the state.
   (a) One (b) Two (c) Three (d) None

   Ans. (d)

3. For the expression ∫pdV to represent the work, which of the following conditions should apply?
   (a) The system is closed one and process takes place in a non—flow system
   (b) The process is non- quasi static
   (c) The boundary of the system should not move in order that work may be transferred.
   (d) If the system is open one, it should be non reversible.

   Ans. (a)
4. What do you understand by Thermodynamics System? Explain different types of the systems.
5. What are the intensive and extensive properties? Explain with examples.
6. What do you understand by Macroscopic and Microscopic approach? Explain.
7. State Zeroth Law of the thermodynamics. What is the application of the zeroth law.
8. Explain the Thermodynamics equilibrium.
9. Explain the concept of Continuum.
10. What do you understand by Quasi-static Process? What is the need to define a quasi-static process?
11. Show that for a closed system heat transfer at constant volume is equal to change in internal energy and heat transfer at constant pressure is equal to change in enthalpy.

    Sol.

(i) for constant volume process $\delta W = 0$…………………(i)

From the first law of thermodynamics for the closed system,

$$\delta Q = dE + \delta W$$

if change in K.E & P.E is negligible then $\delta Q = dU + \delta W$……………..(ii)

from the equation (i) & (ii),

$$\delta Q = dU. \text{ Proved}$$

(ii) for constant pressure process, $\delta W = Pdv$

Enthalpy $H=U+PV$, then $dH=dU+PdV+VdP$ and $dP=0$ (P = constant)

So $dH=dU+PdV$ ……………..(i)

From the first law of thermodynamics for the closed system, $\delta Q=dE+\delta W$

if change in K.E & P.E is negligible, $\delta Q=dU+\delta W$

for constant pressure process $\delta W= PdV$, so $\delta Q=dU+PdV$……………..(ii)

from the equation (i) & (ii),

$$\delta Q= dH. \text{ Proved}$$

12. Convert following readings of pressure to kPa absolute, assuming that the barometer reads 760 mmHg:

a) 90 cm Hg gauge

b) 1.2 m H_2O gauge

c) 3.1 bar gauge.

Sol.

Given, Barometer reads 760mm of Hg so

P_{atm}= 760mm of Hg = $\rho_{Hg} \times g \times h$ =13600×9.81×0.760=101.396 kPa

(a) 90 cm Hg gauge

We know $P_{abs}=P_{atm}+P_{gauge}$, so P_{abs}= 760mm of Hg+ 90 cm of Hg = (0.760+0.9) m of Hg

$\mathbf{P_{abs}}$ = 1.66 m of Hg= 13600×9.81×1.66=**221.47 kPa**

(b) 1.2 m H_2O gauge

P_{gauge}= 1.2 m of H_2O= $\rho_{water} \times g \times h$=1000×9.81×1.2= 11.772 kPa

We know $P_{abs}=P_{atm}+P_{gauge}$,so $\mathbf{P_{abs}}$= 101.396+11.772=**113.168 kPa**

(c) 3.1 bar gauge.

P_{gauge}= 3.1 bar= 3.1×10^3 kPa

We know $P_{abs}=P_{atm}+P_{gauge}$, so $\mathbf{P_{abs}}$= 101.396+3100=**3201.396 kPa**

13. During a heating process, the temperature of the system rises by 10^0C. Express this rise in temperature in K, ^{0}F and R.

Sol.

Given $\Delta T^0C = 10^0C$

We know $\frac{T-T_{ice}}{T_{steam}-T_{ice}} = \frac{K-K_{ice}}{K_{steam}-K_{ice}} = \frac{F-F_{ice}}{F_{steam}-F_{ice}} = \frac{R-R_{ice}}{R_{steam}-R_{ice}}$ ………………….. (i)

Table 1

Temp. Scale	Steam Point	Ice Point
Degree Celsius (^{0}C)	100	0
Kelvin (K)	273.15	373.15
Degree Fahrenheit (^{0}F)	32	212
Rankine (R)	491.67	671.67

Putting all the values from table 1 into equation (i)

$$\frac{T-0}{100-0} = \frac{K-273.15}{373.15-273.15} = \frac{F-32}{212-32} = \frac{R-491.67}{671.67-491.67} \quad \text{……………………(ii)}$$

From equation (ii)

K=T-273.15, so Δ**K**=ΔT= **10K**. **ans**

$F = \frac{9}{5} \times T + 32$, so $\mathbf{\Delta F} = \frac{9}{5}\,\Delta T = \frac{9}{5} \times 10 = \mathbf{18^0F.ans}$

$R = \frac{9}{5} \times T + 491.67$, so $\mathbf{\Delta R} = \frac{9}{5} \times \Delta T = \frac{9}{5} \times 10 = \mathbf{18R.ans}$

14. Explain the type of the system for the given:

a) Turbine

b) Piston cylinder without valve

c) Classroom with closed door

d) Piston Cylinder with valve

Ans.

(a) Open system

(b) Closed System

(c) Closed System

(d) Open System

15. The temperature t on the thermometric scale is defined in terms of property K by relation t= a×lnK + b, where a and b are constants. The values of K are found to be 1.83

and 6.78 at ice point and the steam point, the temperatures of which are assigned the numbers 0 and 100 respectively. Determine the temperature corresponding to a reading of K equal to 2.42 on the thermometer.

Sol.

Given. t=a×lnK+b, t_{ice}=0 and t_{steam}=1000

$K_{ice\ point}$=1.83 and $K_{steam\ point}$ = 6.78, where K is a thermodynamic property.

We know that $\frac{t-t_{ice}}{t_{steam}-t_{ice}} = \frac{K-K_{ice\ point}}{K_{steam\ point}-K_{ice\ point}}$ ………………………(i)

We have to determine the temp. reading corresponding to K=2.42

Putting values of all the parameters in equation (i)

$\frac{t-0}{100-0} = \frac{2.42-1.83}{6.78-2.42}$, so **t = 13.53. ans**

16. The resistance of a platinum wire is found to be 11.00 ohms at the ice point, 15.247 ohms at steam point and 28.887 ohms at the sulpher point. Find the constant A and B in the equation. $R=R_0(1+At+Bt^2)$And plot R against t in the range 0 to 660^{0}C.

Sol.

Given. $R_{ice\ point}=R_0=11.00$, $R_{steam\ point}$=15.247 & $R_{sulpher\ Point}$ =28.887

$R=R_0(1+At+Bt^2)$……………….. (i)

We know that $t_{steam\ point}=100^0C$, $t_{sulpher\ point}= 444.6^0C$

Putting all the values in equation (i)

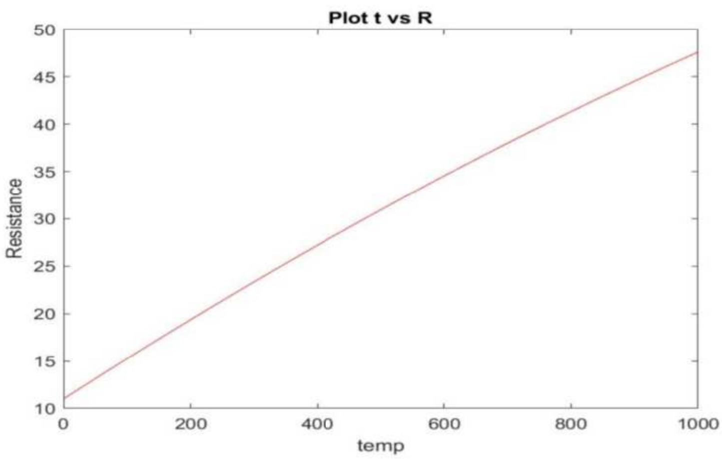
$R_{steam\ point}=R_0(1+At_{steam}+B(t_{steam})^2) \rightarrow 15.247=11.00\times(1+A\times100+B\times100^2)$…………..(ii)

$R_{sulpherpoint}=R_0(1+At_{sulpherpoint}+B(t_{sulpherpoint})^2)$

$\rightarrow$ $28.887=11.00\times(1+A\times444.6+B\times444.6^2)$………………….(iii)

After solving equation (ii) & (iii)

$A= 3.92\times10^{-3}$ /^{0}C & $B= -5.9\times10^{-7}$ /$^0C^2$



17. A new temperature scale in degrees N is to be defined. The boiling and freezing on this scale are 400°N and 100°N respectively. What will be the reading on new scale corresponding to 60°C?

Sol.

Given $N_{B.P.} = 400^0N$ & $N_{F.P.} = 100\ ^0N$

We have to find out reading on new scale corresponding to $T=60^0C$.

We know that $T_{ice/F.P.}=0^0C$ & $T_{steam/B.P.}= 100^0C$ & $\frac{T-T_{ice}}{T_{steam}-T_{ice}} = \frac{N-N_{F.P.}}{N_{B.P.}-N_{F.P.}}$ .... (i)

Putting all values in eq.(i)

$$\frac{60-0}{100-0} = \frac{N-100}{400-100} \quad \text{so} \quad \mathbf{N=280^0N.\ ans}$$

18. A vacuum gauge connected to a chamber reads 40kPa at a location where the atmospheric pressure is 100kPa. Determine the absolute pressure in the chamber.

Sol.

Given. P_{atm}=100 kPa, &

$P_{chamber}$=40 kPa vacuum gauge = -40 kPa (-ve sign because its vacuum pressure)

We know $P_{abs.}=P_{atm}+P_{gauge}$ .... (i)

Putting all values in eq. (i)

$$\mathbf{P_{abs}}=100-40= \mathbf{60\ kPa.\ ans}$$

19. The piston of a vertical piston- cylinder device containing a gas has a mass of 60kg and a cross sectional area of 0.04 m^2. The local atmosphere pressure is 0.97 bar, and gravitational acceleration is 9.81 m/s^2. (a) Determine the pressure inside the cylinder. (b) If some heat is transferred to the gas and its volume is doubled, do you expect the pressure inside the cylinder to change if yes/ no give specific reasons to justify your ans.

Sol.

Given. M_{piston}= 60kg, A_{piston}=0.04 m^2, P_{atm}= 0.97 bar = 0.97×10^5 Pa = 97 kPa & g =9.81 m/s^2.

(a) Fig.2 shows the different forces acting on the Piston.

Applying force balance in vertical direction, $\sum F_y=0$

$P_{atm}\times A_{piston}+W_{piston} - P_{inside}\times A_{piston}=0$

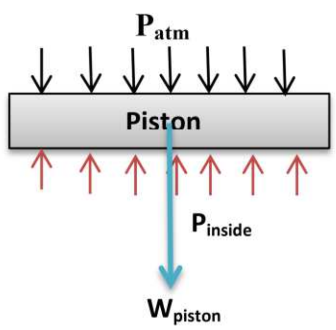


Fig. 2

So $P_{inside} = P_{atm} + \frac{W_{piston}}{A_{piston}}$ ………………………. (i)

Putting all the values in eq.(i)

$P_{inside} = 97 \times 10^3 + \frac{60 \times 9.81}{0.04}$ so **P_{inside} = 111.715 kPa. Ans**

(b) No.

Pressure inside the cylinder will not change because the piston is free to move so if there is even a small increase in P_{inside} due to heat transfer it will lead to movement of piston outwards, so keeping pressure constant.

20. An engine cylinder has a piston of area 0.12 m^2 and contains gas at a pressure of 1.5 MPa. The gas expands according to a process which is represented by a straight line on a pressure- volume diagram. The final pressure is 0.15MPa. Calculate the work done by the gas on the piston if the stroke is 0.3 m.

Sol.

Given A_p=0.12 m^2, P_1=1.5 MPa, P_2 = 0.15 MPa & Stroke Length (L) = 0.3m

Process is represented by a straight line on a pressure- volume diagram so in fig.2 a straight line has been drawn to depict the process from 1-2.

We know work in by a closed System is represented by area under the curve on P-V diag.

W. D. = Area under St. Line 1-2.

= Area of trapezoid $12V_1V_2$.

$W.D. = (\frac{P_1+P_2}{2}) \times (V_2 - V_1)$

$W.D. = (\frac{1.5+0.15}{2}) \times (A_P \times L) \times 10^6$ J

$W.D. = \left(\frac{1.65}{2}\right) \times (0.12 \times 0.3) \times 10^6 J$

$W.D. = 29.7$ kJ. ans

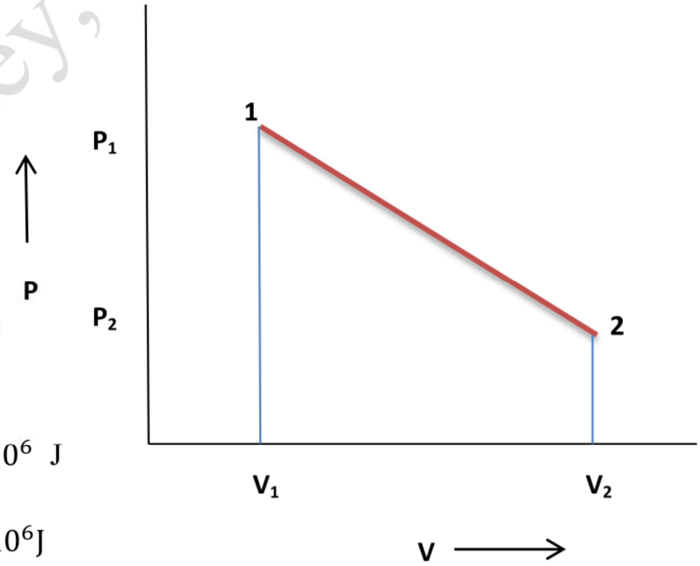


Fig. 3

21. A mass of gas is compressed in a quasi- static process from 80 kPa, 0.1 m^3 to 0.4 MPa, 0.03 m^3. Assuming that the pressure and volume are related by pv^n= constant, find the work done by the gas system.

Sol.

Given P_1=80 kPa, P_2= 0.4 MPa, V_1 = 0.1 m^3 & V_2 = 0.03 m^3

Relation in pressure and volume is PV^n = constant, so $P_1V^n{}_1=P_2V^n{}_2$………… (i)

Putting all the values in eq. (i)

$$80\times 0.1^n = 0.4\times10^3\times0.03^n \text{……………………(ii)}$$

After soling the eq.(ii), we can get n = 1.33

We know that work done by a closed system for the polytropic process is given by

$$\text{W.D.} = \frac{P_1V_1 - P_2V_2}{n-1} \text{…………………………..(iii)}$$

Putting all values of parameters in eq. (iii)

$$\text{W.D.} = \frac{80\times0.1 - 0.4\times10^3\times0.03}{1.33-1}$$

So $$\mathbf{W.D. = -12.12\ kJ.ans}$$

22. Derive the expression for the non- flow work output for the following conditions.
    a) Isothermal process
    b) For a polytropic process (PV^n= constant).
    c) For isochoric process.
23. Proof that for an adiabatic process pv^γ = constant.

Sol.

from first law of thermodynamics for a process when ΔK.E. & ΔP.E. ≈ 0 & W_{other}=0

$$dQ = dU + PdV$$

dQ = 0 Since adiabatic process, so dU + PdV = 0

We know that $dU = mC_vdT$ so, $mC_vdT + PdV = 0$

$$mC_vdT = -PdV \text{ - - - - - - (i)}$$

Enthalpy H = U + PV

Differentiating both side

dH = (dU + PdV) + VdP = 0+VdP

dH = VdP, We know that $dH = mC_pdT$ so $mC_pdT = VdP$ - - - - - - (ii)

dividing eq.(i) by eq.(ii)

$mC_pdT / mC_pdT = -PdV / VdP$

$\gamma = -PdV / VdP$, $\gamma \cdot VdP + VdP = 0$

Integreating both side than we get

$\ln P + \_\ln V^\gamma = C$

$\ln PV^\gamma = C$, **PV^γ = Constant** **Proved.**

24. Derive the steady flow Energy Equation for the open system with the help of suitable diagram.

25. State whether the statement given is true or false.
    a) Internal energy of an ideal gas is a function of temp and pressure.
    b) At very high pressure and low Temperature all gases and vapors approach ideal gas behaviour.
    c) Slop of isothermal curve is greater than adiabatic curve on P-V plot.
    d) Enthalpy is a property and specific enthalpy is an intensive property.

    Sol. (a). False, (b) False, (c) False & (d) True

26. In a cyclic process, heat transfers are +14.7kJ, -25.2 kJ, -3.56 kJ and +31.5 kJ. What is the net work transfer for the cyclic process?

    Sol.

    Given. Q_1=+14.7kJ, Q_2= -25.2 kJ, Q_3=-3.56 kJ & = +31.5 kJ.

    From the first law of Thermodynamics for a cycle, $\sum Q=\sum W$

    So, $14.7 - 25.2 - 3.56 + 31.5 = \sum W$

    Net Work done= 17.44 kJ (by the system). ans

27. The properties of a certain fluid are related as follows: u= 196+0.718t and pv= 0.287(t+273), where u is specific internal energy (kJ/kg), t is in ^{0}C, p is pressure (kN/m^2) and v is specific volume (m^3/kg). For this fluid, find C_v and C_p.

    Sol.

    Given. u = 196 + 0.718t (kJ/kg), pv = 0.287(t + 273)

    We know that, $dU = mC_v dt$ & $du = C_v dT$, so $Cv = du/dt = d/dt(196 + 0.718t)$

    Cv= 0.718 kJ/kgK ans.

    We know that enthalpy H = U + PV & h = u + pv

    So, h = 196 + 0.718(t + 273) + 0.281(t + 273) = 196 + 1.005(t + 273)

    but $dH = mC_p dt$, & $dh = C_p dt$ so, $C_P = dh/dt = d/dt\{196 + 1.005(t + 273)\}$

    Cp = 1.005 kJ/kgK ans.

28. A system composed of 2 kg of the fluid having C_v= 0.718 kJ/kg K and C_p= 1.005 kJ/kg K in a frictionless piston and cylinder machine from initial state of 1 MPa, 100^{0}C to a final temperature of 30^{0}C, If there is no heat transfer, find the net work for the process?

    Sol.

Given. P_i =1MPa , T_i =100°C, T_f= 30°C, m_f=2 kg, C_v= 0.718 kJ/kg K, C_p= 1.005 kJ/kg K & Q_{i-f}=0 (no heat transfer).

From the first law of the thermodynamics when ΔK.E. & ΔP.E. ≈ 0

$$Q_{i-f} = dU + W_{i-f}$$

$0 = dU + W_{i-f}$ so, $W_{i-f} = -dU = -m_f C_v dT = -m_f C_v (T_f - T_i) = -2\times0.718\times(30-100)$

$$\mathbf{W_{i-f} = 100.52\ kJ}\ \textbf{ans.}$$

29. A piston cylinder contains water at 500^0C, 3 MPa. It is cooled in a polytropic process to 200^0C, 1 MPa. Find the polytropic exponent (n) and the specific work in the process.
30. A piston cylinder assembly contains 0.5 kg of air at 500kPa and 500K. The air expands in a process such that P is linearly decreasing with volume to a final state of 100 kPa, 300K. Find the work in the process. Molecular weight of air M= 29.
31. A piston cylinder has 1.5 kg of air at 300K and 150kPa. It is now heated up in a two-step process. First constant volume to 1000K (state 2) then followed by a constant pressure process to 1500K (state 3). Find the final volume and the work in the process.
32. A gas undergoes a thermodynamic cycle consisting of the following processes: (i) Process 1-2: Constant Pressure p= 1.4 bar, V_1= 0.028 m^3, W_{12}=10.5kJ, (ii) Process 2-3: Compression with PV= constant, $U_3=U_2$, (iii) Process 3-1: Constant volume, $U_1- U_3$= -26.4kJ. There are no significant changes in KE and PE. (a) Sketch the cycle on a P-V diagram. (b) Calculate the net work for the cycle in KJ. (c) Calculate the heat transfer for process 1-2 (d) Show that $\sum Q_{cycle} = \sum W_{cycle}$.

Sol.

Given (i) Process 1-2: Constant Pressure p= 1.4 bar, V_1= 0.028 m^3, W_{12}=10.5kJ, (ii) Process 2-3: Compression with PV= constant, $U_3=U_2$, (iii) Process 3-1: Constant volume, $U_1- U_3$= -26.4kJ & ΔK.E. & ΔP.E. ≈ 0, $U_1- U_3$= -26.4kJ.

(a) Sketch the cycle on a P-V diagram.

Fig. 3 show the cycle on the P-V Diagram.

(b) Calculate the net work for the cycle in KJ

$W_{1-2} = P_1\times(V_2-V_1)$
$W_{1-2} = 1.4\times10^5\times(V_2-0.028) = 10.5\times10^3$
$V_2 = 0.103\ m^3$.
Process 2-3:- Isothermal Process (PV=C)

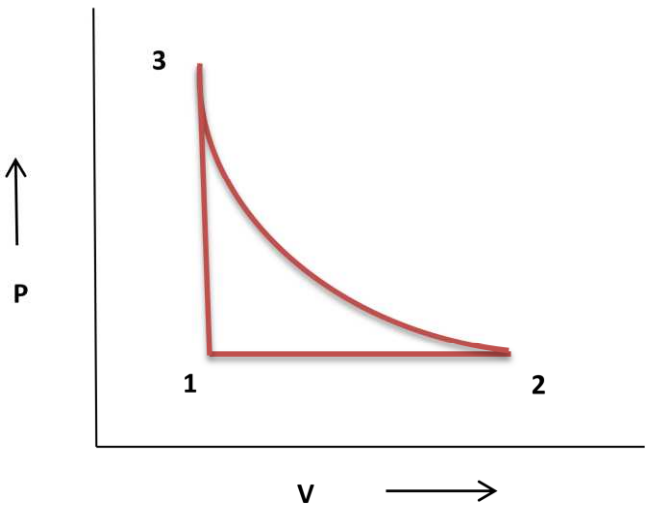


Fig. 4

We know Wisothermal $= PVln(\frac{V_2}{V_1})$

So, $W_{2-3} = P_2V_2\ln\left(\frac{V_3}{V_2}\right) = P_1V_2\ln\left(\frac{V_1}{V_2}\right)$

(because P_1=P_2 & V_3=V_1)

$W_{2-3} = 1.4 \times 10^5 \times 0.103 \times \ln(\frac{0.028}{0.103})$

W_{2-3}= -18.7kJ.

Process 3-1:- Isochoric process (V=C)

So W_{3-1}=0.

Net Work Done= W_{net}= W_{1-2}+W_{2-3}+W_{3-1} = 10.5-18.7+0 = -8.2kJ

W_{net}= 8.2 kJ on the system. Ans

(c) Calculate the heat transfer for process 1-2.

We know that Net change is internal energy for a cycle is zero i.e. ΔU_{cycle}=0.

ΔU_{cycle}= (U_2- U_1)+ (U_3- U_2)+ (U_1- U_3) = 0

Given U_1- U_3= -26.4kJ, & U_3=U_2, So (U_2- U_1)+ 0-26.4=0.

(U_2- U_1) = 26.4 kJ.

From first law of thermodynamics for a process δQ=dE+δW

Since ΔK.E. & ΔP.E. ≈ 0 so δQ=dU+δW

For process 1-2:- Q_{1-2}=U_2-U_1+W_{1-2}

Putting all the values, **Q_{1-2}**= 26.4 + 10.5 =**36.9 kJ. Ans**

(d) Show that $\sum Q_{cycle} = \sum W_{cycle}$.

$\sum Q_{cycle}$= Q_{1-2}+Q_{2-3}+Q_{3-1}……….(i) & $\sum W_{cycle}$ = W_{1-2}+W_{2-3}+W_{3-1}……………..(ii)

We know for process 2-3:- PV=C & U= constant, dU=0

so from the first law of therm. with ΔK.E. & ΔP.E. ≈ 0, δQ=dU+δW=0+ δW

Q_{2-3}=W_{2-3}= -18.7kJ.

For process 3-1:- V=C & W_{3-1}=0,

so from the 1^{st} law of thermo. with ΔK.E. & ΔP.E. ≈ 0, δQ=dU+δW=dU+0=dU

so Q_{3-1}=U_1-U_3= -26.4kJ.

Putting all the values in equation (i) and (ii)

$\sum Q_{cycle}$= 36.9-18.7 -26.4= -8.2kJ…………. (iii)

$\sum W_{cycle}$ = 10.5 – 18.7+0= -8.2kJ……….... (iv)

From eq. (iii) & (iv) **$\sum Q_{cycle} = \sum W_{cycle}$. proved**

33. 680 kg of fish at 5^0C is to be frozen and stored at -12^0C. the specific heat of fish above freezing point is 3.182, and below freezing point is 1.717 kJ/kg K. The freezing point is

-2^{0}C, and the latent heat of fusion is 234.5 kJ/kg. How much heat must be removed to cool the fish, and what percent of this is latent heat?

Sol.

Given. M_{fish}=680kg, T_i=5^{0}C+273=278K, T_f = -12^{0}C+273=261K, $C_{fish\_belowF.P.}$= 3.182 kJ/kg K, $C_{fish\_aboveF.P}$= 1.717 kJ/kg K, $T_{F.P.}$= -2^{0}C+273=271K & L_{fish}= 234.5 kJ/kg.

Heat required to remove to cool the fish = heat removed to cool fish from 5^{0}C to -2^{0}C (Q_1)+ Latent heat of fish (Q_{latent})+ heat removed to cool fish from -2^{0}C to -12^{0}C (Q_2).

$\mathbf{Q_1}$= M_{fish}× $C_{fish\_belowF.P}$× (T_i- $T_{F.P.}$) = 680×3.182×(278-271) = 15146.32 kJ

$\mathbf{Q_{latent}}$= M_{fish}× L_{fish}= 680×234.5= 159460 kJ

$\mathbf{Q_1}$= M_{fish}× $C_{fish\_aboveF.P}$ × ($T_{F.P.}$- T_f) = 680×1.717 ×(271- 261) = 11675.6 kJ

so,

$\mathbf{Q_{total}}$ = 15146.32+ 159460+11675.6 = **186281.91 kJ. Ans**

$$\frac{Q_{latent}}{Q_{total}} \times 100 = \frac{159460}{186281.91} \times 100 = \mathbf{85.6\%.ans}$$

34. A system of volume contains a mass m of gas at pressure P and temperature T. The macroscopic properties of the system obey the following relationship: $\left(P+\frac{a}{V^2}\right)(V-b)=mRT$ where a, b and Rare constants. Obtain an expression for the displacement work done by the system during a constant temperature expansion from volume V_1 to volume V_2. Calculate the work done by a system which contains 10 kg of this gas expanding from 1m^3 to 10 m^3 at a temp. of 293 K. Use the values a= 15.7×10 Nm^4, b= 1.07 ×10-2 m^3, and R= 0.278 kJ/kg-K.

Sol.

Given. $\left(P+\frac{a}{V^2}\right)(V-b)=mRT,$ m_{gas}=10kg, V_1=1m^3, V_2=10m^3, T_1=293K a= 15.7×10 Nm^4, b= 1.07 ×10-2 m^3, and R= 0.278 kJ/kg-K.

We know that work done for a closed system or non-flow work or displacement work $=\int PdV$. System follows the relation $\left(P+\frac{a}{V^2}\right)(V-b)=mRT$.........(i)

So $W_{PdV}=\int_{V_1}^{V_2} PdV$.......(ii), From eq. (i) $P=\frac{mRT}{(V-b)}-\frac{a}{V^2}$........................(iii)

From eq (iii) & (ii) $W_{PdV}=\int_{V_1}^{V_2}\left(\frac{mRT}{(V-b)}-\frac{a}{V^2}\right)dV$,

Upon integrating from V_1 to V_2 $\boldsymbol{W_{PdV}=mRTln\left(\frac{V_2-b}{V_1-b}\right)+a\left(\frac{1}{V_2}-\frac{1}{V_1}\right)}$ **ans.**

Putting values of all the parameters in the above eq. we get

$$W_{PdV} = 10 \times 0.278 \times 293 \times \ln\left(\frac{10-1.07\times10^{-2}}{1-1.07\times10^{-2}}\right) + 15.7 \times 10\left(\frac{1}{10} - \frac{1}{1}\right)$$

$$\mathbf{W_{PdV} = 1042.138\ kJ\ ans.}$$

35. Show that for a polytropic process $\mathbf{Q = W_{Polytropic}\frac{(\gamma - n)}{(\gamma - 1)}}$

36. Warm air is contained in a piston cylinder assembly oriented horizontally. The air cools slowly from an initial volume of $0.003 m^3$ to a final volume of $0.002\ m^3$. During the process the spring exerts a force that varies linearly from an initial value of 900N to final value of zero. Atmospheric pressure is 100 KPa and area of the piston face is $0.018\ m^2$. Friction between the piston and the cylinder wall can be neglected. For the air, determine the initial and final pressures in KPa and the work in KJ.

Sol.

Given. V_i=0.003 m^3, V_f=0.002 m^3, F_i=900N, F_f=0N, P_{atm}=100 kPa & A_p=0.018 m^2.

Applying force balance in x direction at initial condition, $\sum F_x = 0$.

$P_iA_i = P_{atm}A_p + F_i$, so $\mathbf{Pi} = P_{atm} + \frac{F_i}{A_p} = 100 \times 10^3 + \frac{900}{0.018} = \mathbf{150kPa\ ans.}$

Similarly, $\boldsymbol{P_f} = P_{atm} + \frac{F_f}{A_p} = 100 \times 10^3 + \frac{0}{0.018} = \mathbf{100kPa\ ans.}$

Work Done, from fig.4 it is clear that process will follow a straight line because spring force is directly proportional to the displacement, thus work done will be equal to the area under the st. line i-f.

$$\mathrm{W.D.} = \frac{(P_i + P_f)}{2} \times (V_2 - V_1)$$

$$\mathrm{W.D.} = \frac{(150 + 100)}{2} \times (0.003 - 0.002)$$

$$\mathbf{W.D. = 125J\ ans.}$$

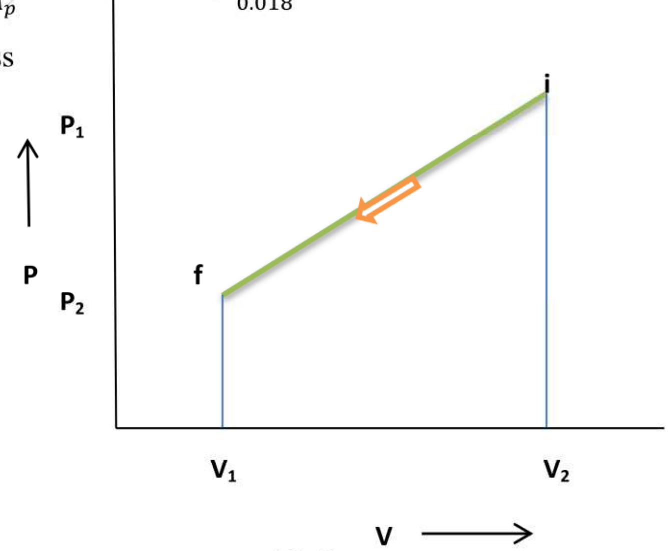


Fig.5

37. A fan is to accelerate quiescent air to a velocity of 10 m/s at a rate of $4m^3/s$. Determine the minimum power that must be supplied to the fan. Take density of air to be 1.18 kg/m3.

Sol.

Given. Velocity C=10m/s, Flow rate Q=$4m^3/s$ & ρ_{air} = 1.18 kg/m3.

$$\text{Power required} = \text{K.E./s} = \frac{1}{2}\dot{m}C^2 = \frac{1}{2}\rho_{air}QC^2 = \frac{1}{2} \times 1.18 \times 4 \times 10^2$$

So, **Power required = 236 J/s or W. ans**

38. A turbine operates under steady flow conditions, receiving steam at the following state: pressure 1.2 MPa, temperature of 188^{0}C, enthalpy of 2785 kJ/kg, velocity of 33.3 m/s and elevation of 3 m. The steam leaves the turbine at the following state: pressure 20 kPa, enthalpy of 2523 kJ/kg, velocity of 100 m/s and elevation of 0 m. Heat is lost to the surrounding at the rate of 0.29 kJ/s. If the rate of steam flow through turbine is 0.43 kg/s, what is the power output of the turbine in kW? Sketch the schematic diagram of the problem.

Sol.

Given. P_i=1.2 MPa, T_i=188^{0}C+273=461K, h_i=2785 kJ/kg, C_i=33.3 m/s, Z_i = 3 m, P_f=20 kPa, h_f=2523 kJ/kg, C_f=100 m/s, Z_f = 0 m, $\dot{Q} = 0.29\frac{\text{kJ}}{\text{s}}$ & $\dot{m} = 0.43\ \text{kg/s}$

Form the first law of thermodynamics for flow process,

$$\dot{m}\left(h_i + \frac{C_i^2}{2} + Z_i\right) + \dot{Q} = \dot{m}\left(h_f + \frac{C_f^2}{2} + Z_f\right) + \dot{W} \text{..................(i)}$$

Putting all the parameters value in eq. (i)

$$0.43\left(2785 \times 10^3 + \frac{33.3^2}{2} + 3\right) + 0.29 \times 10^3 = 0.43\left(2523 \times 10^3 + \frac{100^2}{2} + 0\right) + \dot{W}$$

$$\mathbf{\dot{W} = 111.039\ kW\ ans.}$$

39. Air flows steadily at the rate of 0.8 kg/s through an air compressor, entering at 10 m/s velocity, 100 kPa pressure and 1 m^3/kg volume and leaving at 8 m/s, 700 kPa and 0.2 m^3/kg. The internal energy of the air leaving is 100kJ/kg greater than that of the air entering. Cooling water in the compressor jackets absorbs heat from the air at the rate of 60kW. (i) Estimate the rate of shaft work input to the air in kW and (ii) compute the ratio of the inlet pipe diameter to the outlet diameter.

Sol.

Given. Mass (M) = 0.8 kg/s, Velocity at inlet (C_i) = 10 m/s, Pressure at inlet (P_i) = 100 KPa, Specific volume at inlet (v_i) = 1 m^3 /Kg, Velocity at outlet (C_f) = 8 m/s, Pressure at outlet (P_f) = 700 KPa, Specific volume at outlet (v_f) = 0.2 m^3/Kg, Change in internal energy ($U_f - U_i$) = 100 KJ/Kg, Heat absorbs ($\dot{Q}$) = 60 KW

(i). Form the first law of thermodynamics for flow process,

$$\dot{m}\left(h_i + \frac{C_i^2}{2} + Z_i\right) + \dot{Q} = \dot{m}\left(h_f + \frac{C_f^2}{2} + Z_f\right) + \dot{W} \ldots\ldots\ldots\ldots\ldots\ldots(i)$$

We know that $h = u + Pv$........(ii)

From eq. (i) & (ii)

$$\dot{m}\left(u_i + P_i v_i + \frac{C_i^2}{2} + Z_i\right) + \dot{Q} = \dot{m}\left(u_f + P_f v_f + \frac{C_f^2}{2} + Z_f\right) + \dot{W} \ldots\ldots\ldots\ldots(iii)$$

Putting all the values in eq. (iii)

$$\dot{W} = 0.8\left[-100 \times 10^3 + (100 \times 10^3 \times 1) - (700 \times 10^3 \times 0.2) + \left(\frac{10^2 - 8^2}{2}\right)\right] - 60 \times 10^3$$

$$\boldsymbol{\dot{W} = -171.9856} \textbf{ kW ans.}$$

Here, '-' sign indicates that the work is done on the system.

(ii) We know that $\dot{m} = \rho_i A_i C_i = \rho_f A_f C_f$ also, $\dot{m} = \frac{A_i C_i}{v_i} = \frac{A_f C_f}{v_f}$

$$\frac{d_i^2 C_i}{v_i} = \frac{d_f^2 C_f}{v_f} \ldots\ldots\ldots\ldots\ldots(iv)$$

From eq. (iv) we can find out $\frac{d_i}{d_f}$ **= 2 ans.**

40. A domestic refrigerator is loaded with food and the door closed. During certain period the machine consumes 1kWh of energy and the internal energy of the system drops by 5000 kJ. Find the net heat transfer for the system.

Sol.

Given, Internal Energy $(U_2\text{-}U_1)$ = -5000KJ

Work Done (W) = 1KWh = 1×3600 kJ = 3600 kJ

from the first law of therm. with ΔK.E. & ΔP.E. ≈ 0, Q = ΔU + W

Q = $(U_2 - U_1)$ + W

Q = -5000 kJ - 3600 kJ

So, **Q= − 8.6 MJ ans.**

41. One fourth kg of a gas contained within a piston cylinder assembly undergoes a constant pressure process at 5 bar beginning at v1= 0.20 m^3/kg. For the gas as the system, the work is -15kJ. Determine the final volume of the gas in m^3.

Sol.

Given. m=0.25kg, P= 5bar = 500kPa, v_1=0.20 m^3/kg & W=−15 kJ.

V_2 =?

V_1=m × v_1= (0.25kg) ×(0.20m^3/kg) = 0.05m^3

For constant pressure process, W=P (V_2 −V_1)…………….. (i)

Putting all the values in eq. (i)

-15= 500×(V_2-0.05), so **V_2 = 0.02 m^3 ans.**

42. A gas within a piston cylinder assembly undergoes a thermodynamic cycle consisting of three processes:

Process 1-2: Constant volume, V=0.028m^3, U_2-U_1= 26.4kJ

Process 2-3: Expansion with PV= constant, U_3=U_2

Process 3—1: Constant pressure, P=1.4bar, W_{3-1}= -10.5kJ

There are no significant changes in kinetic or potential energy

(a)Sketch the cycle on P-V diagram.

(b) Calculate the net work for the cycle in KJ.

(c) Calculate the heat transfer for process 2-3 in KJ.

(d)Calculate the heat transfer for process 3-1 in KJ.

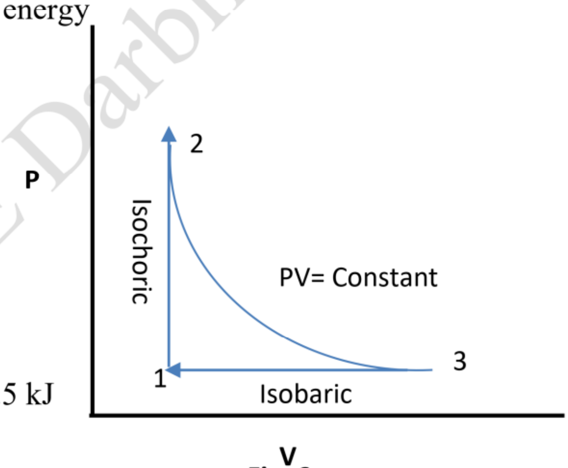


Fig. 6

Sol.

Given. V_1 = V_2 =0.028 m^3, U_2 - U_1 =26.4 kJ,

P_2 V_2 = P_3 V_3, U_3 = U_2, P_3 = P_1 =140 kPa & W_{3-1} =-10.5 kJ

(a) Fig. 5 depicts the cycle on P-V diagram.

(b) Since W_{cycle} = W_{12}+ W_{23} + W_{31}, Since Process 1-2 is constant volume process so closed syste word done for the process will be zero. **W_{1-2} = 0 kJ**

Process 2-3: PV = C, Isothermal process therefore,

$$W_{2-3} = \int_{V_2}^{V_3} P\,dV = C\int_{V2}^{V3} \frac{dV}{V} = C\ln(V3/V2).$$

W_{3-1}= P_3 (V_1-V_3), as process 3-1 is Isobaric (P= constant)

-10.5=140× (0.028-V_3), so V_3 = 0.103 m^3

Now, W_{2-3} = C ln V_3/V_2 = P_3V_3 ln V_3/V_2, W_{2-3} = 18.8 kJ

W_{3-1}= - 10.5 kJ

W_{cycle} = W_{1-2} + W_{2-3} + W_{3-1} **= 8.28 kJ ans.**

(c) 1st Law for process 2-3: Q_{2-3} = U_3 - U_2+ W_{2-3} =0+ W_{2-3},

So **W_{2-3}** = Q_{2-3} = **18.8 kJ ans.**

(d) 1st Law for process 3-1: Q_{3-1} = U_1 - U_3 + W_{3-1}

But, U_2 = U_3, Q_{3-1} - W_{3-1} = U_1 - U_3 = U_1 - U_2 = -(U_2 - U_1)

$Q_{3-1} = W_{3-1} - (U_2 - U_1)$, so **$Q_{3-1}$ = -36.9 kJ ans.**

43. The drive shaft of a building's air handling fan is turned at 300 rpm by a belt running on a 0.3 m diameter pulley. The Net force applied by the belt on the pulley is 2000 N. Determine the torque applied by the belt on the pulley in Nm and power transmitted in kW.

Sol.

Given. N=300 rpm, d_{pully}=0.3 m, F=2000N.

We know torque $\boldsymbol{\tau} = F \times \frac{d_{pully}}{2} = 2000 \times \frac{0.3}{2} = \mathbf{300\ Nm\ ans.}$

Power transmitted $\mathbf{P} = \frac{2\pi N\tau}{60} = \frac{2\times\pi\times300\times300}{60} = \mathbf{9.42\ kW\ ans.}$

44. The pressure, temperature and velocity of air flowing in a pipe are 5 bar, 500 K and 50 m/s, respectively. The specific heats of air at constant pressure and at constant volume are C_p = 1.005 kJ/kg K and C_v = 0.718 kJ/kg K respectively. Neglect change in the potential energy of the air flowing. If the pressure and temperature of the surrounding are 1 bar, and 300 K respectively, what is the available energy in kJ/kg of the air steam.

45. State and prove the inequality of clausius.

46. Find the maximum work obtainable from a finite body and TER (thermal energy reservoir).

47. Explain the kelvin- plank's and clausius statement of second law. And proof how both are equivalent to each other.

48. What is a PMM2? Why it is not possible?

49. Explain the Carnot Cycle of heat engine. What are the different processes involved? Also define engine efficiency.

50. A refrigeration plant for a food store operates as a reversed Carnot heat engine cycle. The store is to be maintained at a temperature of -5^{0}C and the heat transfer from the store to the cycle is at rate of 5kW. If heat is transferred from the cycle to the atmosphere at a temperature of 25 ^{0}C, Calculate the power required to drive the plant.

51. Show that maximum work obtainable if two bodies are allowed to exchange heat via reversible heat engine is $\boldsymbol{Wmax} = (\sqrt{\boldsymbol{T1}} - \sqrt{\boldsymbol{T2}})$.

53. A Carnot cycle is having an efficiency of 0.75. If the temperature of the high temperature reservoir is 727^{0}C what is the temperature of low temperature reservoir?

54. A solar collector receiving solar radiation at the rate of 0.6 kW/ m^2 transforms it to the internal energy of a fluid at an overall efficiency of 50%. The fluid heated to 250 K is

used to run a heat engine which rejects heat at 315 K. If the heat engine is to deliver 2.5 kW power, what is the minimum area of the solar collector required?

55. An inventor claims that his petrol engine operating between temperatures of 2000°C and 600°C will produce 1 kWh consuming 150g of petrol having 45000 kJ/kg calorific value. Check the validity of the claim.

Sol.

Given. T_1=2000^{0}C+273=2273K, T_2=600^{0}C+273=873 K,

$W_{o/p}$=1kWh=3600kJ, m_f=150g & C.V. = 45000 kJ/kg.

According to the Carnot's Principle the efficiency of an actual heat engine can never be more than the efficiency of reversible heat engine operating between the same thermal reservoirs.

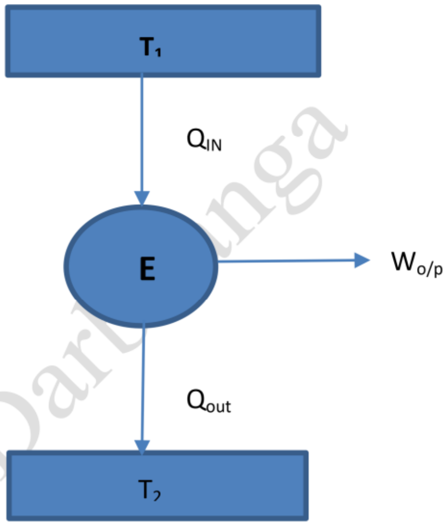


Fig. 7

$\eta_{max} = 1 - T_1/T_2$

$= 1 - 873/2273$

$= 61.59\%$ or 0.6159

Also, Q_{IN} = 0.150*45000KJ = 6750KJ

$W_{O/P}$ = 3600KJ, $\eta_{actual} = W_{O/P}\times100/Q_{IN}$ = 53.33% or 0.5353

Since actual efficiency is less than the maximum obtainable efficiency. Hence the inventor's claim is **feasible.**

56. Two reversible engines take 2400 kJ per minute from a reservoir at 750 K and develops 400 kJ of work per minute when executing complete cycles. The engines reject heat two reservoirs at 650 K and 550 K. Find the heat rejected to each sink.

Sol.

$Q_A + Q_B$ = 2400KJ………………(i)

$W_{net} = W_A + W_B$ = 400KJ

$Q'_A + Q'_B$ = (2400 – 400) = 2000KJ

So $Q'_A + Q'_B$ = 2000KJ………….(ii)

For engine A, η_A = 1 – QA2/QA = 1 – 650/ 750

$Q_A = 1.1539Q'_A$

For engine B, $\eta_B = 1 - Q'_B/Q_B$ = 1 – 550/750

$Q_B = 1.3636Q'_B$

Putting the values of Q_A&Q_B in eq. (i)

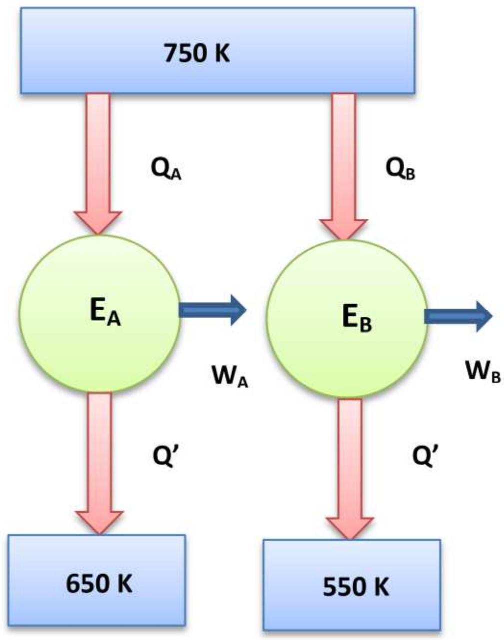


Fig. 8

1.1539Q'$_A$ + 1.3636Q'$_B$= 2400KJ ………………….(iii)

from eq. (iii) & (ii)

We have **Q'$_A$ = 1560.36KJ &Q'$_B$ = 439.67KJ ans.**

Hence , heat rejections in 650K & 550K sink are 1560.32KJ & 439067KJ respectively.

57. A reversible engine operates between temperatures T_1, and T_2, The energy rejected by this engine is received by a second reversible engine at temperature T_2 and rejected to a reservoir at temperature T_3. If the efficiencies of the engines are same then what is the relationship between T_1, T_2 and T_3?

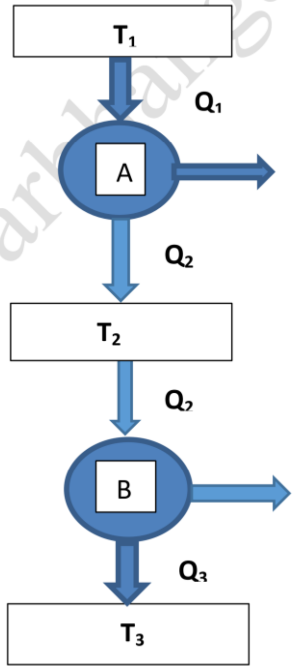


Fig. 9

Sol.

Given $\eta_A = \eta_B$

For reversible engine A, $\eta_A = 1 - T_2/T_1$

For reversible engine B, $\eta_B = 1 - T_3/T_2$

Since $\eta_A = \eta_B$

So, $1 - T1/T2 = 1 - T_2/T_3$

$$T_2 = \sqrt{T_1 T_3}.\ \textbf{Ans}$$

58. One reversible heat engine operates between 1600 K and T_2 K, and another reversible heat engine operates between T_2 K and 400 K. If both the engines have the same heat input and output, then find out the temperature T_2 in K.

Sol.

Since both the engines are reversible & having same heat input (Q_{in}) and output ($W_{o/p}$) so their efficiency will be equal **as $\eta = W_{o/p} / Q_{in}$**

For engine working between 1600K & T_2K thermal reservoirs, $\eta_A = 1 - T_2/1600$

For engine working between T_2K & 400K thermal reservoirs, $\eta_B = 1 - 400/T_2$

Since $\eta_A = \eta_B$, So $\mathbf{T_2} = \sqrt{(1600 \times 400)}$ = **800 K ans.**

59. 5 kg of air is compressed in a reversible polytrophic process from 1 bar and 40°C to 10 bar with an index of compression 1.25. Calculate the entropy change during the process.

Sol.

Given m_{air}=5 kg, P_1=1 bar, P_2= 10 bar, T_1= 40^0C+273=313K & n=1.25.

$C_{P\ air}$=1.005 kJ/kg K, R_{air}=0.287 kJ/kg K.

Since air is an ideal gas so change in entropy for an idea gas,

$$S_2 - S_1 = m_{air}\left\{C_p ln\frac{T_2}{T_1} - R\ ln\frac{P_2}{P_1}\right\} \text{…………………(i)}$$

For polytropic process $\frac{T_2}{T_1} = (\frac{P_2}{P_1})^{\frac{n-1}{n}}$ ………………… (ii)

From eq. (ii) T_2= 496.07K

Putting all the values of the parameters in eq. (i)

S_2-S_1= – 0.9901KJ/K ans.

60. An inventor claims to have developed a power cycle operating between hot and cold reservoirs at 2000K and 500K, that develops net work equal to a multiple of the amount of energy Q_C rejected to the cold reservoir (i.e. Wcycle = NQ_C). What is the maximum theoretical value of the number N for any such cycle?

Sol.

We know that the maximum amount of work output is obtainable From reversible engine.

η_{rev} = 1 – 500/2000 = W_{Cycle}/Q_{in} ………….. (i)

Q_{in} =W_{Cycle} + Q_C = W_{Cycle} + W_{Cycle}/N [W_C = N Q_C]

On solving

W_c/Q_{in} = N/(N+1) ……………………(ii)

From eq. (i) & (ii) we have

$\frac{N}{N+1}$ = 1 - $\frac{500}{2000}$

Solving for N we have **N=3 ans.**

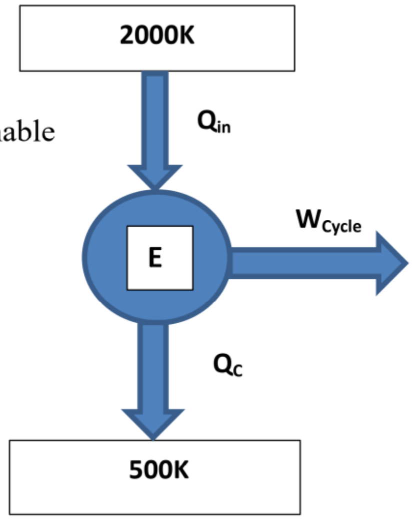


Fig. 10

62. Data for two reversible refrigeration cycle is given below: Cycle 1: T_H = 25^0C, T_C = -10^0C, Cycle 2: T_H = 25^0C, T_C = -25^0C Where T_H and T_C are the temperature of hot and cold reservoirs respectively. Determine the ratio of net work input values of the two cycles if the same amount of heat energy is removed from the cold reservoir by each refrigerator.

Sol.

For cycle 1

COP_1 = Q/W_1 = $T_C/(T_H-T_C)$ = (-10+273)/ (25+10), so W_1 = (35/263)Q ………… (i)

For cycle 2

$COP_2 = Q/W_2 = T_C/(T_H-T_C) = (-25+273)/(25+25)$, so $W_2 = (50/248)Q$ ………… (ii)

From eq. (i) & (ii) we have

$W_1/W_2 = 0.66$ ans.

63. A series combination of two Carnot's engines operates between the temperature of 180^0C and 20^0C. If the engines produces equal amount of work then what will be the intermediate temperature?

Sol.

Given. $T_1=180^0C$, $T_3=20^0C$ & $W_A=W_B$.

$\eta_A = 1 - \frac{T_2}{T_1} = \frac{W_{o/p}}{Q_1}$, so $W_{o/p} = Q_1 \times \left(1 - \frac{T_2}{T_1}\right)$…………..(i)

$\eta_B = 1 - \frac{T_3}{T_2} = \frac{W_{o/p}}{Q_2}$, so $W_{o/p} = Q_2 \times \left(1 - \frac{T_3}{T_2}\right)$ ………....(ii)

From eq. (i) & (ii)

$$Q_1 \times \left(1 - \frac{T_2}{T_1}\right) = Q_2 \times \left(1 - \frac{T_3}{T_2}\right)$$

$$\frac{Q_1}{Q_2} = \frac{\left(1 - \frac{T_3}{T_2}\right)}{\left(1 - \frac{T_2}{T_1}\right)} \text{ ……………….(iii)}$$

But we know that for Carnot's engine $\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$……(iv)

From eq. (iii) & (iv) upon simplifying.

Intermediate temp. $T_2 = \frac{T_1+T_3}{2}$ ans.

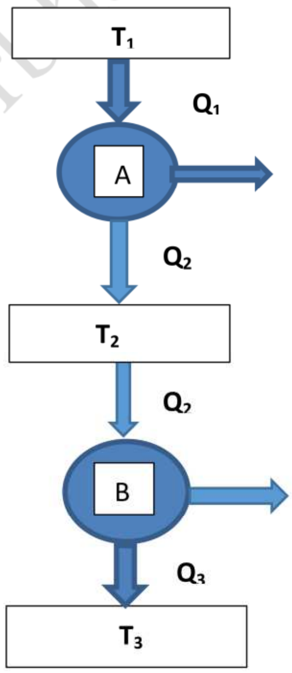


Fig. 11

64. The coefficient of performance of a refrigeration cycle is 70% of the value for a reversible refrigeration cycle. The temperatures of hot and cold reservoirs are 35^0C and -4^0C, respectively. Determine the power input per kW of cooling required in both the cycles (reversible and irreversible).

Sol.

Given. $T_H=35^0C+273=308$ K, $T_C=-4^0C+273=269K$, $Q_C=1$ kW & $COP_{irrev}= 0.7\times COP_{rev}$.

For reversible cycle , $COP_{rev.} = (-4+273)/(35-(-4)) = 269/39 = Q_C/(W_{i/p})_{rev}$

Since Q_C = 1KW

Hence, **$(W_{i/p})_{rev}$**=(1×39)/269 = **0.145 kW ans.**

Now for irreversible cycle

COP_{irrev} = 0.70 ×COP_{rev}=0.70×269/39 = 4.828.

COP_{irrev} = Q_C/ $(W_{i/p})_{irrev}$, Since Q_C = 1kW

Hence, **$(W_{i/p})_{irrev}$** =1/4.828 = **0.207kW ans.**

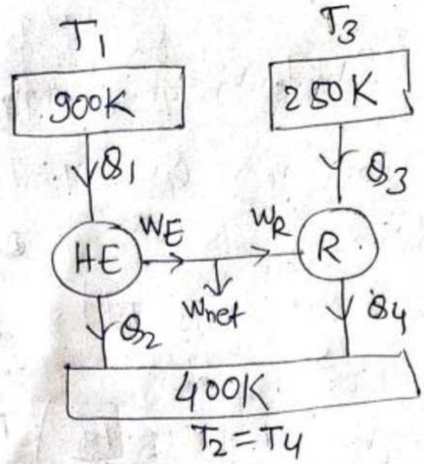
65. A reversible heat engine operates between two reservoirs at temp. 900K and 400K. The engine drives a reversible refrigerator which operates between 400K and 250K. The heat transfer to the heat engine is 2000kJ and net work output of combined engine refrigerator plant is 400kJ.

a) Evaluate the heat transfer to the refrigerator and net heat transfer to the reservoir at 400K.

b) If the efficiency of the heat engine and the COP of refrigerator are each 60% of their maximum possible value, evaluate the heat transfer to the refrigerator and the net heat transfer to the reservoir at 400K.

Sol.

Q.65



Given data:

$T_1 = 900K, \quad T_2 = T_4 = 400K$

$T_3 = 250K$

$Q_1 = 2000 KJ, \quad W_{HE} - W_R = W_{net} = 400 KJ$

(a) $Q_3 = ?, \quad Q_2 + Q_4 = ?$

we know,

$$\eta_{HE} = \frac{W_{HE}}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = \frac{T_1 - T_2}{T_1} \text{ (for rev engine)}$$

$$\Rightarrow W_{HE} = 2000 \times \frac{900 - 400}{900} = \frac{10000}{9} KJ$$

$$= 1111.111 KJ$$

$$\therefore W_R = W_{HE} - W_{net} = 1111.111 - 400 = 711.11 KJ$$

for HE $\quad Q_1 = W_E + Q_2 \Rightarrow Q_2 = 2000 - 1111.111$

$$= 888.889 KJ$$

also, we know

$$(COP)_R = \frac{Q_3}{W_R} = \frac{Q_3}{Q_4 - Q_3} = \frac{T_3}{T_4 - T_3} \text{ (for rev engine)}$$

$$\therefore Q_3 = 711.11 \times \frac{250}{400 - 250} = 1185.185 KJ$$

$$\therefore Q_3 + W_R = Q_4 \Rightarrow Q_4 = 1185.185 + 711.11$$

$$Q_4 = 1896.296 KJ$$

Heat transfer to refrigerator $(Q_3) = 711.11$ kJ Ans

heat transfer to reservoir at 400K $= Q_2 + Q_4$

$= 1896.296 + 888.889$

$= 2785.185$ kJ Ans

(b) if $(\eta_{HE})_{act} = 0.6\,(\eta_{HE})_{ideal}$:

$(COP)_{act} = 0.6\,(COP)_{ideal}$.

$(\eta_{HE})_{actual} = \frac{W'_{HE}}{Q_1} =$

$(\eta_{HE})_{ideal} = \frac{900-400}{900} = \frac{5}{9}$

$(COP)_{ideal} = \frac{250}{400-250} = \frac{5}{3}$

$\therefore (\eta_{HE})_{act} = \frac{5}{9} \times 0.6 = \frac{1}{3}$

$(COP)_{act} = \frac{5}{3} \times 0.6 = 1$

$(\eta_{HE})_{act} = \frac{W'_E}{Q_1} \Rightarrow W_E = \frac{1}{3} \times 2000 = \frac{2000}{3}$ kJ

$(COP)_{act} = \frac{Q'_3}{W_R'} \Rightarrow Q'_3 = W'_R$

where, $W_R' = W'_E - W_{net} = \frac{2000}{3} - 400 = \frac{800}{3}$ kJ

$\therefore Q'_3 = \frac{800}{3}$ kJ

$W'_E = Q_1 - Q'_2 \Rightarrow Q'_2 = 2000 - \frac{2000}{3} = \frac{4000}{3}$ kJ

& $Q'_4 = Q'_3 + W'_R = \frac{1600}{3}$ kJ

$\therefore$ Heat transfer to refrigerator $= Q'_3 = \frac{800}{3} = 266.67$ kJ Ans

Heat transfer to 400K $= Q_2' + Q'_4 =$

$= \frac{4000}{3} + \frac{1600}{3} = \frac{5600}{3}$

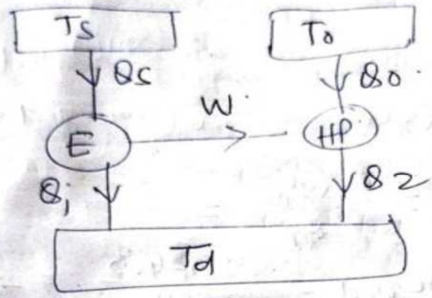
$= 1866.667$ kJ

66. A system consists of a power cycle driving a heat pump. At steady state the power cycle receives Q_S by heat transfer at TS temp and delivers Q_1 to a dwelling at T_d temp. The heat pump receives Q_0 from outdoors at T_0 and rejects Q_2 to the same dwelling at

Td temp. Obtain an expression for the maximum $(Q_1+Q_2)/Q_S$ in terms of the temp ratios T_S/T_d and T_0/T_d.

Sol.

Q.66



IInd method

for Max^m condition, the cycles are reversible.

therefore by clausius inequality.

$$\oint ds = 0 \quad \text{or} \quad \oint \frac{Q}{T} = 0$$

also, Net heat transfer into system = Net heat out of the system.

$$\Rightarrow Q_S + Q_0 = Q_1 + Q_2$$

$$\Rightarrow Q_0 = Q_1 + Q_2 - Q_S$$

now, $\oint ds = 0$

$$\frac{Q_S}{T_S} - \frac{Q_1}{T_d} + \frac{Q_0}{T_0} - \frac{Q_2}{T_d} = 0$$

$$\Rightarrow \frac{Q_1+Q_2}{T_d} = \frac{Q_S}{T_S} + \frac{Q_0}{T_0}$$

$$\Rightarrow \frac{Q_1+Q_2}{T_d} = \frac{Q_S}{T_S} + \frac{Q_1+Q_2}{T_0} - \frac{Q_S}{T_0}$$

$$\Rightarrow (Q_1+Q_2)\left(\frac{1}{T_d} - \frac{1}{T_0}\right) = Q_S\left(\frac{1}{T_S} - \frac{1}{T_0}\right)$$

$$\Rightarrow \frac{Q_1+Q_2}{Q_S}\left(\frac{T_0 - T_d}{T_d \cdot T_0}\right) = \frac{T_0 - T_S}{T_S \cdot T_0}$$

$$\Rightarrow \boxed{\frac{Q_1+Q_2}{Q_S} = \frac{T_d}{T_S}\,\frac{T_0 - T_S}{T_0 - T_d} = \frac{\frac{T_0}{T_S} - 1}{\frac{T_0}{T_d} - 1}}$$

II[nd] method.

$$\because W_E = W_{HP} = W$$

$$(\eta_{HE})_{ideal} = \frac{W_E}{Q_S} = \frac{T_S - T_d}{T_S}$$

$$\Rightarrow W = \frac{Q_S}{T_S}(T_S - T_d) \quad \text{—(i)}$$

$$\& \quad \frac{Q_S}{T_S} = \frac{Q_1}{T_d} \Rightarrow Q_1 = \frac{Q_S}{T_S} \cdot T_d$$

$$\& \quad [(COP)_{HP}]_{ideal} = \frac{Q_2}{W} = \frac{T_d}{T_d - T_0}$$

$$\Rightarrow W = \frac{Q_2}{T_d}(T_d - T_0) \quad \text{—(ii)}$$

equating (i) & (ii), we get

$$\frac{Q_S}{T_S}(T_S - T_d) = \frac{Q_2}{T_d}(T_d - T_0)$$

$$\therefore Q_2 = Q_S \cdot \frac{T_d}{T_S}\left(\frac{T_S - T_d}{T_d - T_0}\right)$$

$$\therefore Q_1 + Q_2 = \frac{Q_S}{T_S} \times T_d + \frac{Q_S}{T_S} T_d \left(\frac{T_S - T_d}{T_d - T_0}\right)$$

$$= \frac{Q_S}{T_S} T_d \left(\frac{T_d - T_0 + T_S - T_d}{T_d - T_0}\right)$$

$$\frac{Q_1 + Q_2}{Q_S} = \frac{T_d}{T_S} \times \frac{T_S - T_0}{T_d - T_0}$$

$$\boxed{\frac{Q_1 + Q_2}{Q_S} = \frac{1 - T_0/T_S}{1 - T_0/T_d} = \frac{\frac{T_0}{T_S} - 1}{\frac{T_0}{T_d} - 1}} \quad A$$

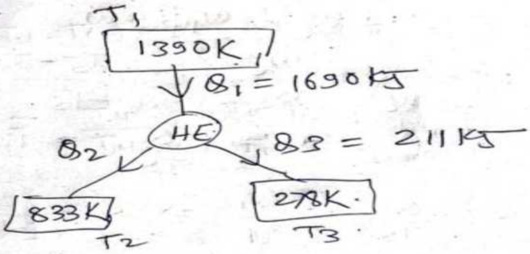
67. A system executes a power cycle, receiving 1690 kJ by heat transfer at a temp of 1390 K & discharging 211 kJ by heat transfer at 278 K. A heat transfer from the system also occurs at a temp of 833 K. There are no other heat transfers. If no irreversibility is present determine the thermal efficiency and net work transfer.

Sol.

Darbhanga College of Engineering

Department of Mechanical Engineering
Mechanical Engineering

8.67



by 2nd law of TD:

$$\Sigma \frac{dQ}{T} = 0 \quad \text{(for reversible)}$$

$$\frac{Q_1}{T_1} - \frac{Q_2}{T_2} - \frac{Q_3}{T_3} = 0$$

$$\Rightarrow Q_2 = T_2\left(\frac{Q_1}{T_1} - \frac{Q_3}{T_3}\right)$$

$$Q_2 = 833 \times \left(\frac{1690}{1390} - \frac{211}{278}\right)$$

$$= 380.54 \text{ kJ}$$

By 1st law of TD

$$\Sigma W = \Sigma Q$$

$$W_{net} = Q_1 - Q_2 - Q_3 = 1690 - 211 - 380.54$$

$$= 1098.46 \text{ kJ}$$

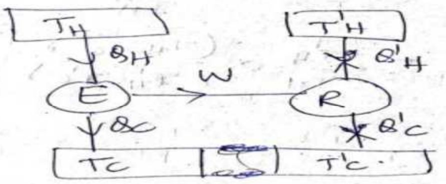
$$\therefore \eta_{HE} = \frac{W_{net}}{Q_{in}} = \frac{W_{net}}{Q_1} = \frac{1098.46}{1690} = 0.6499$$

$$\simeq 65\% \text{ Ans}$$

68. A reversible power cycle receives energy Q_H from a reservoir at temp T_H and rejects Q_C to a reservoir at temp T_C. The work developed by the power cycle is used to drive a reversible heat pump that removes energy Q'_C from a reservoir at temp T'_C and rejects energy Q'_H to a reservoir at temp T'_H. (a) Develop an expression for the ratio of Q'_H/Q_H in terms of the temperatures of four reservoirs, (b) what must be the relationship of the temperatures T_H, T_C, T'_C and T'_H for Q'_H/Q_H to exceed a value of unity.

Sol.

Q 68



given, $W_E = W_R = W$

(a)

$$\eta_E = \frac{W_E}{Q_H} = \frac{T_H - T_C}{T_H}$$

$$\Rightarrow W = \frac{Q_H}{T_H}(T_H - T_C) \quad \text{—(i)}$$

$$(COP)_R = \frac{Q'_C}{W_R} = \frac{T'_C}{T'_H - T'_C}$$

$$\therefore W = \frac{Q'_C}{T'_C}(T'_H - T'_C)$$

for reversible process,

$$\frac{Q'_C}{T'_C} = \frac{Q'_H}{T'_H}$$

$$W = \frac{Q'_H}{T'_H}(T'_H - T'_C) \quad \text{—(ii)}$$

equating eq^n (i) & (ii), we get

$$\frac{Q_H}{T_H}(T_H - T_C) = \frac{Q'_H}{T'_H}(T'_H - T'_C)$$

$$\therefore \boxed{\frac{Q'_H}{Q_H} = \frac{T'_H}{T_H} \times \frac{(T_H - T_C)}{(T'_H - T'_C)}} \quad \text{Ans}$$

(b) $$\frac{Q'_H}{Q_H} > 1$$

$$\Rightarrow \frac{T'_H}{T_H} \times \frac{(T_H - T_C)}{(T'_H - T'_C)} > 1$$

$$\Rightarrow T'_H \cdot T_H - T'_H \cdot T_C > T_H \cdot T'_H - T_H \cdot T'_C$$

$$\Rightarrow T'_H T_C < T_H \cdot T'_C$$

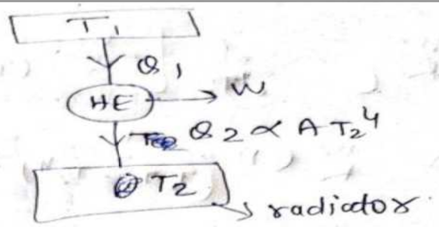
$$\therefore \boxed{\frac{T'_H}{T_H} < \frac{T'_C}{T_C}} \quad \text{Ans}$$

69. Consider an engine in outer space which operates on carnot cycle. The only way in which the heat can be transferred from the engine is by radiation. The rate at which heat is radiated is proportional to the fourth power of the absolute temperature and to the

area of radiating surface. Show that for a given power output and a given T_1, the area of the radiator will be minimum when $\frac{T_2}{T_1} = \frac{3}{4}$

Sol.

Q-69



Given $Q_2 \propto A T_2^4$

$Q_2 = K A T_2^4$ (K = constant)

for Carnot cycle (reversible cycle)

$$\eta_{HE} = \frac{W}{Q_1} = \frac{T_1 - T_2}{T_1}$$

$$\Rightarrow W = \frac{Q_1}{T_1}(T_1 - T_2)$$

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

$$\therefore W = \frac{Q_2}{T_2}(T_1 - T_2)$$

$$= \frac{K A T_2^{4}}{T_2}(T_1 - T_2)$$

$$A = \frac{W}{K \cdot T_2^3 (T_1 - T_2)} = \frac{W}{K(T_1 T_2^3 - T_2^4)}$$

for minm area $\frac{dA}{dT_2} = 0$

$$\frac{d}{dT_2}\left[\frac{W}{K} \cdot \frac{1}{(T_1 T_2^3 - T_2^4)}\right] = 0$$

$$\Rightarrow \frac{W}{K}(-1)\frac{1}{(T_1 T_2^3 - T_2^4)^2} \times \left[3T_1 \cdot T_2^2 - 4T_2^3\right] = 0$$

(BCZ W is const)

$$\Rightarrow 3T_1 \cdot T_2^2 - 4T_2^3 = 0$$

$$\Rightarrow 3T_1 T_2^2 = 4T_2^3$$

$$\Rightarrow \boxed{\frac{T_2}{T_1} = \frac{3}{4}}$$

proved

70. State whether statements are True or False.

(a) Internal energy of an ideal gas is a function of temperature and volume.

(b) The entropy of fixed amount of ideal gas increases in every isothermal compression.

(c) The specific volume of water when heated from 0^oC, first increases then decreases.

(d) The latent heat of vaporization increases with increase in pressure of water.

(e) State of the wet vapor cannot be specified only by pressure and dryness fraction.

Sol. (a) False, (b) False, (c) False, (d) False, (e) False.

71. A rigid tank contains 50 kg of saturated liquid water at 90°C. Determine the pressure in the tank and the volume of the tank.

Sol.

Given. m_l=50 kg, temp= 90^0C.

From saturated steam table, At temp = 90^0C, Saturation pressure **P = 70.18 kPa**, and specific Vol. v_l=0.00103594 m^3/kg.

So **volume of the tank (V)** = $m_l \times v_l$ = 50 kg × 0.00103594 m^3/kg = **0.051797 m^3 ans.**

72. A piston –cylinder device contains $0.06m^3$ of saturated water vapor at 350 kPa pressure. Determine the temperature and mass of the vapor inside the cylinder.

Sol.

Given. V_g= 0.06 m^3, P= 350 kPa.

From saturated steam table, Sat. temp corresponding to pressure 350 kPa, $T_{sat.}$= 138.8^0C.

Sp. Volume of sat. vapour v_g=0.524 m^3/kg.

Mass of the sat. vapour m_g= V_g/ v_g= 0.06/0.524= **0.1145 kg. ans**

73. Show that efficiency of all reversible heat engines operating between the same temperature levels is the same.

74. The latent heat of vaporization with increase in pressure of water:

(a) Increases, (b) Remains constant (c) Decreases (d) None of the above

75. Why do constant temperature lines on Mollier diagram become parallel to abscissa in the superheated region at low pressure?

76. Prove that in T-S diagram slope of constant pressure line is less than that of constant volume line.

77. Why slope of saturated liquid curve is steeper than the saturated vapour curve on P-V diagram? Explain.
78. What do understand by Critical point and Triple point of water?
79. Why triple point is a point only in P-T Plot and a line in all other plots? Explain.
80. Write short note on.
    (a) Superheated vapour. (b) Dryness fraction, (c) Saturation Temperature, (d) Degree of sub cooling, (e) Degree of Superheating, (f) Sub cooled liquid.
81. Derive the efficiency of a Carnot cycle with the help of P-V diagram.
93. Derive the efficiency of a Carnot cycle with the help of T-S diagram.
94. State whether statements are True or False.
    a) Heat addition in an otto cycle takes place at constant volume.
    b) Compression ratio of diesel engine is higher than the petrol engine.
    c) Standard cycle for the steam power plant is Rankine cycle.
    d) Efficiency of an ideal Brayton cycle increases with increase in pressure ratio.
    Sol. (a) True, (b) True, (c) True, (d) True.
95. Drive the expression for the efficiency of Diesel Cycle with the help of P-V and T-S diagram.
96. Drive the expression for the efficiency of Otto Cycle with the help of P-V and T-S diagram.
97. Drive the expression for the efficiency of Brayton Cycle with the help of P-V and T-S diagram.
98. Derive the both Tds equations and explain whether any assumption is required for using Tds equations.
99. What are the different Air Standard assumptions considered for the analysis of air standard cycles.
100. Explain the different processes involved in Rankine cycle also draw schematic diagram of cycle depicting different components.
101. What do you understand by Mean Effective Pressure? Explain.
102. Explain the working of a 4-storke petrol engines with the help of schematic diagram.
103. What are the different processes involved in otto and diesel cycles explain with the help of P-V and T-S plot of the cycles.

104. In case of a dual cycle heat addition at constant volume is done before the heat addition at constant pressure. Why?

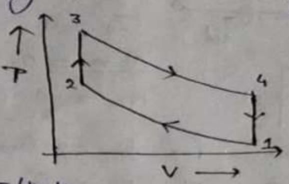
105. An Otto cycle with compression ratio of CR = 9:1. The intake air is at 100 kPa = 1 bar, 20°C, and the volume of the chamber is 500 cm³ prior to the compression stroke. The temperature at the end of adiabatic expansion is T_4 = 800 K. c_p = 1.01 kJ/kgK, c_v = 0.718 kJ/kgK, $\gamma = c_p/c_v$ = 1.4. Calculate:

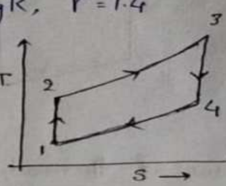
a) the mass of intake air
b) the temperature T3
c) the pressure p3
d) the amount of heat added by burning of fuel-air mixture
e) the thermal efficiency of this cycle
f) the MEP

$r = 9$, $P_1 = 100$ kPa, $T_1 = 20+273 = 293$ K, $V_1 = 500\ cm^3 = 0.5\times10^{-3}\ m^3$

$T_4 = 800$ K, $C_p = 1.01$ KJ/kgK, $C_v = 0.718$ KJ/kgK, $\gamma = 1.4$

① mass of intake air





from ideal gas eqⁿ

$PV = mRT$

R = characteristic gas const

$R_{air} = C_p - C_v = 0.292$ KJ/kgK

$100 \times 0.5\times10^{-3} = m_{air} \times 0.292 \times 293$

$m_{air} = 5.844\times10^{-4}$ kg

② Temp. T_3 for process 1-2 $T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1} \Rightarrow T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1} = T_1 \cdot r^{\gamma-1}$

$T_2 = 705.6$ K

for process 1-2 $P_1V_1^{\gamma} = P_2V_2^{\gamma} \Rightarrow P_2 = P_1\left(\frac{V_1}{V_2}\right)^{\gamma} = P_1 r^{\gamma} = 2167.4$ KPa

for process 3-4 $T_3V_3^{\gamma-1} = T_4V_4^{\gamma-1} \Rightarrow T_3 = T_4\left(\frac{V_4}{V_3}\right)^{\gamma-1} = T_4\left(\frac{V_1}{V_2}\right)^{\gamma-1} = T_4 r^{\gamma-1}$

So $T_3 = 1926.57$ K Ans

③ Press. P_3 Process 2-3 (V = const) $P \propto T$

$\frac{P_3}{P_2} = \frac{T_3}{T_2} \Rightarrow P_3 = P_2\frac{T_3}{T_2} \Rightarrow P_3 = 5917.89$ KPa Ans

④ Q_s we know $Q_s = Q_{2-3} = mC_v(T_3 - T_2) = 5.844\times10^{-4}\times0.718\times(1926.57-705.6)$

$Q_s = 0.5123$ KJ Ans

⑤ η_{otto} we know $\eta_{otto} = 1 - \frac{1}{r^{\gamma-1}} = 1 - \frac{1}{9^{1.4-1}} = 0.584$ or 58.4 %

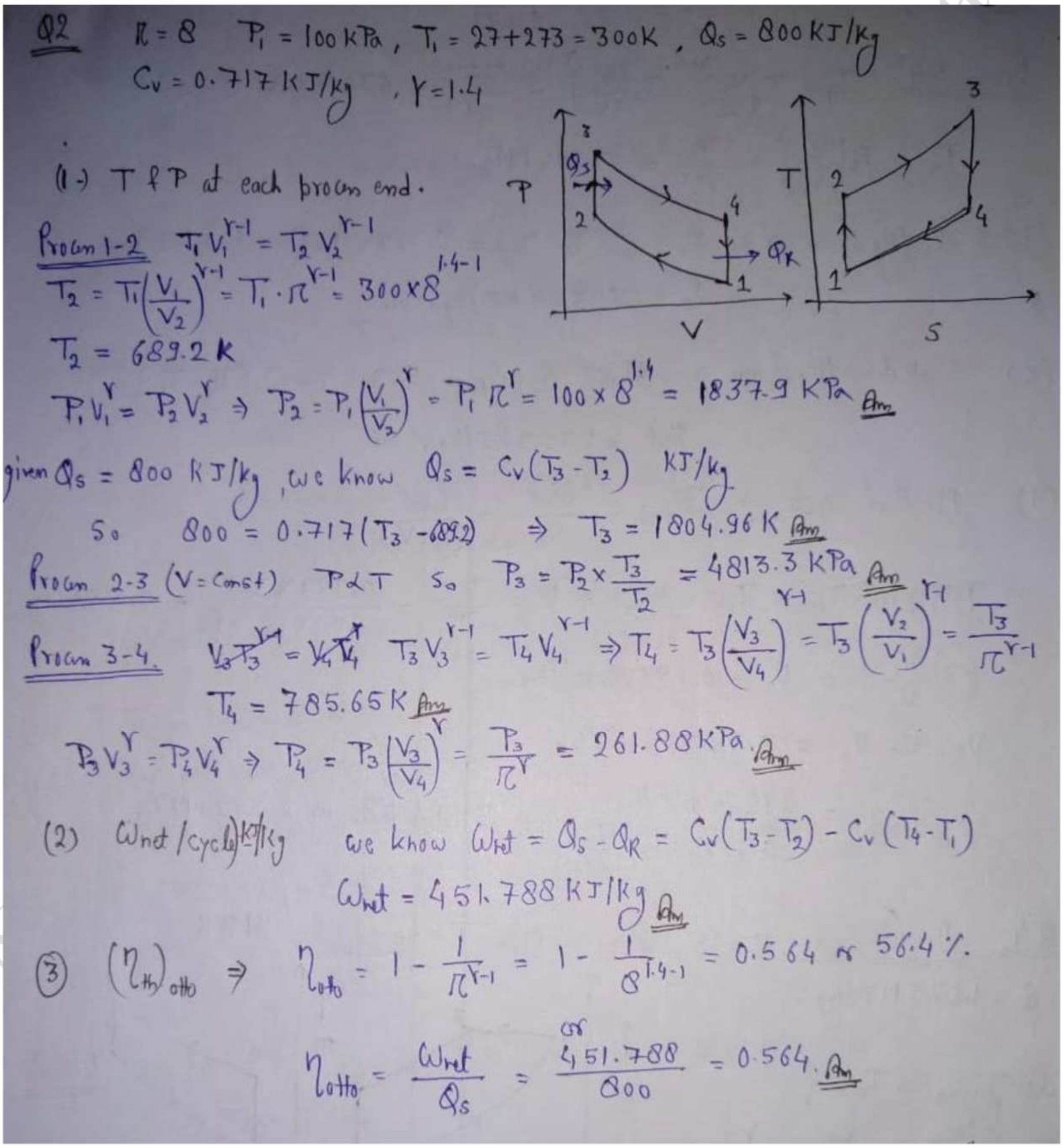
⑥ MEP $\Rightarrow P_{mep} = \frac{W_{net}}{V_s} = \frac{Q_s - Q_R}{V_1 - V_2} = \frac{0.5123 - mC_v(T_4 - T_1)}{V_1 - V_1/r}$

$P_{mep} = 674$ KPa Ans

107. An ideal air-standard Otto cycle engine has a compression ratio of 8. At the beginning of the compression process, the working fluid is at 100 kPa, 27°C (300 K), and 800

kJ/kg heat is supplied during the constant volume heat addition process. Neatly sketch the pressure-volume [*P*-*v*] diagram for this cycle, and using $C_v = 0.717$ kJ/kg.K, and $\gamma = 1.4$, determine:

a) the temperature and pressure of the air at the end of each process
b) the net work output/cycle kJ/kg
c) the thermal efficiency η_{th} of this engine cycle.



Q2 $r = 8$ $P_1 = 100$ kPa, $T_1 = 27+273 = 300$ K, $Q_s = 800$ kJ/kg

$C_v = 0.717$ kJ/kg, $\gamma = 1.4$

(1) T & P at each process end.

Process 1-2 $T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$

$T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1} = T_1 \cdot r^{\gamma-1} = 300 \times 8^{1.4-1}$

$T_2 = 689.2$ K

$P_1V_1^\gamma = P_2V_2^\gamma \Rightarrow P_2 = P_1\left(\frac{V_1}{V_2}\right)^\gamma = P_1 r^\gamma = 100 \times 8^{1.4} = 1837.9$ kPa Ans

given $Q_s = 800$ kJ/kg, we know $Q_s = C_v(T_3 - T_2)$ kJ/kg

So $800 = 0.717(T_3 - 689.2) \Rightarrow T_3 = 1804.96$ K Ans

Process 2-3 (V = Const) $P \propto T$ So $P_3 = P_2 \times \frac{T_3}{T_2} = 4813.3$ kPa Ans

Process 3-4. $T_3V_3^{\gamma-1} = T_4V_4^{\gamma-1} \Rightarrow T_4 = T_3\left(\frac{V_3}{V_4}\right)^{\gamma-1} = T_3\left(\frac{V_2}{V_1}\right)^{\gamma-1} = \frac{T_3}{r^{\gamma-1}}$

$T_4 = 785.65$ K Ans

$P_3V_3^\gamma = P_4V_4^\gamma \Rightarrow P_4 = P_3\left(\frac{V_3}{V_4}\right)^\gamma = \frac{P_3}{r^\gamma} = 261.88$ kPa Ans

(2) W_{net}/cycle kJ/kg we know $W_{net} = Q_S - Q_R = C_v(T_3 - T_2) - C_v(T_4 - T_1)$

$W_{net} = 451.788$ kJ/kg Ans

(3) $(\eta_{th})_{otto} \Rightarrow \eta_{otto} = 1 - \frac{1}{r^{\gamma-1}} = 1 - \frac{1}{8^{1.4-1}} = 0.564$ or 56.4%.

or

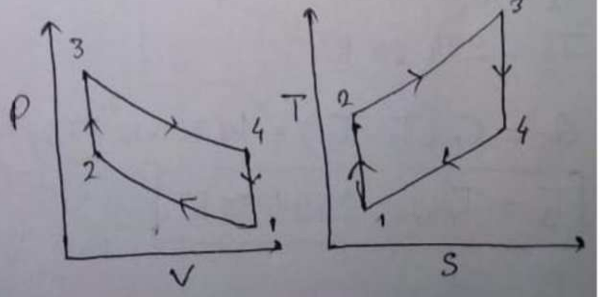
$\eta_{otto} = \frac{W_{net}}{Q_s} = \frac{451.788}{800} = 0.564$ Ans

108. In an air standard Otto cycle, the compression ratio is 7 and the compression begins at

35^0C and 0.1 MPa. The maximum temperature of the cycle is 1100^0C. Find (a) the temperature and the pressure at various points in the cycle, (b) the heat supplied per kg of air, (c) work done per kg of air, (d) the cycle efficiency and (e) the MEP of the cycle.

Q.3. $r = 7$, $T_1 = 35 + 273 = 308K$, $P_1 = 0.1 MPa$. $T_{max} = T_3 = 1100^{\circ}c = 1373 K$

(a) T & P at various points.



Process 1-2 $T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1} = T_1 r^{\gamma-1}$

$T_2 = 670.79 K$

$P_2 = P_1\left(\frac{V_1}{V_2}\right)^{\gamma} = P_1 r^{\gamma} = 1.52 MPa$

Process 2-3 $P_3 = P_2 \frac{T_3}{T_2} = 1.52 \times \frac{1373}{670.79} = 3.12 MPa$

Process 3-4 $T_4 = T_3\left(\frac{V_3}{V_4}\right)^{\gamma-1} = T_3\left(\frac{V_2}{V_1}\right)^{\gamma-1} = \frac{T_3}{r^{\gamma-1}} = 630.42 K$

$P_4 = P_3\left(\frac{V_3}{V_4}\right)^{\gamma} = \frac{P_3}{r^{\gamma}} = 0.204 MPa$

(b) Q_s /kg of air $\Rightarrow$ $Q_s = C_v(T_3 - T_2) = 0.717 \times (1373 - 670.79)$

$Q_s = 503.48$ KJ/kg of air

(c) Work done /kg of air $\Rightarrow$ $W_{net} = Q_s - Q_R = 503.48 - C_v(T_4 - T_1)$

$W_{net} = 272.3$ KJ/kg of air.

(d) MEP of cycle $\Rightarrow$ $P_{mep} = \frac{W_{net}}{V_s} = \frac{W_{net}}{(V_1 - V_2)}$

$P_1V_1 = mRT_1 \Rightarrow P_1v_1 = RT_1 \Rightarrow v_1 = \frac{RT_1}{P_1} = \frac{0.287 \times 308}{0.1 \times 10^3 \text{ KPa}} = 0.8839 \text{ m}^3/\text{kg}$

$r = \frac{V_1}{V_2} \Rightarrow v_2 = 0.12628 \text{ m}^3/\text{kg}$

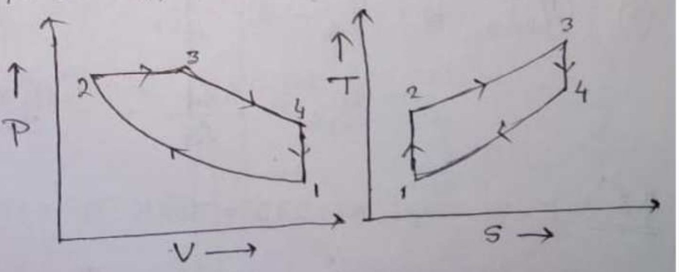
$V_s = v_1 - v_2 = 0.75762 \text{ m}^3/\text{kg}$

$P_{mep} = \frac{272.3 \text{ KJ/kg}}{0.75762 \text{ m}^3/\text{kg}} = 359.4 \text{ KPa}$ or 0.3594 MPa.

109. In a Diesel cycle, the compression ratio is 15. Compression begins at 0.1 MPa, 40^0C. The heat added is 1.675 MJ/kg. Find (a) the maximum temperature in the cycle, (b) work done per kg of air (c) the cycle efficiency (d) the temperature at the end of the isentropic expansion (e) the cut-off ratio and (f) the MEP of the cycle.

Q.4 Diesel cycle. $r = 15$, $P_1 = 0.1$ MPa, $T_1 = 40 + 273 = 313$ K

$Q_s = 1.675$ MJ/kg.



(a) $T_{max} = T_3 = ?$

Process 1-2 $T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$

$T_2 = T_1 r^{\gamma-1} = 313 \times 15^{1.4-1}$

$T_2 = 924.65$ K

$Q_s = C_p (T_3 - T_2) = 1.675 \times 10^3$ KJ/kg $= 1.005 (T_3 - 924.65)$

$T_3 = T_{max} = 2591.32$ K.

(b) Workdone / kg of air

$W_{net} = Q_s - Q_R = 1.675 \times 10^3 - C_v (T_4 - T_1)$

Process 1-2 $P_2 = P_1 r^{\gamma} = 0.1 \times 15^{1.4} = 4.43$ MPa $= P_3$ bcoz $P_2 = P_3$

Process 2-3 (P = const) $V \propto T \Rightarrow \frac{V_3}{V_2} = \frac{T_3}{T_2} = \frac{2591.32}{924.65} = 2.8 = \rho$ (cut off ratio)

Process 3-4 $T_3 V_3^{\gamma-1} = T_4 V_4^{\gamma-1} \Rightarrow T_4 = T_3 \left(\frac{V_3}{V_4}\right)^{\gamma-1} = T_3 \left(\frac{V_3}{V_1} \times \frac{V_2}{V_2}\right)^{\gamma-1}$

$T_4 = T_3 \frac{\rho^{\gamma-1}}{r^{\gamma-1}} = 2591.32 \left(\frac{2.8}{15}\right)^{1.4-1} = 1324.65$ K.

$W_{net} = 1.675 \times 10^3 - 0.717 (1324.65 - 313)$

$W_{net} = 949.64$ KJ/kg of air

(c) Cycle efficiency $\Rightarrow \eta = \frac{W_{net}}{Q_s} = \frac{949.64}{1.675 \times 10^3} = 0.5669$ or 56.69%

(d) $T_4 = 1324.65$ K

(e) cut off ratio $\rho = \frac{V_3}{V_2} = 2.8$

(f) MEP of cycle $\Rightarrow P_{mep} = \frac{W_{net}}{V_s}$

$P_1 v_1 = R T_1 \Rightarrow v_1 = \frac{0.287 \times 313}{0.1 \times 10^3} = 0.89831$ m³/kg $\quad v_2 = \frac{v_1}{r} = 0.05988$ m³/kg

$P_{mep} = \frac{949.64}{v_1 - v_2} = 1.132$ MPa. Ans

110. A diesel engine has a compression ratio of 20:1 with an inlet of 95 kPa, 290 K, with volume 0.5 L. The maximum cycle temperature is 1800 K. Find the maximum pressure, the net specific work and the thermal efficiency.

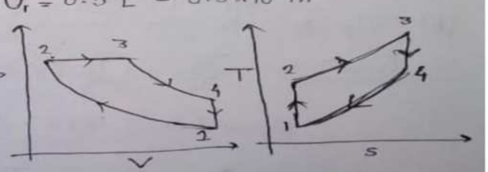
Q.5. $r = 20$, $P_1 = 95$ KPa, $T_1 = 290$K, $V_1 = 0.5$ L $= 0.5\times10^{-3}$ m^3

$T_{max} = T_3 = 1800$K

$(\text{Pressure})_{max} = P_2 = P_3$

Process 1-2 ⇒ $P_2 = P_1 r^{\gamma} = 95\times 20^{1.4}$

So $P_{max} = 6297.46$ KPa.



W_{net}/kg ⇒ $Q_S - Q_R = C_p(T_3 - T_2) - C_v(T_4 - T_1)$

Process 1-2 ⇒ $T_2 = T_1 r^{\gamma-1}$ ⇒ $T_2 = 961.19$ K.

Process 2-3 $\rho = \frac{V_3}{V_2} = \frac{T_3}{T_2} = \frac{1800}{961.19} = 1.872$

Process 3-4. $T_3 V_3^{\gamma-1} = T_4 V_4^{\gamma-1}$ ⇒ $T_4 = T_3\left(\frac{V_3}{V_4}\right)^{\gamma-1} = T_3\left(\frac{V_3}{V_1}\times\frac{V_2}{V_2}\right)^{\gamma-1} = T_3\left(\frac{\rho}{r}\right)^{\gamma-1}$

$T_4 = 1800\left(\frac{1.872}{20}\right)^{1.4-1} = 697.98$ K.

$W_{net} = C_p(T_3 - T_2) - C_v(T_4 - T_1) = 1.005(1800 - 961.19) - 0.717(697.98 - 290)$

$W_{net} = 550.479$ KJ/kg

thermal efficiency $\eta = \frac{W_{net}}{Q_S} = \frac{550.479}{C_p(T_3 - T_2)} = 0.6529$ or 65.29%.

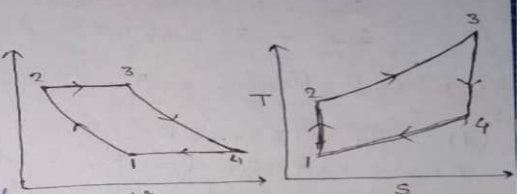
111. In a Brayton cycle based power plant, the air at the inlet is at 27^{0}C, 0.1 MPa. The pressure ratio is 6.25 and the maximum temperature is 800 C. Find (a) the compressor work per kg of air (b) the turbine work per kg or air (c) the heat supplied per kg of air, and (d) the cycle efficiency.

Q.6 Brayton cycle

$T_1 = 27+273 = 300$K, $P_1 = 0.1$ MPa

$r_p = \frac{P_2}{P_1} = 6.25$

$T_{max} = T_3 = 800+273 = 1073$ K



(a) W_c ⇒ $W_c = (h_2 - h_1)$

$W_c = C_p(T_2 - T_1)$ KJ/kg of air

Process 1-2 $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma}$ ⇒ $T_2 = 300\times 6.25^{\frac{1.4-1}{1.4}} = 506.425$K.

$W_c = 1.005(506.425 - 300) = 207.457$ KJ/kg of air (on the system)

(b) W_T ⇒ $W_T = (h_3 - h_4)$

$W_T = C_p(T_3 - T_4)$

Process 3-4. $\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\gamma-1/\gamma} = \left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma}$ ⇒ $T_4 = T_3\left(\frac{P_1}{P_2}\right)^{\gamma-1/\gamma} = \frac{T_3}{r_p^{\gamma-1/\gamma}} = 635.63$ K

$W_T = 1.005(1073 - 635.63) = 439.55$ KJ/kg of air Ans

(c) Q_S ⇒ $Q_S = C_p(T_3 - T_2) = 1.005(1073 - 506.425) = 569.40$ KJ/kg Ans

(d) η_{cycle} ⇒ $\eta = \frac{W_{net}}{Q_S} = \frac{W_T - W_C}{Q_S} = 0.407$ or 40.76%. Ans

112. A large stationary Brayton cycle gas-turbine power plant delivers a power output of 100 MW to an electric generator. The minimum temperature in the cycle is 300 K, and the maximum temperature is 1600 K. The minimum pressure in the cycle is 100 kPa, and the compressor pressure ratio is 14 to 1. Calculate the power output of the turbine. What fraction of the turbine output is required to drive the compressor? What is the thermal efficiency of the cycle?

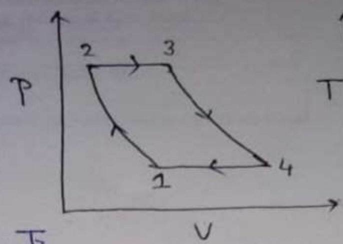
$P = 100\ MW$, $T_{min} = T_1 = 300K$, $T_{max} = T_3 = 1600K$

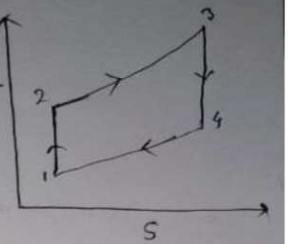
$P_{min} = P_1 = P_4 = 100\ kPa$, $r_p = \frac{P_2}{P_1} = 14$

Process 1-2

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

$T_2 = 637.65\ K$





Process 3-4

$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\gamma-1/\gamma} = \left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma} \Rightarrow T_4 = \frac{T_3}{r_p^{\gamma-1/\gamma}}$

$T_4 = 752.75\ K$

We know Power output $= (W_T - W_c) = \dot{m}(h_3 - h_4) - \dot{m}(h_2 - h_1)$

$100 \times 10^3 = \dot{m}\left[C_p(T_3 - T_4) - C_p(T_2 - T_1)\right]$

$100 \times 10^3 = \dot{m} \times 1.005\left[(1600 - 752.75) - (637.65 - 300)\right]$

$\dot{m} = 195.25\ kg/sec$

turbine Power $W_T = \dot{m}(h_3 - h_4) = \dot{m}C_p(T_3 - T_4) = 166.25\ MW$ Ans

Compressor Power $W_c = \dot{m}(h_2 - h_1) = \dot{m}C_p(T_2 - T_1) = 66.255\ MW$

fraction of turbine o/p to drive Compressor $= \frac{W_c}{W_T} \times 100 = 39.8\%$. Ans

thermal efficiency $\Rightarrow \eta_{th} = \frac{Power}{Q_s} = \frac{100 \times 10^3\ kW}{\dot{m}(h_3 - h_2)\ kW} = \frac{100 \times 10^3}{195.25 \times C_p(T_3 - T_2)}$

$\eta_{th} = 0.529$ or 52.9%. Ans