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PART - A

2 Marks Questions

1.
Sol. In S.I. engine detonation occurs when the end charge auto ignites before the flame reaches it. Hence the factors which helps the fuel to ignite increase the tendency of detonation. Whereas in C.I. engine, the knocking occurs because of the delay in the ignition of fuel, so any factor which increase the tendency of fuel to ignite will definitely reduce knocking, so the factors which increase detonation in S.I. engine reduce knocking in C.I. engines.
2.
Sol. **Effect of combustion chamber shape:** The flame travel should always be shorter in order to have low knocking tendency. Therefore, the combustion chambers are made as spherical as possible to minimize length of the flame travel for a given volume which finally promotes turbulence.
Location of spark plug: In order to reduce knocking, the spark plug should be located near to exhaust valve, suppressing the chance of pre-ignition.
3.
Sol. **Objective of supercharging:**
 1. To increase the power output for a given weight and bulk of the engine. This is important for aircraft, marine and automotive engines where weight and space are important.
 2. To compensate for the loss of power due to altitude. This mainly relates to aircraft engines which lose power at an approximate rate of one percent for 100 metres altitude gain. This is also relevant for other engines which are used at high altitudes.
 3. To obtain more power from an existing engine.
4.
Sol. The problems related to environment due to exhaust emission are
 1. NO_x and HC in presence of sunlight produces smog.
 2. Due to green house gases (e.g. CO) the problem of global warming occurs.
 3. Acid rain due to SO_x emissions
 4. Unpleasant Odours
5.
Sol. **Major exhaust emission are**
 1. Carbon Monoxides (CO)
 2. Oxides of nitrogen (NO_x)
 3. Oxides of sulphur (SO_x)
 4. Particulate matter
 5. Unburnt hydrocarbons
 6. Water vapour
6.
Sol. **Advantages of using LPG in S.I. engine:**
 1. It is cheaper than gasoline.
 2. It is highly knock resistant and does not preignite easily.
 3. It gives better manifold distribution and mixes easily with air.
 4. Residue and oil contamination is small as it burns clearly.
 5. Crank case oil dilution is small.**Disadvantages:**
 1. Much of its advantages are for engines of higher compression ratio.
 2. It reduces volumetric efficiency due to its high heat of vaporization.
 3. Handling has to be done for pressure of about 18 bar.
 4. Response to blending is poor.



- 7.
- Sol. Scavenging of I.C. Engines**
The scavenging, in an internal combustion engine, is the process of removing the burnt gases from the combustion chamber of the engine cylinder.
- 8.
- Sol. Crossflow scavenging:** In this method, the transfer port (or inlet port for the engine cylinder) and exhaust port are situated on the opposite sides of the engine cylinder (as in the case of two stroke cycle engines).
- 9.
- Sol. Back flow or loop scavenging:** In this method, the inlet and outlet ports are situated on the same side of the engine cylinder.
Uniflow scavenging: In this method, the fresh charge, while entering from one side (or sometimes two sides) of the engine cylinder pushes out the gases through the exit valve situated on the top of the cylinder.
Note: The scavenging efficiency of a four stroke cycle diesel engine is between 95 and 100 percent.
- 10.
- Sol. Governing of I.C. Engines**
The process of providing any arrangement, which will keep the engine speed constant (according to the changing load conditions) is known as governing of I.C. engines.
- 11.
- Sol. Hit and miss governing:** In this system of governing, whenever the engine starts running at higher speed (due to decreased load), some explosions are omitted or missed. This is done with the help of a centrifugal governor. This method of governing is widely used for I. C. engines of smaller capacity or gas engines.
- 12.
- Sol. Qualitative governing:** In this system of governing, a control valve is fitted in the fuel delivery pipe, which controls the quantity of fuel to be mixed in the charge. The movement of control valve is regulated by the centrifugal governor through rack and pinion arrangement.
- 13.
- Sol. Quantitative governing:** In this system of governing, the quality of charge (i.e. air-fuel ratio of the mixture) is kept constant. But the quantity of mixture supplied to the engine cylinder is varied by means of a throttle valve which is regulated by the centrifugal governor through rack and pinion arrangement.
- 14.
- Sol. Ignition delay period** in CI engine is counted from the start of injection to the point where the pressure-crank angle curve separates from the motoring curve indicated as start of combustion.
Physical delay: The Physical delay is the time between the beginning of injection and the attainment of chemical reaction conditions
Chemical delay: During the Chemical delay, reactions start slowly and then accelerate until inflammation or ignition takes place.
- 15.
- Sol. Carburettor**
The carburettor is a device for atomising and vaporising the fuel and mixing it with the air in the varying proportions to suit the changing operating conditions of the engine. The process of breaking up and mixing the fuel with the air is called carburation.
- 16.
- Sol. Spark Plug**
A spark plug is a device used to produce spark for igniting the charge of petrol engines. It is always screwed into the cylinder head. It is, usually, designed to withstand a pressure upto 35 bar and operate under a current of 10 000 to 30 000 volts. The spark plug gap is kept from 0.3 mm to 0.7 mm.

17.

Sol. Fuel injector is used in diesel engine to inject and atomize the diesel at the end of the compression stroke.

18.

Sol. SI engine means spark ignition engine. In SI engine air fuel mixture is ignited by spark plug hence it is called spark ignition engine. It is also called as petrol engine.

19.

Sol. CI engine means compression ignition engine. In CI engine the fuel is injected by a fuel injector in atomized form because of high compressed air it gets ignited automatically. Hence it is called as compression ignition engine.

20.

Sol. It is the accounts of heat supplied and heat utilized in various ways in the system. The heat balance is generally done by minute basis or percentage basis.

21.

Sol. It is defined as the average pressure acting on the piston during the entire power stroke that would produce the same amount of net work output during the actual cycle. It is also defined as the ratio of work-done per cycle to swept volume.

22.

Sol.

- To inject the fuel at correct moment, and quantity at various load conditions
- To inject the fuel in a finely atomized condition.
- To distribute the fuel uniformly in the combustion chamber.
- To control the rate of fuel injection.

23.

Sol. It is the time interval between the instant of spark and the instant when there is a noticeable rise in pressure due to combustion.

24.

Sol. **Brake Power:** It is defined as the power developed at output crank shaft of an engine for doing external work.

Indicated Power: It is the power developed by the engine inside the cylinder due to the fuel combustion in the combustion chamber.

25.

Sol. Morse test is a performance test conducted on multi cylinder engines to measure the indicated power without the use of indicator diagram.

26.

Sol. It is the ratio of fuel consumption per unit time of power developed.

27.

Sol.

- To control the delivery stroke effectively.
- To control the amount of fuel supplied to the engine.

28.

Sol. Glycerin has boiling point of 90°C which increases its heat carrying capacity. Thus weight of coolant gets reduced and smaller radiator can be used.

29.

Sol. The S.I. or spark ignition engine uses petrol as a fuel and the C.I. or compression ignition engine uses diesel as a fuel. Both the fuels have different compression ratio.

In SI engine the compression ratio is 8-12:1.

In CI engine the compression ratio is 16-22:1.



So in case of SI engine, the compression ratio is not sufficient for fuel to burn so a spark plug is used, whereas in CI engine, the compression ratio is so high that due to its internal heat the fuel is combusted so there is no need for a spark plug. So the technology used in SI engine is different from CI engine.

30.

Sol.

Air injection system	Air less (solid) injection system
1. Liquid fuel is sprayed into the engine cylinder by means of compressed air.	1. Liquid fuel is injected into the engine cylinder at high pressure by means of fuel pump.
2. It requires multi stage air compressor which increases engine weight and reduces net power output. It is used rarely.	2. This system is used more commonly.

31.

Sol. The frictional power of an engine can be determined by the following methods

1. Willan's line method (used for CI engines only)
2. Morse test
3. Motoring test
4. Difference between I.P. and B.P. 5. Retardation test

32.

Sol. The flame front is a narrow zone separating the fresh mixture from the combustion products. The velocity with which the flame front moves, with respect to the unburned mixture in a direction normal to its surface is called the normal flame velocity.

33.

Sol. Equivalence ratio is the ratio of the actual fuel-air ratio to the stoichiometric fuel-air ratio.

34.

Sol. In a homogeneous gas mixture the fuel and oxygen molecules are more or less, uniformly distributed. In a heterogeneous gas mixture, the fuel and oxygen molecules are not distributed uniformly.

35.

Sol. **Significance of Turbulence:**

Turbulence plays a very important role in combustion phenomenon in S.I. (as well CI) engines. The flame speed is very low in non-turbulent mixtures. A turbulent motion of the mixture intensifies the processes of heat transfer and mixing of the burned and unburned portions in the flame front (diffusion). These two factors cause the velocity of turbulent flame to increase practically in proportion to the turbulent velocity. The turbulence of the mixture is due to admission of fuel-air mixture through comparatively narrow sections of the intake pipe, valves etc., in the suction stroke.

36.

Sol. The main macro mass motion within the cylinder is rotational motion and is called swirl. It is generated by constructing the intake system to give a tangential component to the intake flow as it enters the cylinder. This is done by shaping and contouring the intake manifold, valve ports and even the piston face. This radial inward motion of the gas mixture is called "squish". It adds to other mass motions within the cylinder to mix the air and fuel and to quickly spread the flame front as the piston nears T.D.C. squish motion generates a secondary rotational flow called "tumble". This rotation occurs about a circumferential axis near the outer edge of the piston bowl.

37.

Sol. The factors that tend to prevent knock in SI engines and promote knock in CI engines.

- | | |
|-------------------------------------|--|
| (a) High self ignition temperature. | (b) Long ignition delay |
| (c) Low compression ratio | (d) Low inlet temperature and pressure |
| (e) Low combustion wall temperature | (f) High speed, rpm |
| (g) Small cylinder size. | |

38.

Sol. The free air delivered (F.A.D.) is the actual volume delivered at the stated pressure reduced to intake temperature and pressure, and expressed in m^3/min .

The displacement is the actual volume in m^3/min swept out per minute by the L.P. piston or pistons during the suction strokes.

The free air delivered per minute is less than the displacement of the compressor because of the following reasons:

1. The fluid resistance through the air intake, and valves prevents the cylinder being fully charged with air at atmospheric conditions.
2. On entering the hot cylinder the air expands
3. The high-pressure air trapped in the clearance space, must expand to a pressure below atmospheric before the automatic suction valves can open; a portion of the suction stroke is therefore wasted in effecting this expansion.
4. A certain loss is caused by the leakage.

39.

Sol. **Benefits of Ethanol Blending:**

As ethanol contains oxygen, it burns completely, emitting nil carbon dioxide.

It is expected that the ethanol project will reduce greenhouse gases equivalent to about three lakh tonnes of CO_2 emission per annum.

Using stubble of post-harvest for ethanol production reduces stubble-burning so as air pollution along with helping in increasing farmers' income.

As the ethanol blending program run by various developed nations, global corn, and maize production is down, this may act as an incentive for India's export.

40.

Sol. Given, circulation ratio = 12.5

$$\text{Dryness fraction at the top of a riser} = \frac{1}{\text{CR}} = \frac{1}{12.5} = 0.08$$

41.

Sol. On account of slip, the whirl component of velocity gets reduced which in turn decreases the energy transfer and the pressure developed. Slip factor is the ratio of actual and theoretical values of the whirl components at the exit of impeller tip.

$$\text{Slip} = (C_t)_{\text{Theoretical}} - (C_t)_{\text{Actual}}$$

$$\text{Slip factor} = \frac{(C_t)_{\text{Actual}}}{(C_t)_{\text{Theoretical}}}$$

42.

Sol. Basic rule curve represents accumulation of water in reverse order of time of deficiency between firm load and energy available from stream flow in critically dry periods.

43.

Sol. The power developed by a hydro plant depends upon the discharge and head and is directly proportional to their (discharge and head) product.

44.

Sol. The factors governing the site selection for a hydroelectric plant are:

- (i) Availability of water
- (ii) Water storage
- (iii) Water head
- (iv) Distance from load centre
- (v) Accessibility of the site



- (vi) Water pollution,
- (vii) Sedimentation
- (viii) Large catchment area
- (ix) Availability of land
- (x) Possibility of stream diversion.

45.

Sol. The catchment area is the area, bounded by watersheds, which drains into a stream or river across which the dam has been built at a suitable place.

46.

Sol. A hydrograph is a graphical representation between discharge or flow with time.

47.

Sol. Mass curve is a curve which indicates the total volume of run-off in m^3 up to a certain time.

48.

Sol. The abscissae for the mass curve may be a day, month or year and ordinate may be plotted in terms of second-metre-day or second-metre-month which means the flow collected at the rate of 1 cubic metre per second for one day or one month respectively. It indicates the total volume of run-off in m^3 up to a certain time.

49.

Sol. Mass curve is used in determination of the capacity of the storage reservoir in hydro projects.

50.

Sol. The forebay serves as a regulating reservoir storing water temporarily during light load period and providing the same for initial increase on account of increasing load during which water in the canal is being accelerated. In short a forebay may be considered as an enlarged body of water just above the intake to store water temporarily to meet the hourly load fluctuations. This may either be a pond behind the diversion dam or an enlarged section of a canal spread out to accommodate the required widths of intake.

51.

Sol. A reduction in load on the generator causes the governor to close the turbine gates and thus create an increased pressure in the penstock. This may result in water hammer phenomenon and may need pipe of extraordinary strength to withstand it otherwise the penstock may burst.

52.

Sol. Surge tank is provided to absorb sudden changes in water requirements and reduce water hammer and negative pressure in penstock.

53.

Sol. Kaplan turbine is ideally suited to pumped storage plants because its runner is capable of reverse operation as a pump.

54.

Sol. The operating cost of nuclear power plants is quite low and once the installation is completed, the loading of the power plant will have no effect on the generation cost. Therefore, a nuclear power plant is always operated as a base load plant. The nuclear power plants are usually not operated at a load factor less than 0.8.

55.

Sol. Three important factors in choosing a site for atomic power plants are :

- (i) availability of water supply (ii) distance from populated area and (iii) transportation facilities.

56.

Sol. Three different types of fuels used in nuclear reactor are:

- (i) natural uranium U-235
- (ii) plutonium (iii) enriched uranium.

57.

Sol. 2.57/2.68 MW

58.

Sol. The disintegration or decay of unstable atoms accompanied by emission of radiation is called the radioactivity.

59.

Sol. The decay or disintegration constant may be defined as the proportion of atoms of an isotope decaying per second.

60.

Sol. The half life or half life period of a radioactive isotope is the time required for one half of the isotope to decay.

61.

Sol. The difference between the experimental mass and calculated mass of the nucleus is called the mass defect or mass deficit.

62.

Sol. The energy that binds the nucleus together in the nucleus is called the nuclear binding energy. Binding energy is the energy equivalent of the mass defect.

63.

Sol. 1 amu = 931.5 MeV; amu stands for atomic mass unit.

64.

Sol. When two or more lighter nuclei (H_2 or H_3) with lower binding energy per nucleon are combined or fused together into a heavier and more stable nucleus, there is a release of energy. This process of releasing energy is known as fusion.

The splitting of a heavy nucleus into two or more smaller nuclei is termed nuclear fission.

65.

Sol. The materials which are known to undergo neutron fission are U-235, U-233 and Pu-239. These are fissile materials. There are materials ($^{238}\text{U}_{92}$ and $^{232}\text{Th}_{90}$) which occur in nature, are called fertile materials. Fissionable materials $^{238}\text{U}_{92}$ and $^{233}\text{Th}_{92}$ are formed in the, nuclear reactors during fission process from $^{238}\text{U}_{92}$ and $^{232}\text{Th}_{90}$. Th respectively due to absorption of neutrons without fission.

66.

Sol. The concepts of nuclear power generation are much similar to that of conventional steam power generation. The difference lies only in the steam generation part i.e., coal or oil burning furnace and the boiler are replaced by nuclear reactor and heat exchanger.

67.

Sol. A nuclear power plant consists of a nuclear reactor (for heat generation), heat exchanger (for converting water into steam by using heat generated in the nuclear reactor), steam turbine, alternator, condenser etc.

68.

Sol. Reactor is that part of nuclear power plant where nuclear fuel is subjected to nuclear fission and the energy released in the process is utilised to heat the coolant which may in turn generate steam or be used in a gas turbine.

A nuclear reactor consists of reactor core, moderator, control rods, coolant, reflector, thermal shielding, reactor vessel and biological shield.

69.

Sol. The purpose of a moderator in a nuclear power reactor is to slowdown the neutrons.

70.



Sol. Three commonly used moderators are: (i) graphite (ii) ordinary or natural water and (iii) heavy water.

71.

Sol. Control rods are meant for controlling the rate of fission of U-235.

72.

Sol. The materials used for control rods must have very high absorption capacity for neutrons. The commonly used materials for control rods are cadmium, boron or hafnium.

73.

Sol. The main disadvantages of sodium graphite reactor are (i) relatively complex core (ii) requirement of enriched fuel (iii) requirement of triple cycle cooling system with dual heat exchangers to minimize hazards etc.

74.

Sol. The nuclear waste is disposed of as follows:

1. Solid waste is stored in suitable containers, which are sunk to the bottom of seas and oceans.
2. Liquid waste is diluted and disposed in river and sea after treatment.
3. Gaseous waste is discharged to atmosphere at high level after filtration and treatment.

75.

Sol. **Load curve:** The curve obtained by plotting time in hours (Day, month, or year) on X-axis and load (kW or MW) on Y-axis is known as the load curve.

76.

Sol. **Load Duration Curve:** The load curve gives the variations of load. But in the Load Duration Curve, all the loads are arranged in descending order of magnitudes from the greatest load on the left and the least loads on the extreme right.

77.

Sol. **Load Factor:** The load factor is defined as the ratio of the average load to the maximum demand of a power station during a certain period of time.

$$\text{Load Factor} = \frac{\text{Average load (Demand)}}{\text{Maximum Demand (peak load)}}$$

78.

Sol. **Demand Factor:** The demand factor is defined as the ratio of maximum demand on the power station to its connected load, the demand factor formula is as follows,

$$\text{Demand Factor} = \frac{\text{Maximum Demand}}{\text{Connected load}}$$

79.

Sol. **Diversity Factor:** It is defined as the ratio of the sum of the individual demands of all consumers to the maximum demand of the power station. The diversity factor formula is as follows:

$$\text{Diversity Factor} = \frac{\text{Sum of individual Maximum Demands}}{\text{Maximum Demand of Power Station}}$$

80.

Sol. **Plant use factor:** It is the ratio of kWh generated to the product of plant capacity and the number of hours for which the plant was in operation i.e

$$\text{Plant use Factor} = \frac{\text{Station Output in kWh}}{\text{Plant Capacity} \times \text{Hrs of use}}$$

81.

Sol. **Base Load:** Base load is the minimum amount of power demand on an electrical grid over a given period of time. It is usually considered as a constant load being maintained.

82.

Sol. **Peak load:** Peak load is the highest level of electricity demand on an electrical grid over a given period of time. This peak is the maximum load, sometimes.

PART - B

5 Marks Questions

83.

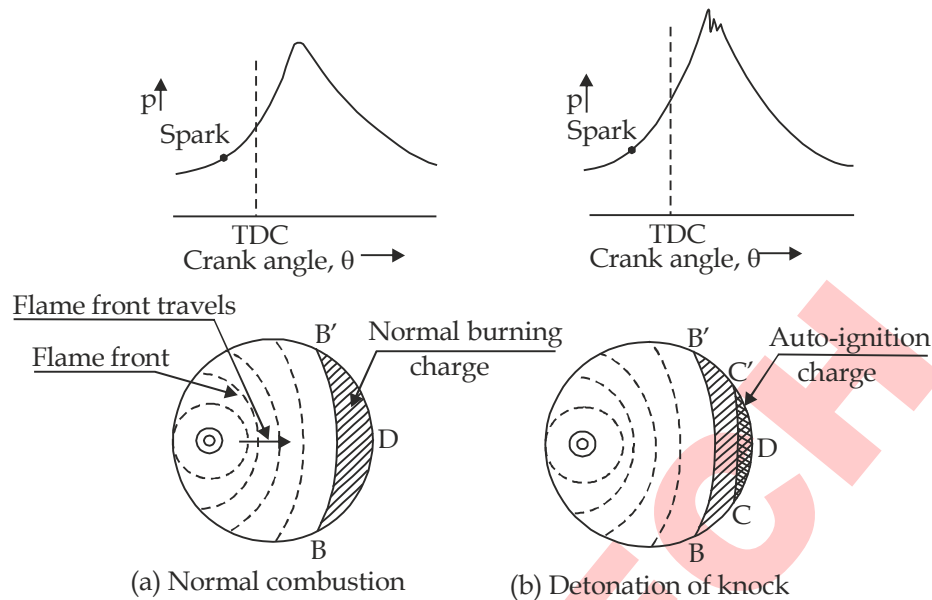
- Sol.**
1. **Basic cycle:** S.I. engine works on otto cycle whereas C.I. engine works on diesel cycle.
 2. **Fuel:** Fuel used in S.I. engine should be of high self ignition temperature and high octane number (petrol). In C.I. engine, the fuel should have low self ignition temperature and high cetane number.
 3. **Introduction of fuel in cylinder:** In S.I. engine a mixture of air and fuel mixed through carburettor is introduced in the cylinder. In C.I. engine, the fuel is injected directly into the combustion chamber of the end of compression stroke.
 4. **Ignition:** In S.I. engine, there is spark ignition, whereas in C.I. engine, ignition is through compression.
 5. **Compression ratio:** In S.I. engine usually the compression ratio is 6-11 which is restricted by detonation. In C.I. engine compression ratio is about 13-22. Higher compression ratio reduces knocking but is restricted by mechanical and thermal strength of the engine.
 6. **Speed:** S.I. engine operates at a higher speed (2000-6000 rpm) as compared to C.I. engine (400 - 1200) rpm.
 7. **Efficiency:** Higher efficiency of S.I. engine for same compression ratio and heat input than C.I. engine.
 8. **Weight:** Weight per unit power in S.I. is lower as compared to C.I. engine.

84.

- Sol.**
1. **Pre-ignition:** Due to formation of localised overheated spots which might occur at spark plug, combustion chamber deposits or exhaust valves, the ignition might occur before passing of spark. This ignition is called pre-ignition.
 2. **Detonation:** In normal combustion, a normal flame front travels across the combustion chamber from A to D.

As the flame front propagates, the temperature of the end charge increases due to 3 reasons:

- (i) Compression of end charge due to expansion of already burnt fuel.
- (ii) Radiation from the flame front.
- (iii) Hotspot like exhaust valve.



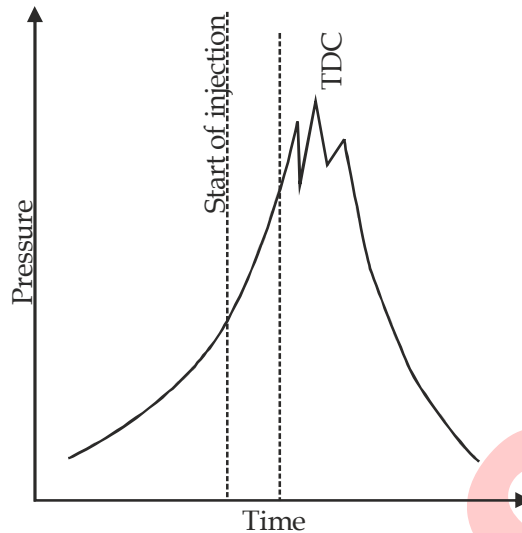
If this end charge, CCD auto ignites before the flame front reaches it this is called detonation. In S.I. engine detonation occurs near the end of combustion.

3. **Diesel Knock:** The injection process in C.I. engine takes place over a define interval of time. Consequently as the first droplets to be injected are passing through the ignition delay period, additional droplets are being injected into the chamber. If the ignition delay of the injected fuel is longer, the actual burning of the first droplets is delayed and a greater quantity of fuel droplets will get accumulated in the chamber. When actual burning commences, the additional fuel can cause too rapid rate of pressure rise, resulting in jamming of the piston and rough engine operation.

85.

Sol. The injection process in C.I. engine takes place over a define interval of time. Consequently as the first droplets to be injected are passing through the ignition delay period, additional droplets are being injected into the chamber. If the ignition delay of the injected fuel is longer, the actual burning of the first droplets is delayed and a greater quantity of fuel droplets will get accumulated in the chamber. When actual burning commences the additional fuel can cause too rapid rate of pressure rise, resulting in jamming of the piston and rough engine operation.

1. In the SI engine, the detonation occurs near the end of combustion whereas in the CI engine detonation occurs near the beginning of combustion.
2. The detonation in the SI engine is of a homogeneous charge causing vary high rate of pressure rise and very high maximum pressure. In the CI engine, the fuel and air are imperfectly mixed and hence the rate of pressure rise is normally lower than that in the detonating part of the charge in the SI engine.
3. Since, in the CI engine, the fuel is injected into the cylinder only at the end of the compression stroke there is no question of 'preignition' or 'premature ignition', as in the SI engine.



Comparison of Knocking in SI & CI engine:

Effect of operating variables on delay period and diesel knock.

Compression ratio: High compression ratio results in high pressure and temperature at the time of injection, hence reducing delay period and thus reduce knocking.

Speed: As speed increases, the delay period in terms of millisecond decreases but in terms of crank angle increases, hence chances of knocking increases.

A/F ratio: Increasing A/F ratio will result in less maximum temperature and hence it increases delay period and increases chances of knocking.

86.

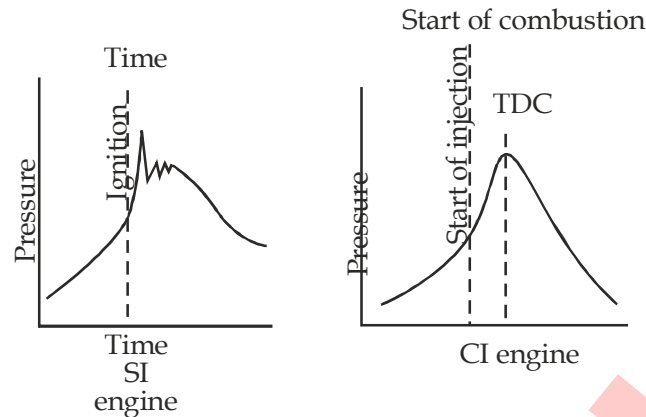
Sol. Delay period is the time elapsed during which although the fuel is injected but no ignition has taken place.

Factors affecting delay period:

1. Fuel: A fuel having higher cetane number (lower self ignition temp) has lower delay period.
2. Injection pressure on size of droplet: In order to achieve complete combustion the size of the droplet should be small. So higher the injection pressure (droplet size), smaller is the size of droplet.
3. Injection advance angle: As the pressure and temperature are lower when the injection begins, the delay period increases with increase in injection advance angle.
4. Compression ratio: Increase in compression ratio reduces the delay period as it raises both temperature and density.
5. Water jacket temperature
6. Fuel temperature
7. Air fuel ratio

87.

Sol. In spark ignition engines, the autoignition of the end gas away from the spark plug, most likely near the end of the combustion causes knocking. But in compression ignition engines the autoignition of the charge causing knocking is at the start of combustion. It is the first charge that autoignites and causes knocking in the compression-ignition engines. This is illustrated in the figure.



It is clear from the figure that explosive auto-ignition is more before the peak pressure for the compression-ignition engines. But for spark ignition engines, the condition for explosive autoignition of the end charge is more favourable after the peak pressure.

88.

- Sol.**
- (1) **High compression ratio:** As the compression ratio is increased, the pressure, the temperature and the overall density of the charge increase. Therefore, an increase in compression ratio increases the knocking tendency of the engine.
 - (2) **Super Charging:** The mass of the induced charge can be increased by supercharging the engine. The charge density will be increased which in turn will increase the tendency to knock.
 - (3) **Increased inlet temperature of the mixture:** An increase in the inlet temperature of the mixture increases the temperature at the end of compression, which in turn increases the temperature of the last part of the charge to burn, thus shortening the delay period and greatly increasing the tendency to knock.
 - (4) **Increase in spark timing:** An increase in spark advance from the optimized timing increases the peak pressure of the cycle and therefore increases the pressure and temperature to which the last part of the charge is subjected. This shortens the delay period and increases the tendency to knock.
 - (5) **Increased Power Output:** An increase in the power output of the engine increases the temperatures of the cylinder and combustion chamber walls and also increases the temperature and pressure of the end-gas, thus, reducing the delay period. Therefore, the tendency to knock increases.

89.

Sol. Comparison of knocking phenomena in SI and CI engines:

- In SI engines, the autoignition of the end gas away from the spark plug, most likely near the end of the combustion causes knocking. But in CI engines, the autoignition of the charge causing knocking is at the start of combustion. It is the first charge that autoignites and causes knocking in the CI engines. In order to avoid knocking in SI engines, it is necessary to prevent autoignition of the end gas to take place at all. In CI engine, the earliest possible autoignition is necessary to avoid knocking.
- In SI engines, the charge that autoignites is homogeneous and therefore intensity of knocking or the rate of pressure rise at explosive autoignition is likely to be more than that in CI engines where the fuel and air are not homogeneously mixed even when explosive autoignition of the charge occurs. Therefore, it is often called detonation in SI engine.
- In CI engines, only air is compressed during the compression stroke and the ignition can take place only after fuel is injected just before the top dead centre. Thus there can be no pre ignition in CI engines as in SI engines.
- A good fuel for spark-ignition engine is a poor fuel for CI engine. The SI engine fuels have high octane rating and low cetane rating, whereas diesel fuels have high cetane rating and low octane rating.

90.

Sol. Blending ethanol to a certain extent with petrol that makes it burn fewer fossil fuels while running vehicles is called ethanol blending.

The Department of Food and Public Distribution (DFPD) is the nodal agency for the promotion of fuel-grade ethanol-producing distilleries in the country.

In the current vehicle, ethanol added to petrol has no impact. Since ethanol contains oxygen, it aids in more complete combustion, lowers emissions, and improves the fuel's environmental performance.

Ethanol is an agricultural byproduct, mainly obtained from the processing of sugar. It can also be obtained from other sources such as rice husk or maize.

By 2023, all vehicles will be E20 (20% ethanol in petrol) material compatible, as committed by the auto industry. Therefore, in order to carry or store fuel that contains 20% ethanol, the fuel points, plastics, rubber, steel, and other components in cars would need to be compatible.

91.

Sol.

• SI Engine	CI Engine
- The ideal cycle for the SI engine is the Otto cycle - Heat addition is at constant volume. - It uses spark plug for ignition - It uses carburettor to supply air fuel mixture - Lower compression ratio engine (6 to 10.5)	- The ideal cycle for the CI engine is the diesel cycle - Heat addition is at constant pressure. - It does not use spark plug for ignition but self ignition take place due to compression of air - It uses fuel pump and injector to supply fuel. - High compression ratio engine (14 to 22)

92.

Sol. Supercharging: The power output of an engine depends on the amount of air inducted per unit time, the degree of utilization of this air and the thermal efficiency of the engine. The amount of air inducted power unit time can be increased by increasing the density of air at intake. The method of increasing inlet air density is called supercharging.

It is achieved by providing high density air through compressor or rootblowers to the engine.

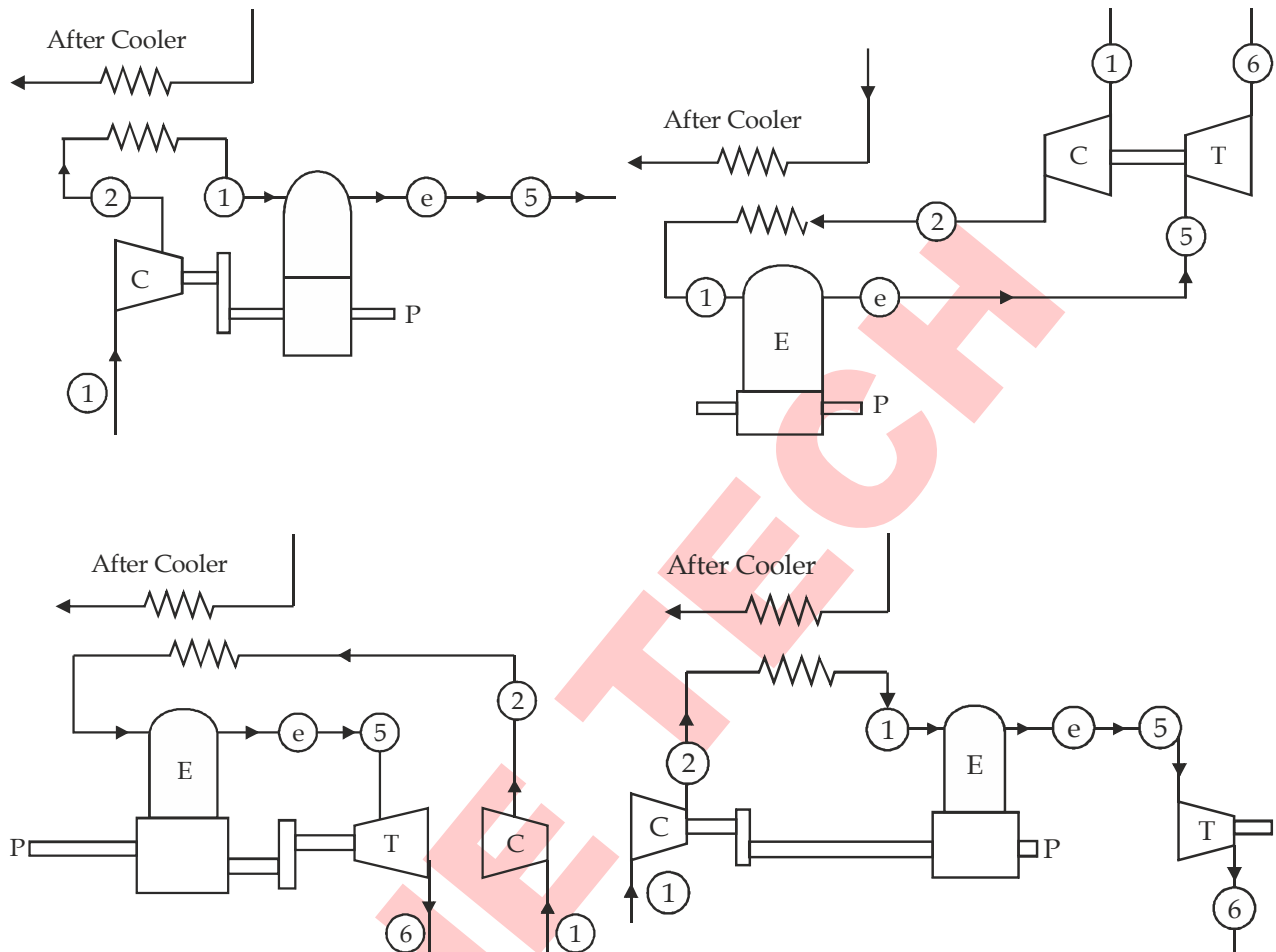
The effect of supercharging on various parameters is as follows:

- Power Output:** The power output of a supercharged engine increases.
- Mechanical efficiency:** Mechanical efficiency of a supercharged engine is slightly better than that of a naturally aspirated engine.
- Fuel consumption:** Specific fuel consumption in a supercharged engine is slightly lesser than that of naturally aspirated engine.



93.

Sol. Various configuration of superchargers:



1 = inlet to compressor C = Compressor
 2 = outlet from compressor E = Engine
 5 = inlet to turbine P = Power output
 6 = outlet from turbine T = Turbine
 i = inlet to engine
 e = exhaust from engine
 w = water

94.

Sol. Supercharging is generally not preferred for single-cylinder engines for several reasons:

- 1. Complexity:** Adding a supercharger increases the complexity of the engine design. Single-cylinder engines are often used in applications where simplicity and reliability are key, such as small motorcycles, lawnmowers, or generators.
- 2. Weight and Size:** Superchargers add weight and bulk to the engine. For single-cylinder engines, which are typically designed to be lightweight and compact, this can be a significant disadvantage.
- 3. Power Delivery:** Single-cylinder engines inherently have uneven power delivery due to their design. Adding a supercharger can exacerbate this issue, making the engine feel less smooth and more prone to vibration.

4. **Cost:** The cost of integrating a supercharger into a single-cylinder engine can be prohibitive, especially when considering the target market for these engines, which often prioritizes low-cost solutions.
5. **Efficiency:** Supercharging can lead to increased fuel consumption, which is counterproductive in applications where fuel efficiency is essential. Single-cylinder engines are often designed for maximum efficiency, and adding a supercharger may negate those benefits.
6. **Limited Gains:** The performance gains from supercharging a single-cylinder engine may not be significant enough to justify the additional complexity and cost. Multi-cylinder engines typically benefit more from forced induction due to their ability to manage airflow and combustion more effectively.

95.

Sol. The emission from the S.I. and C.I. engine are as follows:

1. **Evaporative losses:** Due to evaporation of fuel in fuel tank and carburetter.
2. **Crankcase blow-by:** It is the phenomena of leakage past the piston and piston rings from the cylinder.
3. **Carbon monoxide:** CO is a product of incomplete combustion due to insufficient amount of air in the air-fuel mixture.
4. **Hydrocarbons:** Unburnt hydrocarbon emissions are the direct result of incomplete combustion. The factors affecting are induction system design, combustion chamber design, air-fuel ratio etc.
5. **NO_x:** Oxides of nitrogen which also occur only in the engine exhaust are a combination of nitric oxide (NO) and nitrogen oxide. Nitrogen and oxygen react at relatively high temperatures. Therefore, high temperatures and availability of oxygen are the two main reasons for the formation of NO_x.

Emission control can be achieved through:

1. **Engine design modification:**
 - (i) Use of leaner air-fuel ratios
 - (ii) Retarding ignition timing
 - (iii) Modification of combustion chamber configuration
 - (iv) Reduced valve overlap
2. **Exhaust gas oxidation:**
 - (i) After burner
 - (ii) Exhaust manifold reactor
 - (iii) Catalytic converter
3. **Fuel modification**
4. **Blow by control**
5. **Using evaporation loss control device (ELCD)**
6. **Control of oxides of nitrogen**
 - (i) Exhaust gas recirculation
 - (ii) Water injection
 - (iii) Use of catalyst

96.

- Sol.**
- Most modern cars are equipped with three-way catalytic converters. "Three-way" refers to the three regulated emissions which helps to reduce - carbon monoxide, unburnt hydrocarbons and nitrogen oxide molecules. The converter uses two different types of catalysts, a reduction catalyst and an oxidization catalyst. Both types consist of a ceramic structure coated with a metal catalyst, usually platinum, rhodium and/or palladium. The idea is to create a structure that exposes the maximum surface area of the catalyst to the exhaust stream, while also minimising the amount of catalyst required (they are very expensive).
 - There are three main types of structures used in catalytic converters - ceramic honeycomb, metal plate and ceramic beads (now almost obsolete) - the Scorpio like most cars today use a ceramic honeycomb structure.

The Reduction Catalyst: The reduction catalyst is the first stage of the catalytic converter. It uses rhodium to help reduce the nitrogen oxide emissions. When such molecules come in contact with the catalyst, the catalyst rips the nitrogen atom out of the molecule and holds on to it, freeing the oxygen in the form of O_2 . The nitrogen atoms bond with other nitrogen atoms that are also stuck to the catalyst, forming N_2 .

The Oxidization Catalyst: The oxidation catalyst is the second stage of the catalytic converter. It reduces the unburned hydrocarbons and carbon monoxide by burning (oxidizing) them over a platinum and palladium catalyst. This catalyst aids the reaction of the CO and hydrocarbons with the remaining oxygen in the exhaust gas.

Reactions taking place in catalytic converter:

1. **Oxidation:** Oxidation of carbon monoxide to carbon dioxide: $2CO + O_2 \rightarrow 2CO_2$
Oxidation of unburnt hydrocarbons (unburnt and partially-burnt fuel) to carbon dioxide and water :
 $C_xH_{2x} + 2 + [(3_x + 1)/2] O_2 \rightarrow xCO_2 + (x + 1) H_2O$ (a combustion reaction).
2. **Reduction:** Reduction of nitrogen oxides to nitrogen and oxygen: $2NO_x \rightarrow xO_2 + N_2$
Unleaded petrol is preferred in cars equipped with catalytic converters because lead can damage the catalytic converter.

97.

Sol. NO_x formation:

Oxides of nitrogen which also occur only in the engine exhaust are a combination of nitric oxide (NO) and nitrogen oxide (NO_2). Nitrogen and oxygen react at relatively high temperature. Therefore high temperature and availability of oxygen are the two main reasons for the formation of NO_x . When proper amount of oxygen is available, higher the peak combustion temperature, the more is NO formed. The combination of HC and NO_x in the presence of sunlight and certain atmospheric conditions produce photochemical smog.

Effect of various factors:

1. **Compression ratio:** Higher compression ratio increase NO_x formation as maximum temperature increases.
2. **Air fuel ratio:** Higher air fuel ratio reduces maximum temperature and NO_x formation.
3. **Retard spark timing:** Retarding spark timing decreases NO_x formation.
4. **Exhaust gas recirculation:** It reduces the maximum temperature and hence reduces NO_x formation
5. **Temperature and pressure of the inlet charge:** A higher pressure and temperature gives higher NO_x formation.

98.

Sol. To regulate the pollution emitted by cars and two-wheelers, the government has put forth regulations known as Bharat Stage Emission Standard (BSES). The central government has mandated that all vehicle manufacturers, both two-wheelers and four-wheelers, should manufacture, sell and register only BS6 (BSVI).

Emission norms for BS6

- BS6 emission norms allow a motorcycle to emit not more than 60 mg/km of NO_2 (Nitrogen oxide).
- The particulate matter (PM) for petrol vehicles has been restricted to 4.5 mg/km.
- The limit of NO_x for diesel engines is 80 mg/km. The HC + NO_x limit has been set to 170 mg/km and PM level limit has been set to 4.5 mg/km.
- The BS6 fuel has less sulphur and NO_x . The content of sulphur in BS6 fuel is 10 ppm.

Devices and technology introduced to meet BS-VI norms:

- **Selective catalytic reduction technology:** It reduces oxides of nitrogen by injecting an aqueous urea solution into the system. Hence, NO_x from diesel cars can be brought down by nearly 70%. In the petrol cars, they can be reduced by 25%.

- **Mandatory on-board diagnostics** which inform the vehicle owner or the repair technician about how efficient the systems in the vehicles are.
- **RDE (Real driving emission)** is introduced for the first time that will measure the emission in real-world conditions and not just under test conditions.

99.

Sol. Indicated Power (I.P): The power produced inside the engine cylinder is called indicated power.
Brake power (B.P): The power output of the engine at the crank shaft is called brake power. It is also called shaft power.

$$B.P = \frac{2\pi NT}{60000} \text{ in KW}$$

$$T = (w-s) R_m$$

N = speed in rpm

Friction Power (F.P): The difference between indicated power and brake power. It is the power wasted due to friction at the bearings and sliding parts

$$F.P = I.P - B.P$$

Mechanical efficiency: It is the ratio of brake power to the indicated power. It is denoted by η_m

$$\eta_m = \frac{\text{Brake Power}}{\text{Indicate Power}} = \frac{B.P}{I.P}$$

Brake thermal efficiency: It is defined as the ratio of heat utilized to produce brake power to heat supplied. It is denoted by η_b

$$\text{Brake thermal efficiency} = \frac{\text{Heat equivalent to B.P}}{\text{Heat supplied}}$$

$$\eta_b = \frac{B.P \times 60}{m_f \times C_v}$$

m_f = mass of fuel supplied per min, in kg/min

C_v = calorific value of fuel, kg/kg

Indicated thermal efficiency: It is defined as the ratio of heat utilized to produce indicated power to heat supplied. It is denoted as η_i

$$\text{Indicated thermal efficiency} = \frac{\text{Heat equivalent to I.P}}{\text{Heat supplied}}$$

$$\eta_i = \frac{I.P \times 60}{m_f \times C_v}$$

Indicated mean effective pressure (IMEP): It is defined as hypothetical pressure which is thought to be acting on the piston through out the power stroke and based on indicated power.

$$P_{mi} = \frac{I.P}{LAN}$$

Brake thermal effective pressure (BMEP): It is defined as hypothetical pressure which is thought to be acting on the piston through out the power stroke and based on brake power.

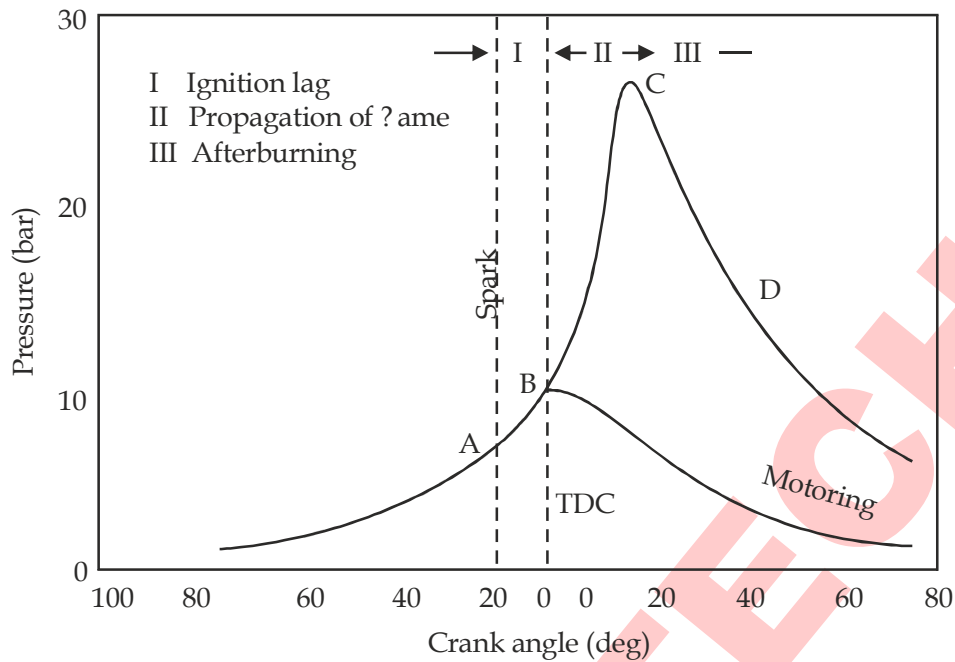
$$P_{mb} = \frac{B.P}{LAN}$$

Specific heat consumption (SFC): It is the mass of fuel consumed per KW developed per hour.

$$S.F.C = \frac{m_f}{B.P} \text{ kg / KWh}$$

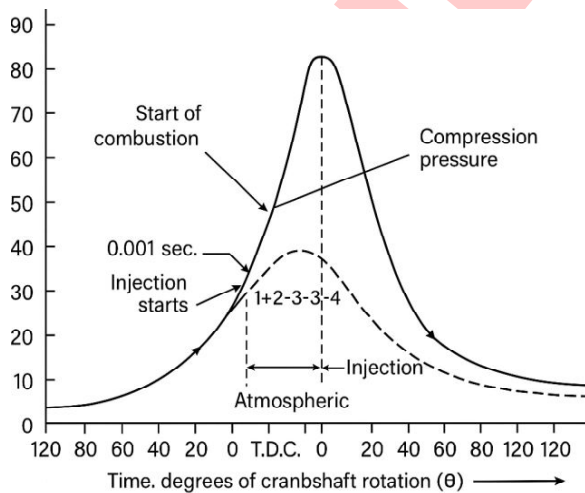
100.

Sol.



Three phases of combustion in SI engine

1. Ignition lag
2. Propagation of flame
3. After burning



Four phases of combustion in CI engine

1. Ignition delay period.
2. Period of rapid or uncontrolled combustion.
3. Period of controlled combustion.
4. After burning



101.

Sol. Compressor efficiency = $\frac{\text{isothermal horse power}}{\text{indicated horse power}}$

Isenthal efficiency = $\frac{\text{isothermal horse power}}{\text{shaft horse power}}$

The 'adiabatic efficiency' of an air compressor is the ratio of the horse power required to drive the compressor compared with the area of the hypothetical indicator diagram assuming adiabatic compression.

or Adiabatic efficiency $\eta_{\text{adiabatic}} = \frac{\left(\frac{\gamma}{\gamma-1}\right) p_1 V_1 \left[\left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} - 1 \right] \times \frac{N}{4500}}{\text{B.H.P. required to drive the compressor}}$

Mechanical efficiency. In general, the mechanical efficiency is the ratio of the mechanical output to the mechanical input. For an air compressor,

Mechanical efficiency, $\eta_{\text{mech.}} = \frac{\text{I.H.P. of compressor}}{\text{Shaft horse power}}$

102.

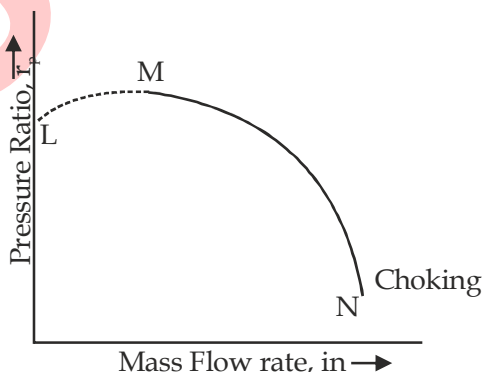
Sol. **First-Generation and Second-Generation Ethanol**

The government has augmented procurement of ethanol produced from other sources besides molasses, which is known as first-generation ethanol (1G). First-generation ethanol is produced from crops directly from the fields, such as cereals, maize, sugar beet, sugarcane, rapeseed, etc.

Ethanol can be extracted from materials other than molasses such as rice straw, wheat straw, corn stover, corn cobs, bamboo, and woody biomass, which is known as second-generation ethanol sources or 2G. Thus, second-generation biofuels are produced from residual and waste products.

103.

Sol. In the compressor where the flow is against the pressure gradient, the incidence loss due to incorrect fluid angles relative to the blades becomes more important and pressure ratio falls sharply at conditions away from the design point. This loss, added to the friction loss, which will increase with increase of mass flow rate, gives a pressure ratio-mass flow rate relation as shown in Fig.



- At point N, the compressor is choked and is passing the maximum mass flow rate.
- On the section MN of the curve the flow is stable. A fall in mass flow rate will result in a rise in pressure ratio which will tend to restore the fall.
- On the section LM of the curve, the flow is not stable. A fall in mass flow rate will be accompanied by a fall in pressure ratio. In this situation any small disturbance causing a change in mass flow



will cause a fall in pressure ratio and the flow may reverse at some point. When the temporary disturbance is removed, the flow will pick up and it is found that small disturbances cause the flow to oscillate rapidly. The oscillations are noisy and can, if allowed to continue, cause structural damage in the compressor. It is called 'surge' and the point M on the curve marks the limit of useful operation of the compressor.

104.

Sol. Comparison between axial flow and centrifugal compressors:

S.No.	Particulars	Axial flow compressors	Centrifugal compressors
1	Pressure ratio per stage	1.2:1 (For high pressure ratio more number of stages are required.)	4:1
2	Isentropic efficiency	85 to 88% (with modern aerofoil blades)	70%
3	Flexibility of operation	Less	More (due to adjustable pre-whirl and diffuser vanes)
4	Frontal area	Less (main cause in adopting the axial flow compressors for aircraft)	More
5	Effect of deposit formation on impeller rotor	Performance affected	Performance not affected
6	Starting torque	High	Low comparatively
7	Suitability	Used universally with large gas turbines	Suitable for super-charging I.C. engines and compressors for refrigerants and industrial gases
8	Efficiency vs speed curve	Less flat (Fig. 24.51)	More flat comparatively (Fig. 24.51)

105.

Sol. **Air Rate:** Mass of air supplied per second and in gas turbine cycle for combustion of fuel is called as air rate.

Specific Power: Specific power is defined as power output per unit mass of air supplied/sec.

Work Ratio: In gas turbine cycle work is produced in turbine at the same time work is also consumed in compressor. So network output is given as

$$W_{\text{net}} = W_T - W_c$$

Work ratio is ratio of network to turbine work

$$WR = \frac{W_{\text{net}}}{W_T}$$

Air rate is significant in deciding the size of the compressor and specific power decides the efficiency of the combustion process. Also it tells complete combustion is taking place or not work ratio is significant in deciding the ratio between compressor work and turbine work and hence efficiency of the cycle.



106.

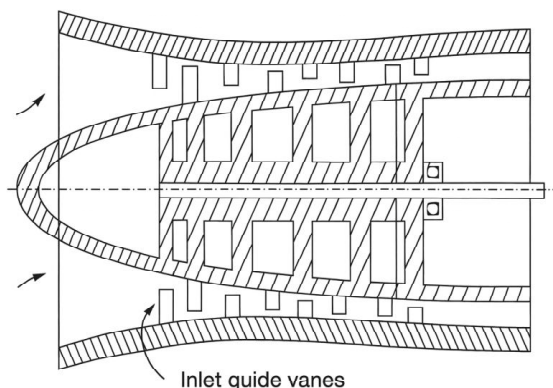
Sol.

S. No.	Centrifugal compressor	Axial flow compressor
1	The flow of air is perpendicular to the axis of the compressor.	The flow of air is parallel to the axis of the compressor.
2	It has low manufacturing and running cost.	It has high manufacturing and running cost.
3	It requires low starting torque.	It requires high starting torque.
4	It requires large frontal area for a given rate of flow.	It requires less frontal area for a given rate of flow and it makes the compressor suitable for aircrafts.
5	Lighter.	Heavier for the same pressure rise.
6	Efficiency is less (70%). Hence consumes more power.	Efficiency (85 to 88%) is more. Hence preferred in industrial plants.
7	It runs at higher speeds (30,000 rpm) giving smaller pressure ratio. Supplies large amount of air.	Pressure ratio delivering up to 100,000 kg of air/hour at speeds up to 20,000 rpm.
8	Normal pressure ratio per stage, 4 : 1.	Normal pressure ratio per stage, 1.2 : 1.
9	Separation does not occur due to centrifugal head.	Separation and stalling can occur. It can be avoided by using aerofoil blading.
10	Wide mass flow range is possible with adjustable pre-whirl & diffuser vanes.	Only less mass flow range is possible.
11	Any deposit formation on the impeller does not affect performance.	Any deposit on the vane affects performance.

107.

Sol. An axial-flow compressor consists of an alternating sequence of fixed and movable sets of blades. The sets of fixed blades are spaced around the inside periphery of an outer stationary casing, and together constitutes stator. The sets of movable blades are fixed to a spindle and the combination constitutes the rotor.

For the same overall weight, the centrifugal stresses are lower in the disc type rotor than the drum type rotor.



The basic principle of operation of the axial-flow compressor is the kinetic energy is imparted to the air by means of the rotating blades, which is then converted into a pressure rise.

The air enters axially from the left into the inlet guide vanes where it is turned through a certain angle to impinge on the first row of rotating blades with the proper angle of attack. The rotating vanes add kinetic energy to the air. Here slight pressure rise also takes place. The air then is discharged at the proper angle to the first row of stator blades where the pressure is further increased by diffusion.

The air is then directed to the second row of moving blades and the process is repeated through the remaining stages of the compressor.

108.

Sol. Given,

$$\dot{m} = 10 \text{ kg/s},$$

$$\frac{P_2}{P_1} = 2.5,$$

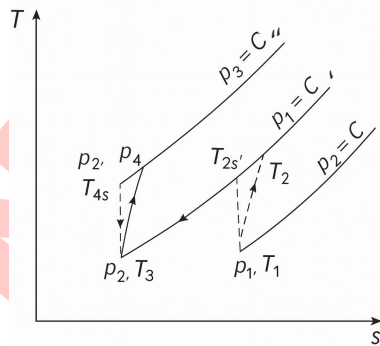
$$\frac{P_3}{P_2} = 2.1,$$

$$P_1 = 101.3 \text{ kPa},$$

$$T_1 = 293 \text{ K},$$

$$T_2 - T_3 = 60^\circ\text{C and}$$

$$\eta_c = 0.9$$



For isentropic compression

$$T_{2s} = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} = 293(2.5)^{0.4/1.4}$$

or

$$T_{2s} = 380.68 \text{ K}$$

$$\frac{T_{2s} - T_1}{T_2 - T_1} = 0.9 \Rightarrow \frac{380.68 - 293}{T_2 - 293} = 0.9$$

$$T_2 = 390.43 \text{ K}$$

$$T_3 = (390.43 - 60) = 330.43 \text{ K}$$

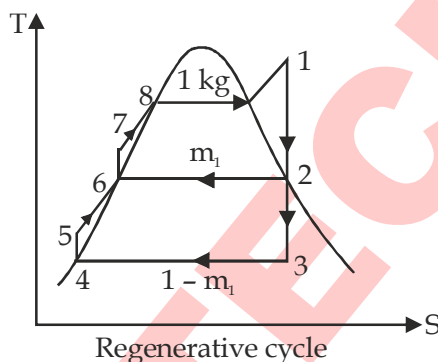
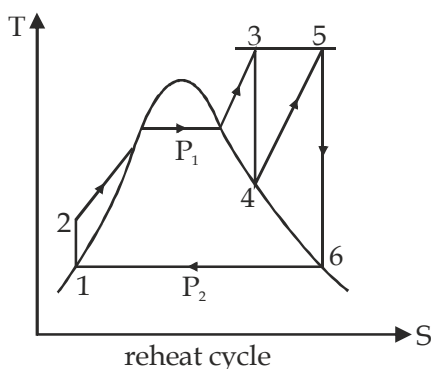
$$T_{4s} = T_3 \left(\frac{P_3}{P_1} \right)^{\frac{\gamma-1}{\gamma}} = 408.45 \text{ K}; \quad \frac{T_{4s} - T_3}{T_4 - T_3} = 0.9 = \eta_c$$

$$T_{4s} = 417.12 \text{ K}$$

$$\text{Compressor power} = \dot{m} c_p [(T_2 - T_1) + (T_4 - T_3)] = 10 \times 1.005 [390.43 - 293 + 417.12 - 330.43] \\ = 1850.3055 \text{ kW}$$

109.

Sol.



Significance of Reheat: The reheat cycle has been developed to take advantage of the increased efficiency with higher pressure but the chief advantage is in decreasing to a safe value the mixture content in the low-pressure stages of the turbine.

Significance of Regenerative cycle:

- Average temperature of heat addition is increased.
- Heating process in the boiler tends to become reversible.
- less amount of steam is passed through the low pressure stages so blade height will be less resulting is low cost of L.P. turbine.

110.

Sol.

Given:

$$p = 20 \text{ kPa};$$

$$\dot{m}_s = 20 \times 10^3 \text{ kg/h} = 5.55 \text{ kg/s};$$

$$(\Delta T)_w = 10^\circ\text{C}$$

Let inlet conditions to the condenser are represented as

$$x_1 = 0.95$$

$$h_1 = h_f + x_1 h_{fg} = 251.4 + 0.95 \times 2358.30 = 2491.785 \text{ kJ/kg}$$

Outlet condition,

$$h_2 = h_f = 251.4 \text{ kJ/kg}$$

Let mass flow rate of colling water = $\dot{m}_w$

Energy balance in condenser will give,

$$\dot{m}_w c_{pw} (\Delta T)_w = \dot{m}_s (h_1 - h_2)$$

$$\dot{m}_w \times 4.18 \times 10 = 5.55 \times (2491.785 - 251.40)$$

$$\dot{m}_w = 297.46 \text{ kg/s}$$



111.

Sol.

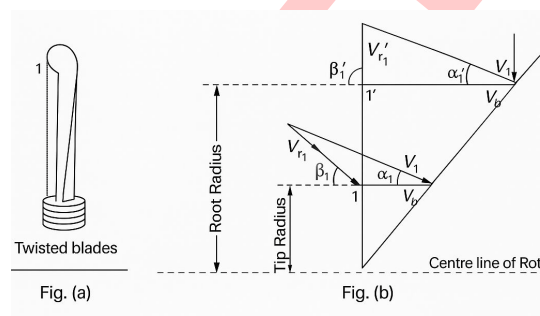
- In an impulse turbine, if the whole pressure drop from the boiler to condenser pressure takes place in a single row of nozzles, then the steam velocity entering the turbine is very high. This velocity may be reduced by three techniques - velocity compounding, pressure compounding and pressure velocity compounding.
- (i) **Velocity Compounding:** Only part of the velocity of the steam is used up in each row of blades, so a slower turbine results. But there is no loss of output because the rows of blades are connected to the same shaft.
- (ii) **Pressure Compounding:** Only part of pressure drop occurs in each stage, the steam velocities will not be as high, so the turbine will run slower.
- (iii) **Pressure velocity Compounding:** Combines the technique of pressure compounding and velocity compounding.

112.

Sol.

Blades act as cantilevers with one end fixed at rotor and other end is free. Due to load of steam and high rotational speed blades are subjected to both bending and centrifugal stresses. Due to these stresses both blade height (h_b) mean blade diameter (D_m) get restricted and. For straight blades, the maximum blade height ($h_{b_{\max}}$) is about 20% of the D_m , or $(h_b / D_m)_{\max} = 0.2$.

Where it is necessary to exceed this ratio, because of flow requirements, the blades may be tapered or twisted, thereby reducing both bending and centrifugal stresses. With these modification the blade height may approach about 30% of the mean blade diameter, or $(h_b / D_m)_{\max} = 0.3$, for twisted blades.



The velocity at the blade root $\left[\frac{\pi D_{\text{root}} N}{60} \right]$ will be much smaller than that at the mid-point, and still smaller than that at the tip $\left[\frac{\pi D_{\text{tip}} N}{60} \right]$. Hence, for a good efficiency the blade angles should vary with the diameter as shown in figure (b). For this reason, twisted (or warped) blades are used in the later stages of the turbine. Hence twisted blades are strong and provide good efficiency.

113.

Sol.

Different stresses developed are:

1. Centrifugal stresses due to high rotational velocity of blade.
2. Bending stresses due to differential pressure on two faces of blades.
3. Transient thermal stresses due to thermal gradient at time of startups.
4. Stresses due creep due large plastic deformation.
5. Dynamic stresses as a result of natural frequency excitation.

These stress can be calculated with help of finite element analysis performing simulation at actual working conditions.

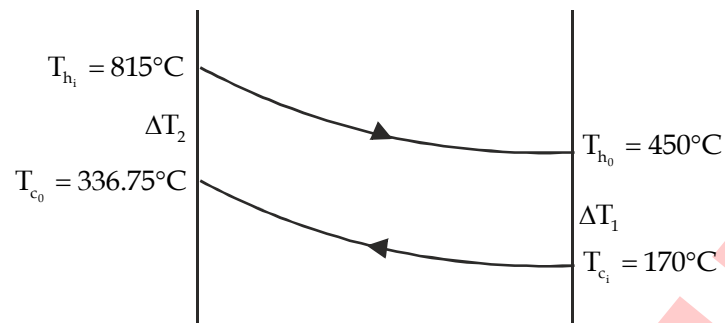
To safeguard blades under above stress they are designed considering above factors, the material selected has high strength at high temperature.

Material with high creep strength is used, such as Nickel based superalloys which incorporate Chromium, Cobalt and Rhenium.



114.

Sol. Economizer temperature distribution, considering counter flow heat exchanger as it is more efficient.



Total heat transfer through economizer = 511134 kW

$$\text{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

$$\Delta T_1 = T_{ho} - T_{ci} = 450 - 170 = 280^\circ\text{C}$$

$$\Delta T_2 = T_{hi} - T_{co} = 815 - 336.75 = 478.3^\circ\text{C}$$

$$\text{LMTD} = \frac{280 - 478.30}{\ln\left(\frac{280}{478.30}\right)}$$

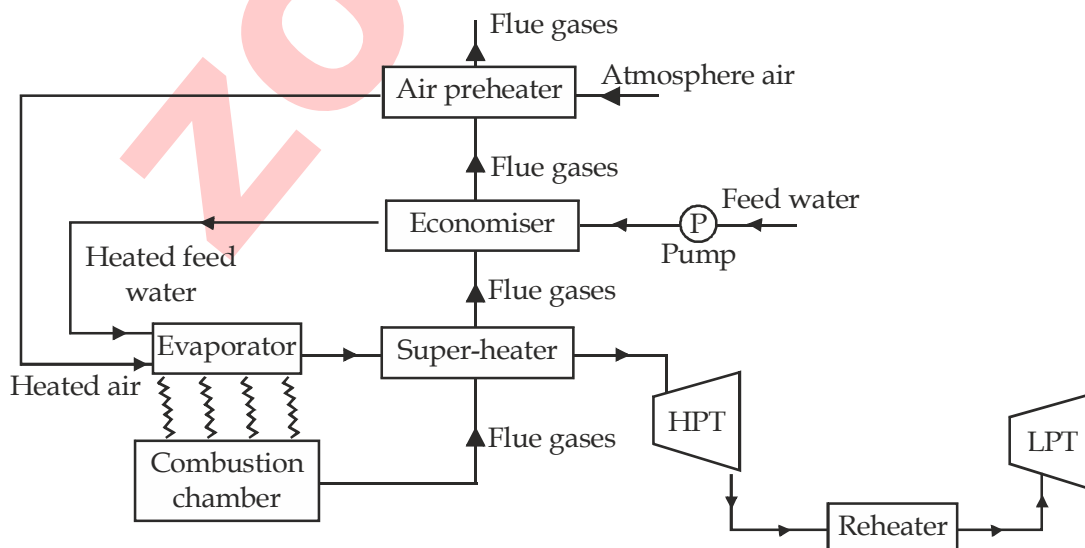
$$\text{LMTD} = 370.34^\circ\text{C}$$

$$Q = UA_0 (\Delta T_{\text{LMTD}})$$

$$511134 \times 10^3 = 70 \times A_0 \times 370.34$$

$$A_0 = 19716.785 \text{ m}^2$$

115.

Sol.

- **Evaporator:** It is placed near the combustion chamber before the steam drum where it receives hot combustion gases and the conversion of water into wet steam takes place.
- **Superheater:** It is placed after the evaporator but before the high pressure turbine so that it can utilize the heat going away with the hot gases by superheating the steam. More specifically, it converts wet steam into dry or superheated steam as they contain more thermal energy.
- **Reheater:** Steam coming out from the HPT is sent to reheater where it provides heat to steam at reheat pressure and then sent to LPT for further expansion. This results in enhancement of efficiency of plant.
- **Economizer:** It is a device which utilizes the heat from hot flue gases coming out of superheater to preheat the feed water. Due to this the heat supplied in the evaporator reduces by some amount; increasing the efficiency at the same time. Thus, the most appropriate position where the economizer can be placed is after superheater.

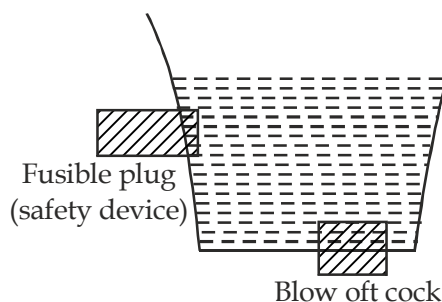
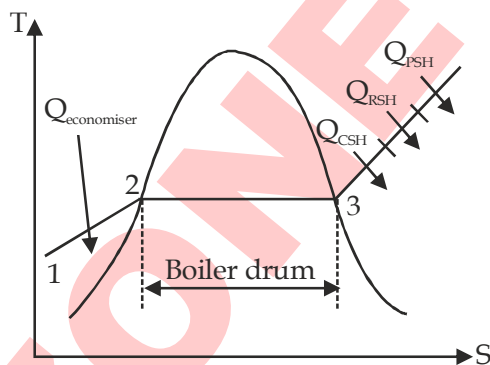
116.

Sol.

A fusible plug is a threaded metal cylinder, often made from bronze, brass or gunmetal, which has a tapered hole drilled completely through its length.

The function of a fusible plug is to protect the boiler against damage due to overheating for low water level. It is fitted on the fire box crown plate or over the combustion chamber at its appropriate place.

Under normal condition when the water level in the boiler shell is normal, the fusible plug is fully submerged under water. In this case the heat from the fusible plug is being conducted to water which keeps the fusible metal at almost a constant temperature and below its melting point. But when the water level falls below the fusible plug, it gets uncovered from water and is exposed to steam. The heat conduction from the fusible plug to steam is very little compared with that to water. Hence fusible plug becomes overheated and it melts with the result that the hollow gun metal plug falls down making a hole. The steam and water being under pressure immediately rush to fire box and extinguish the fire.



117.

Sol.

No. of atoms in 235 gm $U_{235} = 6.02 \times 10^{23}$

Given; Power output = 5×10^6 W

$$\therefore \text{Power produced} = \frac{5 \times 10^6}{0.3} \text{ W} = 16.67 \times 10^6 \text{ W}$$

$$\text{or Power produce} = 16.67 \times 10^6 \times 6.241 \times 10^{12} = 1.04 \times 10^{20} \text{ MeV}$$

No. of atoms required to produce this much of energy

$$N = \frac{1.04 \times 10^{20}}{190} \text{ MeV} = 5.47 \times 10^{17}$$

$$\text{Mass of } U^{235} \text{ required} = \frac{5.47 \times 10^{17}}{6.02 \times 10^{23}} \times 235 = 213.53 \times 10^{-6} \text{ gm}$$



118.

Sol. As mentioned earlier, all the neutrons released in the fission reaction are not used up in propagating the chain reaction but some of these are lost to the surroundings. For maintaining chain reaction, it is therefore, essential that the number of neutrons after the fission should be slightly more than the number before it to allow for the escape or leak of neutrons from the reactor core. The ratio is known as multiplication factor. The multiplication factor k for any reactor is defined as

$$k = \frac{\text{Number of neutrons produced in one generation}}{\text{Number of neutrons produced in the preceding generation}}$$

Unity value of k indicates that the chain reaction will continue at a steady rate (critical). If k is less than unity, the chain reaction will stop and the system is called subcritical. While for k exceeding unity, the chain reaction will build up and the system is called super critical.

Thus, for keeping chain reaction continuous multiplication factor in a nuclear reactor is kept almost equal to one.

PART - C

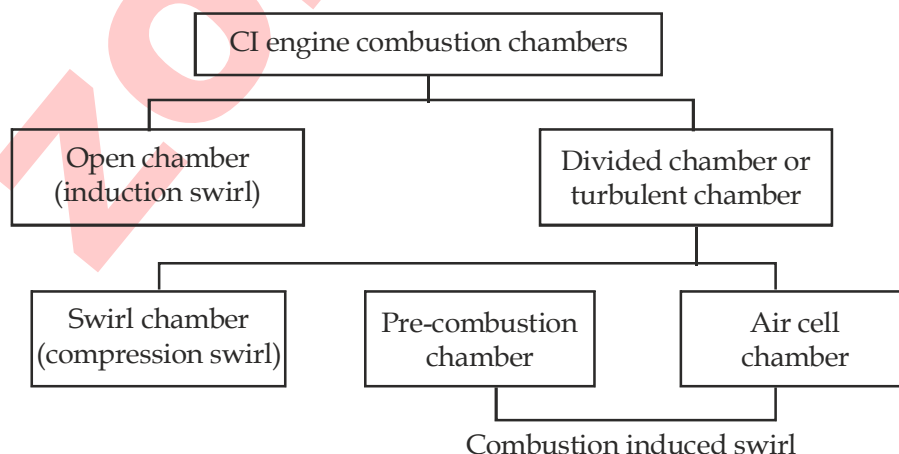
20 Marks Questions

119.

Sol. The most important function of the CI engine combustion chamber is to provide proper mixing of fuel and air in a short time. For this purpose an organised air movement, called air swirl, is provided to produce high relative velocity between the fuel droplets and air.

There are three basic methods of generating swirl in a CI engine combustion chamber, according to which they are classified:

1. By directing the flow of the air during its entry to the cylinder, known as induction swirl. This method is used in open combustion chambers.
2. By forcing the air through a tangential passage into a separate swirl chamber during the compression stroke, known as compression swirl. This method is used in swirl chambers.
3. By use of the initial pressure rise due to partial combustion to create swirl turbulence, known as combustion induced swirl. This method is used in pre-combustion chambers and air-cell chambers.



Open Combustion Chamber:

In four-stroke engines induction swirl can be obtained by two methods:

- (i) By careful formation of the air intake passages, and

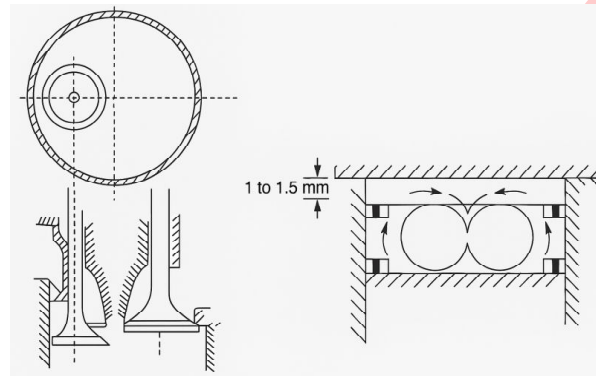


- (ii) By masking or shrouding a portion of the circumference of the inlet valve. The disadvantage of masking is that certain restriction of the free passage area occurs.

In the two stroke engine, the induction swirl is created by suitable inlet port forms.

The induction swirl is usually augmented by secondary air movement called squish. Squish is the flow of air radially inwards towards the combustion recess by squeezing it out between the piston and the cylinder head as they approach each other at the end of the stroke.

The induction swirl, if it is formed by air intake passages, it is very weak indeed. If a masked inlet valve is used, it provides an obstruction in the passage which reduces the volumetric efficiency and hence we cannot have too much of masking. Therefore, even with this method, the swirl generated is weak. With a weak swirl, single orifice injector cannot provide the desired air-fuel mixing. Therefore, with induction swirl we have to use multiple-orifice injector.



Atomisation of fuel oil through such fine holes requires high injection pressure generally not less than 175 bar and goes up to 1000 bar.

Advantages of Open Combustion Chamber

1. The high excess air allows lower average combustion chamber temperatures. This coupled with low turbulence and low heat losses permits engine indicated thermal efficiency to approach the ideal air cycle efficiency.
2. In the open combustion chamber, the intensity of swirl is low. Therefore, the heat loss to the chamber walls is relatively low, resulting in easier cold starting.
3. The swirl is obtained during induction stroke, no additional work is done in producing the swirl. This is coupled with high indicated thermal efficiency means high brake thermal efficiency, and therefore lower fuel consumption.
4. Open chamber is generally used for large low speed engines (Almost all large engines over 200 mm diameter and many of the smaller engines, use open chamber). In low speed engines, injection is spread through a greater period of time and thus ignition delay is a relatively less important factor. Consequently, less costly fuels with longer ignition delay may be used. With high speeds, this type of chamber with low ignition quality fuel will tend to knock.

Disadvantages of Open Combustion Chamber

1. As the swirl induced by induction is generally weak in intensity, multi-orifice nozzles with high injection pressure are required. The small nozzle openings are more frequently clogged or cause change of fuel spray pattern by carbon deposits with consequent higher maintenance cost.
2. The other disadvantages of small nozzle openings is that it influences the minimum quantity of fuel that can be delivered per injection and introduces complications at light loads and under idling conditions.
3. The use of shrouded valve lowers the volumetric efficiency. Further, in the interest of symmetry, the multiple orifice injector has to be placed near the centre of the cylinder and therefore between the valves; this restricts the diameter of the somewhat and therefore further restricts the breathing capacity (i.e., the volumetric efficiency).

4. Weak swirl necessitates excess air, i.e., low air utilization, say about 60%. This results in lower mean effective pressure and hence large size (and therefore costlier) engine for a given power.
5. One of the major disadvantage of induction swirl is that it is not proportional to speed and hence efficiency is not maintained over a wide range in a variable speed engine.

120.

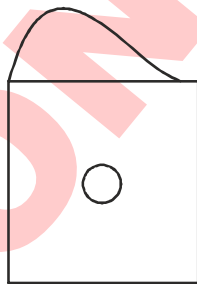
Sol. (i) Multi valve engines have following advantages which makes it suitable for application in modern day engines:

- (a) It increases the coverage area of the valves over the combustion chamber allowing faster breathing, thus enhancing power at high revolution.
- (b) It allows the spark plug to be positioned at the centre of combustion chamber, enabling quicker flame propagation resulting in more even and more efficient burning.
- (c) Using more but smaller valves instead of two large valve means lower mass for each valve. This prevent the valve "float" from its designed position thus enabling the engine to run at high revolutions and make more power.

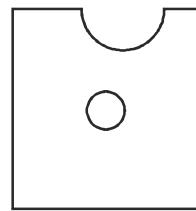
Inlet valves are larger while exhaust valves are smaller. It is so because our priority at inlet is to give more cylinder area more to inlet valve so that more air flows into the engine which increases its volumetric efficiency. While exhaust air is at already at high pressure which can escape by itself from the cylinder even with a smaller area available at the valve. New design of exhaust valve have vanes or blades around the stem just have the seat. This is for rotation of the valve and for removal of carbon particles that might be accumulated on the valve seats and causing erosion. Intake valves do not have blades.

- (ii) Pistons are made tapered with the smallest diameter at the piston head in order to compensate for thermal expansion and thermal growth. Thermal growth is the increase in size of a material when heated with little or no change back to original dimensions. The taper design allows the piston to move freely in the cylinder bore regardless of the heat supplied to the piston head.

Two stroke engine piston can be identified by visualizing as it has a deflector on the top of it, which is used to deflect the fresh air-fuel mixture entering the cylinder exhaust towards the top of cylinder for minimizing the loss of fresh air-fuel mixture during scavenging process. In a four stroke engine, there is a shallow hole type projection at the top of the piston.



Piston of two stroke engine

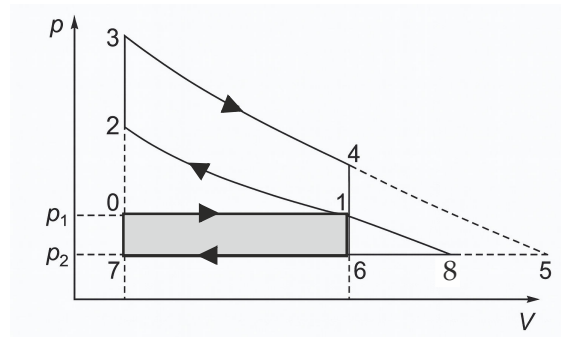


Piston of four stroke engine

121.

Sol. Supercharging: The power output of an engine depends upon the amount of air inducted per unit time, the degree of utilization of this air and the thermal efficiency of the engine. The amount of air inducted per unit time can be increased by increasing the density of air at intake. The method of increasing inlet air density, called supercharging, is usually employed to increase the power output of engine.





Above figure shows p-V diagram for an ideal otto cycle super charged engine.

P_1 : Supercharging pressure

P_5 : Exhaust pressure

Processes:

(i) 0-1-Admission of air at supercharging pressure (which is greater than atmospheric pressure)

(ii) 1-2-Isentropic compression

(iii) 2-3- Heat addition at constant volume.

(iv) 3-4-Isentropic expansion

4-1-6-Heat rejection at constant volume

(blowdown to atmospheric pressure)

6-7-Driving out exhaust at constant atmospheric pressure

For supercharger

(i) 7-6-8-Admission of air at atmospheric pressure

(ii) 8-1-Isentropic compression to pressure p_1 .

(iii) 1-0-Delivery of supercharged air at a constant pressure p_1 .

The pressure p_1 represents the super charging pressure and p_5 is exhaust pressure. Area 8-6-7-0-1-8 represents the work done by the supercharger in supplying air at a pressure p_1 while area 1-2-3-4-1 is the output of the engine. Area 0-1-6-7-0 represents gain in work during the gas exchange process due to supercharging. This a part of supercharger work is recovered. However the area 1-6-8-1 cannot be recovered represents a loss of work. C.I. engine is more suitable for supercharging. This is because, due to supercharging, there is an increase in pressure and temperature of intake air, which reduces ignition delay and hence reduces knocking in C.I. engines.

122.

Sol.

Given: Number of cylinders = 16, Total power output = 800 kW, $N = 900$ rpm

Specific fuel consumption = 0.238 kg/kWh, Maximum pressure in injector = 600 bar

Injector set pressure = 214 bar, Initial pressure in the cylinder = 32.4 bar

Maximum pressure in the cylinder = 55 bar, For the orifice, $C_d = 0.6$

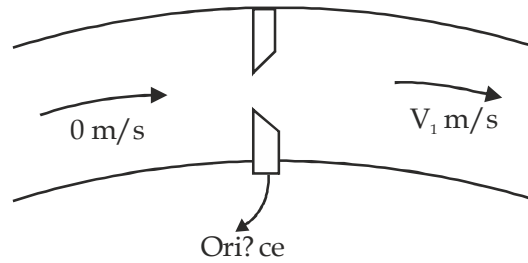
$$\text{For the fuel, } \frac{\rho_f}{\rho_w} = 0.86$$

$$\text{Crank rotation for fuel injection} = 10^\circ$$

$$\text{Initial pressure difference between the injector and cylinder} = 214 - 32.4 = 181.6 \text{ bar}$$

$$\text{Final pressure difference between the injector and cylinder} = 600 - 55 = 545 \text{ bar}$$

$$\text{Now, mean pressure difference, } \Delta P_m = \frac{181.6 + 545}{2} = 363.3 \text{ bar}$$



Applying Bernoulli's equation across the orifice, we get

$$V_f = \sqrt{\frac{2\Delta p_m}{\rho_f}} = \sqrt{\frac{2 \times 363.3 \times 10^5}{0.86 \times 1000}} \quad [\because \rho_t = 0.86 \rho_w]$$

$$V_f = 290.6688 \text{ m/s}$$

For the real situation, considering losses $\dot{m}_f = C_d \cdot \rho_f \cdot A \times V_f = 0.6 \times 0.86 \times 1000 \times A \times 290.6688$

$$\dot{m}_f = 149985.1193A \text{ kg/s} \quad \dots(i)$$

Calculating mass flow rate of fuel per cylinder,

$$(\text{sfc}) = \frac{\dot{m}_f \times 3600}{\text{BP}}$$

$$0.238 = \frac{\dot{m}_f \times 3600}{800}$$

$$\dot{m}_f = 0.05288 \text{ kg/s}$$

Where, $\dot{m}_f$ is the total mass flow rate of the fuel.

For each cylinder:

$$\dot{m}_f = \frac{\dot{m}_f}{\text{Number of cylinders}} = \frac{0.05288}{16} = 3.3055 \times 10^{-3} \text{ kg/s} \quad \dots(ii)$$

Since, 900 revolutions are made per minute, so time for one revolution will be $\frac{1}{900}$ minute or

$$T_{\text{cycle}} = \frac{60}{900} \text{ sec}$$

For a four stroke engine,

$$T_{\text{stroke}} = 2T_{\text{cycle}}$$

Where T_{stroke} : Time to complete all 4 strokes

$$\text{So, } T_{\text{stroke}} = \frac{2 \times 60}{900} \quad \dots(iii)$$

$$\text{Now, time for one injection, } T_{\text{inj}} = \frac{\theta_{\text{inj}}}{360} \times T_{\text{cycle}} = \frac{10}{360} \times \frac{60}{900} \text{ sec} \quad \dots(iv)$$

Mass conservation for one cylinder

$$\left(\begin{array}{c} \text{Mass of fuel flowed through} \\ \text{the orifice for one complete} \\ \text{stroke} \end{array} \right) = \left(\begin{array}{c} \text{Mass of fuel used for} \\ \text{one complete stroke} \end{array} \right)$$

$$\dot{m}_f \times T_{inj} = m_f \times T_{stroke}$$

$$149985.1193A \times \frac{10}{360} \times \frac{60}{900} = 3.3055 \times 10^{-3} \times \frac{2 \times 60}{900}$$

$$A = 1.587 \times 10^{-6} \text{ m}^2 = 1.587 \text{ mm}^2$$

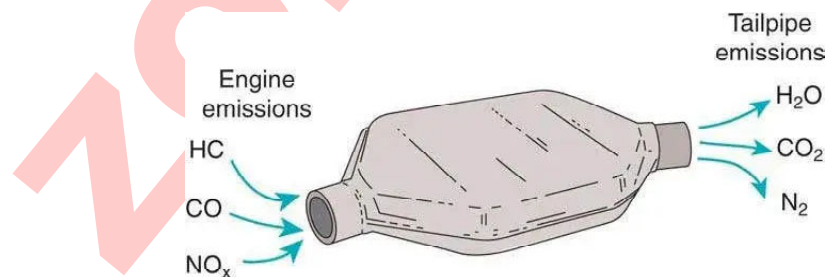
123.

Sol. A catalytic converter is an exhaust emission control device that reduces toxic gases and pollutants in exhaust gas from an internal combustion engine into less-toxic pollutants by catalyzing a redox reaction (an oxidation and a reduction reaction). Catalytic converters are usually used with internal combustion engines fueled by either gasoline or diesel. A catalytic converter is a large metal box, bolted to the underside of car, that has two pipes coming out of it. One of them (the converter's "input") is connected to the engine and brings in hot, polluted fumes from the engine's cylinders (where the fuel burns and produces power). The second pipe (the converter's "output") is connected to the tail pipe (exhaust). As the gases from the engine fumes blow over the catalyst, chemical reactions take place on its surface, breaking apart the pollutant gases and converting them into other gases that are safe enough to blow harmlessly out into the air.

There are two types of catalytic convertors:

- Two-way catalytic convertor (oxidation)
- Three-way catalytic convertor (oxidation-reduction)

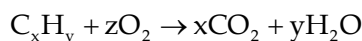
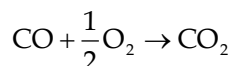
The three-way catalyst, is generally a multicomponent material, containing the precious metals rhodium, platinum and (to a lesser extent) palladium, ceria (CeO_2), γ -alumina (Al_2O_3), and other metal oxides. It typically consists of a ceramic monolith of cordierite ($2\text{Mg} \cdot 2\text{Al}_2\text{O}_3 \cdot 5\text{SiO}_2$) with strong porous walls enclosing an array of parallel channels. This design allows a high rate of flow of exhaust gases. Cordierite is used because it can withstand the high temperatures in the exhaust, and the high rate of thermal expansion encountered when the engine first starts - typically, the exhaust gas temperature can reach several hundred degrees in less than a minute. Metallic monoliths are also used, particularly for small converters, but these are more expensive.



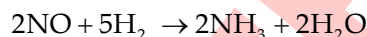
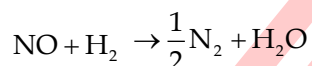
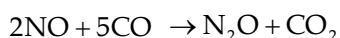
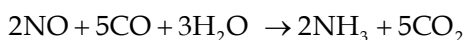
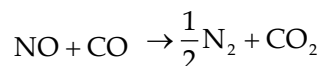
The catalytic converter, in a metal canister, is placed in the exhaust system of the vehicle. As the exhaust gases pass through it, they flow through the channels in the ceramic monolith, where they encounter the particles of alumina impregnated with the metal catalysts.

To achieve a large surface area for catalysis, the internal surfaces of the monolith are covered with a thin coating (30-50 μm) of a highly porous material, known as the wash coat. The total surface area is now equivalent to that of about two or three football pitches. The wash coat generally consists of alumina (70-85%) with a large surface area, with oxides, such as BaO, added as structural promoters (stabilisers to maintain surface area) and others, for example CeO_2 , as chemical promoters. This system becomes the support for the precious metal components (Pt, Pd and Rh). These metals constitute

only a small fraction (1-2%) of the total mass of the wash coat, but they are present in a highly dispersed form. They are generally applied by deposition from solution, although they may instead be introduced during formation of the wash coat itself.



Palladium and platinum promote the oxidation of CO and HC as in above equation, with platinum especially active in the hydrocarbon reaction. Rhodium promotes the reaction of NO_x in one or more of the following reactions:



Also often used in cerium oxide, which promotes the so-called water gas shift

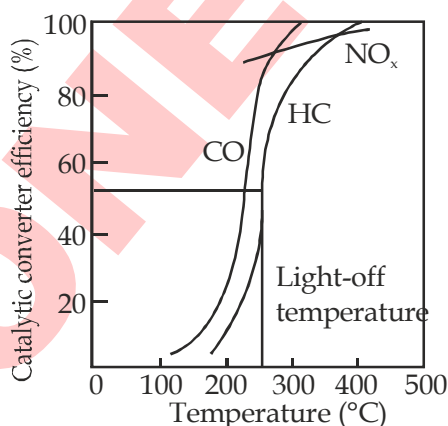
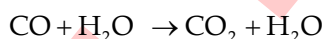


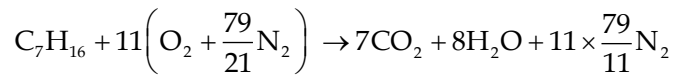
Fig.: Conversion efficiency of catalytic converters as a function of converter temperature

They reduces CO by using water vapor as an oxidant instead of O_2 , which is very important when the engine is running rich.

The figure given above shows that the efficiency of a catalytic converter is very much dependent on temperature. When a converter in good working order is operating at a fully warmed temperature of 400°C or above, it will remove 98-99% of CO, 95% of NO_x , and more than 95% of HC from exhaust flow emissions.

124.

Sol. If stoichiometric air had been used

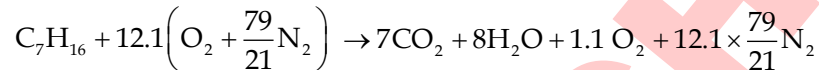


So, for 1 mole of C_7H_{16} , 11 moles of air is required if the air is stoichiometric.

Now, if 10% excess air is supplied, then

$$\text{mole of air} = \left(1 + \frac{10}{100}\right) \times 11 = 12.1$$

1. Actual reaction



$\therefore$ For 1 mole of $\text{C}_7\text{H}_{16} \rightarrow 12.1$ moles of air

$\therefore$ For $(7 \times 12 + 16)\text{kg } \text{C}_7\text{H}_{16} \rightarrow 12.1 \times \left(32 + \frac{79}{21} \times 28\right)\text{kg air}$

$\therefore$ For 1 kg $\text{C}_7\text{H}_{16} \rightarrow \frac{12.1 \times \left(32 + \frac{79}{21} \times 28\right)}{(7 \times 12 + 16)}\text{kg air}$

So, mass of air supplied per kg fuel = 16.6173 kg air.

2. Dry exhaust analysis

Constituent	Moles	Mass (kg)	Mass (%)	Moles or Volume (%)
CO_2 (44 kg/kmol)	7	$7 \times 44 = 308$	$\frac{308}{1617.76} \times 100 = 19.04\%$	$\frac{7}{53.62} \times 100 = 13.05\%$
O_2 (32 kg/kmol)	1.1	$1.1 \times 32 = 35.2$	$\frac{35.2}{1617.76} \times 100 = 2.17\%$	$\frac{1.1}{53.62} \times 100 = 2.05\%$
N_2 (28 kg/kmol)	$12.1 \times \frac{79}{21} = 45.52$	$45.52 \times 28 = 1274.56$	$\frac{1274.56}{1617.76} \times 100 = 78.78\%$	$\frac{45.52}{53.62} \times 100 = 84.89\%$

$\Sigma \text{moles} = 53.62, \Sigma \text{mass} = 1617.76 \text{ kg}$

125.

Sol. Given: 4-stroke engine,

Number of cylinders (k) = 6

Bore, $D = 8 \text{ cm}$

Stroke, $L = 10 \text{ cm}$

Speed, $N = 3200 \text{ rpm}$

Net brake load, $W = 350 \text{ N}$

Fuel consumption, $\dot{m}_f = 0.33 \text{ kg/min}$

Calorific value,

$$C_v = 43 \text{ MJ/kg}$$

Average brake load by 5 cylinder = 250 N

Brake radius,

$$r = 40 \text{ cm}$$

Brake power,

$$BP = \frac{2\pi NT}{60} = \frac{2\pi N(Wr)}{60}$$

$$BP = \frac{2\pi \times 3200 \times 350 \times 0.4}{60} = 46914.45 \text{ W}$$

$$BP = 46.914 \text{ kW}$$

Brake power when 1 cylinder is in operative.

$$(BP)' = \frac{2\pi NT'}{60} = \frac{2\pi N(W'r)}{60}$$

$$(BP)' = \frac{2\pi \times 3200 \times 250 \times 0.4}{60}$$

$$(BP)' = 33.51 \text{ kW}$$

$$\text{Indicated power } IP = 6 \times (BP - BP')$$

$$IP = 6 \times (46.914 - 33.51) = 80.424 \text{ kW}$$

We know,

$$IP = P_{mep} \times \frac{LAN \times k}{60 \times 2}$$

$$80.424 \times 10^3 = P_{mep} \times 0.1 \times \frac{\pi}{4} \times (0.08)^2 \times \frac{3200 \times 6}{120}$$

$$P_{mep} = 9.99 \text{ bar} = 10 \text{ bar}$$

Heat balance conditions

(i) Heat added,

$$HA/\text{min} = \dot{m}_f \times C_v = 0.33 \times 43000 = 14191 \text{ kJ/min}$$

(ii) Brake power (equivalent)

$$BP_{eq} = BP \times 60 = 46.914 \times 60 = 2814.84 \text{ kJ/min}$$

(iii) Heat carried away by cooling water

$$q_w = \dot{m}_w \times 4.18 \times (\Delta T) = 70 \times 4.18 \times 10 = 2926 \text{ kJ/min}$$

(iv) Heat carried away by ventilation air,

$$Q_{air} = \dot{m}_a \times C_{pa} (T_2 - T_1) = 15 \times 1.005 \times (62 - 17) = 678.375 \text{ kJ/min}$$

(v) Unaccounted losses [friction, radiation, other losses]

$$Q_{unc} = 14190 - (2814.84 + 2926 + 678.375) = 7770.785 \text{ kJ/min}$$

Heat Balance Sheet

Heat Equivalent	Value (kJ/min)	Percentage
1. Heat Added	14190	100
2. BP equivalent	2814.84	19.83
3. Heat carried away water	2926	20.62
4. Heat carried away by ventilating air	678.375	4.78
5. Unaccounted losses	7770.785	54.77



126.

Sol.

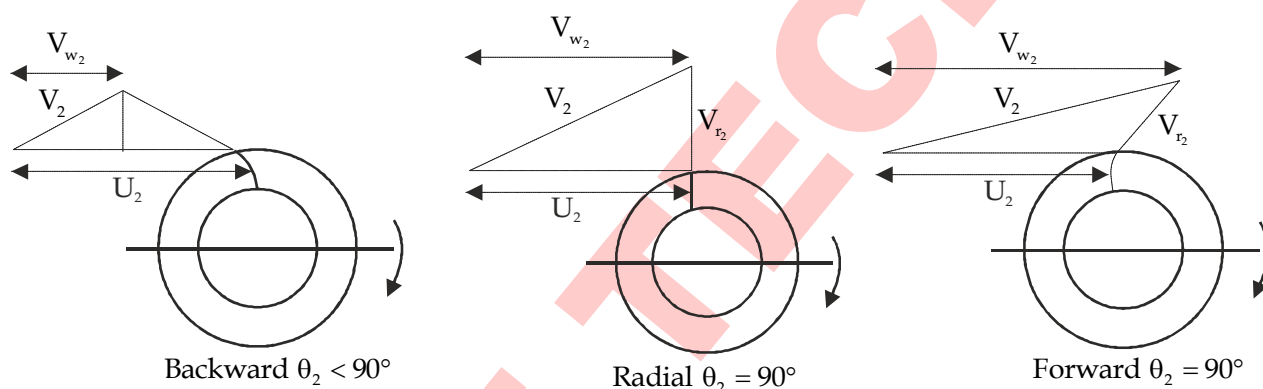
$$H = a - bQ \cot(\theta_2)$$

For backward curved vanes, $\theta_2 < 90^\circ$ and $\cot \theta_2$ is positive. Consequently from above equation, it is apparent that an increase in mass flow rate, the Euler head H goes on falling. In other words the head-capacity characteristic has a negative slope.

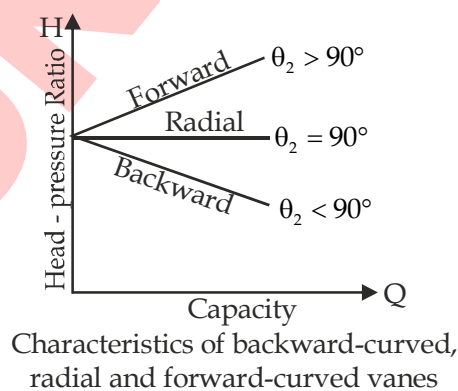
For radial vanes, $\theta_2 = 90^\circ$ and $\cot \theta_2 = 0$. Thus the head remains constant with variation in mass flow rate.

For forward curved vanes, $\theta_2 > 90^\circ$ and $\cot \theta_2$ is negative. Consequently with increase in mass flow rate, the Euler head would rise and the head capacity characteristic will have a positive slope.

The velocity diagrams and the theoretical head-capacity variation for different type of impeller vanes are shown in figure.



- It may be seen from figure that for backward-curved vanes the tangential component V_{w2} is much reduced and consequently for a given impeller speed, the impeller will have a low energy transfer (equation $m/g V_{w2} U_2$).



- In the case of forward curved vanes, V_{w2} is increased and consequently the energy transfer for forward curved vanes is maximum. However the absolute velocity at impeller outlet (V_2) is also increased. The high value of V_2 is not desirable as its conversion into static pressure cannot be very efficiently carried out in the diffuser section.



In the diffusion process, there is always a tendency for the air to break away from the walls of the diverging passages. If the diffusion is too rapid, i.e., it is carried out in a small diffuser section, the air may reverse its direction and flow back in the direction of pressure gradient. The reversal results in the formation of eddies and turbulence which cause conversion of some of kinetic energy into heat rather than useful pressure energy.

Normally backward vanes with θ between $20-25^\circ$ are employed except in the case where high head is the major consideration. Sometimes compromise is made between the low energy transfer (backward curved vanes) and high outlet velocity (forward curved vanes) by using radial vanes. Moreover the radial vanes can be manufactured easily and are free from complex bending stresses.

127.

Sol. Water-Intensive Nature of Ethanol Production: Ethanol production in India is heavily dependent on sugarcane, which requires enormous water resources, exacerbating water stress in already drought-prone regions.

This raises concerns about unsustainable agricultural practices and groundwater depletion, particularly in states like Maharashtra and Uttar Pradesh.

Alternative feedstocks like maize and sorghum are being promoted, but their adoption remains limited due to lower ethanol yields and farmer preferences.

According to NITI Aayog, sugarcane and paddy combined use 70% of irrigation water of the country, posing risks for long-term sustainability of ethanol.

Impact on Food Security and Inflation: As ethanol demand increases, more food grains like rice and maize are diverted for fuel, potentially driving up food prices and affecting food security.

The use of FCI rice and maize for ethanol production may reduce surplus buffer stocks, limiting government capacity to stabilize food prices during shortages.

This raises ethical concerns about using edible grains for energy when malnutrition remains a challenge in India.

FAO 2023 report warned that biofuel expansion could tighten global food supply chains, impacting vulnerable populations.

Limited Ethanol Production Capacity and Supply Chain Bottlenecks: Despite rapid growth, India's ethanol production and distribution infrastructure remain inadequate to meet the 20% blending target by 2025.

Supply chain inefficiencies, including transport challenges and storage constraints, make uniform ethanol availability difficult across all regions.

Many states lack sufficient distilleries and blending facilities, making them dependent on ethanol imports from other states.

Technological and Vehicle Compatibility Challenges: India's vehicle fleet is largely designed for E10 fuel, and transitioning to E20 and beyond requires modifications in engine design and fuel systems.

- Higher ethanol content can cause corrosion and reduced fuel efficiency, leading to long-term maintenance challenges for consumers.
- Automobile manufacturers are working on E20-compatible engines, but existing vehicles may face performance issues unless retrofitted.

Financial Viability and Price Volatility: Ethanol production is subject to price fluctuations due to variable sugarcane and grain output, impacting industry profitability and investment stability.

- Distilleries depend on government-fixed procurement prices, which may not always align with market dynamics, creating uncertainty for investors.
- The energy content of ethanol is lower than that of gasoline, requiring more fuel for the same mileage, which can offset cost benefits for consumers.

Environmental Concerns in Ethanol Production: While ethanol reduces carbon emissions in vehicles, its production process-especially from sugarcane and molasses-leads to high water usage, deforestation, and industrial waste discharge.

- Ethanol distilleries generate large amounts of waste water. This wastewater, known as vinasse, contains high concentrations of organic matter, residual sugars, and other pollutants.
- If not properly treated, it can pose significant environmental risks, including water pollution and depletion of oxygen in aquatic ecosystems.

Heavy Dependence on Government Subsidies: Ethanol production in India is heavily reliant on government incentives, including interest subvention schemes, differential pricing, and tax exemptions.

- Any policy reversal or reduction in financial support could make ethanol production economically unviable for distillers and farmers.
- The Pradhan Mantri JI-VAN Yojana has been extended until 2028-29 to boost second-generation ethanol, but adoption remains slow due to high capital costs.
- Policy fluctuations in ethanol blending targets, such as the shift from 2030 to 2025, create implementation challenges for industry stakeholders.

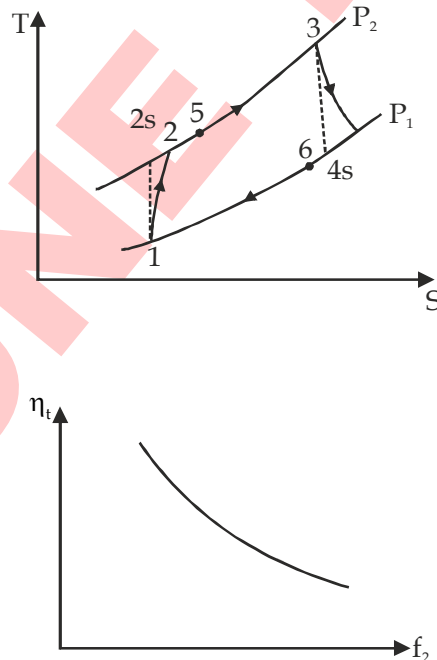
128.

Sol. Effect of Regeneration in Gas Turbine Cycle: The exhaust temperature of gas leaving the turbine is usually quite high. The exhaust gas from the gas turbine can be utilized to preheat the air at temperature T_2 before it goes to the combustion chamber. This is called regeneration and the regenerator effectiveness ϵ is defined as:

$$\epsilon = \frac{\text{Actual temperature rise of air}}{\text{Maximum temperature rise possible}}$$

i.e.

$$\epsilon = \frac{T_5 - T_2}{T_4 - T_2}$$



Effects:

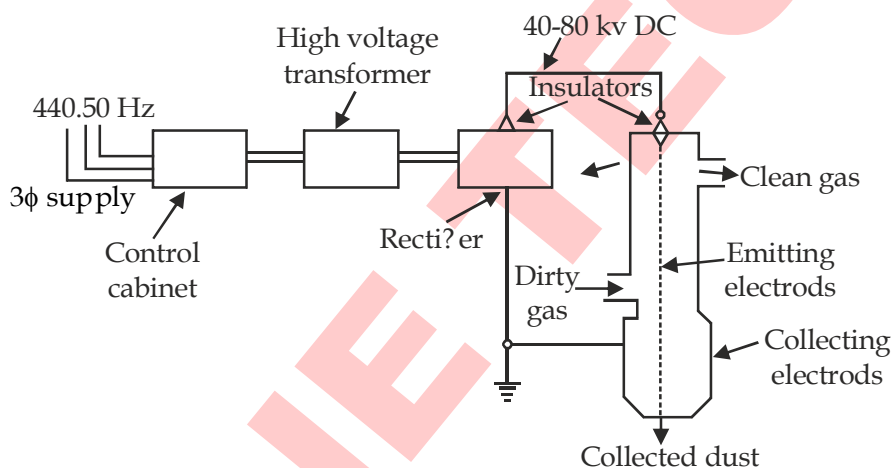
- Net heat addition i.e. $Q_1 = m_a c_p (T_3 - T_5)$ and heat rejection $Q_2 = m_a c_p (T_6 - T_1)$ both of which decrease.
- Net work output ($W_{\text{net}} = W_T - W_C$) remains unchanged due to regeneration.
- Thus cycle efficiency $\left(\eta = \frac{W_{\text{net}}}{Q_1} \right)$ increases with regeneration.

Cycle efficiency vs pressure ratio curve for regeneration Brayton cycle:

The efficiency of Brayton cycle with regeneration decreases as the pressure ratio (r_p) increases. With the increase in pressure ratio, the temperature of air at the end of compression increase and becomes greater than the temperature of gases at the end of turbine expansion. Hence, if a regenerator is used the compressed air gets cooled and exhaust gases get heated. Thus it increases the net heat addition in the cycle and therefore efficiency reduces.

129.

Sol. Electrostatic Precipitator: The principal components of an electrostatic precipitator (ESP) are two sets of electrodes insulated from each other. The first set is composed of rows of electrically grounded vertical parallel plates, called the collection electrodes, between which the dust-laden gas flows. The second set of electrodes consists of wires, called the discharge or emitting electrodes that are centrally located between each pair of parallel plates. The wires carry a unidirectional negatively charged high-voltage current from an external DC source. The applied high voltage generates a unidirectional, non-uniform electrical field. When forces in the corona accelerate the free electrons present in the gas so that they ionize the gas molecules. that voltage is high enough, a blue luminous glow called a corona, is produced around them. Electrical forming more electrons and positive gas ions.



The positive ions travel to the negatively charged wire electrodes. The electrons follow the electrical field toward the grounded electrodes but their velocity decreases toward the plates. Gas molecules capture the low velocity electrons and become negative ions.

As these ions move to the collecting electrode, they collide with the fly ash particles in the gas stream and give them negative charge. The negatively charged fly ash particles are driven to the collecting plate. Collected particulate matter must be removed from the collecting plates on a regular schedule to ensure efficient collector operation. Removal is usually accomplished by a mechanical hammer scrapping system. An electrostatic precipitator like a cyclone separator, has an overall collection efficiency, η_o , is defined by

$$\eta_o = \frac{\text{mass of all particles retained by collector}}{\text{mass of all particles entering collector}} = 1 - \exp\left(-\frac{AV_{mo}}{Q}\right)$$

where

A = Area of collector plate (m^2)

V_{mo} = effective migration velocity of particles (m/sec)

Q = Flue gas volume flow rate for each plate (m^3/sec)

- (i) With increase in collector area, collection efficiency increases.
- (ii) With increase in migration velocity, collection efficiency increases.
- (iii) With decrease in mass flow rate, collection efficiency increases.

130.

Sol. (i) Parson's reaction turbine

$$D_1 = 1.25 \text{ m}, N = 3000 \text{ rpm}, u/V_1 = 0.72 \text{ m}, \beta_1 = ?, \beta_2 = 22^\circ$$

For Parson's reaction turbine

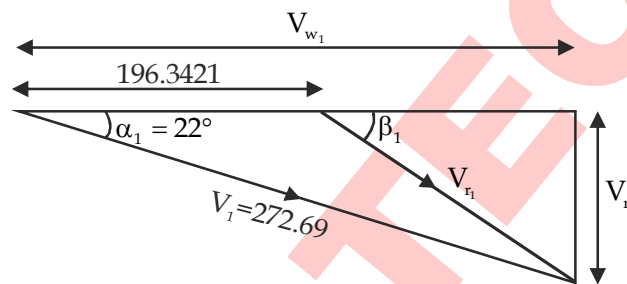
$$[\alpha_1 = \beta_2 \quad V_{r_2} = V_{f_1}]$$

$$[\alpha_2 = \beta_1 \quad V_{r_1} = V_{f_2}]$$

$$u = \frac{\pi D n}{60} = \frac{\pi \times 1.25 \times 3000}{60} = 196.34 \text{ m/s}$$

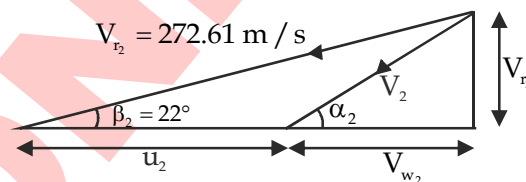
$$V_1 = \frac{u}{0.72} = 272.69 \text{ m/s} = V_{f_2}$$

Inlet velocity triangle



Outlet velocity triangle

where

 α_1, α_2 = nozzle angle β_1, β_2 = moving blade angle

From inlet velocity triangle

$$V_{w_1} = 272.69 \cos 22^\circ = 252.83 \text{ m/s}$$

$$V_{f_1} = 272.69 \sin 22^\circ = 102.15 \text{ m/s}$$

$$\tan \beta_1 = \frac{V_{f_1}}{V_{w_1} - u_1} = \frac{102.15}{252.83 - 196.34}$$

$$\beta_1 = 61.05^\circ$$

$$\alpha_2 = \beta_1 = 61.05^\circ$$

$$\alpha_1 = \beta_2 = 22^\circ$$

(ii) Diagram efficiency

$$\eta_D = \frac{\text{Power}}{\frac{1}{2} [V_1^2 + V_{r_1}^2 - V_{r_1}^2]}$$

$$V_{r_1} = \frac{V_{f_1}}{\sin \beta_1} = \frac{102.15}{\sin 61.05^\circ} = 116.74 \text{ m/s}$$

$$\text{Power} = mu(V_{w_1} + V_{w_2})$$

where

$$u = 196.34 \text{ m/s}, V_{w_1} = 252.83 \text{ m/s}$$

From outlet velocity triangle:

$$V_{r_2} \cos \beta_2 = u + V_{w_2}$$

$$272.69 \cos 22^\circ = 196.34 + V_{w_2}$$

$$V_{w_2} = 56.50 \text{ m/s}$$

$$\text{Power} = 1 \times 196.34 \times (252.83 + 56.50) = 60.734 \text{ kW/kg}$$

$$\eta_1 = \frac{60.734 \times 10^3}{\frac{1}{2} [(272.69)^2 + (272.69)^2 - (116.74)^2]}$$

$$= 0.8991 = 89.91\%$$

IInd Case: For best condition

$$\rho = u / V_1 = \cos \alpha_1$$

$$u = V_1 \cos \alpha_1 = 272.69 \cos 22^\circ = 252.83 \text{ m/s}$$

$$u = \frac{\pi D_m N_2}{60}$$

$$252.83 = \frac{\pi \times 1.25 \times N_2}{60}$$

or

$$N_2 = 38622.96 \text{ rpm}$$

$$\therefore \% \text{increase in rpm} = \left(\frac{N_2 - N_1}{N_1} \right) \times 100 = \left(\frac{38622.96 - 3000}{3000} \right) \times 100 = 28.765\%$$

$$\therefore \% \text{increase in diagram efficiency} = \frac{\eta_2 - \eta_1}{\eta_1} \times 100\%$$

$$\eta_2 = \frac{2 \cos^2 \alpha}{1 + \cos^2 \alpha} = \frac{2 \cos^2 22^\circ}{1 + \cos^2 22^\circ} = 0.9245$$

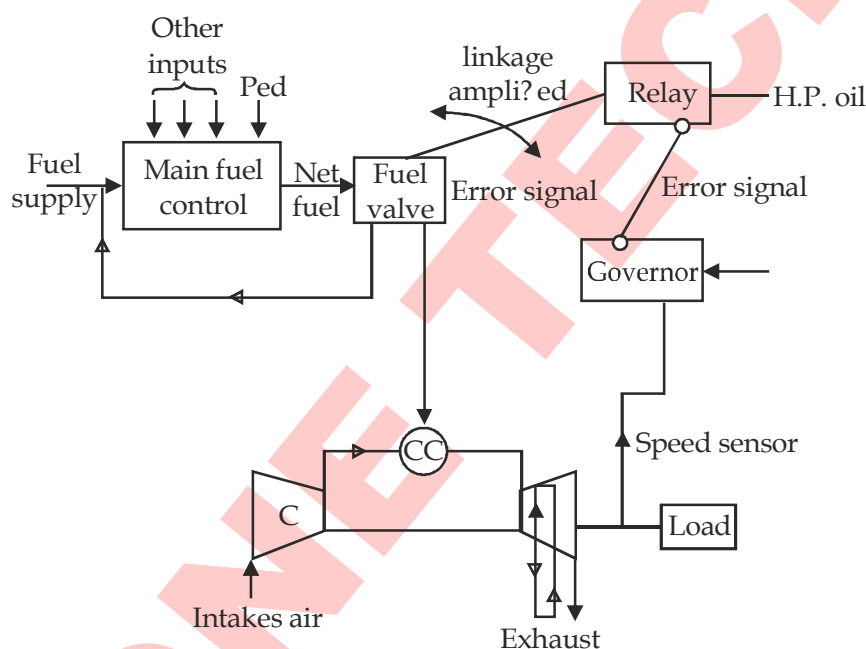
$$\% \text{increase in } \eta = \frac{0.9245 - 0.8991}{0.8991} \times 100 = 2.825\%$$

131.

Sol. Steam Turbine Governing: Governing of steam turbine means to regulate the supply of steam to the turbine in order to maintain speed of rotation sensibly constant under varying load conditions. Some of the method employed are as follows:

- (i) Bypass governing
- (ii) Nozzle control governing
- (iii) Throttle governing

- In this system the steam enters the turbine chest (C) through a valve (V) controlled by governor. In case of loads of greater than economic load a bypass valve (V_b) opens and allows steam to pass from the first stage nozzle box into the steam belt (S). In this method of governing the supply of steam of various nozzle groups N_1 , N_2 and N_3 is regulated by means of valves V_1 , V_2 and V_3 respectively.
- In this method of governing the double valve is used to regulate the flow of steam into the turbine. When the load on the turbine decreases, its speed will try to increase. This will cause the fly bar to move outward which will in return operate the lever arm and thus the double beat valves will get moved to control the supply of steam to turbine. In this case the valve will get so adjusted that less amount of steam flows to turbine.



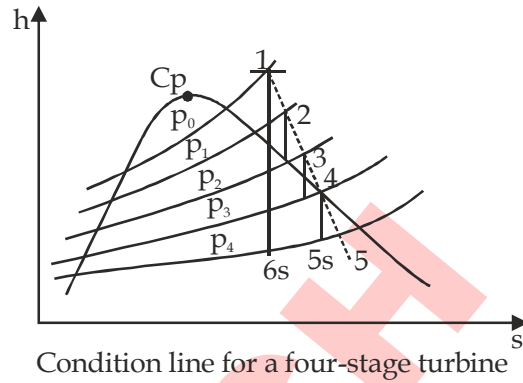
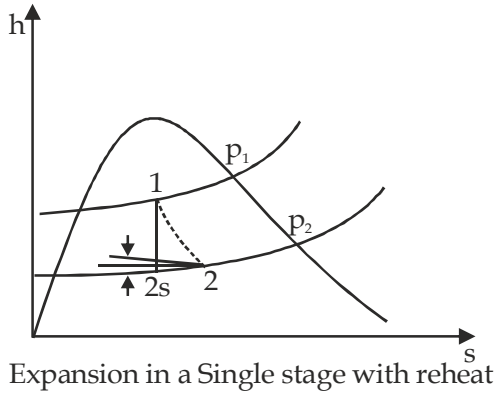
Prime Control (Hydro-Mechanical):

In hydro mechanical speed governing system (Prime Control), the governing loop is similar to that discussed in the case of steam turbine.

The system uses a centrifugal governor (mechanical) to sense the speed of the turbine and the reference is set for rated speed of the turbine figure. The governor senses the speed through the accessory drive shaft and fly weights. Internally, the governor hydraulically amplifies the error signal and provides an actuator output position that can be linked to a fuel valve. The fuel valve either throttles or by passes the metered fuel from the main fuel control. The speed sensing device may be electrical or hydraulic.

132.

Sol.



As we can see in figure the process 1-2 is not fully isentropic due to which the resulting enthalpy h_2 is slightly higher than the enthalpy achieved isentropically. The difference $h_2 - h_{2s}$ is termed as reheat and it is the portion of available energy which is not converted to work.

The stage efficiency is given by, $\eta_{\text{stage}} = \left(\frac{h_1 - h_2}{h_1 - h_{2s}} \right)$

- Now considering figure, the expansion in a 4-stage turbine, taking into account the effect of reheat, it can be seen that sum of isentropic enthalpy drops for each stage is greater than the available energy for whole turbine.
- The condition representing the actual expansion in the turbine is approximately the locus of points indicating the actual conditions of steam at the exit of the each stage.

The internal efficiency is thus given by, $\eta_{\text{int}} = \frac{h_1 - h_5}{h_1 - h_{6s}}$

The Reheat factor is defined as,

$$\text{RF} = \frac{(h_1 - h_{2s}) + (h_2 - h_{3s}) + (h_3 - h_{4s}) + (h_4 - h_{5s})}{(h_1 - h_{6s})} \quad \dots(i)$$

Now if stage efficiency is assumed to be the same in all stages stage

$$\eta_{\text{stage}} = \frac{h_1 - h_2}{h_1 - h_{2s}} = \frac{h_2 - h_3}{h_2 - h_{3s}} = \frac{h_3 - h_4}{h_3 - h_{4s}} = \frac{h_4 - h_5}{h_4 - h_{5s}}$$

Substituting in equation (i)

$$\text{RF} = \frac{\frac{h_1 - h_2}{\eta_{\text{stage}}} + \frac{h_2 - h_3}{\eta_{\text{stage}}} + \frac{h_3 - h_4}{\eta_{\text{stage}}} + \frac{h_4 - h_5}{\eta_{\text{stage}}}}{h_1 - h_{6s}}$$

or

$$\text{RF} = \frac{1}{\eta_{\text{stage}}} \times \frac{h_1 - h_5}{h_1 - h_{6s}} = \frac{1}{\eta_{\text{stage}}} \eta_{\text{int}}$$

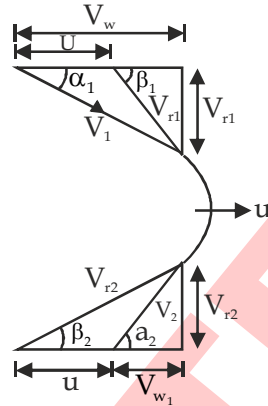
$$\eta_{\text{int}} = \text{RF} \times \eta_{\text{stage}}$$

133.

Sol.

$$\eta = \frac{\text{Output}}{\text{Input}} = \frac{m(V_{w1} + V_{w2})u}{m \frac{V_1^2}{2} + m \left(\frac{V_2^2 - V_{r1}^2}{2} \right)}$$

$$= \frac{V_{w1} + V_{w2}}{\left(\frac{V_1^2}{2} + \frac{V_2^2}{2} - \frac{V_{r1}^2}{2} \right)}$$



Let us assume that turbine is Parson's reaction turbine means (50% reaction turbine)

$$\alpha_1 = \beta_2 \quad V_1 = V_{r2}$$

$\therefore$

$$\alpha_2 = \beta_1 \quad V_2 = V_{r1}$$

$$\eta = \frac{(V_{w1} + V_{w2})u}{\frac{V_1^2}{2} + \left(\frac{V_2^2}{2} - \frac{V_{r1}^2}{2} \right)}$$

$$V_{w1} = V_1 \cos \alpha_1$$

$$V_{w2} = V_{r2} \cos \beta_2 - u$$

$$V_{w2} = V_1 \cos \alpha_1 - u$$

$$\text{Input power per unit mass} = \frac{V_1^2}{2} + \frac{V_2^2}{2} - \frac{V_{r1}^2}{2} = \frac{V_1^2}{2} + \frac{V_1^2}{2} - \frac{V_{r1}^2}{2} = (V_1^2) - \left(\frac{V_{r1}^2}{2} \right)$$

From inlet velocity triangle we have

$$V_{r1}^2 = V_{f1}^2 + (V_{w1} - u)^2 = V_{f1}^2 + V_{w1}^2 + u^2 - 2V_{w1}u$$

$\therefore$

$$V_{f1}^2 + V_{w1}^2 = V_1^2$$

and

$$V_{w1} = V_1 \cos \alpha_1$$

$\therefore$

$$V_1^2 + u^2 - 2V_{w1}u = V_1^2 + u^2 - 2uV_1 \cos \alpha_1$$

$$\eta = \frac{(V_{w1} + V_{w2})u}{\left\{ \frac{V_1^2}{2} + \left(\frac{V_{f2}^2}{2} - \frac{V_{f1}^2}{2} \right) \right\}} = \frac{(V_1 \cos \alpha + V_1 \cos \alpha_1 - u)u}{V_1^2 - \left(\frac{V_{f1}^2}{2} \right)}$$

$$= \frac{2u(2V_1 \cos \alpha_1 - u)}{2V_1^2 - V_1^2 - u^2 + 2uV_1 \cos \alpha_1} = \frac{4uV_1 \cos \alpha_1 - 2u^2}{V_1^2 - u^2 + 2uV_1 \cos \alpha_1}$$

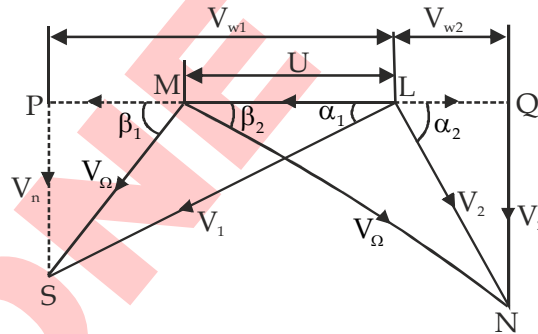
Divide numerator & denominator by V_1^2

$$= \frac{4uV_1 \cos \alpha_1 - \frac{2u^2}{V_1^2}}{\frac{V_1^2}{V_1^2} - \frac{u^2}{V_1^2} + \frac{2uV_1}{V_1^2} \cos \alpha_1}$$

Let blade speed ratio $\rho = \frac{u}{V_1}$

$$\eta = \frac{4\rho \cos \alpha_1 - 2\rho^2}{1 - \rho^2 + 2\rho \cos \alpha_1} = \frac{2(-\rho^2 + 2\rho \cos \alpha_1)}{(1 - \rho^2 + 2\rho \cos \alpha_1)}$$

$$\Rightarrow \frac{2[2\rho \cos \alpha_1 - \rho^2 + 1 - 1]}{1 - \rho^2 + 2\rho \cos \alpha_1} = 2 \left[1 - \frac{1}{1 + 2\rho \cos \alpha_1 - \rho^2} \right]$$



Differentiate w.r.t. ρ we get

$$\frac{d\eta}{d\rho} = 0$$

$$\Rightarrow 2 \left[0 - \frac{(-1)(-\rho + 2 \cos \alpha_1)}{(1 - \rho^2 + 2\rho \cos \alpha_1)^2} \right] = 0$$

$$-2\rho + 2 \cos \alpha_1 = 0$$

$$\rho = \cos \alpha_1 \quad (\text{for } 50\% \text{ degree of reaction})$$

$\therefore$ max η of reaction turbine

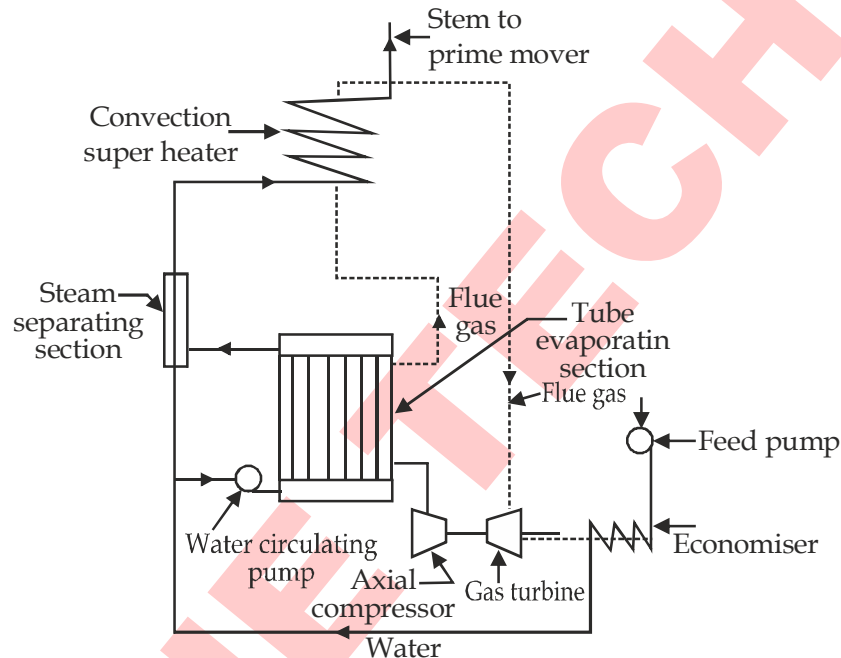
$$\eta_{\max} = \frac{4\rho \times \rho - 2\rho^2}{1 - \rho^2 + 2\rho \times \rho} = \left(\frac{2\rho^2}{1 + \rho^2} \right) = \left(\frac{2 \cos^2 \alpha_1}{1 + \cos^2 \alpha_1} \right)$$

$$\eta_{\max} = \frac{2 \cos^2 \alpha}{1 + \cos^2 \alpha} \text{ for 50\% degree of reaction.}$$

134.

Sol. The Velox Boiler:

- It is a well known fact that when the gas velocity exceeds the sound-velocity, the heat is transferred from the gas at a much higher rate than rates achieved with sub-sonic flow. The advantage of this theory is taken the large heat transfer from a smaller surface area in this boiler takes place.
- This boiler makes use of pressurised combustion.



- The gas turbine drives the axial flow compressor which raises the incoming air from atmosphere pressure to furnace pressure. The combustion gases after heating the water and steam flow through the gas turbine to the atmosphere.

The feed water after passing through the economiser is pumped by a water circulating pump to the tube evaporating section. Steam separated in steam separating section flows to the superheater, from there it moves to the prime mover.

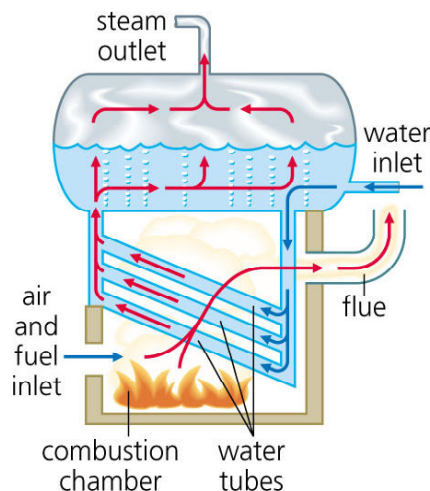
- The size of the Velox boiler is limited to 100 tonnes/h because 600 bhp is required to run the air compressor at this output. The power developed by the gas turbine is not sufficient to run the compressor and therefore some power from external source must be supplied.

Advantages:

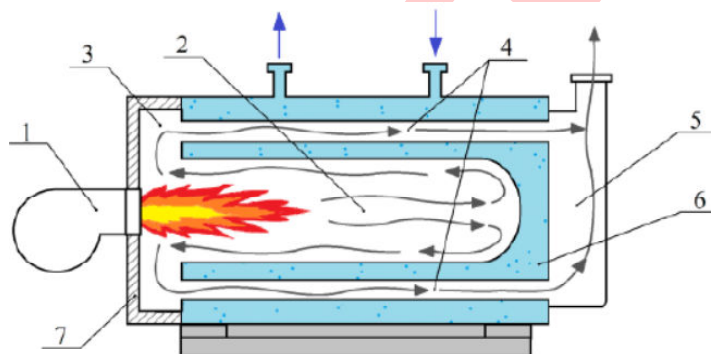
1. The boiler is very compact and has greater flexibility.
2. Very high combustion rates are possible.
3. It can be quickly started.
4. Less excess air is required as the pressurized air is used and the problem of draught is simplified.

135.

Sol. Water tube boiler



Fire tube boiler



Fire Tube Boilers	Water Tube Boilers
(1) Hot gases inside the tubes and water outside the tubes	(1) Water inside the tubes and hot gases outside the tubes
(2) Generally internally fired	(2) Externally fired
(3) Operating pressure limited to 16 bar	(3) Can work under as high pressure as 100 bar
(4) Lower steam production rate	(4) Higher rate of steam production
(5) Various parts not so easily accessible for cleaning, repair and inspection	(5) Various parts are more accessible
(6) Difficult in construction	(6) Simple in construction

136.

Sol. An industry has a maximum demand of 200 kW with a load factor of 50%. The load is maintained at a power factor of 0.8 lagging. Calculate the annual electricity bill and over all cost per kWh consumed for the following tariffs.

- Rs.1000 per kW of maximum demand per annum + Rs 2.20 per kWh of energy consumed.
- Rs.500 per kVA of maximum demand per annum + Rs.1.80 per kWh of energy consumed.



Sol. 2: Given,

- Maximum demand = 200 kW
- Load factor 50% = 0.5
- Power factor = 0.8 lagging

We know that ($\text{kW} = \text{kVA} \times \cos \theta$)

hence

$$\text{kVA} = \frac{\text{kW}}{\cos \theta} = \frac{200}{0.8} = 250 \text{ kVA}$$

Total Energy consumed per annum = L.F $\times$ M.D $\times$ 8760

$$= 0.5 \times 200 \times 8760$$

$$= 8,76,000 \text{ kWh}$$

a. Annual electricity bill = Rs. $(1000 \times 200 + 2.20 \times 876 \times 10^3)$
= Rs. 21,27,200/-

b. Annual electricity bill = Rs. $(500 \times 250 + 1.80 \times 876 \times 10^3)$
= Rs. 17,01,800/-