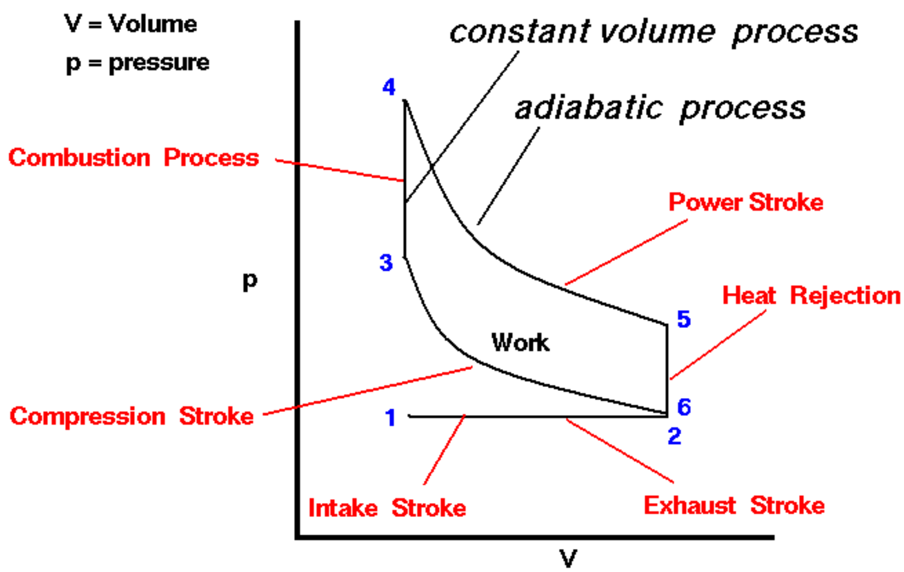
III/IV BTech Examination NOV-2019

14ME503 IC Engines & Gas Tubine

Scheme of valuation

1. a.



b. It is defined as the volume percent of n-hexadecane in a blend of n-hexadecane and 1-methylnapthalene that gives the same ignition delay period as test sample.

c. volumetric efficiency= actual volume / theoretical volume

d. abonormal combustion in SI engine is due to the following

Autoignition theory holds when fuel-air mixture in the end-gas region is compressed to sufficiently high p and T, the fuel oxidation process - starting with the preflame chemistry and ending with rapid energy release - can occur spontaneously in parts or all of the end-gas region.

Detonation theory postulates that under knocking conditions, advancing flame front accelerates to sonic velocity and consumes the end-gas at a rate much faster than would occur with normal flame speeds.

e. the chemical correct air fuel ration which is just enough for complete combustion is called stoichiometric air fuel ratio which is 14.7 : 1.

f. the **injection** of atomized fuel oil into the combustion chamber of a diesel engine under the pressure of the liquid fuel itself — compare air **injection**.

g. air crafts and power plants

h. pre whirl:

- The relative velocity at the inlet should be minimum, which reduces the Mach number for a given eye tip diameter.
- For a fixed eye tip diameter the Mach number can be reduced by providing pre-whirl at the inlet using guide vanes.

i. Difference between positive and non-positive displacement pumps:-

i. **Pressure -** Positive displacement pumps work for high pressure applications, pressure might be upto 800 bar. Non-positive displacement pumps are basically used for low pressure applications and are designed to work for a maximum pressure of 18 to 20 bar.
ii. **Efficiency** - In positive displacement pumps, efficiency increases with increasing pressure. Whereas in non-positive displacement pumps, efficiency peaks at best-efficiency-point. At higher or lower pressures, efficiency decreases.
iii. **Viscosity** - In positive displacement pumps, efficiency increases with increasing viscosity. On the other hand, efficiency of non-displacement pumps decreases with increasing viscosity due to frictional losses inside the pump.
iv. **Performance** - Flow is constant with changing pressure in a positive displacement pump whereas Flow varies with changing pressure in a non-positive displacement pump.

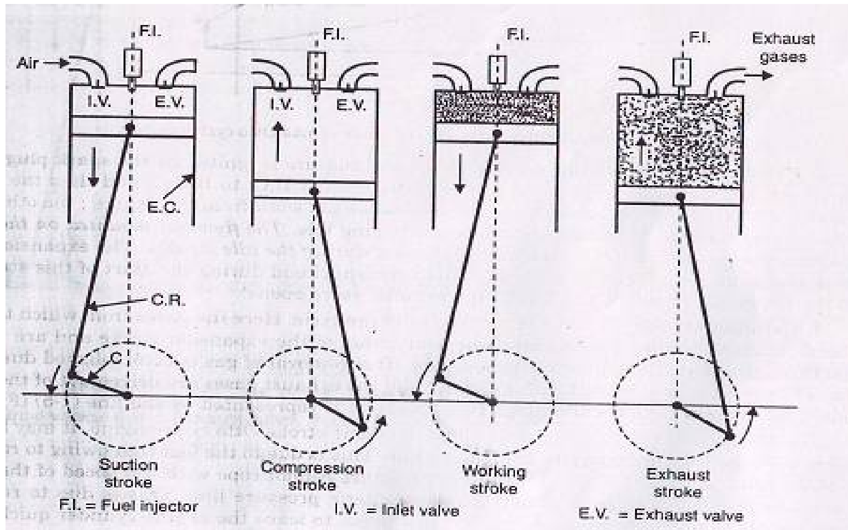
j. work ratio is the ratio of network output to total work done in a gas turbine plant.

k Propulsive efficiency is the ration of propulsive power to thrust power.

$$\therefore \quad \eta_{propulsive} = \frac{2V_a}{V_5 + V_a} = \frac{2}{V_5 / V_a + 1}$$

l. The propulsion of all rockets, jet engines, deflating balloons, and even squids and octopuses is explained by the same physical principle: Newton's third law of motion. Matter is forcefully ejected from a system, producing an equal and opposite reaction on what remains.

2. a. It is known as *compression ignition engine* because the ignition takes place due to the heat produced in the engine cylinder at the end of compression stroke. The four strokes of a diesel engine sucking pure air are described below:



1. Suction stroke – In this stroke, the inlet valve opens and pure air is sucked into the cylinder as the piston moves downwards from the *TDC*. It continues till the piston reaches its *BDC*.

2. Compression stroke – In this stroke, both the valves are closed and the air is compressed as the piston move upwards from *BDC* to *TDC*. As a result of compression, pressure and temperature of the air increases considerably. This completes one revolution of the crank shaft.

3. Expansion stroke – Shortly before the piston reaches the *TDC*, the fuel oil is injected in the form of very fine spray into the engine cylinder, through fuel injection valve. At this moment, temperature of the compressed air is sufficiently high to ignite the fuel. It suddenly increases the pressure and temperature of the products of combustion. The fuel oil is assumed to be burnt at constant pressure. Due to increased pressure, the piston is pushed down with a great force. The hot burnt gases expand due to high speed of the piston. During this expansion, some of the heat energy is transformed into mechanical work. During this working stroke, both the valves are closed and the piston moves from *TDC* to *BDC*.

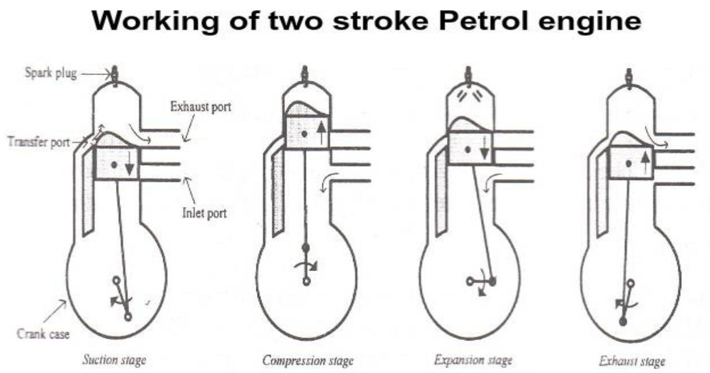
4. Exhaust stroke – In this stroke, the exhaust valve is open as the piston moves from *BDC* to *TDC*. The movement of the piston pushes out the products of combustion from the engine cylinder through the exhaust valve into the atmosphere. This completes the cycle and the engine cylinder is ready to suck the fresh air again.

2. b.

Description	SI Engine	CI Engine
Basic cycle	Works on Otto cycle or constant volume heat addition cycle.	Works on Diesel cycle or constant pressure heat addition cycle.
Fuel	Gasoline, a highly volatile fuel. Self-ignition temperature is high.	Diesel oil, a non-volatile fuel. Self-ignition temperature is comparatively low.
Introduction of fuel	A gaseous mixture of fuel-air is introduced during the suction stroke. A carburettor and an ignition system are necessary. Modern engines have gasoline injection.	Fuel is injected directly into the combustion chamber at high pressure at the end of the compression stroke. A fuel pump and injector are necessary.
Load control	Throttle controls the quantity of fuel-air mixture introduced.	The quantity of fuel is regulated. Air quantity is not controlled.
Ignition	Requires an ignition system with spark plug in the combustion chamber. Primary voltage is provided by either a battery or a magneto.	Self-ignition occurs due to high temperature of air because of the high compression. Ignition system and spark plug are not necessary.
Compression ratio	6 to 10. Upper limit is fixed by antiknock quality of the fuel.	16 to 20. Upper limit is limited by weight increase of the engine.
Speed	Due to light weight and also due to homogeneous combustion, they are high speed engines.	Due to heavy weight and also due to heterogeneous combustion, they are low speed engines.
Thermal efficiency	Because of the lower CR, the maximum value of thermal efficiency that can be obtained is lower.	Because of higher CR, the maximum value of thermal efficiency that can be obtained is higher.
Weight	Lighter due to lower peak pressures.	Heavier due to higher peak pressures.

3. a.**Two-stroke Cycle Petrol Engine**

In this cycle, the *suction*, *compression*, *expansion* and *exhaust* takes place during two strokes of the piston. There is one working stroke after every revolution of the crankshaft. A two stroke engine has ports instead of valves. All the four stages of a two stroke petrol engine are described below



1. Suction stage – In this stage, the piston, while going down towards bottom dead centre (*BDC*), uncovers both the transfer port and the exhaust port. The fresh fuel-air mixture flows into the engine cylinder from the crank case

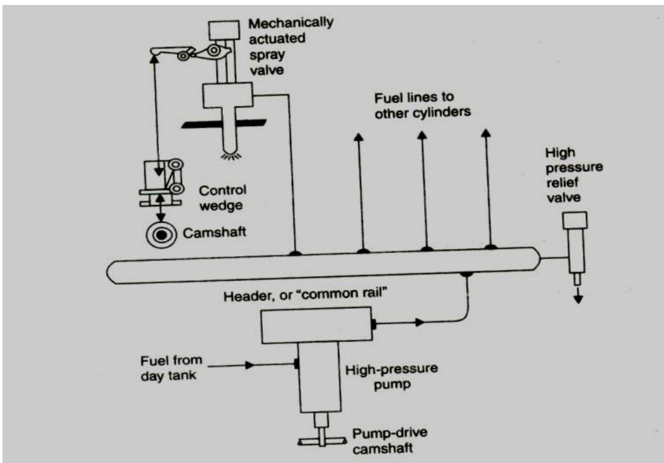
2. Compression stage – In this stage, the piston, while moving up, first covers the transfer port and then exhaust port. After that the fuel is compressed as the piston moves upwards. In this stage, the inlet port opens and fresh fuel-air mixture enters into the crank case.

3. Expansion stage – Shortly before this piston reaches the top dead centre (*TDC*) during compression stroke, the charge is ignited with the help of a spark plug. It suddenly increases the pressure and temperature of the products of combustion but the volume remains constant. Due to rise in the pressure, the piston is pushed downwards with a great force. The hot burnt gases expand due to high speed of the piston. During this expansion, some of the heat energy produced is transformed into mechanical work.

4. Exhaust stage - In this stage, the exhaust port is opened as the piston moves downwards. The products of combustion, from the engine cylinder are exhausted through the exhaust port into the atmosphere. This completes the cycle and the engine cylinder is ready to suck the charge again.

3. b

A single pump supplies high pressure fuel to header, a relief valve holds the pressure constant. The control wedge adjusts the lift of mechanically operated valve to set amount and time of injection.



Advantages:

1. System is simple and less maintenance cost
2. Only one pump is sufficient for multi cylinder engine
3. It fulfills requirements of either constant load with variable speeds or variable loads with constant speed
4. Variation in pump supply pressure effects all the cylinders equally

Dis advantages

1. Leaks in the injection valve
2. Accurate design and work man ship is required

4. a.start of injection and the start of combustion. This delay period consists of (a) physical delay, wherein atomisation, vaporization and mixing of air fuel occur and (b) of chemical delay attributed to pre-combustion reactions.

Factors effecting delay period:

1. Compression ratio: With the increase in compression ratio reduces ignition lag, a higher pressure increases density resulting in closer contact of the molecules which reduce the time of action when fuel is injected.

2. Inlet air temperature: With the increase in inlet temperature increases the air temperature after compression and hence decreases the ignition delay.

3. Coolant temperature: Increase in engine speed increases cylinder air temperature and thus reduces ignition lag. The increase in engine speed increases turbulence and this reduces the ignition lag.

4. Jacket water temperature: With the increase in jacket water temperature also increases compressed air temperature and hence delay period is reduced.

5. Fuel temperature: Increase in fuel temperature would reduce both physical and chemical delay period.

6. Intake pressure (supercharging): Increase in intake pressure or supercharging reduces the auto-ignition temperature and hence reduces delay period. Since the compression pressure will increase with intake pressure, the peak pressure will be higher. Also, the power output will be more air and hence more fuel can be injected per stroke.

7. Air-fuel ratio (load): With the increase in air-fuel ratio (leaner mixture) the combustion temperatures are lowered and cylinder wall temperatures are reduced and hence the delay period increases, with an increase in load, the air-fuel ratio decreases, operating temperature increases and hence, delay period decreases.

8. Engine size: The engine size has little effect on the delay period in milliseconds. As large engines operate at low revolutions per minute (rpm) because of inertia stress limitations, the delay period in terms of crank angle is smaller and hence less fuel enters the cylinder during the period. Thus combustion in large slow speed Compression Ignition engines is smooth.

4. b

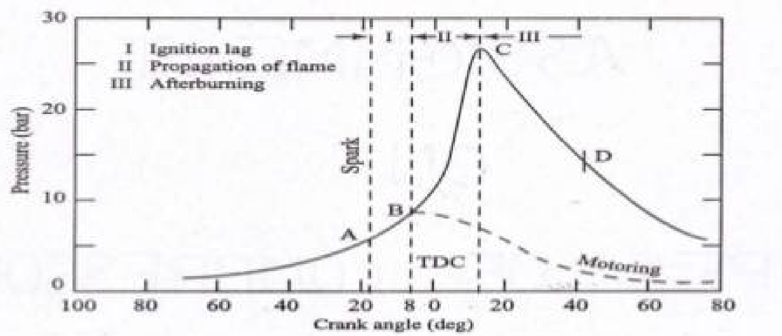
STAGE OF COMBUSTION IN SI ENGINE

There are three stages of combustion in SI Engine as shown

1. Ignition lag stage

2. Flame propagation stage

3. After burning stage



Stages of Combustion in an SI Engine

1. Ignition lag stage: There is a certain time interval between instant of spark and instant where there is a noticeable rise in pressure due to combustion. This time lag is called IGNITION LAG. Ignition lag is the time interval in the process of chemical reaction during which molecules get heated up to self ignition temperature , get ignited and produce a self propagating nucleus of flame. The ignition lag is generally expressed in terms of crank angle (q1). The period of ignition lag is shown by path ab. Ignition lag is very small and lies between 0.00015 to 0.0002 seconds. An ignition lag of 0.002 seconds corresponds to 35 deg crank rotation when the engine is running at 3000 RPM. Angle of advance increase with the speed. This is a chemical process depending upon the nature of fuel, temperature and pressure, proportions of exhaust gas and rate of oxidation or burning.

2. Flame propagation stage:

Once the flame is formed at “b”, it should be self sustained and must be able to propagate through the mixture. This is possible when the rate of heat generation by burning is greater than heat lost by flame to surrounding.

After the point “b”, the flame propagation is abnormally low at the beginning as heat lost is more than heat generated. Therefore pressure rise is also slow as mass of mixture burned is small. Therefore it is necessary to provide angle of advance 30 to 35 deg, if the peak pressure to be attained 5-10 deg after TDC. The time required for crank to rotate through an angle q2 is known as combustion period during which propagation of flame takes place.

3.After burning:

Combustion will not stop at point “c” but continue after attaining peak pressure and this combustion is known as after burning. This generally happens when the rich mixture is supplied to engine.

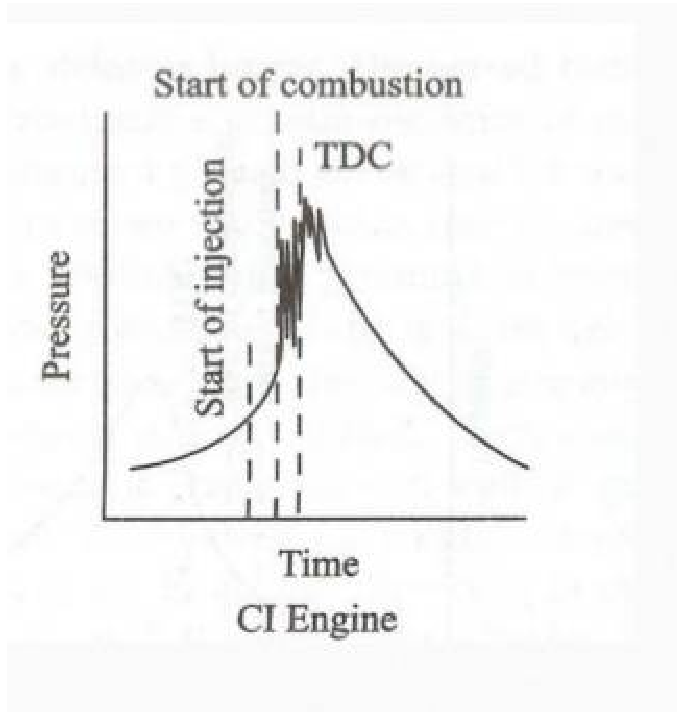
5. a.

Diesel knock

-CI engine detonation occurs in the beginning of combustion

-In CI engine the fuel and air are imperfectly mixed and hence the rate of pressure rise is normally cause audible knock. Rate of pressure rise may reach as high as 10 bar/°CA -High engine vibration is the symptoms of knocking

-no pre-ignition or premature ignition as like SI engine



Delay period is directly related to Knocking in CI engine. An extensive delay period
can be due to following factors:

A low compression ratio permitting only a marginal self ignition temperature to be
reached.

A low combustion pressure due to worn out piston, rings and bad valves

Low cetane number of fuel

Poorly atomized fuel spray preventing early combustion

Coarse droplet formation due to malfunctioning of injector parts like spring

Low intake temperature and pressure of air

5) (b) Given data :-

Bore = 150 mm = 0.15 m = D

Stroke L = 250 mm = 0.25 m

Speed N = 420 rpm.

P_{im} = 7.34 bar

T = 216 N-m.

C.V = 44,000 kJ/kg

Air-fuel ratio = 16.

Brake Power BP = $\frac{2\pi NT}{60,000} = \frac{2\pi \times 420 \times 210}{60,000}$ = 9.2 kW

Indicated power IP = $\frac{\eta\ P_{mi}\ LANk \times 10}{6}$

$= \frac{1 \times 7.34 \times 0.25 \times \frac{\pi}{4}(0.15)^2 \times 420 \times \frac{1}{2} \times 10}{6}$

IP = 11.34 kW

(i) Mechanical Efficiency $\eta_{mech} = \frac{BP}{IP} = \frac{9.2}{11.34}$ = 81.12%

(ii) Brake thermal efficiency $\eta_{th(B)} = \frac{B.P}{m_f \times C.V.} = \frac{9.2}{0.0625 \times 44,000}$ = 0.33 %

(iii) Indicated thermal efficiency $\eta_{th(I)} = \frac{IP}{m_f \times C.V.}$ = 5.2 %

(iv) Brake specific fuel consumption (BSFC) = $\frac{m_f\ (kg/h)}{B.P.\ (kW)}$ = 0.24 kg/kWh.

Assume $\dot{m}_a$ = 1 kg/s

$\frac{\dot{m}_a}{\dot{m}_f}$ = 16

$\dot{m}_f$ = 0.0625 kg/s

$m = \frac{PV}{RT}$ $V = \frac{\pi}{4} D^2 L \frac{N}{2}$

$= \frac{\pi}{4} \times 0.15^2 \times 0.25 \times \frac{420}{2}$ (OR)

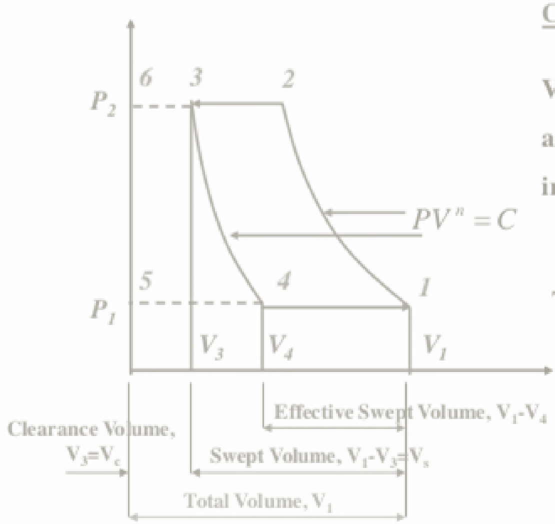
$V = 0.927\ m^3/min$ => 0.9 density = 0.927 ×

Fuel consumption = $\frac{1.02}{\text{Air-fuel ratio}}$ $m = 1.02$ $= \frac{1.02}{16}$

= 0.06375 kg/s.

6. a

Reciprocating Compressor – Equation for Work



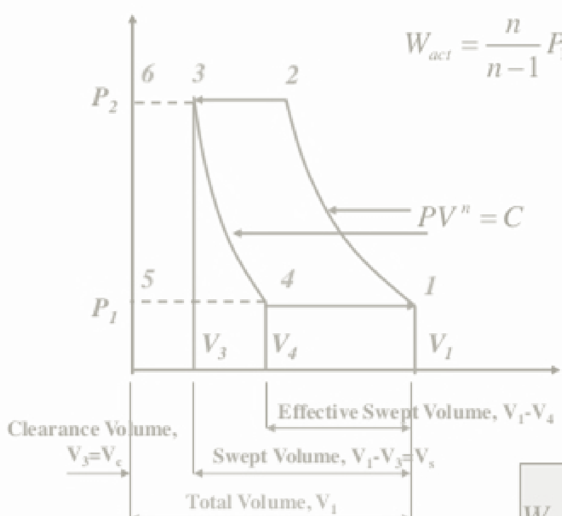
__Clearance Volume__ :

Volume that remains inside the cylinder after the piston reaches the end of its inward stroke.

Thus, *Effective Stroke Volume* = $V_1 - V_4$

Actual Work = W_{act} **= Area 1-2-3-4**

W_{act} **= Area (5-1-2-6) – Area (5-4-3-6)**



$$W_{act} = \frac{n}{n-1} P_1 V_1 \left\{ 1 - \left(\frac{P_2}{P_1} \right)^{\frac{m-1}{n}} \right\} - \frac{n}{n-1} P_4 V_4 \left\{ 1 - \left(\frac{P_3}{P_4} \right)^{\frac{m-1}{n}} \right\}$$

But, $P_4 = P_1$ **and** $P_3 = P_2$

$$\Rightarrow \quad W_{act} = \frac{n}{n-1} P_1 V_1 \left\{ 1 - \left(\frac{P_2}{P_1} \right)^{\frac{m-1}{n}} \right\}$$

$$- \frac{n}{n-1} P_1 V_4 \left\{ 1 - \left(\frac{P_2}{P_1} \right)^{\frac{m-1}{n}} \right\}$$

$$\boxed{W_{act} = \left(\frac{n}{n-1} \right) P_1 \left(V_1 - V_4 \right) \left\{ 1 - \frac{P_2}{P_1} \left(\frac{P_1}{P_2} \right)^{1/n} \right\}}$$

6. b

6) (b)

$P_1 = 1$ bar

$T_1 = 15^\circ C = 288$ K

$N = 450$ rpm

$P_2 = 6.5$ bar

$\eta_{mech} = 0.8$

$V = 20 \; m^3/hr. = 8.3 \times 10^{-3} \; m^3/sec$

$m = \frac{P_1 V_1}{R T_1}$

$m = \frac{1 \times 10^5 \times 30}{287 \times 288} = 36.29 \; m^3/hr.$

Clearance ratio $k = 8.9\% = 0.089$

(i) volumetric efficiency $\eta_{vol} = 1 + k - k\left(\frac{P_2}{P_1}\right)^{1/n}$

$= 1 + 0.089 - 0.089 \left[\frac{6.5}{1}\right]^{1/1.3}$

$\eta_{vol} = 71.4\%$

~~work done~~ Indicated Power $= \left[\frac{n}{n-1}\right] m R T_1 \left[\left(\frac{P_2}{P_1}\right)^{n-1/n} - 1\right]$ (or) $P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{n-1/n} - 1\right]$

$= \frac{1.3}{1.3-1} = \frac{1.3}{1.3-1} \times 10^5 \times 8.3 \times 10^{-3} \left[\left(\frac{6.5}{1}\right)^{\frac{1.3-1}{1.3}} - 1\right]$

$= 833 \times 0.053 = 449$ kW

Brake Power $BP = \frac{\text{Indicated Power}}{\eta_{mech}}$

$= 56.12$ kW.

7. a.

S.no	**Centrifugal Compressors**	**Axial Flow Compressors**
1	In centrifugal compressors air flows radially in the compressor	In Axial flow compressors air flows parallel to the axis of shaft
2	Low maintenance and running cost	High maintenance and running cost
3	Low starting torque is required	Requires high starting torque
4	Not suitable for multi staging	Suitable for multi staging

5	Suitable for low pressure ratios up to 4	Suitable for only multi staging ratio of 10
6	For given mass flow rate, it requires a larger frontal area.	For a given mass flow rate, it requires less Frontal area.
7	Isentropic efficiency is 80 to 82%	Isentropic efficiency is 86 to 88%
8	Better performance at part load	Poor performance at part load

7. b.

7) (b) $\eta_{isen} = 75\% = 0.75$

$D = 1.05\ m$

$T_1 = 300\ K$

$N = 4800\ rpm$

Slip factor $\phi_s = 0.82$

$\rightarrow$ $C_{bl_2} = \dfrac{\pi D N}{60} = \dfrac{\pi \times 1.05 \times 4800}{60}$

$= 263.9\ m/s$

$\rightarrow$ work done per kg of air $= C_{w_2} C_{bl_2} - C_{w_1} \cdot C_{bl_1}$

$\therefore C_{w_1} = 0$ $\qquad = C_{bl_2}^2 \times \phi_s$

$\therefore \phi_s = \dfrac{C_{w_2}}{C_{bl_2}} \Rightarrow C_{w_2} = \phi_s C_{bl_2}$

$\Rightarrow C_{w_2} =$

$W = 57{,}104.7 = 57.104\ kJ/kg$

$= \cancel{0.95}\ kg/s$

$= \cancel{0.95}$

$\rightarrow$ Temperature rise of air $T_2 - T_1 = ?$

$\therefore$ work done $= C_p(T_2 - T_1) \Rightarrow 57.10 = 1.005\,[T_2 - T_1]$

$\Rightarrow T_2 - T_1 = 56.81\ K.$

$\therefore \eta_{isen} = \dfrac{T_2' - T_1}{T_2 - T_1}$

$\Rightarrow 0.75 = \dfrac{T_2' - 300}{56.81}$

$\Rightarrow T_2' = 342.61\ K$

$\rightarrow$ Static Pressure ratio :

$\dfrac{P_2}{P_1} = \left(\dfrac{T_2'}{T_1}\right)^{\frac{\gamma}{\gamma-1}} = (1.14)^{\frac{1.3}{1.3-1}} = 1.76$

8. a)

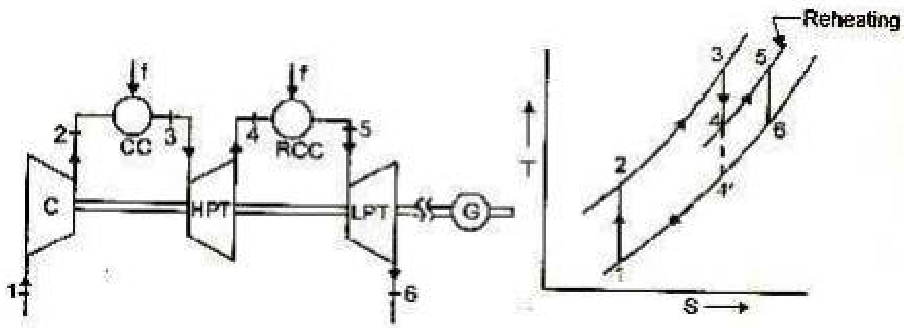


Figure: Reheat gas turbine cycle.

Reheat gas turbine cycle arrangement is shown in figure. In order to maximize the work available from the simple gas turbine cycle one of the option is to increase enthalpy of fluid entering gas turbine and extend its expansion upto the lowest possible enthalpy value. This can also be said in terms of pressure and temperature values i.e., inject fluid at high pressure and temperature into gas turbine and expand upto lowest possible pressure value. Upper limit at inlet to turbine is limited by metallurgical limits while lower pressure is limited to near atmospheric pressure in case of open cycle. For further increasing in net work output the positive work may be increased by using multistage expansion with reheating in between. In multistage expansion is divided into parts and after part expansion working fluid may be reheated for getting larger positive work in left out expansion. For reheating another combustion chamber may be used.

Here in the arrangement shown ambient air enters compressor and compressed air at high pressure leaves at 2. Compressed air is injected into combustion chamber for increasing its temperature upto desired turbine inlet temperature at state3. High pressure and high temperature fluid enters high pressure turbine (HPT) for first phase of expansion and expanded gases leaving at 4 are sent to reheat combustion chamber (reheater) for being further heated. Thus reheating is a kind of energizing the working fluid. Assuming perfect reheating (in which temperature after reheat is same as temperature attained in first combustion chamber), the fluid leaves at state 5 and enters low pressure turbine (LPT) for remaining expansion upto desired pressure value. Generally temperature after reheating at state 5, is less than temperature at state 3. In the absence of reheating the expansion process within similar pressure limits goes upto state 4'.Thus reheating offers an obvious advantage of work output increase since constant pressure lines T-S diagram diverge slightly with increasing entropy, the total work of the two stage turbine is greater that that of single expansion from state 3 to state 4'

Here it may be noted that the heat addition also increases because of additional heat supplied for reheating. Therefore, despite the increase in network due to reheating the cycle thermal efficiency would not necessarily increases. Let us now carry out air standard cycle analysis.

Network output in reheat cycle, W net, reheat = WHPT + WLPT - WC

WHPT = m (h3 –h4), WLPT = m(h5 –h6), WC = m(h2 –h1)

W net, reheat = m {(h3 –h4) + (h5 –h6) –(h2 –h1)}

W net , reheat = m cp {(T3 –T4) + (T5 –T6) –(T2 - T1)}

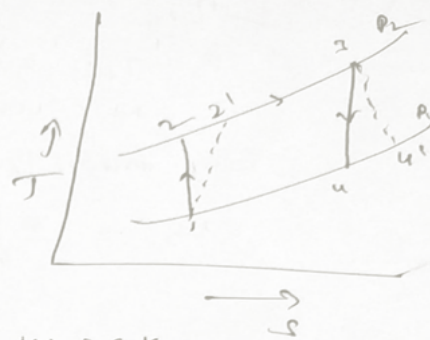
8. b.

8) b) $T_1 = 27°c = 300 K$

$T_3 = 550°c = 823 K$

$\eta_{comp} = 0.85$, $\eta_{Tur} = 0.83$

Pr. ratio $= \frac{P_2}{P_1} = 4$



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

$\Rightarrow T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = 300 \times 4^{\frac{1.4-1}{1.4}} = 445.8 K$

$\therefore \eta_{comp} = \frac{T_2 - T_1}{T_2' - T_1} \Rightarrow T_2' = 471.5 K$

$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = 4^{\frac{1.34-1}{1.34}} = 1.48$

$\Rightarrow T_4 = 553.8 K$

$\therefore \eta_{Tur} = \frac{T_3 - T_4'}{T_3 - T_4} = \frac{823 - T_4'}{823 - 553.8}$

$\Rightarrow T_4' = 600 K$

$\therefore$ Compressor work $= W_{Comp} = C_P (T_2' - T_1) = 172.35$ kJ/kg

Turbine work $= W_{Tur} = C_P (T_3 - T_4') = 224.1$ kJ/kg

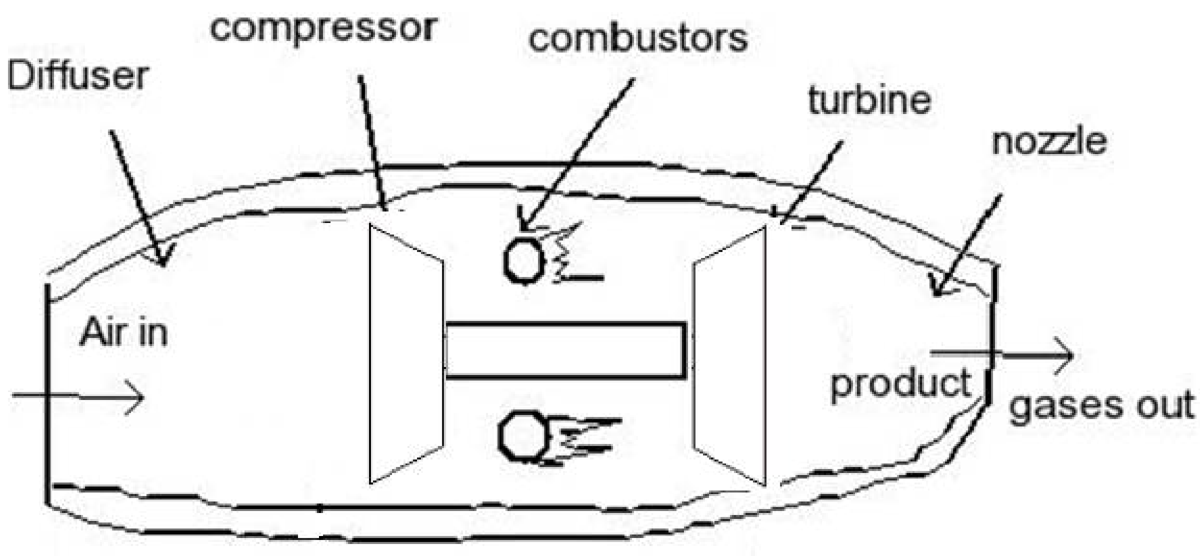
Network output. $W_{net} = W_T - W_{Comp} = 51.76$ kJ/kg

Work ratio $= \frac{W_{net}}{W_{Tur}} = \frac{51.76}{224.1} = 0.23$

Overall efficiency $= \eta = \frac{W_{net}}{\text{Heat supplied}} =$ 1[illegible].6 %.

Heat supplied $= C_P (T_3 - T_2') =$ 353.2[illegible] kJ/kg

9.a



The turbojet engine consists of a gas turbine, the output of which is used solely to provide power to the compressor.

• Air is taken into the engine through an approximate diffuser duct, passes through the compressor and enters the combustions chamber, where it is mixed and burned with fuel.

• Most common fuels are hydrocarbons (Aviation kerosene). The ratio of fuel to air is determined by the maximum allowable gas temperature permitted by the turbine. Normally, a considerable excess air is used.

• The hot high pressure gases are then expanded through the turbine to a pressure which is higher than the ambient atmosphere, and yet sufficiently lower than the combustion chamber pressure, to produce just enough power in the turbine to run the compressor.

• After leaving the turbine, the gas is expanded to the ambient pressure through an appropriate nozzle. As this occurs, the gas is accelerated to a velocity, which is greater than the incoming velocity of the ingested air, and therefore produces a propulsive thrust.

9.b:

A Rocket is a non-air-breathing engine and it has a few moving parts. It consists of a combustion chamber and exhaust nozzle. It carries fuel and oxidizer(such as liquid oxygen) on the board of the craft. The fuel oxidizer react chemically in the combustion chamber and then high pressure combustion gases act as rocket propellant.

These gases expand through the nozzles, and are accelerated to extremely high speed to exert a large reactive thrust on the rocket(since every action has an equal and opposite reaction).

Features of Rocket Propulsion

1. It is a self-contained, non-air breathing system.

2. Rockets are highly efficient at very high speed
3. It develops high thrust per unit area. Thrust-to-weight ratio is over.
4. It has simple air inlet and high compression ratio.
5. It needs lots of propellant and has very low specific impulse; typically 100-450 seconds
6. It offers extreme thermal stresses of combustion chamber
7. Carrying oxidizer on-board makes the rocket a very risky vehicle
8. It is extremely noisy.