APPLIED THERMAL ENGINEERING (UMT303)

Diesel Engine Power Plant

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Application of Diesel Engine Power Plant

(a) *Peak load plant* Diesel plants can be used in combination with thermal or hydro-plants as peak load units. They can be easily started or stopped at a short notice to meet the peak demand.

(b) *Mobile plant* Diesel plants mounted on trailers can be used for temporary or emergency purposes such as for supplying power to large civil engineering works.

(c) *Standby unit* If the main unit fails or cannot cope up with the demand, a diesel plant can supply the necessary power. For example, if water available in a hydro-plant is not adequately available due to less rainfall, the diesel station can operate in parallel to generate the short fall in power.

(d) *Emergency plant* During power interruption in a vital unit like a key industrial plant or a hospital, a diesel electric plant can be used to generate the needed power.

(e) *Nursery station* In the absence of main grid, a diesel plant can be installed to supply power in a small town. In course of time, when electricity from the main grid becomes available in the town, the diesel unit can be shifted to some other area which needs power on a small scale. Such a diesel plant is called a "nursery station".

(f) *Starting stations* Diesel units can be used to run the auxiliaries (like *FD* and *ID* fans, *BFP*, etc.) for starting a large steam power plant.

(g) *Central stations* Diesel electric plants can be used as central station where the capacity required is small.

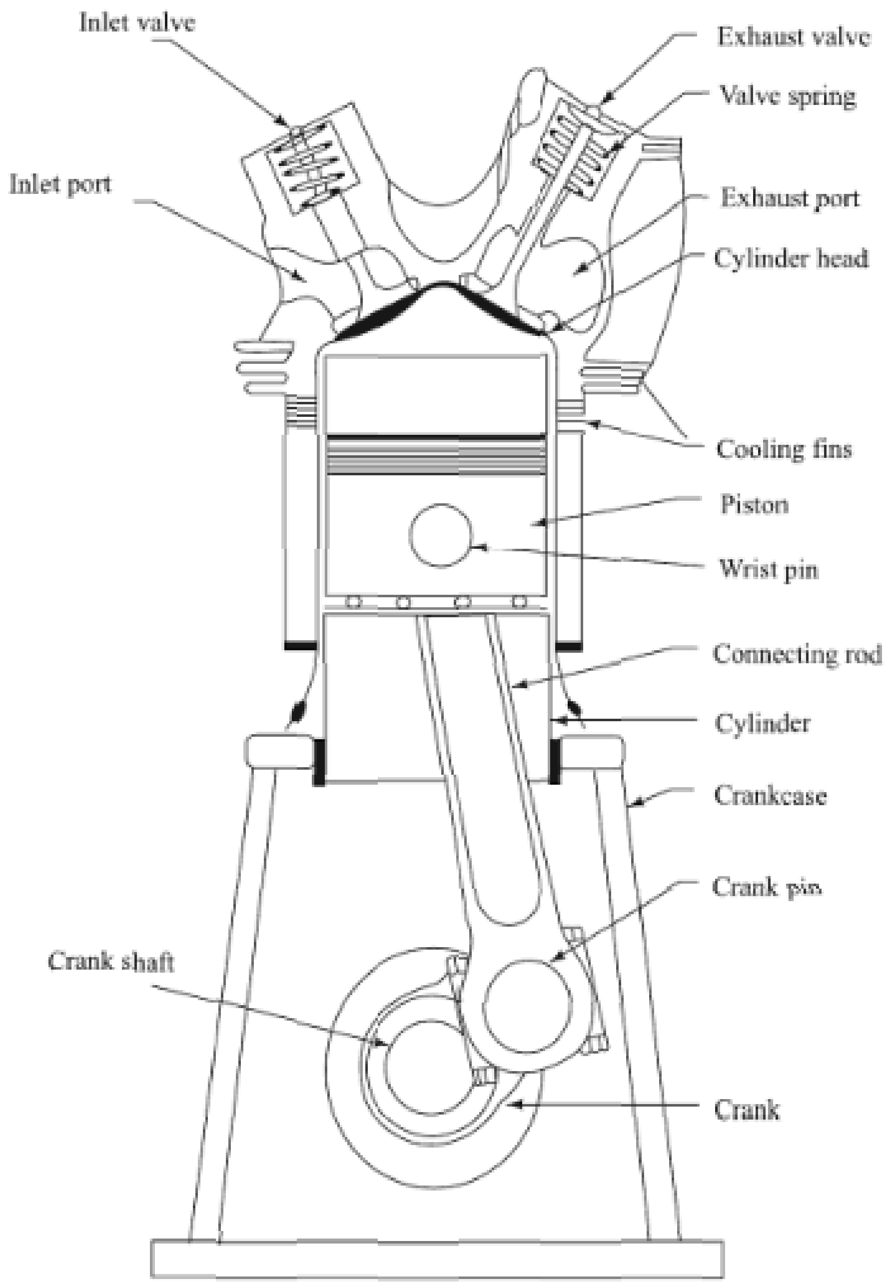
Advantages of Diesel Engine Power Plant

1. It is easy to design and install these electric stations.
2. They are easily available in standard capacities.
3. They can respond to load changes without much difficulty.
4. There are less standby losses.
5. They occupy less space.
6. They can be started and stopped quickly.
7. They require less cooling water.
8. Capital cost is less.
9. Less operating and supervising staff required.
10. High efficiency of energy conversion from fuel to electricity.
11. Efficiency at part loads is also higher.
12. Less of civil engineering work is required.
13. They can be located near the load centre.
14. There is no ash handling problem.
15. Easier lubrication system.

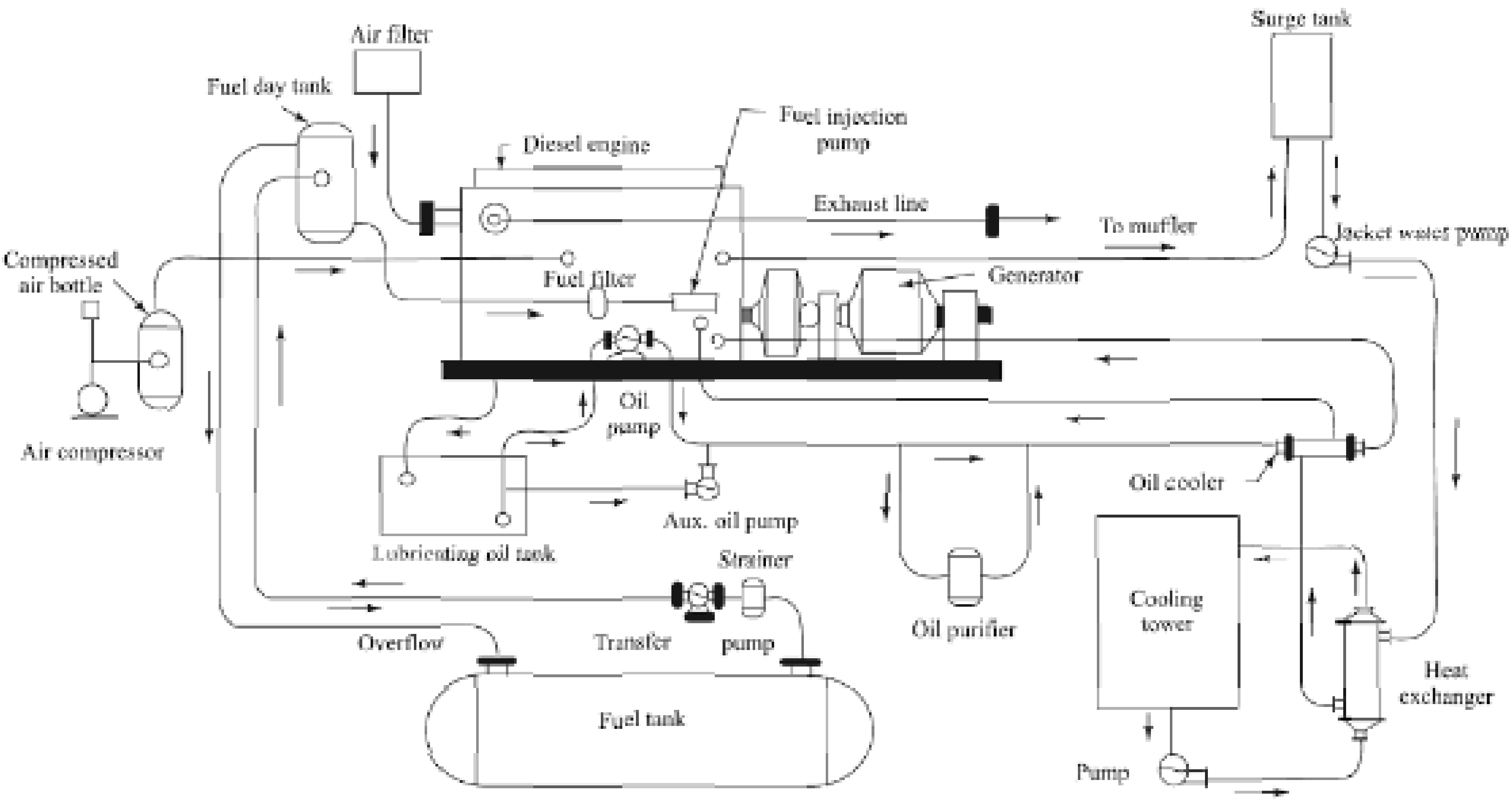
Disadvantages of Diesel Engine Power Plant

1. High operating cost.
2. High maintenance and lubrication cost.
3. Capacity is restricted. Cannot be of very big size.
4. Noise problem.
5. Cannot supply overload.

Cross-Section of an Air-cooled IC Engine

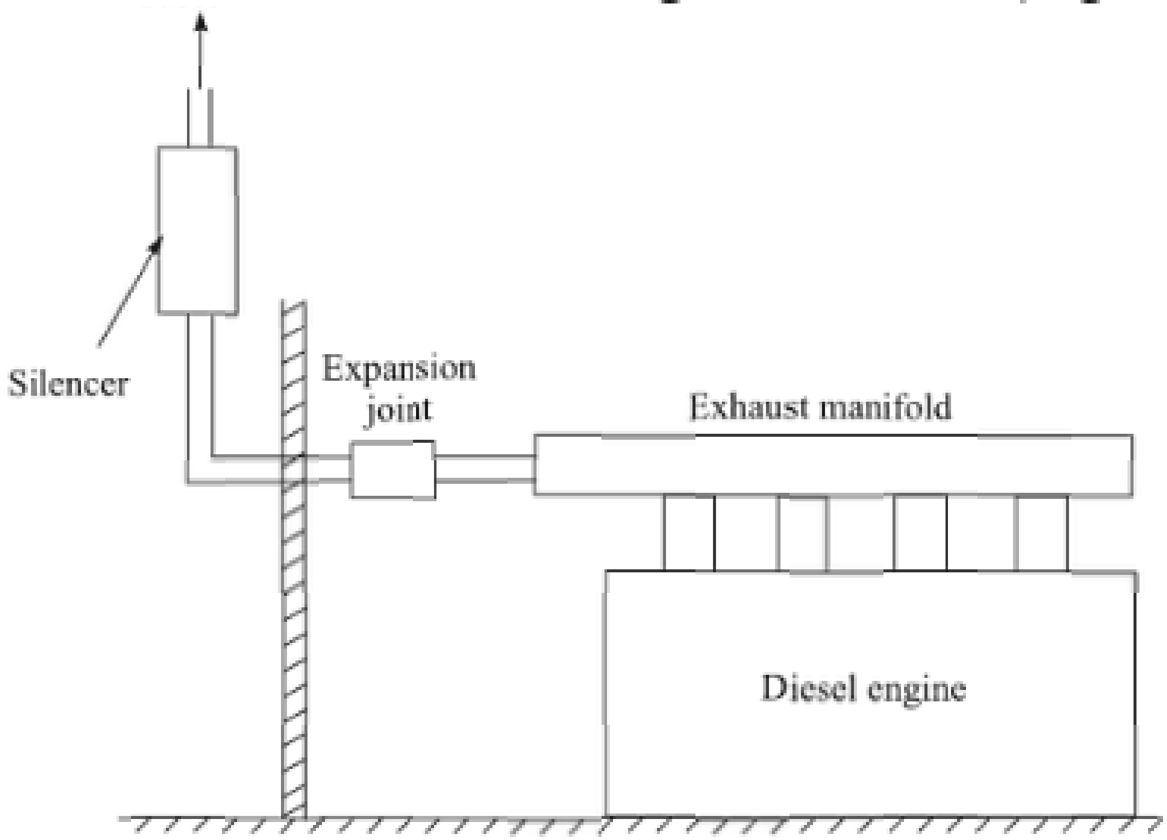


Schematic of a Diesel Engine Power Plant



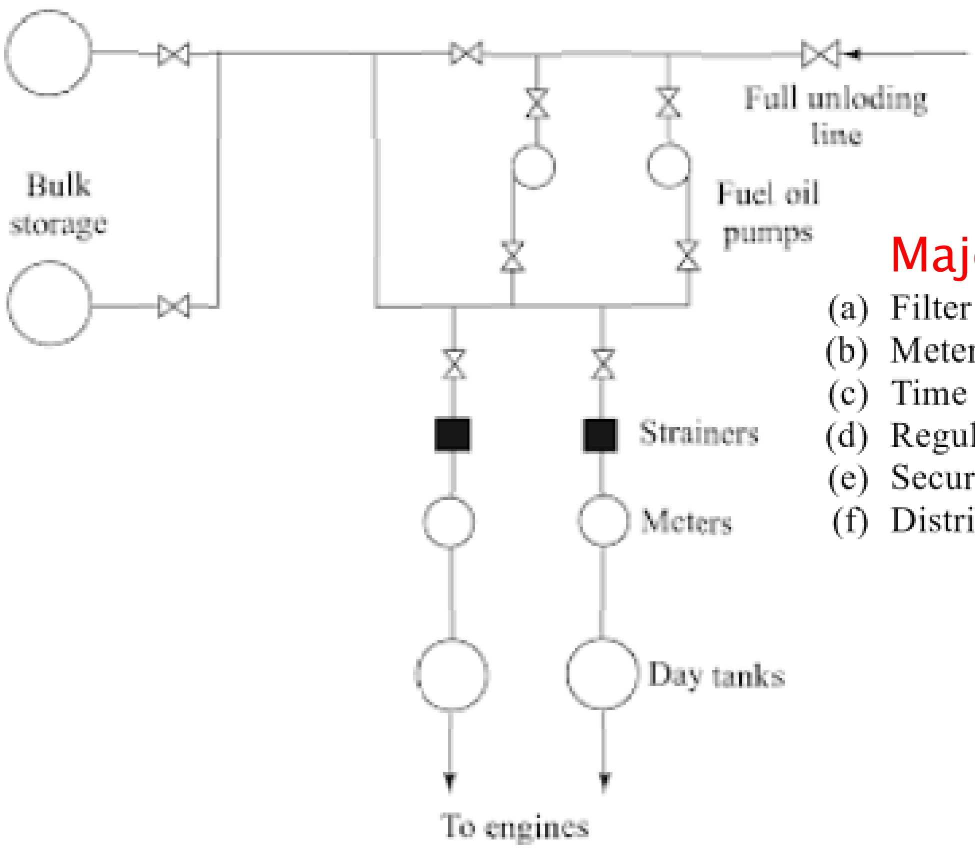
Exhaust System

3. *Exhaust system* It discharges the engine exhaust to the atmosphere. The exhaust manifold connects the engine cylinder exhaust outlets to the exhaust pipe which is provided with a muffler or silencer to reduce pressure on the exhaust line and eliminate most of the noise which may result if gases are discharged directly to the atmosphere. The exhaust pipe should have flexible tubing system to take up the effects of expansion due to high temperature and also isolate the exhaust system from the engine vibration (Fig. 11.3).



Fuel System

4. *Fuel system* Fuel oil may be delivered at the plant site by trucks, railway wagons or barges and oil tankers. An unloading facility delivers oil to the main storage tanks from where oil is pumped to small service storage tanks known as engine day tanks, which store oil for approximately eight hours of operation (Fig. 11.4). Coils heated by hot water or steam reduce oil viscosity to reduce pumping power.



Major Function

(a) Filter the fuel
(b) Meter the correct quantity of the fuel to be injected
(c) Time the injection process
(d) Regulate the fuel supply
(e) Secure fine atomization of fuel oil
(f) Distribute the atomized fuel properly in the combustion chamber.

Injection Classification

(a) Common rail injection system
(b) Individual pump injection system
(c) Distributor system

Cooling System

5. *Cooling system* The temperature of the gases inside the cylinder may be as high as 2750°C. If there is no external cooling, the cylinder walls and piston will tend to assume the average temperature of the gases which may be of the order of 1000° to 1500°C. The cooling of the engine is necessary for the following reasons.

(a) The lubricating oil used determines the maximum engine temperature that can be used. This temperature varies from 160°C to 200°C. Above these temperatures the lubricating oil deteriorates very rapidly and may evaporate and burn damaging the piston and cylinder surfaces. Piston seizure due to overheating may also occur.

(b) The strength of the materials used for various engine parts decreases with increase in temperature. Local thermal stresses can develop due to uneven expansion of various parts, often resulting in cracking.

(c) High engine temperatures may result in very hot exhaust valve, giving rise to pre-ignition and detonation or knocking.

(d) Due to high cylinder head temperature, the volumetric efficiency and hence power output of the engine are reduced.

Following are the two methods of cooling the engine.

(i) Air cooling

(ii) Water cooling

Air cooling is used in small engines, where fins are provided to increase heat transfer surface area.

Big diesel engines are always water cooled. The cylinder and its head are enclosed in a water jacket which is connected to a radiator. Water flowing in the jacket carries away the heat from the engine and becomes heated. The hot water then flows into the radiator and gets cooled by rejecting heat to air from the radiator walls. Cooled water is again circulated in the water jacket.

Lubrication System

6. *Lubricating system* Lubrication is the flow of oil between two surfaces having relative motion. The following are the important functions of a lubricating system.

(a) *Lubrication* To keep moving parts sliding freely past each other, thus reducing engine friction and wear.

(b) *Cooling* To keep the surfaces cool by taking away a part of the heat caused by friction.

(c) *Cleaning* To keep the bearings and piston rings clean of the products of wear as well as of combustion by washing them away.

(d) *Sealing* To form a good seal between the piston rings and cylinder walls.

(e) *Reducing noise* To reduce the noise of the engine by absorbing vibration.

Various lubrication systems used for IC engines may be classified in the following manner.

(a) Mist lubrication system

(b) Wet sump lubricating system

(c) Dry sump lubricating system

Starting of Diesel Engine

7. *Starting of engine* Following are the three common methods of starting an engine.

(i) By an auxiliary engine, which is mounted close to the main engine and drives the latter through a clutch and gears.

(ii) By using an electric motor, in which a storage battery of 12 to 36 volts is used to supply power to an electric motor that derives the engine.

(iii) By compressed air system, in which compressed air at about 17 bar supplied from an air tank is admitted to a few engine cylinders making them work like reciprocating air motors to run the engine shaft. Fuel is admitted to the remaining cylinders and ignited in the normal way causing the engine to start. The compressed air system is commonly used for starting large diesel engines employed for stationary power plant service.

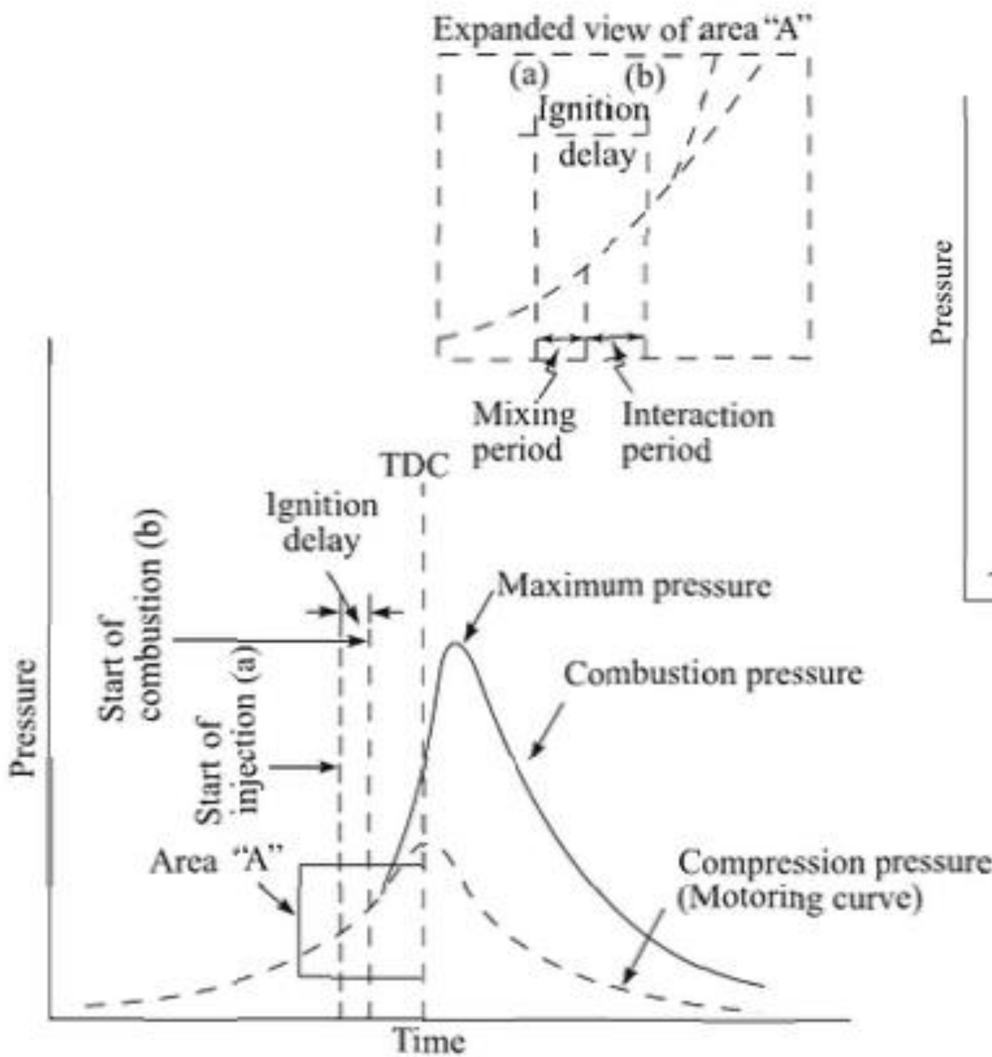
Combustion in CI Engine

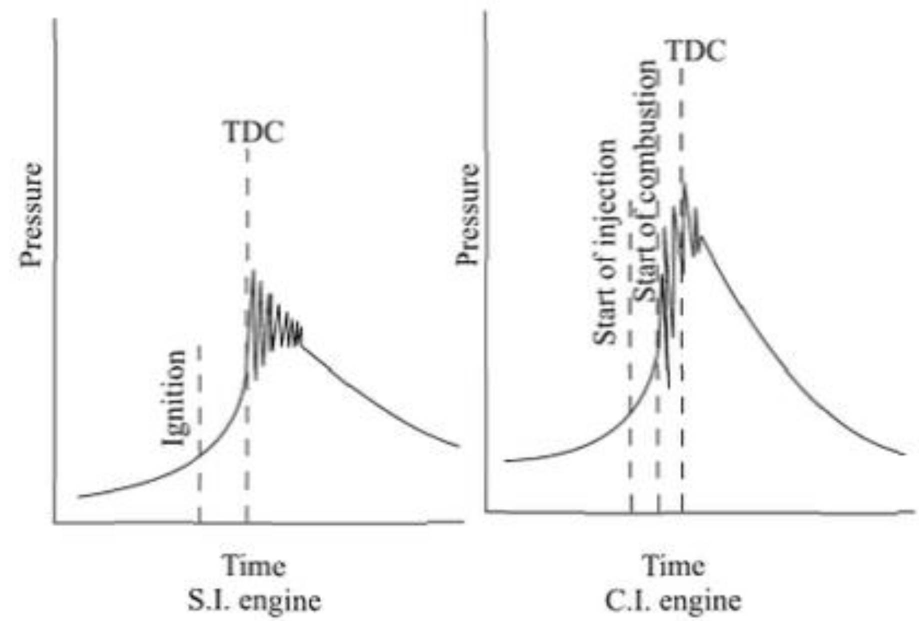
In a CI engine combustion of fuel occurs due to the high temperature produced by the compression of air and hence it is an auto-ignition engine. For this, a minimum compression ratio of 12 is required. The efficiency of the cycle increases with higher values of compression ratio, but the maximum pressure reached in the cylinder also increases. This requires heavier construction. The upper limit of compression ratio is a compromise between high efficiency and low weight and cost. The normal compression ratios are in the range of 14 to 17, but they may be up to 23. The air fuel ratios used in CI engines lie between 18 and 25 as against about 15 in the SI engine. So, for same power CI engines are bigger and heavier than SI engines.

In a CI engine the intake is air alone and the fuel is injected at high pressure in the form of fine droplets near the end of compression. This leads to the delay period, as explained below.

Due to the practical limitations caused by smoke at engine exhaust (smoke limit), CI engines are operated at air fuel ratios higher than the stoichiometric requirement. Due to shortcomings of distribution and limited intermixing of fuel with air within the combustion chamber, CI engines always operate with excess air (unlike SI engines).

Combustion in CI Engine

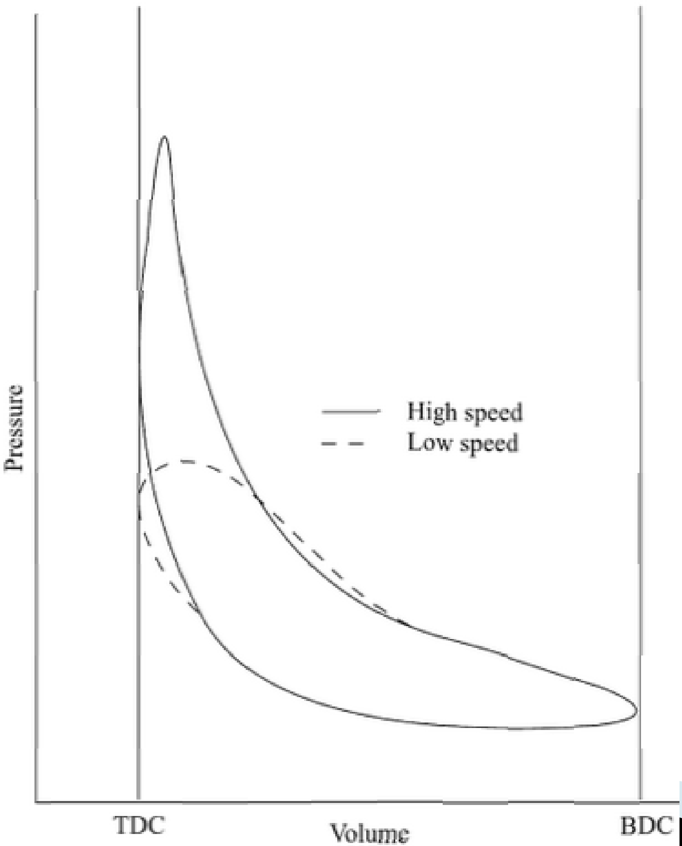


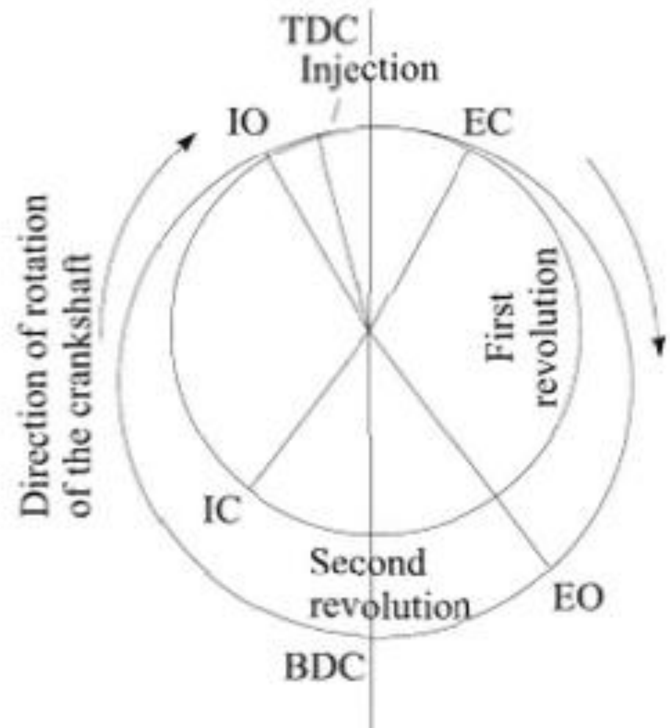


Valve Timing Diagram

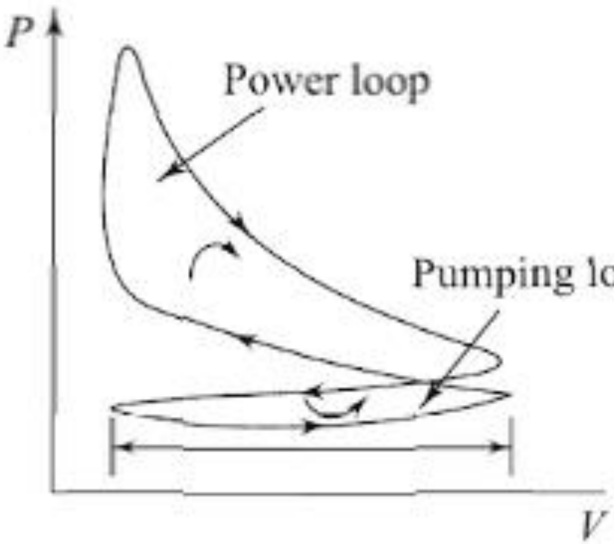
IO	up to	30°	before	TDC
IC	up to	50°	after	BDC
EO	about	45°	before	BDC
EC	about	30°	after	TDC
Injection	about	15°	before	TDC

where IO = Inlet valve opens
IC = Inlet valve closes
EO = Exhaust valve opens
EC = Exhaust valve closes
TDC = Top dead centre
BDC = Bottom dead centre





Indicated Power, Brake Power, Friction Power



Pressure-volume diagram of a reciprocating engine taken by an indicator

$$p_i = \frac{\text{net area of indicator diagram}}{\text{length of diagram}} \times \text{constant}$$

$$\text{Work done per cycle} = P_i AL$$

Indicated power (ip) is given by

$$ip = \frac{p_i AL(N/2 \text{ or } N)n}{60}$$

where N = rpm and n = number of cylinders.

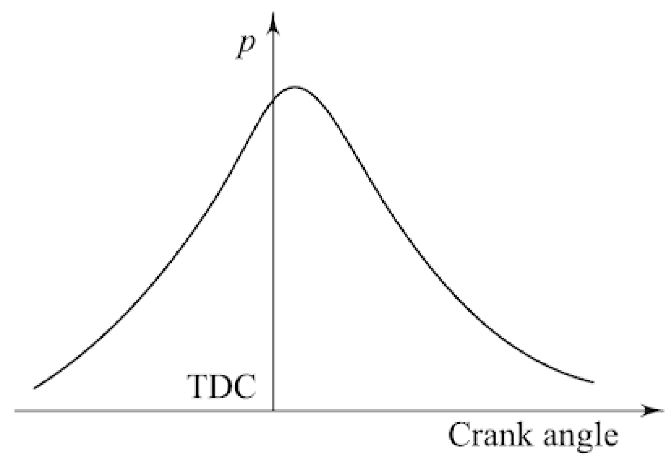
For a four-stroke engine, the number of cycles per minute is $N/2$ and for a two-stroke engine, the number of cycles per minute is N.

$$bp = \frac{2\pi TN}{60} \qquad fp = ip - bp$$

where T is the torque measured.

The mechanical efficiency (η_M) of the engine is defined as

$$\eta_M = bp/ip$$



Morse Test

The Morse test can be used to measure the *ip* of multi-cylinder engines. The engine, say having four cylinders, is run at the required speed and the torque is measured. One cylinder is cut out by disconnecting the injector of a CI engine (or by shorting the spark plug of an SI engine). The speed falls because of the loss of power with one cylinder cut out, but is restored by reducing the load. When the speed has reached the original value, the torque is again measured. It is repeated by cutting out other cylinders one by one. If the values of *ip* of the cylinders are denoted by I_1, I_2, I_3 and I_4 and the power losses in each cylinder are denoted by L_1, L_2, L_3 and L_4, then the value of *bp*, B, at the test speed with all cylinders firing is given by

$$B = (I_1 - L_1) + (I_2 - L_2) + (I_3 - L_3) + (I_4 - L_4)$$

If number 1 cylinder is cut out, then the contribution I_1 is lost. If the losses due to that cylinder remain the same as when it was firing, then the *bp*, B_1, obtained at the same speed is

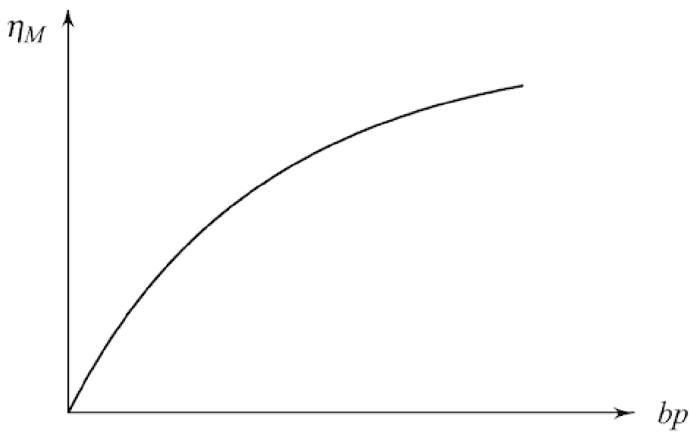
$$B_1 = (0 - L_1) + (I_2 - L_2) + (I_3 - L_3) + (I_4 - L_4) \quad \Rightarrow \quad B - B_1 = I_1$$

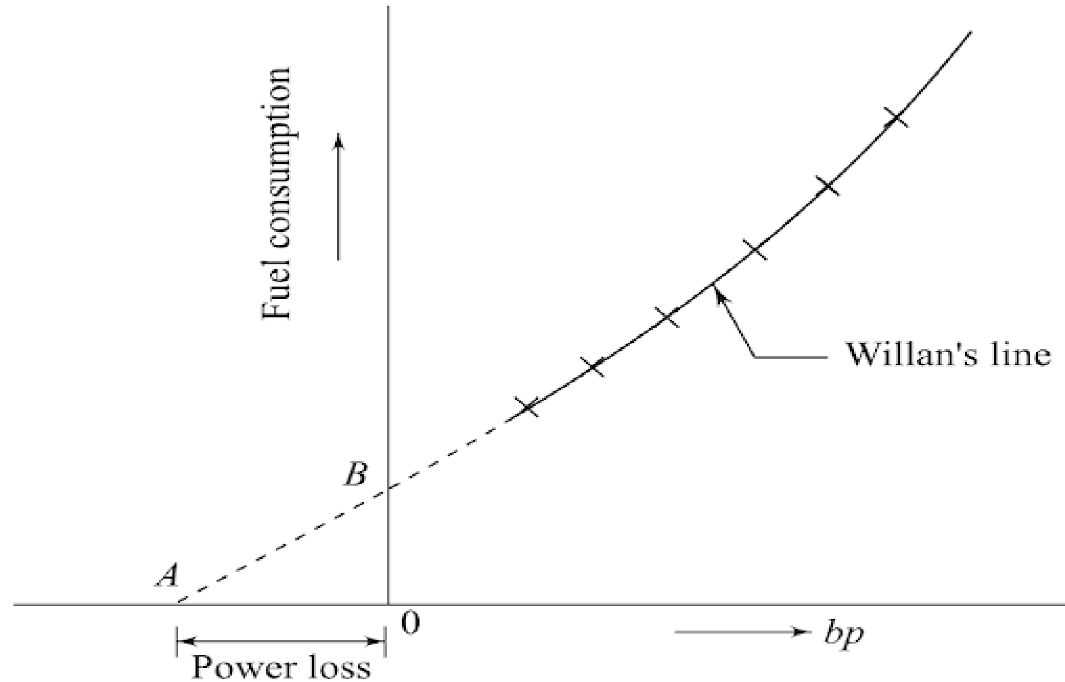
$$I = I_1 + I_2 + I_3 + I_4$$

Willan's Line

At a constant engine speed if the load is decreased in steps and the corresponding *bp* and fuel consumption are measured and plotted, a graph called the "Willan's Line" is obtained as shown in Fig. 11.26.

$$bp = \eta_M \times ip = \eta_M \times \frac{P_i AL \frac{N}{2} n}{60}$$





Since η_M and p_i are difficult to obtain they may be combined and replaced by a brake mean effective pressure (bmep), p_b, i.e.

$$bp = \frac{p_b AL \frac{N}{2} n}{60}$$

$$p_b = \eta_M \times p_i$$

$$\frac{p_b AL \frac{N}{2} n}{60} = \frac{2\pi TN}{60}$$

$$p_b = KT$$

where K is a constant.

Efficiency Relations

The power output of the engine is obtained by burning a fuel. The overall efficiency of the engine is given by the brake thermal efficiency, η_{BT}, which is

$$\eta_{BT} = \frac{\text{Brake work}}{\text{Energy supplied}} = \frac{bp}{\dot{m}_f \times CV}$$

$$bsfc = \dot{m}_f / bp$$

The indicated thermal efficiency, η_{IT}, is defined in a similar way as follows.

$$\eta_{IT} = \frac{ip}{\dot{m}_f \times CV}$$

$$\frac{\eta_{BT}}{\eta_{IT}} = \frac{bp}{ip} = \frac{bmep}{imep} = \eta_M \implies \eta_{BT} = \eta_{IT} \times \eta_M$$

Volumetric efficiency The power output of an IC engine depends directly upon the amount of charge which can be induced into the cylinder. This is called the breathing capacity of the engine and is expressed quantitatively by the volumetric efficiency, which is defined as the ratio of the volume of air induced (V), measured at the free air conditions, to the swept volume of the cylinder (V_S), i.e.

$$\eta_V = V / V_s$$

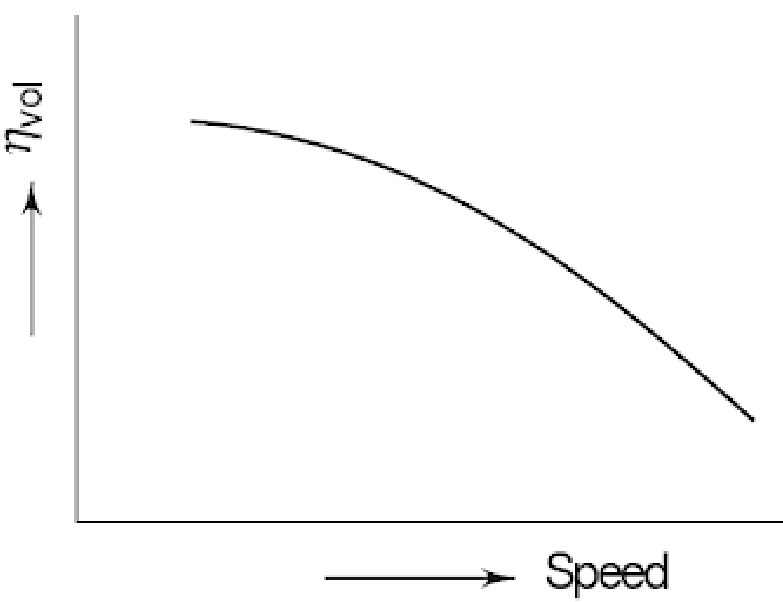
Energy Balance

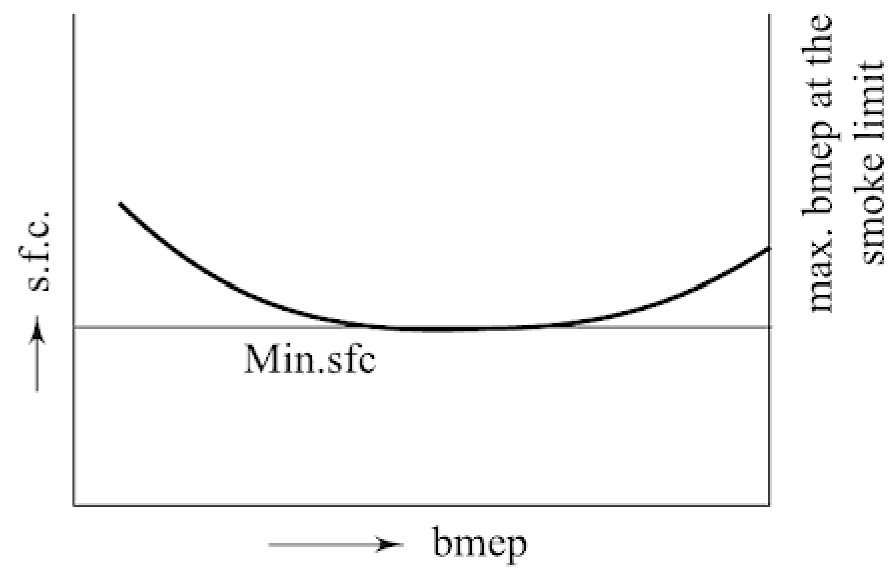
Energy balance Energy supplied by the fuel $\dot{m}_f \times CV = bp$ + the heat transferred to cooling water (Q_c) + the energy of the exhaust referred to inlet condition (Q_{ex}) + unaccounted energy losses which include losses by radiation and convection.

$$\text{Energy to exhaust is } (Q_{ex}) = (\dot{m}_a + \dot{m}_f)h_e - \dot{m}_a h_a$$

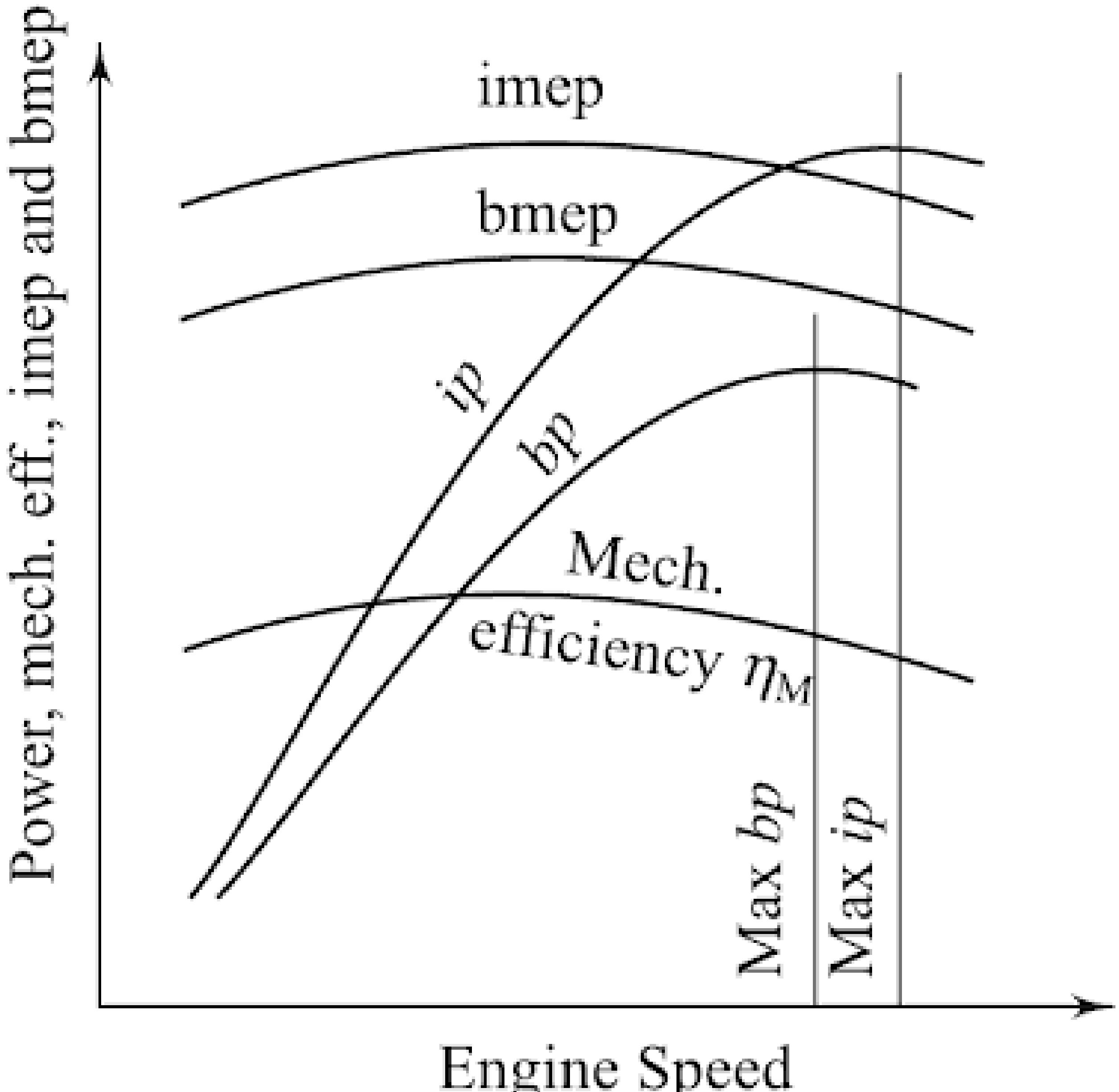
where $\dot{m}_a$ and $\dot{m}_f$ are the air and fuel mass flow rates, h_e is the enthalpy of the exhaust gas (dry exhaust + steam), reckoned from 0 °C, and h_a is the enthalpy of air at inlet, reckoned from 0 °C.

For a diesel engine at full load, typical values are: to *bp* 35%, to cooling water 20%, to exhaust 35% and to radiation, etc. 10%. The heat to the jacket cooling water and exhaust can be utilized in industries which have heating loads as space heating and hot water systems.

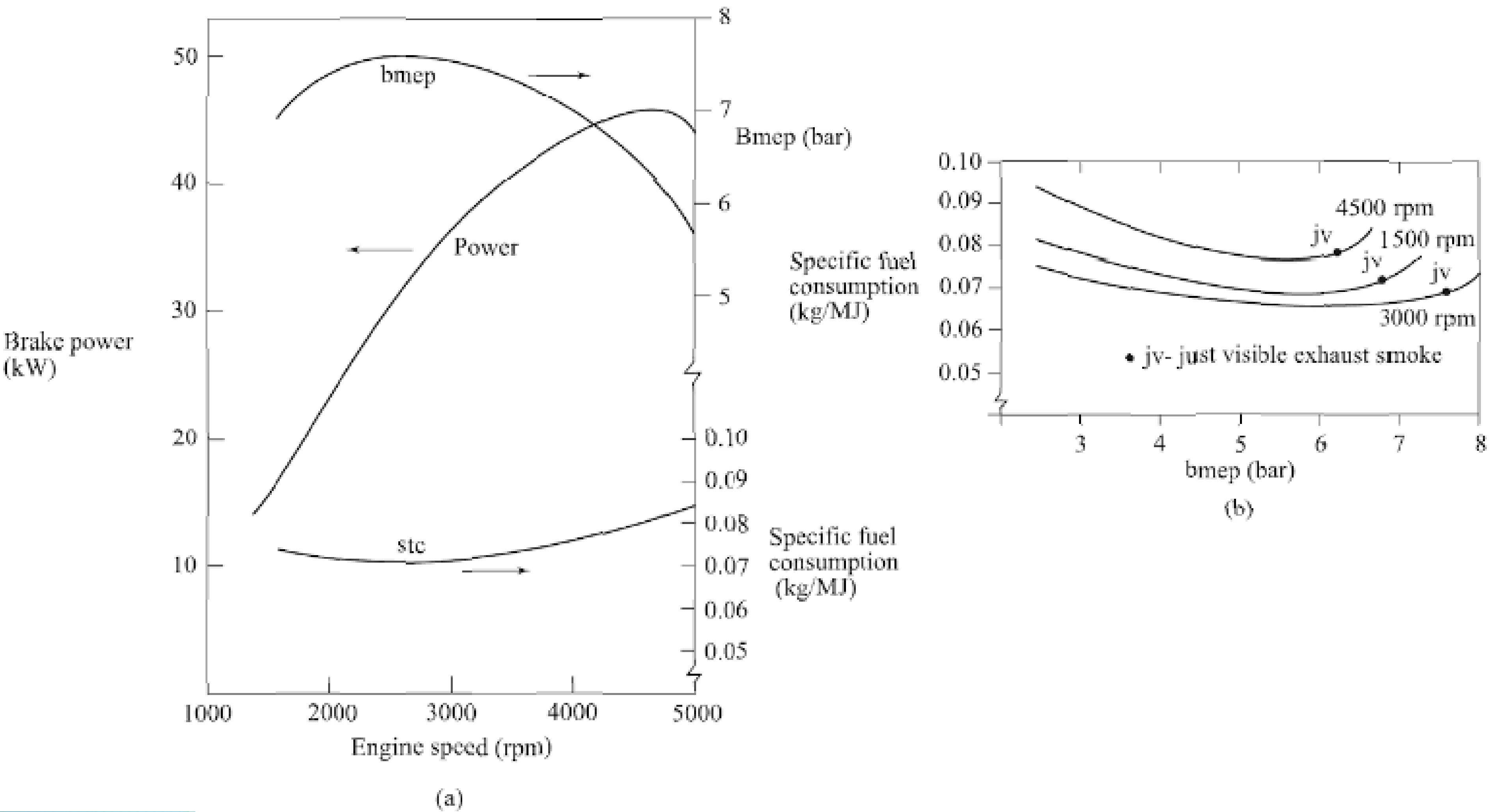




Engine Characteristics



Performance at different Speed and Load



Typical performance for a CI engine at (a) Full load and (b) Part load at different speeds

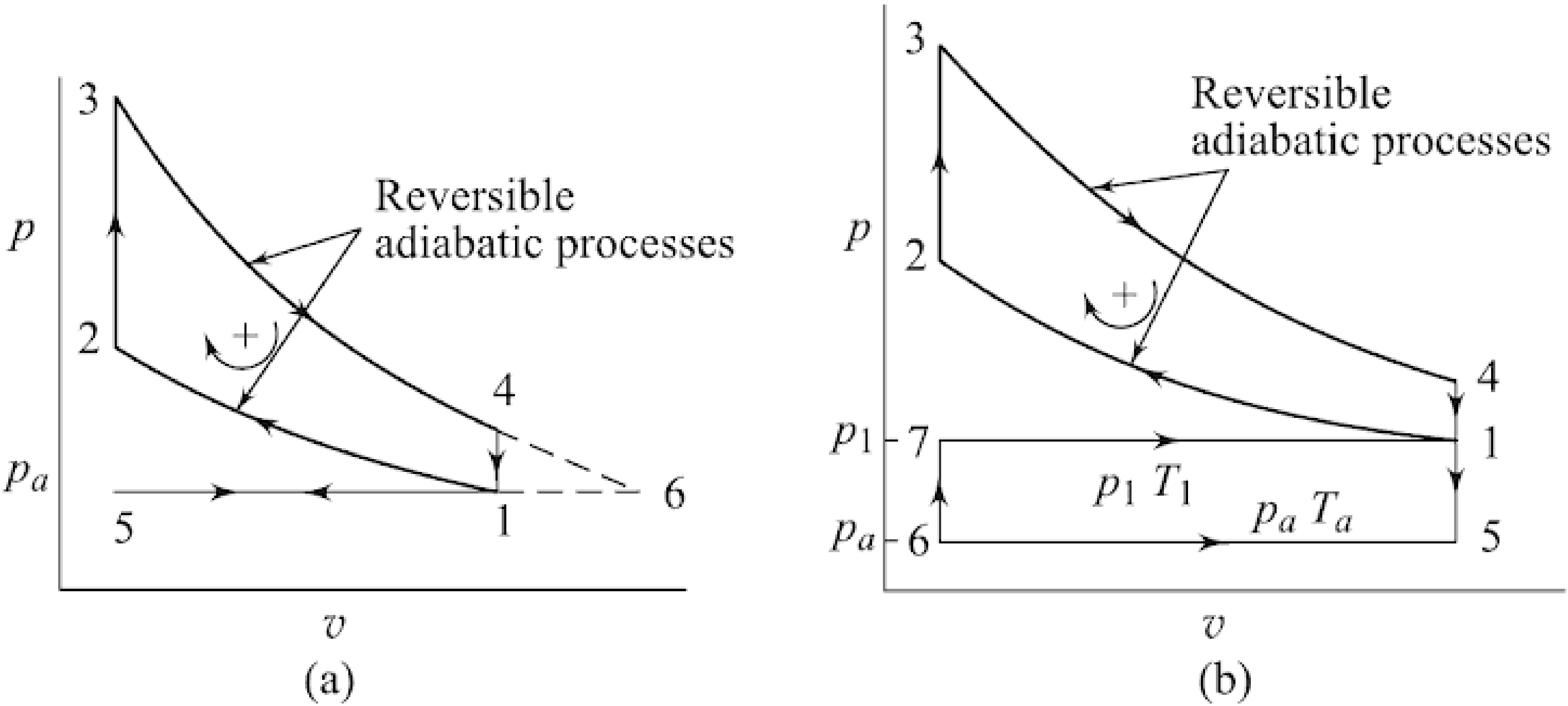
Super Charging

The power output of an engine is affected by the reduction in volumetric efficiency at increased engine speed (Fig. 11.28). The object of supercharging is to increase the volumetric efficiency above that obtained with normal aspiration. Supercharging of air by a compressor or blower increases its density and also its mass flow rate which permits the burning of more fuel and thus augments the output of the engine.

The increase in pressure and temperature of the intake air in diesel engine reduces ignition delay, lowers the rate of pressure rise and makes the combustion process better, quieter and smoother. There is a decrease in the exhaust gas temperature due to high expansion ratio as well as A/F ratio. Increased reliability, durability and better fuel consumption are some other benefits of supercharging. In a spark ignition engine, however, supercharging promotes knocking tendency, which leads to the use of lower compression ratio and hence leads to less efficiency.

The main features of supercharging are illustrated in p-V diagrams for the idealized constant volume four-stroke cycle in Fig. 11.30 and the plant line diagrams in Fig. 11.31. Figure 11.30 (a) shows the normally aspirated cycle with line 5–1 representing both the inlet and exhaust strokes at about ambient air pressure p_a. The supercharged cycle is shown in Fig. 11.30 (b), where p_i, T_i refer to the engine inlet condition. Two ways of supercharging, viz. (a) mechanical supercharging with a blower driven by the engine itself and (b) turbocharging,

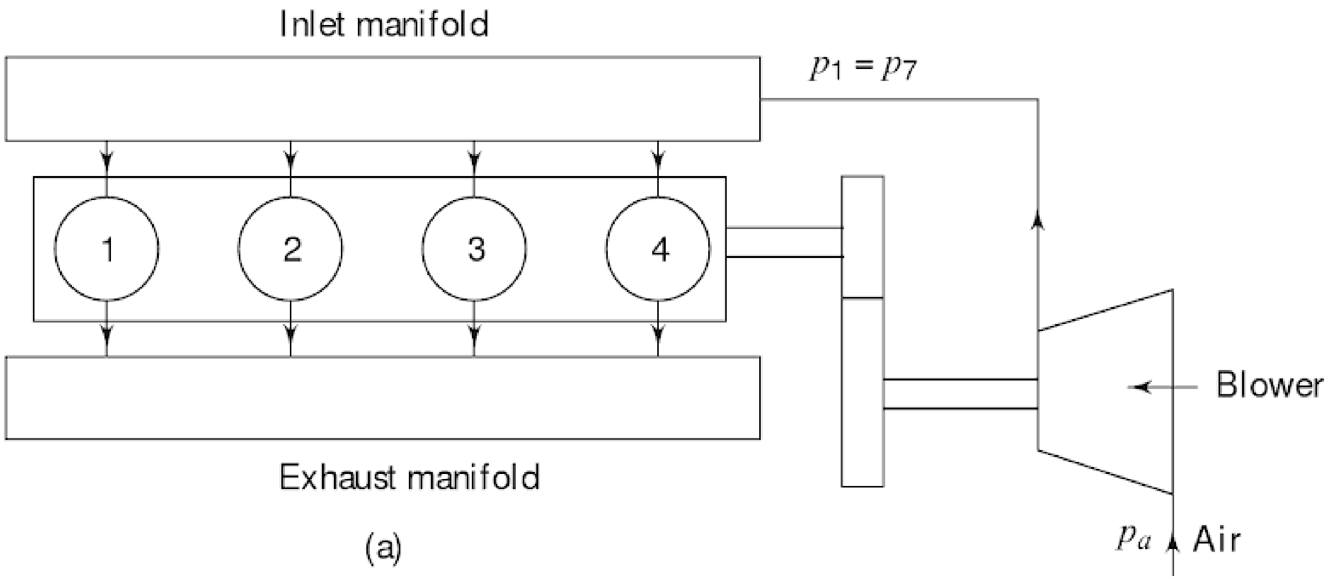
Super Charging



Pressure-volume diagram for a four-stroke CI engine (a) Without supercharging and (b) With supercharging

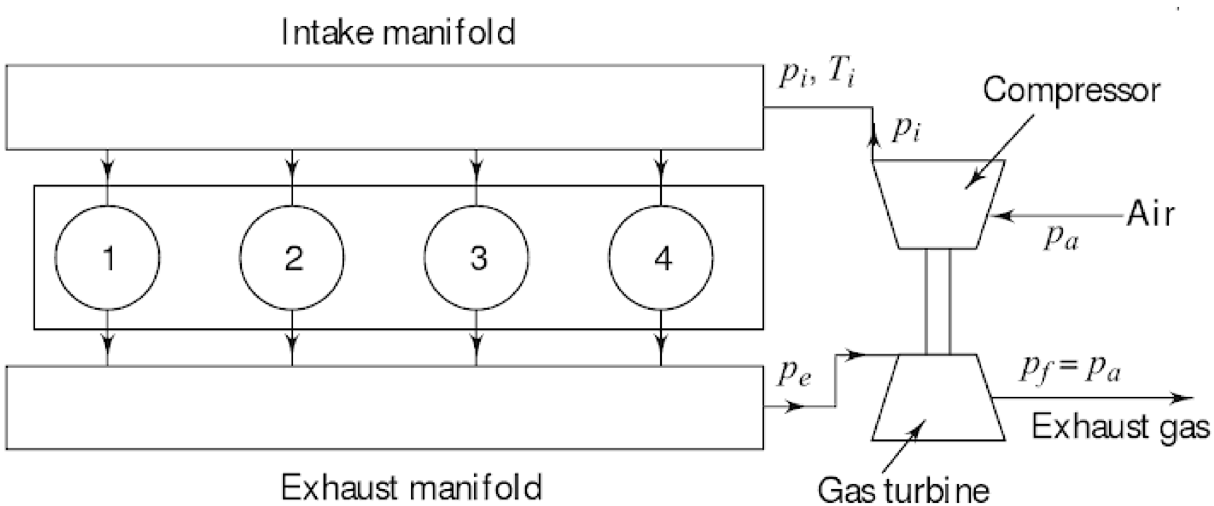
Super Charging vs Turbo Charging

Mechanical Supercharging



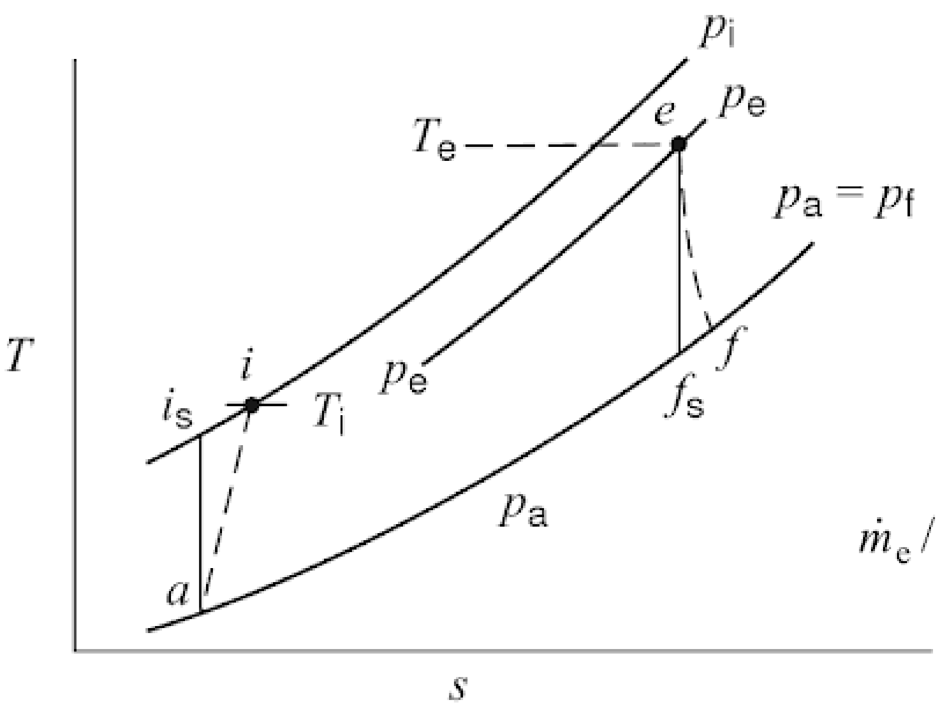
(a)

Turbocharging



(b)

Turbo-Charging



$$\dot{W}_c = \dot{m}_a \, Cp_a \, T_a \, [(p_i/p_a)^{(\gamma_a - 1)/\gamma_a} - 1]/\eta_c$$

$$\dot{W}_T = \dot{m}_g \, cp_e \, T_e \, [1 - (p_a/p_e)^{(\gamma_a - 1)/\gamma_a}] \times \eta_T$$

$\dot{m}_e$ = rate of flow of exhaust gas from the engine

$= \dot{m}_a + \dot{m}_f$

$\dot{m}_e / \dot{m}_a = 1 + (\dot{m}_f / \dot{m}_a) = 1 + F/A$

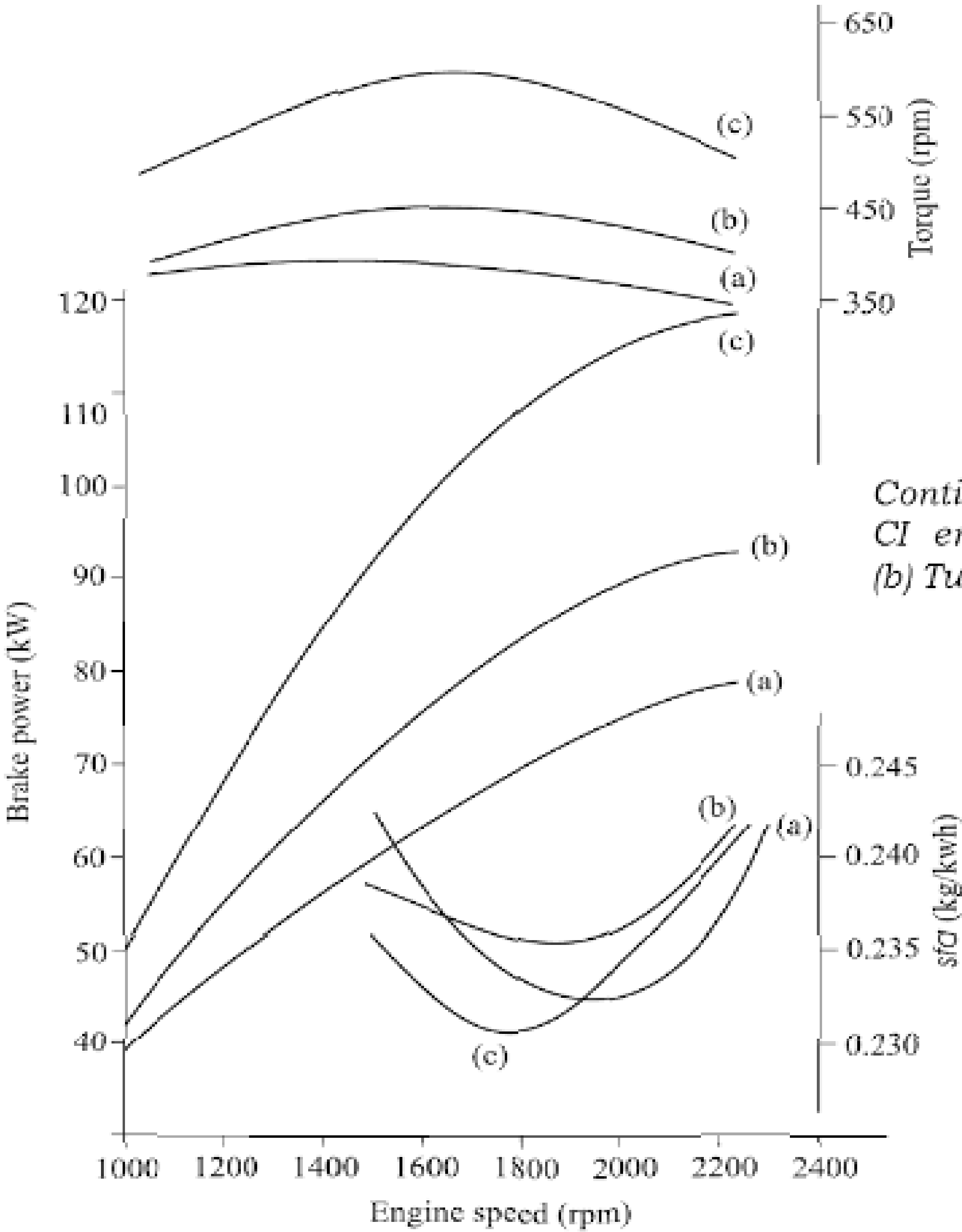
$$W_c = W_T \times \eta_M$$

, η_M is the mechanical efficiency.

$$[(p_i/p_a)^{(\gamma_a - 1)/\gamma_a} - 1] = [1 - (p_a/p_e)^{(\gamma_e - 1)/\gamma_e}] \, [c_{pe}/c_{pa}] \, [T_e/T_a] \, [1 + F/A] \times \eta_0$$

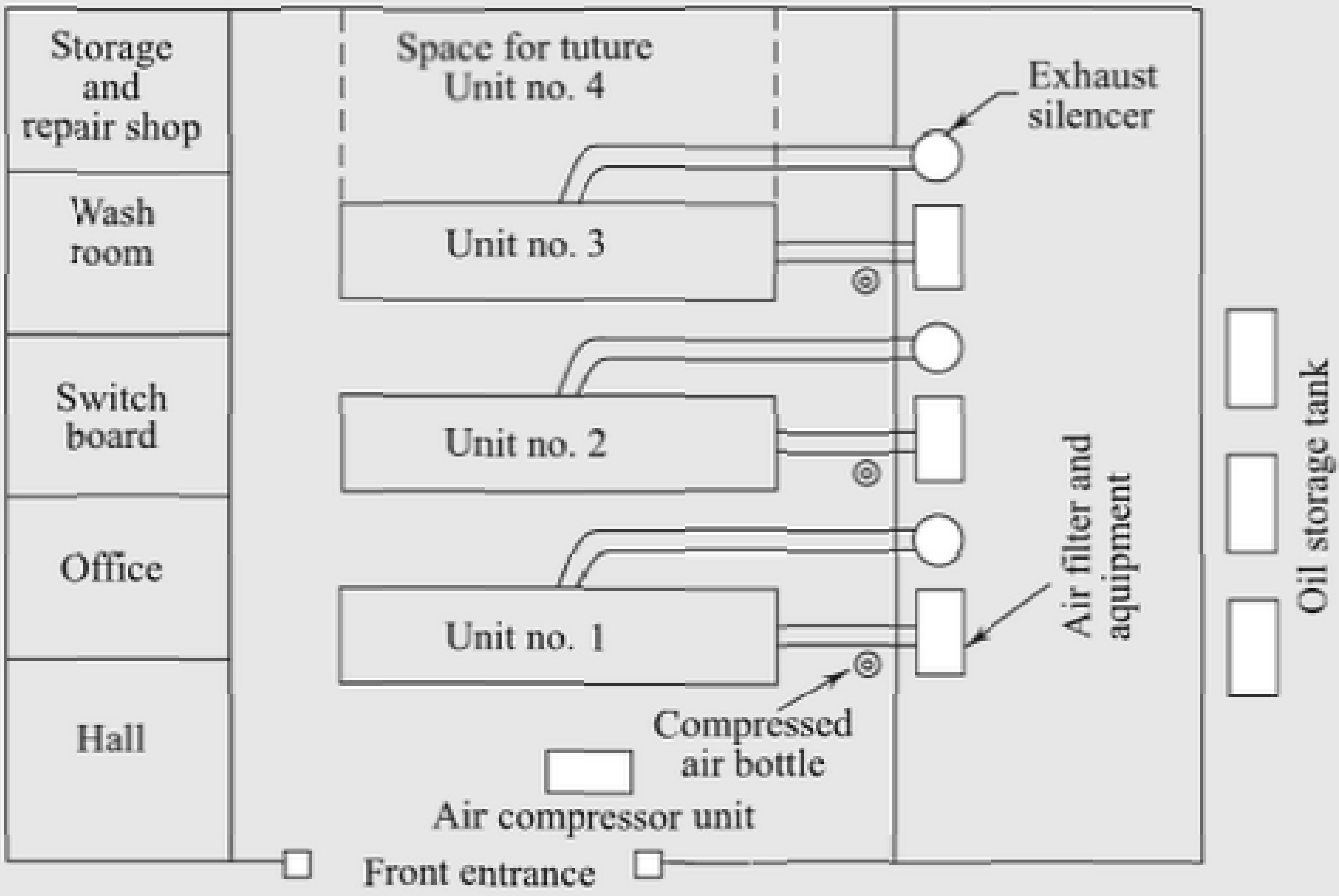
where, $\eta_0 = \eta_M \times \eta_T \times \eta_c$ = Overall efficiency of the supercharger.

Turbo-Charging Compressor



Continuous running performance characteristics of a CI engine in three modes: (a) Normally aspirated, (b) Turbocharged and (c) Turbocharged with intercooling

Typical Layout of Diesel Engine Power Plant



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