Q.1) A) State first law of thermodynamics. What is its limitation?

Ans: Fist law of Thermodynamics-

First law of thermodynamics is nothing but the law of conservation of energy which states that, "Energy can neither be created nor be destroyed but it can be transfer from one form to another form."

In other words when a closed system undergoes any cyclic process, the cyclic integral of work is proportional to the cyclic integral of heat.

i.e. $\int \delta W = \int \delta Q$

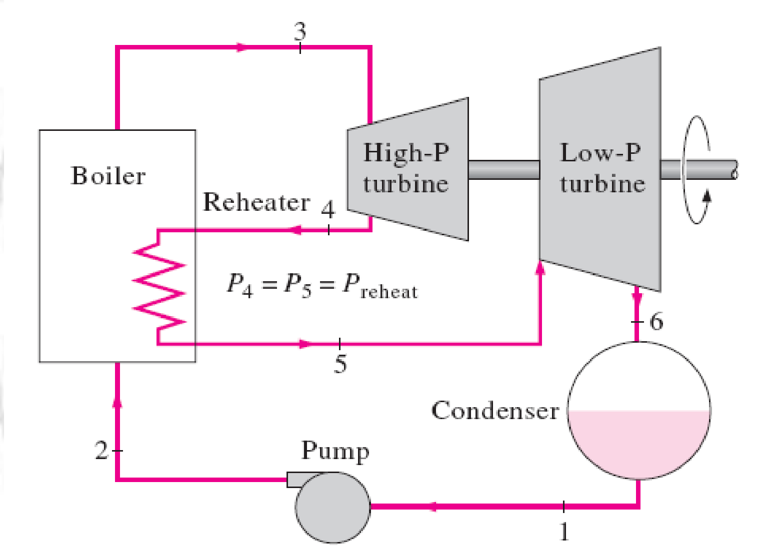
Limitations of first law of thermodynamics-

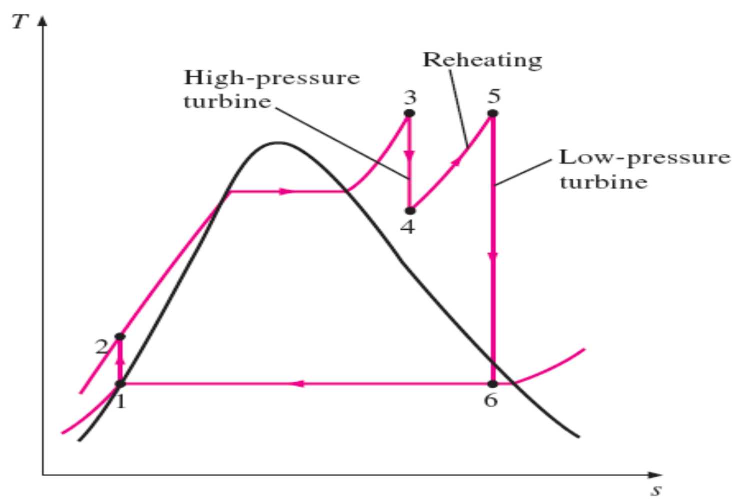
It does not give any idea of the of conversion of energy from one form to the another

It does not give any idea of direction of heat transfer

B) Draw a simple schematic of thermal plant with one reheater. Also represent it on T-S diagram.

Ans:





C) What are the assumptions for air standard cycle?

Ans: Assumption of air standard cycle-

1) The working medium is air & behaves like a perfect gas & obeys all gas laws.
2) All process include in the cycle are reversible adiabetic.
3) The compression & expansion process are reversible adiabetic.
4) The specific heats Cp & Cv of air do not change with temperature.
5) There is no change in mass of working substance.
6) There should not be any chemical reaction takes place.
7) There is no any heat loss from the system to the surrounding.

D) Prove that $[COP]_{HP} = 1 + [COP]_{REF}$

Ans: $[COP]_{HP} = 1 + [COP]_{REF}$

Now $[COP]_{HP} = \left[\frac{Q_1}{Q_1 - Q_2}\right]$ &

$[COP]_{HP} = \left[\frac{Q_2}{Q_1 - Q_2}\right]$

From 1

$$\frac{Q_1}{Q_1 - Q_2} = \frac{Q_2}{Q_1 - Q_2} + 1$$

$$= \frac{Q_2 + Q_1 - Q_2}{Q_1 - Q_2}$$

$$= \frac{Q_1}{Q_1 - Q_2}$$

LHS=RHS

Therefore $[COP]_{HP} = 1 + [COP]_{REF}$

F) What do you understand by the degree of superheat & the degree of subcooling

Ans: Degree of Superheat-

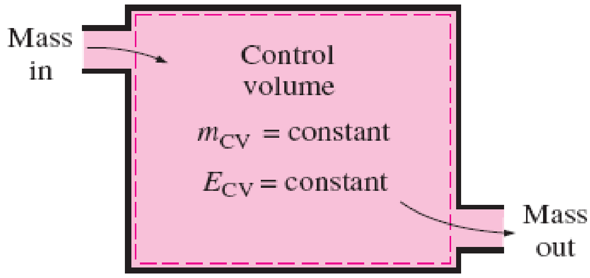
The difference between temperature of superheated vapour & saturation temperature is called degree of superheat.

Degree of Subcooling-

The difference between temperature of saturation temperature & actual liquid temperature is termed as the degree of subcooling.

Q.2) A) Derive the general equation for steady flow process. Explain the physical significance of the several terms of the equation.

Ans:



The *mass balance* for a general steady-flow system was given

$$\sum_{in} \dot{m} = \sum_{out} \dot{m} \qquad \text{(kg/s)}$$

The mass balance for a single-stream (one-inlet and one-outlet) steady-flow system was given as

$$\dot{m}_1 = \dot{m}_2 \quad \rightarrow \quad \rho_1 V_1 A_1 = \rho_2 V_2 A_2$$

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc., energies}}} \overset{0 \text{ (steady)}}{} = 0$$

Energy balance:

$$\underbrace{\dot{E}_{in}}_{\substack{\text{Rate of net energy transfer in} \\ \text{by heat, work, and mass}}} = \underbrace{\dot{E}_{out}}_{\substack{\text{Rate of net energy transfer out} \\ \text{by heat, work, and mass}}} \qquad \text{(kW)}$$

Noting that energy can be transferred by heat, work, and mass only, the energy balance in Eq. 5–34 for a general steady-flow system can also be written more explicitly as

$$\dot{Q}_{in} + \dot{W}_{in} + \sum_{in} \dot{m}\theta = \dot{Q}_{out} + \dot{W}_{out} + \sum_{out} \dot{m}\theta$$

or

$$\dot{Q}_{in} + \dot{W}_{in} + \sum_{in} \underbrace{\dot{m}\left(h + \frac{V^2}{2} + gz\right)}_{\text{for each inlet}} = \dot{Q}_{out} + \dot{W}_{out} + \sum_{out} \underbrace{\dot{m}\left(h + \frac{V^2}{2} + gz\right)}_{\text{for each exit}}$$

since the energy of a flowing fluid per unit mass is u _ *h* _ ke _ pe _ *h* _ *V*2/2 _ *gz*. The energy balance relation for steady-flow systems first appeared in 1859 The first-law or energy balance relation in that case for a general steady-flow system becomes

$$\dot{Q} - \dot{W} = \sum_{out} \underbrace{\dot{m}\left(h + \frac{V^2}{2} + gz\right)}_{\text{for each exit}} - \sum_{in} \underbrace{\dot{m}\left(h + \frac{V^2}{2} + gz\right)}_{\text{for each inlet}}$$

Obtaining a negative quantity for Q or W simply means that the assumed direction is wrong and should be reversed. For single-stream devices, the steady-flow energy balance equation becomes

$$\dot{Q} - \dot{W} = \dot{m}\left[h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)\right]$$

Dividing above equation by m gives the energy balance on a unit-mass basis as

$$q - w = h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)$$

Q.2) B) A system containing 0.2 m^3 of air at a pressure of 4 bar & 160 ^{0} C expands isentropically to pressure of 1.o6 bar & after this the gas is heated at the constant pressure till the enthalpy increases by 65 Kj. Calculate the work done. Now imagine that these processes are replaced by a single reversible polytropic process producing same work between initial & final state. Find the index of expansion in this case. Take Cp of air =1.005 Kj/Kg.K

Ans: Given Data-:

$V_1 = 0.2m^3$,

$P_1 = 4bar = 4*10^5 \frac{N}{m^2}$,

$T_1 = 160^0 C = 433^0 K, P_2 = 1.06bar = 1.02*10 \frac{N}{m^2}, Enthalpy = 65KJ$

i) Work Done

Total Work done= $W_{1-2} + W_{2-3}$

$$= \frac{P_1V_1 - P_2V_2}{\gamma - 1} + P(V_3 - V_2)$$

Process 1-2 is adiabatic Process

So $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$

$$\frac{T_2}{T_1} = \left(\frac{1.06*10^5}{4*10^5}\right)^{\frac{1.4-0.4}{1.4}}$$

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

$$\frac{296.17}{433} = \left(\frac{0.2}{V_2}\right)^{0.4}$$

V_2=0.517 m$^{3.}$

Process 2-3 is constant pressure process

$$\frac{V_2}{T_2} = \frac{V_3}{T_3}$$

We know

Enthalpy=$mC_p\Delta_T$

$= mC_p(T_3-T_2)$

We know P_1V_1=mRT_1

m=$\frac{4\times10^5\times0.2}{433\times287}$

m=0.644 Kg

Change in Enthalpy=$mC_p(T_3-T_2)$

65=0.644×1.005(T_3-296.17)

T_3=396.6 K

Now

$$\mathbf{\frac{V_2}{T_2} = \frac{V_3}{T_3}}$$

$$\mathbf{V_3 = \frac{0.517}{296.17} \times 396.6\ K}$$

Total Work done=$W_{1-2} + W_{2-3}$

$$= \frac{P_1V_1 - P_2V_2}{\gamma - 1} + P(V_3 - V_2)$$

$$= \frac{44\times10^5\times0.2 - 1.02\times10^5\times0.517}{1.4-1} + 1.06\times10^5(0.612 - 0.517)$$

=62995-18550

=81545 J

ii) Index of Expansion

If above total work done is at polytropic process then

$$W_{1-2-3} = \frac{P_1V_1 - P_2V_2}{n-1}$$

$$= \frac{44\times10^5\times0.2 - 1.02\times10^5\times0.517}{n-1} =$$

$$= \frac{80000 - 73352}{n-1}$$

n-1=0.08153

n=1.08153

Q.3 A) State & explain Kelvin-Planks & Clausius statement of second law of thermodynamics.

Ans: KELVIN PLANCK STATEMENT

It is impossible to construct a cyclically operating device such that it produces no other effect than the absorption of energy as heat from a single thermal reservoir and performs an equivalent amount of work.

The only option then is that the engine converts part of the energy it receives as heat into work and rejects the rest to another thermal reservoir the temperature of which is less than the temperature of the source. Two thermal reservoirs, one of high temperature (source), from which the working fluid receives energy as heat, and the other of low temperature (sink), to which the working fluid rejects energy as heat, are needed for a heat engine. Once the heat engine rejects a part of the energy it receives, its efficiency becomes less than one. Thus the Kelvin Planck statement further implies that no heat engine can have a thermal efficiency of one (hundred percent). This does not violate the first law of thermodynamics either.

Clausius Statement of the Second Law

Heat always flows from a body at higher temperature to a body at a lower temperature. The reverse process never occurs spontaneously. Clausius' statement of the second law gives:

It is impossible to construct a device which operating in a cycle, will produce no effect other than the transfer of heat from a low temperature body to a high temperature body. This statement tells us that it is impossible for any device, unaided by an external agency, to transfer energy as heat from a cooler body to a hotter body. Consider the case of a refrigerator or a heat pump

Q.3) B) A heat engine receives 1000 Kw of heat at a constant temperature 285^0C. The heat rejected at 5^0 C. The possible heat rejected are -:
1) 840 Kw 2) 498 Kw 3) 300 Kw
Classify which of the result report a reversible cycle or irreversible cycle or impossible results.

Ans: Apply the Clausius Inequality in each case with proper sign convention

a) $\int \frac{\delta Q}{T} = \int \left(\frac{\delta Q}{T}\right)_{add} - \int \left(\frac{\delta Q}{T}\right)_{rej}$

$= \frac{1000}{285+273} - \frac{840}{5+273}$

$= -1.229 < 0$

Hence the cycle is irreversible

b) $\int \frac{\delta Q}{T} = \int \left(\frac{\delta Q}{T}\right)_{add} - \int \left(\frac{\delta Q}{T}\right)_{rej}$

$= \frac{1000}{285+273} - \frac{492}{5+273}$

$= 0.00007 \cong 0$

Hence the cycle is Reversible

c) $\int \frac{\delta Q}{T} = \int \left(\frac{\delta Q}{T}\right)_{add} - \int \left(\frac{\delta Q}{T}\right)_{rej}$

$= \frac{1000}{285+273} - \frac{300}{5+273}$

$= 0.713$

The Clausius inequality does not hold good hence the cycle is not possible.

Q.3) C) Calculate the change in entropy of air, if it is throttled from 5 bar, 27^0 C to 2 bar adiabatically.

Ans: P_1=5 bar, T_1=300 K,
P_2= 2 bar, Cp=1.005 KJ/Kg.K
R=0.287 KJ/Kg.K

$S_2 - S_1 = Cp \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$

For Throttling Process

$h_1 = h_2$

so $Cp\, T_1 = Cp\, T_2$

$T_1 = T$

Therefore $S_2 - S_1 = Cp \ln(1) - R \ln \frac{2}{5}$

$= 0.263$ KJ/Kg.

Q.4) A) Draw the following chart for steam
i) T-S & ii) h-s

T-S diagram for steam

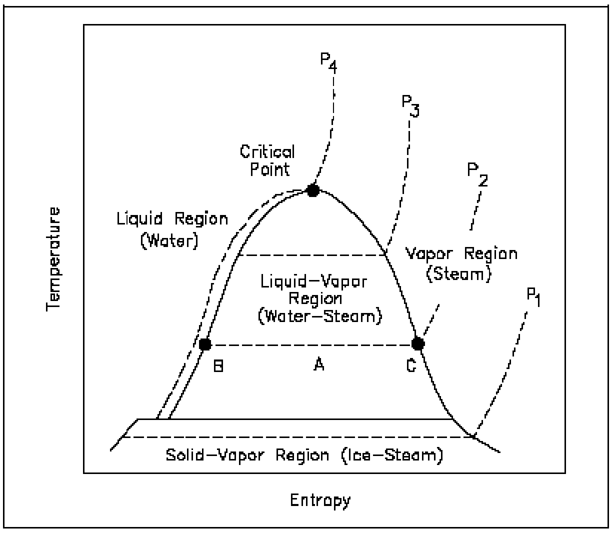
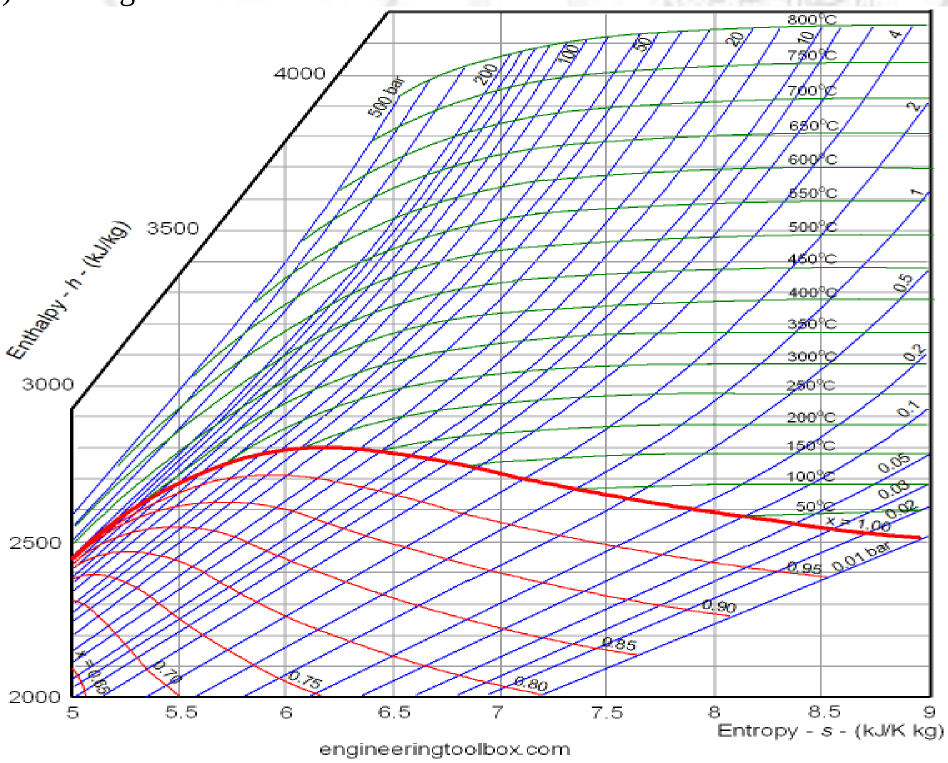


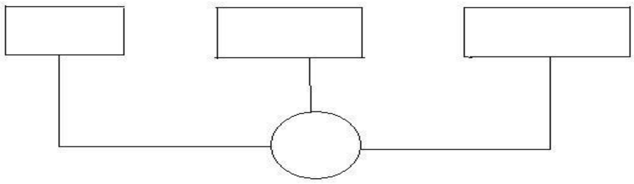
Figure 13 T-s Diagram for Water

ii) H-S diagram for steam



B) A reversible heat engine absorbs 30t 500 K00 Kj from a reservoir at 1000 K & rejects 2500 Kj at 500 K. Find the heat interchanged with the reservoir at 300 K & the net work output of the engine.

Ans:



Since the engine is reversible $\Delta S = 0$

Therefore $\frac{3000}{1000} - \frac{2500}{500} - \frac{Q}{300} = 0$

Q= 600 KJ

Wnet = Q_H - Q_L

= (3000+600-2500)

=1100 KJ

Q.4) C) Define-:

1) Available energy-

The availability of the system represents the maximum amount of theoretical work i.e. without dissipative effect that can be obtained from a system when it is brought down from the given state to dead state i.e. surrounding condition. The maximum useful work thus obtained under ideal conditions is called the available energy.

ii) Dryness fraction-

The ratio of mass of dry-saturated steam in a given mass of wet steam is defined as dryness fraction.

Dryness fraction=X=m_s/m_s+m

The dryness fraction (x) represents the mass of dry saturated steam in 1 kg of wet steam.

iii) Joule-Thomson co efficient-

Joule-Thomson co efficient is defined as the rate of change of temperature with pressure during an isenthalpic or throttling process.

The rate of change of temperature T with respect to pressure P in a Joule–Thomson process (that is, at constant enthalpy H) is the *Joule–Thomson (Kelvin) coefficient* μ_{JT}. This coefficient can be expressed in terms of the gas's volume V, its heat capacity at constant pressure C_p, and its coefficient of thermal expansion α

See the Derivation of the Joule–Thomson (Kelvin) coefficient below for the proof of this relation. The value of μ_{JT} is typically expressed in °C/bar (SI units: K/Pa) and depends on the type of gas and on the temperature and pressure of the gas before expansion. Its pressure dependence is usually only a few percent for pressures up to 100 bar.

iv) Equality of temperature-

Two bodies have equality of temperature if, when they are in thermal communication, no change in any observable property occurs. The title may also be read as Equilibrium of Temperature.

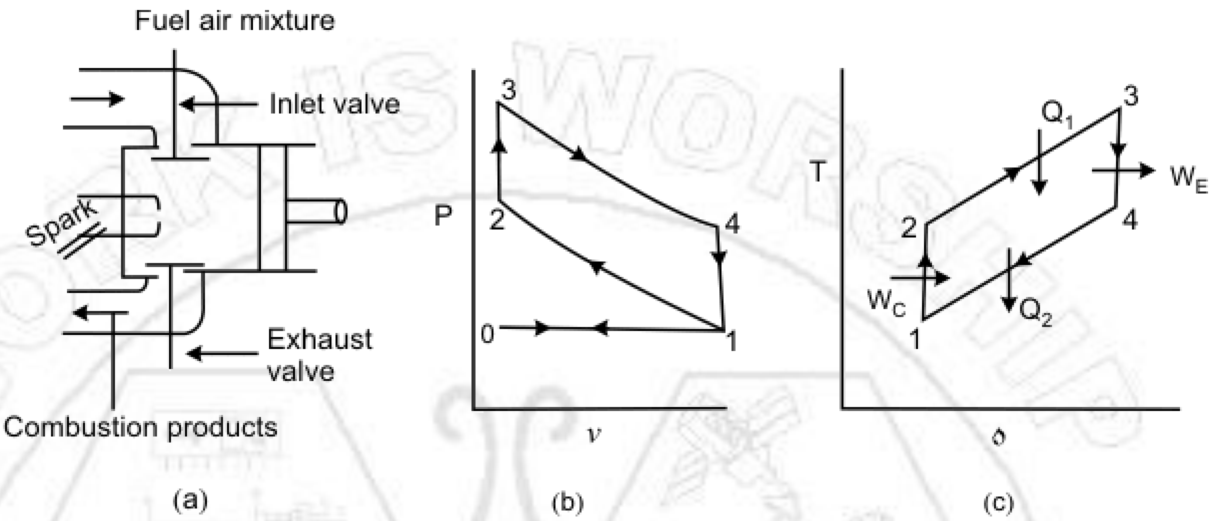
Although temperature is a familiar property, defining it exactly is difficult. Temperature may be understood in terms of a sense of hotness or coldness when touching an object. When a hot body and a cold body are brought into contact, the hot body becomes cooler and the cold body becomes warmer. If these bodies remain in contact for some time, they usually appear to have the same hotness or coldness. However, one's sense of hotness or coldness is very unreliable. Sometimes very cold bodies may seem hot, and bodies of different materials that are at the same temperature appear to be at different temperatures.

Because of these difficulties in defining temperature, the equality of temperature is defined.

Q.5) A) Show that for maximum work to be done per Kg of air in Otto cycle between given upper & lower limits of absolute temperature T_3 & T_1 respectively, The ratio of compression should have the value

$r=(T_3|T_1)^{1.25}$ when $\gamma=1.4$

Ans-



From above figure

Work done per cycle W=Heat added-Heat rejected

$= C_v(T_3-T_2) - C_v(T_4-T_1)$ KJ/Kg

From isentropic compression process 1-2

$T_2=T_1(r)^{\gamma-1}$ Where $r = \frac{V_1}{V_2} = \frac{V_4}{V_3}$

From isentropic expansion process 3-4

$T_4=T_3(1/r)^{\gamma-1}$

So $W= C_v[T_3-T_1(r)^{\gamma-1} - T_3 (1/r)^{\gamma-1} - T_1]$ KJ/Kg

To obtain maximum work differentiate work done wrt r & equate to 0. Thus

$\frac{dW}{dr} = [-T_1 (\gamma-1) (r)^{\gamma-2} - T_3 (1-\gamma) (r)^{-\gamma}]$

$T_1 (\gamma-1) (r)^{\gamma-2} = T_3 (1-\gamma) (r)^{-\gamma}$

$\frac{T_3}{T_1} = \frac{r^{\gamma-2}}{r^{-\gamma}}$

$= (r)^{2\gamma-2}$

$When\ \gamma = 1.4\ then$

$\frac{T_3}{T_1} = r^{2.8-2} = r^{0.8}$

$$r = \left(\frac{T_3}{T_1}\right)^{\frac{1}{0.8}}$$

$$r = \left(\frac{T_3}{T_1}\right)^{1.25}$$

So for maximum work to be done in Otto cycle the value of compression ratio should have

$$r = \left(\frac{T_3}{T_1}\right)^{1.25}$$

Q.5) B) A diesel engine has 20 cm bore & 30 cm stroke. The clearance volume is 420 cm³. The fuel is injected at constant pressure for 5% of the stroke. Calculate the air standard efficiency. If the cut-off is 5% to 8% what will be the percentage loss in efficiency. In both case, the compression ratio is the same.

Ans: Given data

D=20 cm, L=30 cm

Clearance volume $V_c = V_2 = 420\ cm^3$

Swept volume $= V_s = V_1 - V_2$

$$= \frac{\pi}{4} \times d^2 \times L$$

$$= \frac{\pi}{4} \times 20^2 \times 30$$

$= 9424.778\ cm^3$

Cylinder volume $V_1 = V_s + V_2$

$= 9424.778 + 420$

$= 9844.77\ cm^3$

But $V_3 = V_2 + 0.05 * V_s$

$= 420 + 0.05 * 9424.778$

$= 891.238\ cm^3$

Fuel cut of ratio $\rho = \frac{V_3}{V_2} = \frac{891.238}{420}$

$= 2.121$

Compression $r = \frac{V_1}{V_2} = \frac{9844.778}{420} = 23.439$

Now efficiency of diesel engine is given by

$$= 1 - \frac{1}{(r^{\gamma-1})\gamma}\left[\frac{(\rho^{\gamma}-1)}{(\rho-1)}\right]$$

$$= 1 - \frac{1}{(23.439^{0.4})1.4}\left[\frac{(2.121^{1.4}-1)}{(2.121-1)}\right]$$

$= 66.34\%$

If the fuel is cut off at 8% of the stroke

$V_3 = 420 + 0.08 * 9424.778$

$= 1173.982\ m^3$

Fuel cut off ratio $\rho = \frac{V_3}{V_2} = \frac{1173.982}{420}$

$= 2.795$

So thermal efficiency

$$=1-\frac{1}{(r^{\gamma-1})\gamma}\left[\frac{(\rho^{\gamma}-1)}{(\rho-1)}\right]$$

$$=1-\frac{1}{(23.439^{0.4})1.4}\left[\frac{(2.795^{1.4}-1)}{(2.795-1)}\right]$$

= 0.6375

= 63.75 %

Percentage loss = (η_{the1}- η_{the2} / η_{the1}) * 100

$$=\frac{0.6634-0.63759}{0.6634}\times 100$$

= 3.89 %

Q.6) A) Give reasons why Carnot cycle cannot be conceder as the theoretical cycle for steam power plant even through its efficiency is maximum.

Ans: Carnot cycle has two main limitations as follows-:

1. At the end of expansion of steam in turbine the steam becomes wet. So water vapors present in the steam. If such water vapors particles are come in contact with turbine blade, then there will be corrosion of blade.
2. In actual Carnot cycle the condensation process is incomplete. Due to incomplete condensation vapor particles are present with water. If such wet steam is feed by using pump into the boiler then feed pump handles large volume of wet steam. So Feed pump consume more power & overall efficiency will decreases.

Due to above two main reasons Carnot cycle can not be considered as the theoretical cycle for steam power plant even though its efficiency is maximum.

Q.6) B) Steam is supplied to the turbine at a pressure of 32 bar & a temperature of 395^0 C. It expands isentropically to a pressure of 0.08 bar. What is the dryness fraction at the end of expansion & the thermal efficiency? Calculate the modified condition & thermal efficiency if the steam is reached at 5,5 bar to a temperature of 395^0 C & then expanded isentropically *to a pressure of 0.08 bar*

Ans: a) From steam table

h_{f2}=174 KJ/Kga

From Mollier chart

h_1=3230 KJ/Kg

h_2= 2140 KJ/Kg

x_2=0.825

Work done = h_1-h_2

= 3230-2140

=1090 KJ/Kg

Heat supplied = h_1-h_{f2}

= 3230-173.9

=3056.1 KJ/Kg

Thermal efficiency = $\frac{Work\ done}{Heat\ supplied}$

$= \frac{1090}{3056.1}$

η_{the} =35.60 %

b) In the modified case the reheating of steam takes place at 5.5 bar to a temperature of 395^0 C. From Mollier chart

h_1= 3230 KJ/Kg, h_2= 2800 KJ/Kg,

h_3 = 3270 KJ/Kg, h_4 = 2420 KJ/Kg

Work done = $(h_1-h_2) + (h_3-h_4)$

= (3230-2800) + (3270- 2420)

= 430 + 850

= 1280 KJ/Kg

Heat supplied = $(h_1-h_{f4}) + (h_3-h_2)$

= (3230-173.9) + (3270-2800)

=3056 + 470

=3526 KJ/Kg

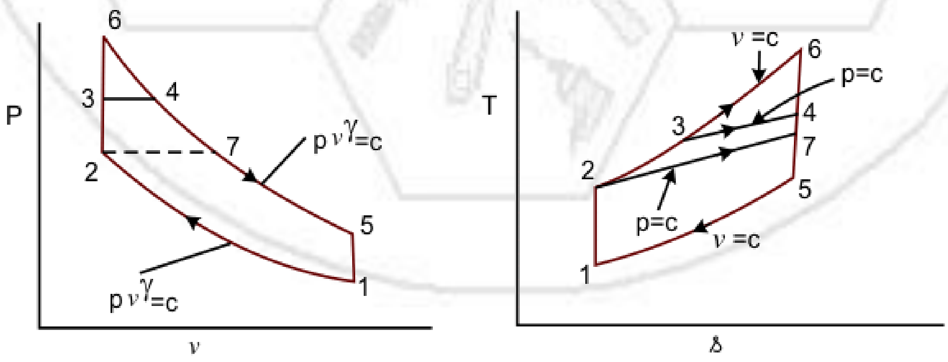
Thermal efficiency = $\frac{1280}{3526}$ KJ/Kg

η_{the} = 36.3%

Dryness fraction= 0.93

C) *Compare the efficiency of Otto cycle, Diesel cycle & Duel cycle under the condition of i) equal compression ratio & heat input ii) constant maximum pressure & heat input with neat sketch on T-S diagram. Comparison of Otto, Diesel & Dual Cycles*

Ans: For same compression ratio and heat rejection (Figures 30.2 (a) and (b))

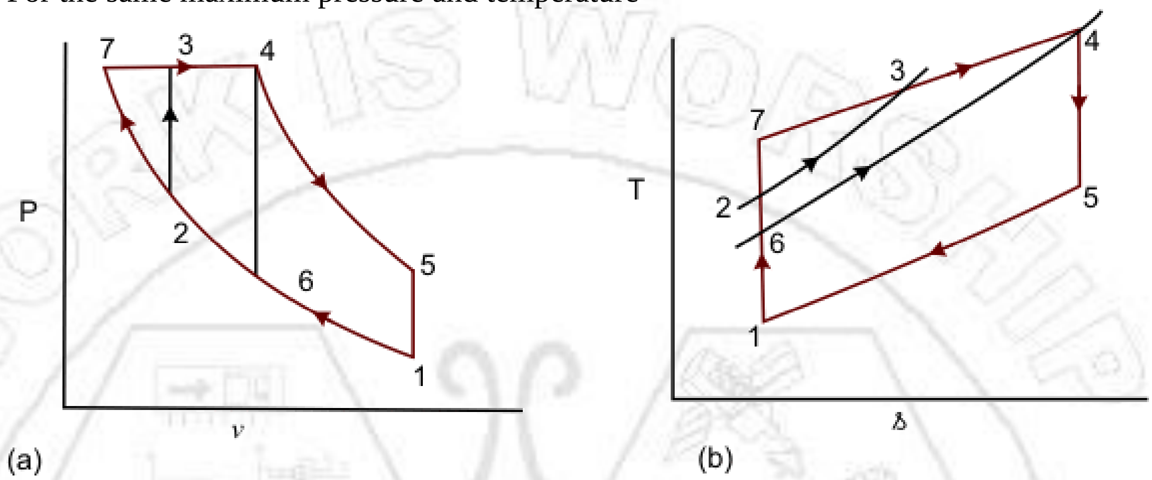


(a) (b)

1-6-4-5: Otto cycle
1-7-4-5: Diesel cycle
1-2-3-45 Dual cycle
For the same Q_2 , the higher the Q_1 , the higher is the cycle efficiency

$$\eta_{Otto} > \eta_{Dual} > \eta_{Diesel}$$

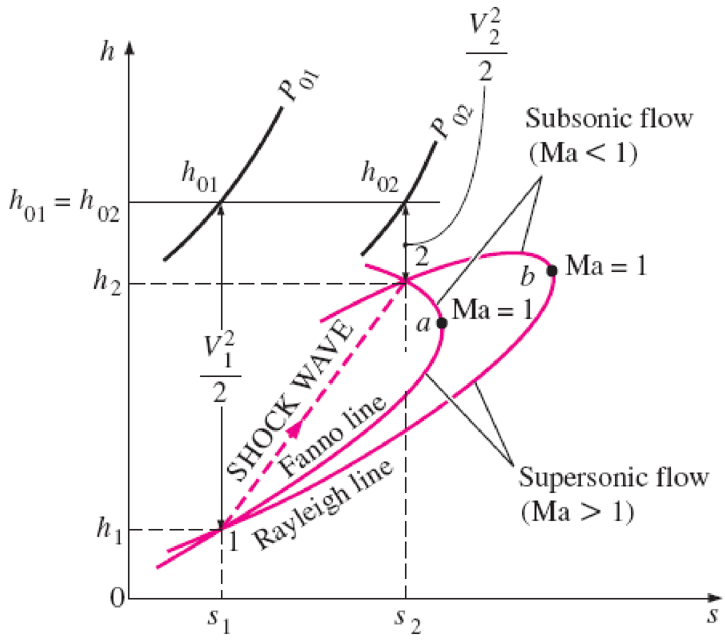
For the same maximum pressure and temperature



1-6-4-5: Otto cycle
1-7-4-5: Diesel cycle
1-2-3-45 Dual cycle
Q_1 is represented by:
Area under 6-4 $\rightarrow$ for Otto cycle area under 7-4 $\rightarrow$ for Diesel cycle and area under 2-3-4 $\rightarrow$ for Dual cycle and Q_2 is same for all the cycles

$$\eta_{Diesel} > \eta_{Dual} > \eta_{Otto}$$

Q.7) A) Discuss the Fanno & Releigh line on h-s diagram as a solution to normal shock equation.



First we consider shock waves that occur in a plane normal to the direction of flow, called normal shock waves. The flow process through the shock wave is highly irreversible and *cannot* be approximated as being isentropic.

We can combine the conservation of mass and energy relations into a single equation and plot it on an *h-s* diagram, using property relations. The resultant curve is called the Fanno line, and it is the locus of states that have the same value of stagnation enthalpy and mass flux (mass flow per unit flow area). Likewise, combining the conservation of mass and momentum equations into a single equation and plotting it on the *h-s* diagram yield a curve called the Rayleigh line. Both these lines are shown on the *h-s* diagram in Fig. As proved later in Example 17–8, the points of maximum entropy on these lines (points *a* and *b*) correspond to Ma = 1. The state on the upper part of each curve is subsonic and on the lower part supersonic. The Fanno and Rayleigh lines intersect at two points (points 1 and 2), which represent the two states at which all three conservation equations are satisfied. One of these (state 1) corresponds to the state before the shock, and the other (state 2) corresponds to the state after the shock. Note that the flow is supersonic before the shock and subsonic afterward. Therefore the flow must change from supersonic to subsonic if a shock is to occur. The larger the Mach number before the shock, the stronger the shock will be. In the limiting case of Ma = 1, the shock wave simply becomes a sound wave. Notice from Fig. 17–31 that $s2 > s1$. This is expected since the flow through the shock is adiabatic but irreversible.

Q.7) B) Air enters a c-d Nozzle at 1 Mpa & 800 K with a negligible velocity. The flow is steady, one dimensional & isentropic with γ= 1.4 For an exit mach number of M=2 & a throat area of 20 cm^3, determine i) the throat condition ii) the exit plan condition iii) the mass flow rate through the nozzle.

Ans: $\rho = \frac{P_0}{RT_0} = 4.355\ Kg/m^3$

i) At the throat of the nozzle M=1

$\frac{P^*}{P_0}$=0.5283, $\frac{T^*}{T_0}$=0.8333, $\frac{\rho^*}{\rho_0}$=0.6339

$P^* = 0.5283\ Mpa$

$T^* = 666.6\ K$

$\rho^* = 2{,}761\ Kg/m^3$

$V^*=C^*=\sqrt{\gamma RT^*}$ = 517.5 m/s

ii) Since the flow is isentropic at the exit (M_e=2)

$\frac{P_e}{P_0}$ =0.1278, $\frac{T_e}{T_0}$=0.5556, $\frac{\rho_e}{\rho_0}$=0.2301, M_e=1.6330,

$\frac{A_e}{A_*}$ = 1.6875

P_e=0.1278 MPa,

T_e=444.5 K,

$\rho_e = 1.002 Kg/m^3$

A_e = 33.75 cm^2,

$V_e = M^* C^*$=845.1 m/s

iii) Mass flow rate

$m^* = P^* A^* C^*$

= 2.858 Kg/s.