III/IV B.Tech (Regular) DEGREE EXAMINATION
Mechanical Engineering
I.C. Engines & Gas Turbines (18ME502)
SCHEME OF Evaluation

Answer Question No.1 compulsorily. (1X10 = 10 Marks)
(4X10=40 Marks)

Answer ONE question from each unit.

1.a) The function of a carburettor is to atomize and meter the liquid fuel and mix it with the air as it enters the induction system of the engine . Maintaining fuel-air proportion under all conditions of operation appropriate to the conditions.

b) Electronic Control System, Fuel System, Air Induction System.

c) Atomization, Distribution of fuel, Prevention of impingement on walls.

d) The fuel does not ignite immediately upon injection into the combustion chamber. There is a definite period of inactivity between the time when the first droplet of fuel hits the hot air in the combustion chamber and the time it starts through the actual burning phase. This period is known as the ignition delay period.

e)

It is the ratio between the mass of the air and mass of the fuel supplied to the engine. It is expressed as

$$A/F = \frac{\dot{m}_a \text{ (mass flow rate of air)}}{\dot{m}_f \text{ (mass flow rate of fuel)}} \quad ...(4.16)$$

f) Oxides of Nitrogen, Carbon monoxide, CO_2, Hydrocarbons, Smoke, Particulate matter.

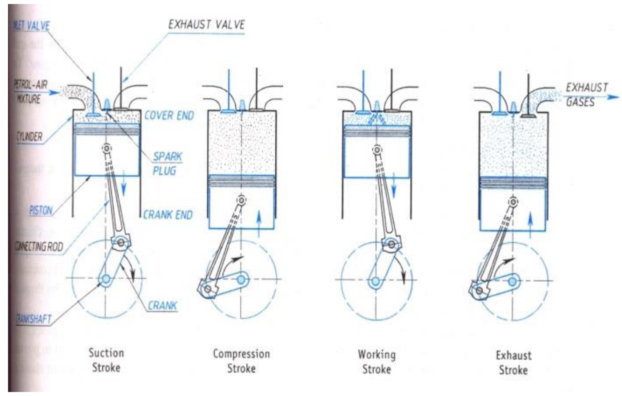
g) Propane and butane.

h) Intercooling, Reheating and Regeneration.

I) Inability if the ramjet to be self starting.

j) The fuel and the oxidizer are known as Propellents in rocket propulsion.

2. A) Four stroke Spark Ignition Engine:
    1. Suction or Intake Stroke: Inlet is open exhaust is closed. Piston moves from TDC to BDC and crankshaft revolves half the revolution. Cranking during first cycle.Due to the pressure difference *air enters the cylinder* through air filter.



    2. Compression stroke: Inlet and exhaust are closed. Piston moves from BDC to TDC. Cranking required in first cycle. Air will be compressed to a ratio of 1:20. Diesel oil is *sprayed* into cylinder by *injector* and *auto-ignition* takes place.
    3. Expansion or Power stroke: Piston moves from TDC to BDC. Inlet and exhaust valves are closed. burnt gases generate energy and force the piston to move down till injection of fuel is complete.
    4. Exhaust stroke: exhaust is open and inlet is closed. Piston moves from BDC to TDC. crankshaft revolves half the rotation. energy for this stroke is supplied by flywheel. Burnt gases are expelled out through outlet port.

   B)

According to	*Two-Stroke Engine*	*Four-Stroke Engine*
1. Working stroke	There is one working stroke in each revolution. Hence engine has more even torque and reduced vibration.	There is one working stroke in two revolutions. Hence engine has uneven torque and large vibration.
2. Engine dsign	It uses ports and hence engine design is simple.	It uses valves, therefore, mechanism involved is complex.
3. Mechanical efficiency	The working cycle completes in one revolution and hence it has high mechanical efficiency.	Working cycle completes in two revolution, hence, it has more friction, thus less mechanical efficiency.
4. Scavenging	The burnt gases are not completely driven out. It results in dilution of fresh charge.	It has separate stroke for explusion of burnt gases, thus ideally no dilution of fresh charge.
5. Thermal fficiency	Poor thermal efficiency due to poor scavenging and escaping of charge with exhaust gases.	Very good thermal efficiency.
6. Cost	Less cost due to less parts in engine.	More cost due to large number of parts.
7. Maintenance	Cheaper and simple.	Costlier and slightly complex.
8. Weight	Lighter engine body.	Heavier engine body.

3. A) The process of formation of a combustible fuel-air mixture by mixing the proper amount of fuel with air before admission to engine cylinder is called carburetion.
   Both air and fuel are drawn through the carburetor and into the engine cylinders by the suction created by the downward movement of the piston. This suction is due to the an increase in the volume of the

cylinder and a decrease in the pressure in this chamber. It is the difference in pressure b/n the atmosphere and cylinder that causes the air to flow into the chamber. In the carburetor, air passing into the combustion chamber picks up fuel discharged from a tube. This tube has a fine orifice called as carburetor jet which is exposed to the air path. The fuel from the nozzle thoroughly atomized because of the small outlet nozzle. Throat is provided to increase the velocity of the flow and suction effect is created.

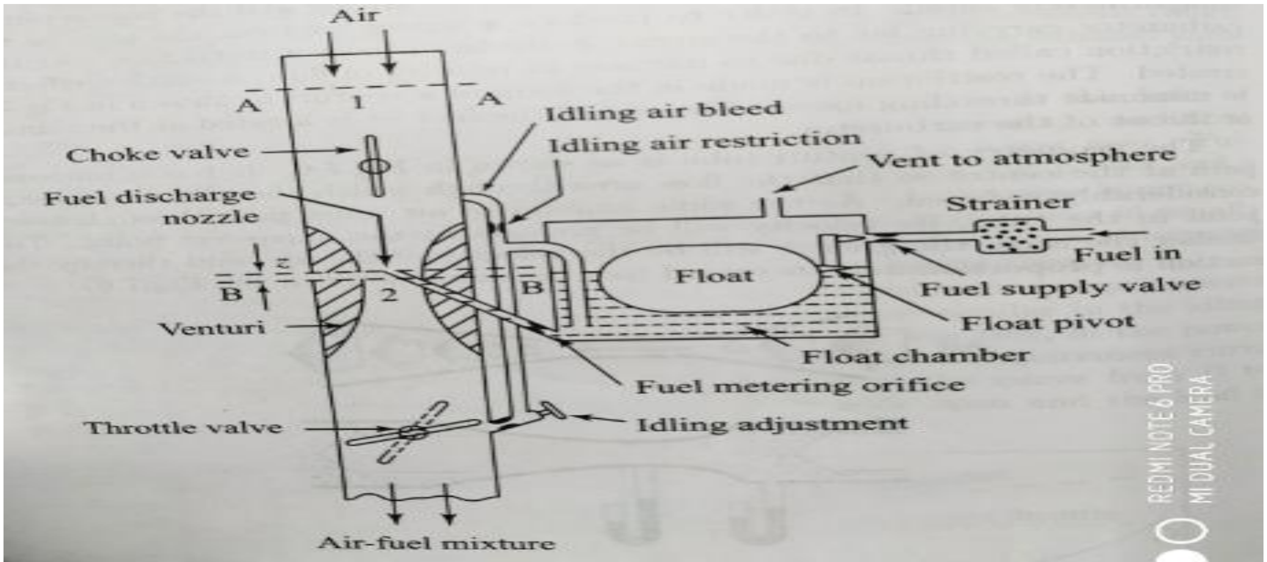
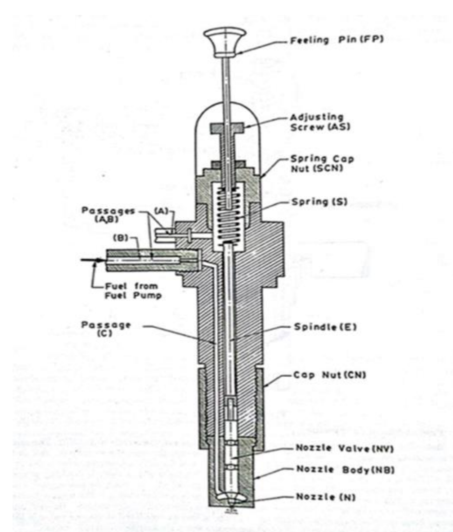


Fig. 7.7 Simple carburetor

3. B) Fuel Injector: Quick and complete combustion is ensured by a well designed fuel injector. By atomizing the fuel into very fine droplets, it increases the surface area of the fuel droplets resulting in better mixing and subsequent combustion. Atomization is done by forcing the fuel through a small orifice under high pressure. Fuel injector consists of a nozzle valve (NV) fitted in the nozzle body (NB).The nozzle valve is held on its seat by a spring (S) which exerts pressure through the spindle (E). The nozzle lift can be adjusted by the adjusting screw (AS). Feeling pin (FP) indicates whether the valve is working properly or not. The oil under pressure from the fuel (injection) pump enters the injector through the passages B & C and lifts the nozzle valve. The fuel travels down the nozzle (N) and injected into the engine cylinder in the form of fine sprays. When the pressure of oil falls, the nozzle valve occupies its seat under the spring force and fuel supply is cut off.



4. A) The combustion in a CI engine takes place in four stages:

Ignition delay period: It is also called as preparatory phase during which some fuel has already been admitted but has not ignited. This period is counted from the start of injection to the point where the pressure –time curve separates from the motoring curve indicated as start of combustion in the Fig.11.11. The delay period in the CI engine exerts a very great influence on both engine design and performance. The fuel does not ignite immediately upon injection into the combustion chamber. There is a definite period of inactivity between the time when the first droplet of fuel hits the hot air in the combustion chamber and the time it starts through the actual burning phase. This period is known as the ignition delay period.

The period of rapid combustion: The period of rapid combustion also called the uncontrolled combustion, is that phase in which the pressure rise is rapid. During the delay period, the droplets have had time to spread over a wide area and fresh air is always available around the droplets.

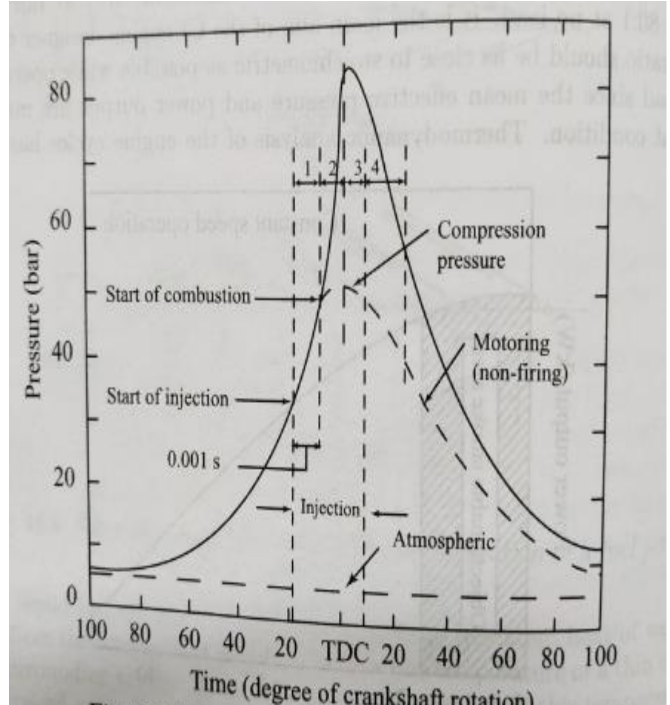


Fig. 11.11 Stages of combustion in a CI engine

The period of controlled combustion: The rapid combustion period is followed by the third stage, the controlled combustion. The temperature and pressure in the second stage is already quite high. Hence the fuel droplets injected during the second stage burn faster with reduced ignition delay as soon as they find the necessary oxygen and any further pressure rise is controlled by the injection rate.

The period of after burning: Combustion does not cease with the completion of the injection process. The unburnt and partially burnt fuel particles left in the combustion chamber start burning as soon as they come into contact with the oxygen. This process continues for a certain duration called the after-burning period. Usually this period starts from the point of maximum cycle temperature and continues over a part of the expansion stroke. Rate of after-burning depends on the velocity of diffusion and turbulent mixing of unburnt and partially burnt fuel with the air.

4. B) If the temperature of the un burnt mixture exceeds the self-ignition temperature of the fuel and remains at or above this temperature during the period of pre flame reactions (ignition lag), spontaneous ignition or auto ignition occurs at various pin point locations. This phenomenon is called knocking. The phenomenon of knock may be explained by referring to Fig.11.6(a) which shows the cross-section of the combustion chamber with flame advancing from the spark plug location A without knock whereas Fig.11.6(c) shows the combustion process with knock. In the normal combustion the flame travels across the combustion chamber from A towards D. The advancing flame front compresses the end charge BB’D farthest from the spark plug, thus raising its temperature. The temperature is also increased due to heat transfer from the hot advancing flame-front. Also some preflame oxidation may take place in the end charge leading to further increase in temperature. In spite of these factors if the temperature of the end charge had not reached its self-ignition temperature, the charge would not auto ignite and the flame will advance further and consume the charge BB D. This is the normal combustion process which is illustrated by means of the pressure-time diagram, Fig.11.6(b). However, if the end charge BB’D reaches its auto ignition temperature and remains up to the time of preflame reactions the charge will auto ignite, leading to knocking combustion. In Fig.11.6(c), it is assumed that when flame has reached the position BB’ the charge ahead of it has reached critical auto ignition temperature. During the preflame reaction period if the flame front could move from BB’ to only CC’ then the charge ahead of CC’ would auto ignite. Because of the auto ignition, another flame front starts travelling in the opposite direction to the main flame front. When the two flame fronts collide, a severe pressure pulse is generated. The gas in the chamber is subjected to compression and rarefaction along the pressure pulse until pressure equilibrium is restored. This disturbance can force the walls of the combustion chambers to vibrate at the same frequency as the gas. The pressure-time trace of such a situation is shown in Fig.11.6(d).

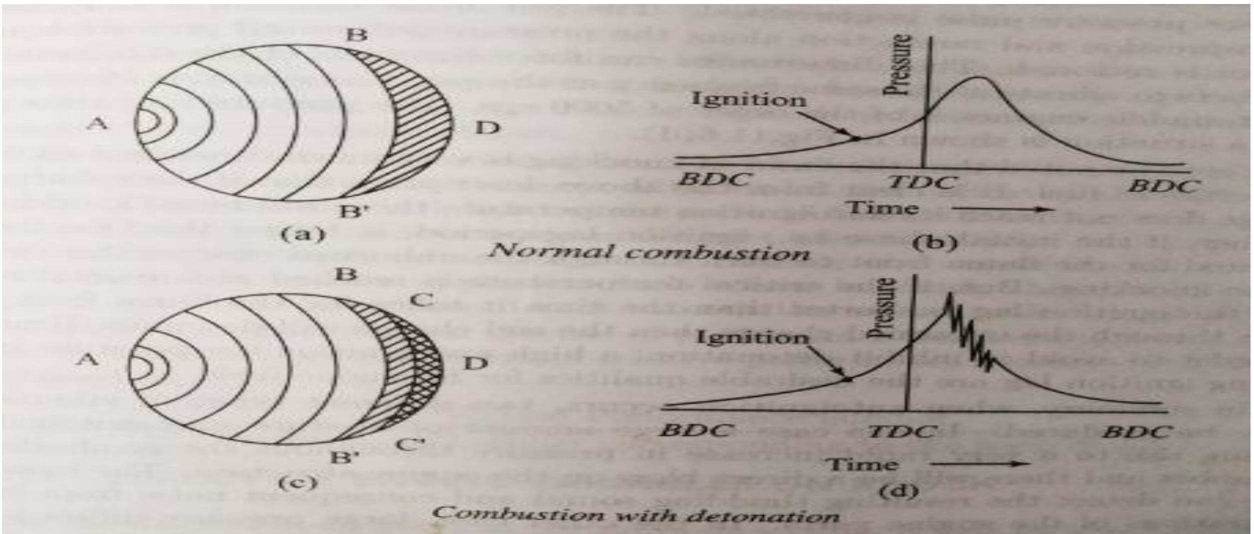


Fig. 11.6 Normal and abnormal combustion

5.A)

It is defined as the ratio of the mass of fuel consumed per hour per unit power output (*BP*). It is also designated as *Bsfc* (*brake specific fuel consumption*). It is a parameter which decides the economics of power production from an engine.

$$Bsfc \text{ or } sfc = \frac{\dot{m}_f \text{ (kg/h)}}{BP \text{ (kW)}} \text{(kg/kWh)} \quad ...(4.12)$$

The power output of an engine is obtained from the combustion of charge. Thus the *overall efficiency* of an engine is given by brake thermal efficiency, i.e.,

$$\eta_{bth} = \frac{\text{Brake power}}{\text{Energy supply rate}} = \frac{BP}{\dot{m}_f \times CV} \quad ...(24.11)$$

where, $\dot{m}_f$ = mass flow rate of the fuel (kg/s)
CV = Calorific value of fuel, (kJ/kg)

4.7.3 Mechanical Efficiency (η_{mech})

It is the ratio of the brake power and indicated power.

$$\eta_{mech} = \frac{\text{Brake power}}{\text{Indicated power}} = \frac{BP}{IP} \quad ...(4.24)$$

It can also be expressed as

$$\eta_{mech} = \frac{\text{Brake thermal efficiency}}{\text{Indicated thermal efficiency}} = \frac{\eta_{bth}}{\eta_{ith}} \quad ...(4.25)$$

5.B)

$$bp = \frac{2\pi NT}{60000} = \frac{2\pi NWR}{60000} = \frac{WN2\pi R}{60000}$$

$$= \frac{40 \times 9.81 \times 1600 \times 3}{60000} = 31.39 \text{ kW}$$

$$\eta_{bth} = \frac{bp}{\dot{m}_f \times CV} \times 100 = \frac{31.39 \times 60}{0.2 \times 44000} \times 100 = \mathbf{21.40\%} \quad \underleftarrow{\textbf{Ans}}$$

$$\eta_{ith} = \frac{\eta_{bth}}{\eta_m} \times 100 = \frac{0.214}{0.80} \times 100 = \mathbf{26.75\%} \quad \underleftarrow{\textbf{Ans}}$$

$$imep = \frac{\frac{bp}{\eta_m} \times 60000}{LAnK} = \frac{\frac{31.39}{0.8} \times 60000}{0.12 \times \frac{\pi}{4}0.1^2 \times \frac{1600}{2} \times 4}$$

$$= 7.8 \times 10^5 \text{ Pa} = \mathbf{7.8 \text{ bar}}$$

$$bsfc = \frac{\dot{m}_f}{bp} = \frac{0.2 \times 60}{31.39} = \mathbf{0.382 \text{ kg/kW h}}$$

6. a)

6.4 LIQUID FUELS

Liquid fuels are preferred for IC engines because they are easy to store and have reasonably good calorific value. In the liquid fuel category the main alternative is the alcohol.

6.4.1 Alcohol

Alcohols are an attractive alternate fuel because they can be obtained from both natural and manufactured sources. Methanol (methyl alcohol) and ethanol (ethyl alcohol) are two kinds of alcohols that seem most promising. The advantages of alcohol as a fuel are:

(i) It can be obtained from a number of sources, both natural and manufactured.

(ii) It is a high octane fuel with anti-knock index numbers (octane number) of over 100. Engines using high-octane fuel can run more efficiently by using higher compression ratios. Alcohols have higher flame speed.

(iii) It produces less overall emissions compared to gasoline.

(iv) When alcohols are burned, it forms more moles of exhaust gases, which gives higher pressure and more power in the expansion stroke.

(v) It has high latent heat of vapourization (h_{fg}) which results in a cooler intake process. This raises the volumetric efficiency of the engine and reduces the required work input in the compression stroke.

(vi) Alcohols have low sulphur content in the fuel.

Methanol:

Of all the fuels being considered as an alternate to gasoline, methanol is one of the most promising and has experienced major research and development. Pure methanol and mixtures of methanol and gasoline in various percentages have been extensively tested in engines and vehicles for a number of years. The most common mixtures are M85 (85% methanol and 15% gasoline) and M10 (10% methanol and 90% gasoline). The data of these tests which include performance and emission levels are compared with pure gasoline (M0) and pure methanol (M100).

One problem with gasoline-alcohol mixtures as a fuel is the tendency for alcohol to combine with any water present. When this happens the alcohol separates locally from the gasoline, resulting in a non-homogeneous mixture. This causes the engine to run erratically due to the large air-fuel ratio differences between the two fuels.

➢Ethanol:

➢Ethanol has been used as automobile fuel for many years in various countries of the world. Brazil is probably the leading user, where in the early 1990s.

➢About 5 million vehicles operated on fuels that were 93% ethanol. For a number of years gasohol (gasoline + alcohol) has been available at service stations in the United States.

➢Gasohol is a mixture of 90% gasoline and 10% ethanol. As with methanol, the development of systems using mixtures of gasoline and ethanol continues. Two mixture combinations that are important are E85 (85% ethanol) and E10 (gasohol). E85 is basically an alcohol fuel with 15% gasoline added to eliminate some of the problems of pure alcohol (i.e., cold starting, tank flammability, etc.).

➢E10 reduces the use of gasoline with no modification needed to the automobile engine.

Table 6.3 Comparison of petrol and LPG

Petrol	Liquefied Petroleum Gas (LPG)
Fuel consumption in petrol engine is less when compared to LPG.	Compared to petrol, running the engine on LPG results in around a 10% increase in consumption.
Petrol has odour	LPG is odourless
Octane rating of petrol is 81	Octane rating of LPG is 110
Petrol engine is not as smooth as LPG engine	Due to higher octane rating, the combustion of LPG is smoother and knocking is eliminated and the engine runs smoothly.
In order to increase octane number petrol required lead additives.	LPG is lead-free with high octane number

6. b)

6.9 GASEOUS FUELS

Gaseous fuels are best suited for IC engines since physical delay is almost zero. However, as fuel displaces equal amount of air the engines may have poor volumetric efficiency. There are quite few gaseous fuels that can be used as alternate fuels. We will discuss them in details in the following sections.

6.9.1 Hydrogen

A number of automobile manufacturers have built with prototype or modified engines which operate on hydrogen fuel. The advantages of hydrogen as an IC engine fuel include:

- Low emissions. Essentially no CO or HC in the exhaust as there is no carbon in the fuel. Most exhaust would be H_2O and N_2 and NO_x.
- Fuel availability. There are a number of different ways of making hydrogen, including electrolysis of water.
- Fuel leakage to environment is not a pollutant.
- High energy content per volume when stored as a liquid. This would give a large vehicle range for a given fuel tank capacity, but see the following.

6.10.1 Natural Gas

Natural gas is found in various localities in oil and gas bearing sand strata located at various depths below the earth surface. The gas is usually under considerable pressure, and flows out naturally from the oil well. If the gas is used in an engine located near the well any entrained sand must be separated from the gas before its use. Natural gas obtained from oil wells is called casing head gas. It is usually treated for the recovery of gasoline. After this, it is called dry gas. It is delivered into the pipeline systems to be used as fuel. Natural gas can be used in the production of natural gasoline. Natural gas is a mixture of components, consisting mainly of methane (60–95%) with small amounts of other hydrocarbon fuel components. The composition varies considerably from place to place and from time to time. But usually contain

6.10.4 Compressed Natural Gas (CNG)

Petroleum and natural gas are obtained by the process of drilling wells. As already known crude petroleum is composed of hydrocarbons. It contains some amount of water, sulphur and other impurities. Petroleum when mixed with natural gas produces a highly volatile liquid. This liquid is known as natural gasoline. When this petroleum-natural gas mixture is cooled, the gasoline condenses.

The natural gas can be compressed and then it is called Compressed Natural Gas (CNG). CNG is used to run an automobile vehicle just like LPG. The CNG fuel feed system is similar to the LPG fuel feed system. CNG conversion kits are used to convert petrol-driven cars into CNG-driven cars. These kits contain auxiliary parts like the converter, mixer and other essential parts required for conversion. Emission levels and a comparison between CNG-driven

6.10.5 Liquefied Petroleum Gas (LPG)

Propane and butane are obtained from oil and gas wells. They are also the products of the petroleum refining process. For automobile engines, two types of LPG are used. One is propane and the other is butane. Sometimes, a mixture of propane and butane is used as liquid petroleum gas in automobile

engines. Liquid petroleum gases serve as fuel in place of petrol. They are used widely in buses, cars and trucks. Liquid petroleum gases are compressed and cooled to form liquid. This liquid is kept in pressure tanks which are sealed.

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In order to increase octane number petrol required lead additives.	LPG is lead-free with high octane number

7. a)

14.5.1 Exhaust Emissions

As already mentioned major exhaust emissions are

(i) unburnt hydrocarbons, (HC)

(ii) oxides of carbon, (CO and CO_2),

(iii) oxides of nitrogen, (NO and NO_2)

(iv) oxides of sulphur, (SO_2 and SO_3)

(v) particulates, soot and smoke.

Carbon monoxide is a colorless and odorless but a poisonous gas. It is generated in an engine when it is operated with a fuel-rich equivalence ratio, as shown in Fig.14.1. When there is not enough oxygen to convert all carbon to CO_2, some fuel does not get burned and some carbon ends up as CO. Typically the exhaust of an SI engine will be about 0.2 to 5% carbon monoxide. Not only is CO considered an undesirable emission, but it also represents lost chemical energy. CO is a fuel that can be combusted to supply additional thermal energy:

$$CO + \frac{1}{2} O_2 \rightarrow CO_2 + \text{ heat} \tag{14.1}$$

NO_x is created mostly from nitrogen in the air. Nitrogen can also be found in fuel blends. Further, fuel may contain trace amounts of NH_3, NC, and HCN, but this would contribute only to a minor degree. There are a number of possible reactions that form NO. All the restrictions are probably occurring during the combustion process and immediately after. These include but are not limited to:

$$O + N_2 \rightarrow NO + N \tag{14.2}$$

$$N + O_2 \rightarrow NO + O \tag{14.3}$$

$$N + OH \rightarrow NO + H \tag{14.4}$$

Hydrocarbon emissions will be different for each gasoline blend, depending on the original fuel components. Combustion chamber geometry and engine operating parameters also influence the HC component spectrum.

When hydrocarbon emissions get into the atmosphere, they act as irritants and odorants; some are carcinogenic. All components except CH_4 react with atmospheric gases to form photochemical smog.

7. b)

The most effective aftertreatment for reducing engine emissions is the catalytic converter found on most automobiles and other modern engines of medium or large size. CO and HC can be oxidized to CO_2 and H_2O in exhaust systems and thermal converters if the temperature is held at 600–700 °C. If certain catalysts are present, the temperature needed to sustain these oxidation processes is reduced to 250–300 °C, making for a much more attractive system.

A catalyst is a substance that accelerates a chemical reaction by lowering the energy needed for it to proceed. The catalyst is not consumed in the reaction and so functions indefinitely unless degraded by heat, age, contaminants, or other factors.

Catalytic converters are chambers mounted in the flow system through which the exhaust gases pass through. These chambers contain catalytic material, which promotes the oxidation of the emissions contained in the exhaust flow. Generally, they are called three-way converters because they are used to reduce the concentration of CO, HC, and NO_x in the exhaust. It is usually a stainless steel container mounted somewhere along the exhaust pipe of the engine. Inside the container is a porous ceramic structure through which the exhaust gas flows. In most converters, the ceramic is a single honeycomb structure with many flow passages (Fig.14.7). Some converters use loose granular ceramic with the gas passing between the packed spheres. Volume of the ceramic structure of a converter is generally about half the displacement volume of the engine. This results in a volumetric flow rate of exhaust gas such that there are 5 to 30 changeovers of gas each second, through the converter. Catalytic converters for CI engines need larger flow passages because of the solid soot in the exhaust gases. The surface of the ceramic passages contains small embedded particles of catalytic material that promote the oxidation reactions in the exhaust gas as it passes. Aluminum oxide (alumina) is the base ceramic material used for most catalytic converters. Alumina can withstand the high temperatures, it remains chemically neutral,

8. a)

1. Intercooling. A compressor in a gas turbine cycle utilises the major percentage of power developed by the gas turbine. The work required by the compressor can be reduced by compressing the air in two stages and *incorporating an intercooler* between the two as shown in Fig. 25.3. The corresponding *T-s* diagram for the unit is shown in Fig. 25.4. The actual processes take place as follows :

1-2′	...	L.P. (Low pressure) compression
2′-3	...	Intercooling
3-4′	...	H.P. (High pressure) compression
4′-5	...	C.C. (Combustion chamber)-heating
5-6′	...	T (Turbine)-expansion

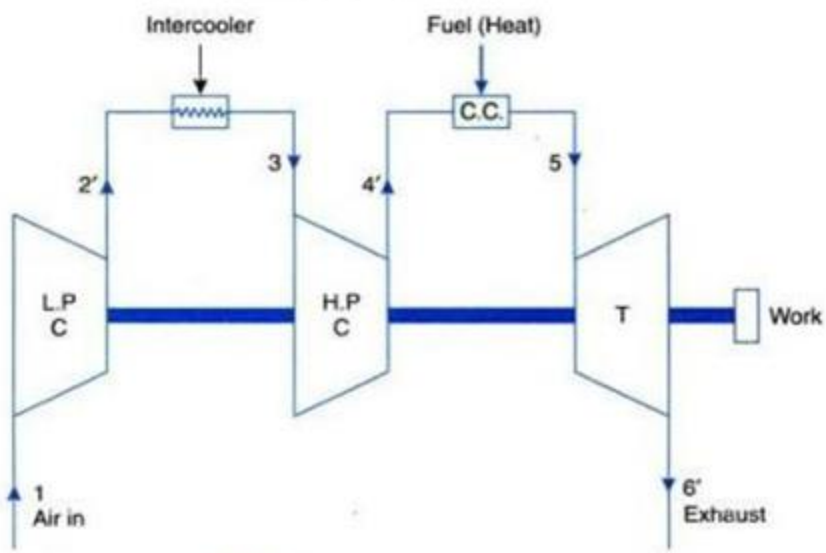

Fig. 25.3. Turbine plant with intercooler.

The ideal cycle for this arrangement is 1-2-3-4-5-6 ; the compression process without intercooling is shown as 1-L' in the actual case, and 1-L in the ideal isentropic case.

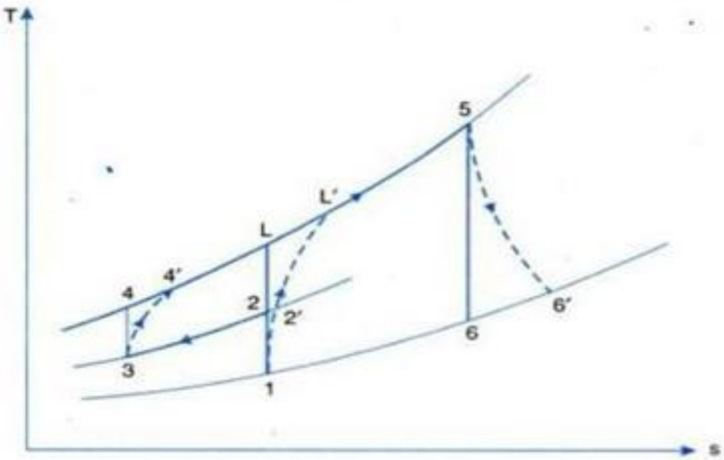

Fig. 25.4. T-s diagram for the unit.

Now,

Work input (*with intercooling*)

$$= c_p(T_2' - T_1) + c_p(T_4' - T_3) \quad ...(25.3)$$

Work input (*without intercooling*)

$$= c_p(T_L' - T_1) = c_p(T_2' - T_1) + c_p(T_L' - T_2') \quad ...(25.4)$$

However, the heat supplied in the combustion chamber when intercooling is used in the cycle, is given by,

Heat supplied *with intercooling* $= c_p(T_5 - T_4')$

Also the heat supplied when intercooling is not used, with the same maximum cycle temperature T_5, is given by

Heat supplied *without intercooling* $= c_p\ (T_5 - T_L')$

8. a)

For isentropic compression process 1–2 :

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{6.2}{1}\right)^{\frac{1.4-1}{1.4}} = 1.684$$

$\therefore$ $$T_2 = 300 \times 1.684 = 505.2 \text{ K}$$

Now, $$\eta_{compressor} = \frac{T_2 - T_1}{T_2' - T_1}$$

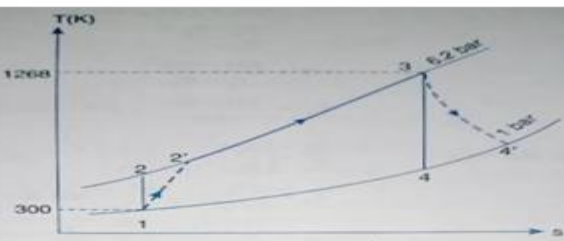

Fig. 25.21

$$0.88 = \frac{505.2 - 300}{T_2' - 300}$$

$$T_2' = \left(\frac{505.2 - 300}{0.88} + 300\right) = 533.2 \text{ K}$$

Heat supplied $$= (m_a + m_f) \times c_p(T_3 - T_2') = m_f \times C$$

or $$\left(1 + \frac{m_f}{m_a}\right) \times c_p(T_3 - T_2') = \frac{m_f}{m_a} \times C$$

or $$(1 + 0.017) \times 1.005(T_3 - 533.2) = 0.017 \times 44186$$

$\therefore$ $$T_3 = \frac{0.017 \times 44186}{(1 + 0.017) \times 1.005} + 533.2 = 1268 \text{ K}$$

For isentropic expression process 3–4 :

$$\frac{T_4}{T_3} = \left(\frac{p_4}{p_3}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{1}{6.2}\right)^{\frac{1.333-1}{1.333}} = 0.634$$

$\therefore$ $T_4 = 1268 \times 0.634 = 803.9$ K ($\because$ $\gamma_g = 1.333$ ......Given)

Now, $\eta_{turbine} = \dfrac{T_3 - T_4'}{T_3 - T_4}$

$$0.9 = \frac{1268 - T_4'}{1268 - 803.9}$$

$\therefore$ $T_4' = 1268 - 0.9(1268 - 803.9) = 850.3$ K

$W_{compressor} = c_p(T_2' - T_1) = 1.005(533.2 - 300) = 234.4$ kJ/kg

$W_{turbine} = c_{pg}(T_3 - T_4') = 1.147(1268 - 850.3) = 479.1$ kJ/kg

Network $= W_{turbine} - W_{compressor}$

$= 479.1 - 234.4 = 244.7$ kJ/kg

Heat supplied per kg of air

$= 0.017 \times 44186 = 751.2$ kJ/kg

$\therefore$ **Thermal efficiency,** $\eta_{th.} = \dfrac{\text{Network}}{\text{Heat supplied}}$

$= \dfrac{244.7}{751.2} = 0.3257$ or **32.57%. (Ans.)**

9.

25.8.3. Ram-jet :

Ram-jet is also called *athodyd, Lorin tube* or *flying stovepipe*. Ram-jet engines have the capability to fly at *supersonic speeds*. Fig. 25.44 shows a schematic diagram of a ram-jet engine (compressor and turbine are not necessary as the entire compression depends only on the ram compression).

- The ram-jet engine consists of a *diffuser* (used for compression), *combustion chamber* and *nozzle*.
- The air enters the ram-jet plant with *supersonic speed* and is slowed down to *sonic velocity* in the *supersonic diffuser*, consequently the pressure suddenly increases in the supersonic diffuser to the formation of shock wave. The pressure of air is further increased in the subsonic diffuser *increasing the temperature of the air above the ignition temperature*.
- In the combustion chamber, the fuel is injected through injection nozzles. The fuel air mixture is then ignited by means of a spark plug and combustion temperatures of the order of 2000 K are attained. The expansion of gases towards the diffuser entrance is restricted by pressure barrier at the after end of the diffuser and as a result the hot gases are constrained to move towards the nozzle and undergo expansion ; the pressure

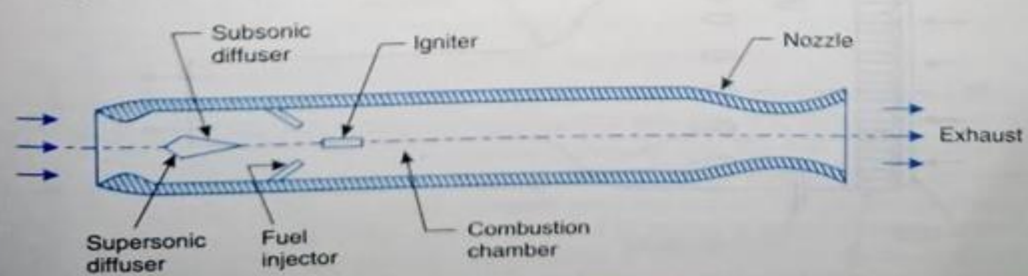

Fig. 25.44. Schematic diagram of a Ram-jet propulsion unit.

energy is converted into the kinetic energy. The high velocity gases leaving the nozzle provide forward thrust to the unit.

The best performance of ram-jet engine is obtained at flight speed of 1700 km/h to 2000 km/h.

Advantages of ram-jet engine

The ram-jet engine possesses the following *advantages* over other types of jet engines :

1. No moving parts.
2. Light in weight.
3. Wide variety of fuels may be used.

Shortcomings/Limitations

1. It *cannot be started of its own*. It *has to be accelerated to a certain flight velocity by some launching device*. A ram-jet is *always equipped with a small turbo-jet which starts the ram-jet*.

2. The fuel consumption is too large at low and moderate speeds.

3. For successful operation, the diffuser needs to be designed carefully so that kinetic energy associated with high entrance velocities is efficiently converted into pressure.

4. To obtain steady combustion, certain elaborate devices in form of flame holders or pilot flame are required.

25.8.4. Pulse-jet Engine

A *pulse-jet engine* is an intermittent combustion engine and it operates on a cycle similar to a reciprocating engine, whereas the turbo-jet and ram-jet engines are continuous in operation and are based on Brayton cycle. A pulse-jet engine like an athodyd, develops thrust by a high velocity of jet of exhaust gases without the aid of compressor or turbine. Its development is primarily due to the inability of the ram-jet to be self starting. Fig. 25.45 shows a schematic arrangement of a pulse-jet propulsion unit.

- The incoming air is compressed by ram effect in the diffuser section and the grid passages which are opened and closed by V-shaped non-return valves.
- The fuel is then injected into the combustion chamber by fuel injectors (worked from the air pressure from the compressed air bottles). The combustion is then initiated by a spark plug (once the engine is operating normally, the spark is turned off and the residual flame in the combustion chamber is used for combustion).

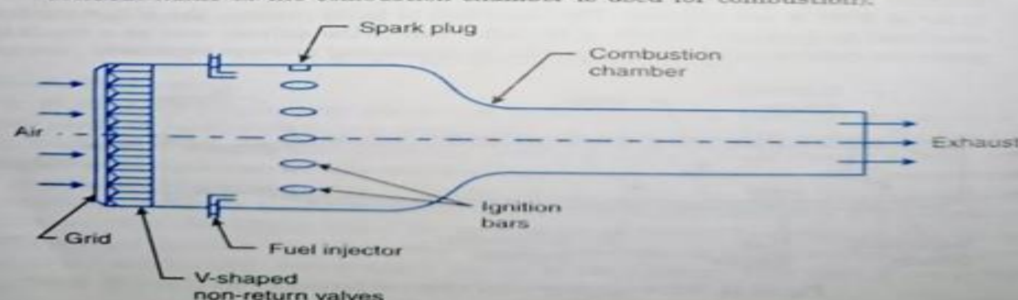

Fig. 25.45. Pulse-jet engine.

- As a result of combustion (of mixture of air and fuel) the temperature and pressure of combustion products increase. Because the combustion pressure is higher than the ram pressure, the non-return valves get closed and consequently the hot gases flow out of the tail pipe with a high velocity and in doing so give a forward thrust to the unit.
- With the escape of gases to the atmosphere, the static pressure in the chamber falls and the high pressure air in the diffuser forces the valves to open and fresh air is admitted for combustion during a new cycle.

Advantages :

1. Simple in construction and very inexpensive as compared to turbo-jet engine. Well adapted to pilotless aircraft.

2. Capable of producing static thrust and thrust in excess of drag at much low speeds.

Shortcomings :

1. High intensity of noise.
2. Severe vibrations.
3. High rate of fuel consumption and low thermodynamic efficiency.
4. Intermittent combustion as compared to continuous combustion in a turbo-jet engine.
5. The operating altitude is limited by air density consideration.
6. Serious limitation to mechanical valve arrangement.