1. **Suction Stroke.** The piston is at the top most position (TDC) and is ready to move down drawing its mixture of fuel (petrol) and air (Fig. 22.3). The inlet valve is open and exhaust valve is closed. As the piston moves downwards, a fresh charge of fuel-air mixture enters the cylinder through the inlet valve due to the suction created. This continues until piston reaches BDC. At this position, the inlet valve closes. This downward movement of the piston is known as suction stroke and the crank rotates by 180° during this period.

2. **Compression Stroke.** During this stroke, both valves (inlet and exhaust) are closed and the piston moves upward and compresses the charge enclosed in the cylinder. The pressure and temperature of the mixture increases continuously during this process. As the piston reaches the top dead centre position, the mixture is ignited by an electric spark. The burning of the mixture is more or less instantaneous and the pressure and temperature of the gases increase while the volume remains constant.

3. **Power Stroke or Expansion Stroke.** The increased pressure of the mixture exerts a large force and pushes the piston down. During the expansion stroke, both valves remain closed. The high pressure and high temperature gases push the piston downwards and the gas pressure gradually decreases. During this stroke, the piston moves from TDC to BDC. This stroke is known as power stroke, as work is done during this stroke. The exhaust valve opens as the piston reaches BDC position and pressure falls suddenly to atmospheric pressure at constant volume.

5. **Exhaust Stroke.** During the upward motion of the piston, the exhaust valve is open and inlet valve is closed. The piston moves up in the cylinder pushing out the burnt gases through the exhaust valve. As the piston reaches the TDC, again the inlet valve opens and fresh charge is taken in during next downward movement of the piston and the cycle is repeated.

The engine is known as 4-stroke cycle engine, because one power stroke is achieved in every 4-strokes of the piston or two revolutions of the crankshaft.

22.4.2. Theoretical and Actual p-v Diagrams for 4-stroke Petrol Engine

In the above operations, the following assumptions were made :

1. Suction and exhaust take place at atmospheric pressure.
2. Suction and exhaust take place through 180° rotation of crank.
3. Compression and expansion also take place through 180 degrees rotation of the crank.
4. Compression and expansion are isentropic.
5. The combustion takes place instantaneously at constant volume at the end of compression stroke.
6. Pressure suddenly falls to the atmospheric pressure at the end of expansion stroke.

With these assumptions the working of the cycle on *p-v* diagram is as shown in Fig. 22.4, which is similar to the theoretical otto-cycle.

5-1 → Suction stroke and 1-2 → Compression stroke.

3-4 → Expansion stroke and 1-5 → Exhaust stroke.

2-3 → Instantaneous-combustion and 4-1 → Sudden fall in pressure.

The working of the engine during four strokes is shown in Fig. 22.4.

In the above operations, all the ideal conditions are assumed but in practice, the actual conditions differ from the ideal as described below.

1. The suction of mixture in the cylinder is possible only if the pressure inside the cylinder is below atmospheric pressure.

2. The burnt gases can be pushed out into the atmosphere only if the pressure of the exhaust gases is above atmospheric pressure.

3. The compression and expansion do not follow the isentropic law, as there will be heat exchange during these processes.

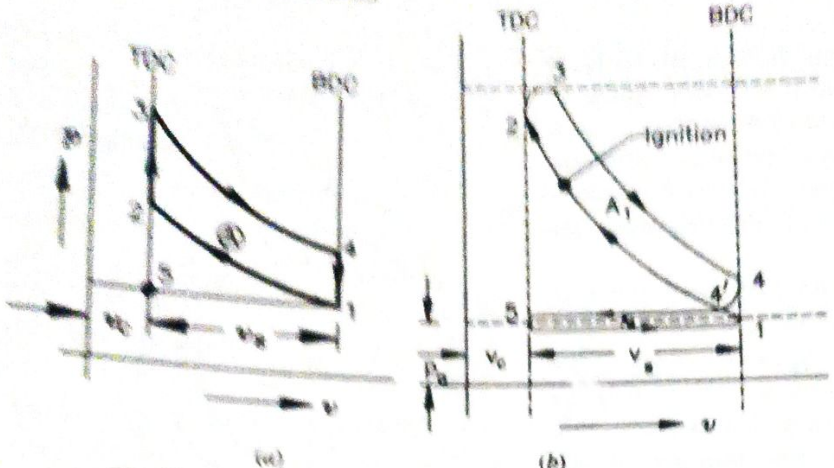


Fig. 22.4. Theoretical and actual p-v diagrams for 4-stroke petrol engine.

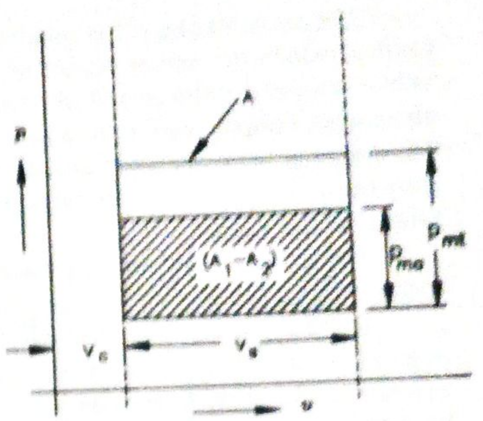


Fig. 22.5.

4. Sudden pressure rise is not possible after the ignition as combustion takes some time for completion and actual pressure rise is less than theoretical considered. The pressure increase takes place through some crank rotation, or increase in volume.

5. Sudden pressure release after the opening of expansion valve is not possible and it also takes place through some crank rotation.

If all these modifications are taken into account, then the cycle can be represented on *p-v* diagrams as shown in Fig. 22.4 (*b*).

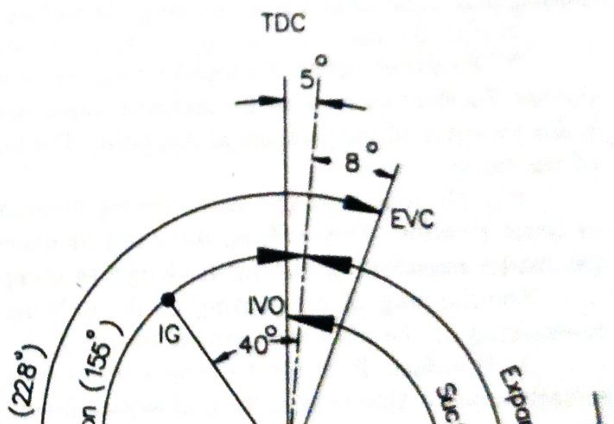
The area 4′-5-1-4′ representing negative work is called *negative loop or* pumping loop. This work is required for admitting the fresh charge and for exhausting the burnt gases. This loss of work is known as *pumping loss* and power consumed for this is known as pumping horse-power.

The net work per cycle of the engine is given by the area $(A_1 - A_2)$. This area $(A_1 - A_2)$ is always less than the area A as shown in Fig. 22.4 (*a*) due to the actual deviations of operations from the theoretical ones.

If both the areas are represented in the form of rectangles taking v_s as base, then the ordinates give the mean effective pressures as shown in Fig. 22.5.

22.4.3. Valve Timing Diagram for 4-Stroke Petrol Engine

The valve timing diagram shows the position of the crank when the various operations *i.e.*, suction, compression, expansion exhaust begin and end.



IVO = Inlet valve opens
IVC = Inlet valve closes
EVO = Exhaust valve opens
EVC = Exhaust valve closes
IG = Ignition of charge

Fig. 22.6 (*a*) Actual valve timing diagram for low speed 4-stroke spark ignition engine.

The valve timing is the regulation of the positions in the cycle at which the valves are set to open and close. Since the valves require a finite period of time to open or close without abruptness, a slight 'lead' time is necessary for proper operation. The design of valve operating cam provides for smooth transition from one position to the other, while cam setting determines the timing of the valve.

The actual valve timings used for low speed and high speed engines are shown in Figs. 22.6 (*a*) and (*b*).

1. **Inlet valve.** The inlet valve opening occurs a few degrees prior to the arrival of the piston at TDC during the exhaust stroke. This is necessary to insure that the valve will be fully open and fresh charge starts to flow into the cylinder as soon as the piston starts to move down.

If the inlet valve is allowed to close at BDC, the cylinder would receive less charge than its capacity and the pressure of the charge at the end of suction stroke will be below atmosphere. To avoid this, the inlet valve is kept open for 40° – 50° rotation of the crank after the suction stroke for high speed engine and 20° to 25° for low speed engine.

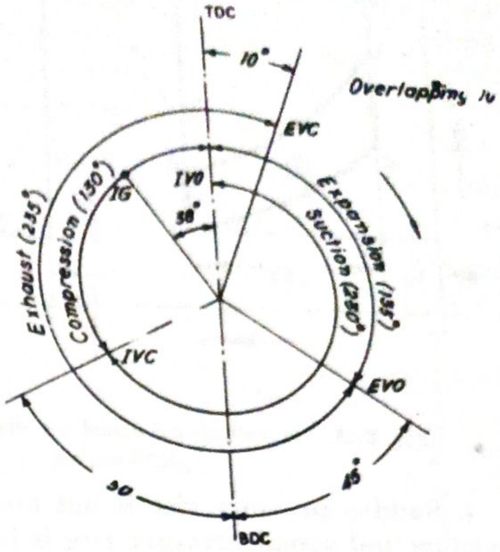


Fig. 22.6 (*b*) Actual valve timing diagram for high speed 4-stroke spark ignition engine.

The kinetic energy of the charge produces a ram effect which packs more charge into the cylinder during this additional valve opening. Therefore, the inlet valve closing is delayed.

Higher the speed of the engine, the inlet valve closing is delayed longer to take advantage of ram effect.

2. **Exhaust valve.** Complete clearing of the exhaust from the cylinder is necessary to take in more charge. Earlier opening of the exhaust valve before reaching to TDC facilitates the removal of the burnt gases by virtue of the pressure at this point. The kinetic energy of the fresh charge may also assist the removal of the burnt gases.

It is obvious from the valve timing diagram, that the inlet and exhaust valves overlap for 13 degrees of crank rotation. This overlap must not be excessive enough to allow the burned gases to be sucked into the intake manifold or the fresh charge to escape through the exhaust valve.

Overlapping of the closing of the exhaust and the opening of the intake valve makes possible the scavenging of the clearance space, resulting in an increased output.

3. **Ignition.** It would be proper to produce spark at the end of compression if the charge could burn instantaneously. However, there is always a time lag between the spark and ignition of the charge. The ignition starts some time after giving the spark, therefore it is necessary to produce the spark before piston reaches the TDC to obtain proper combustion without losses. The angle through which the spark is given earlier is known as "Ignition Advance" or "Angle of Advance".

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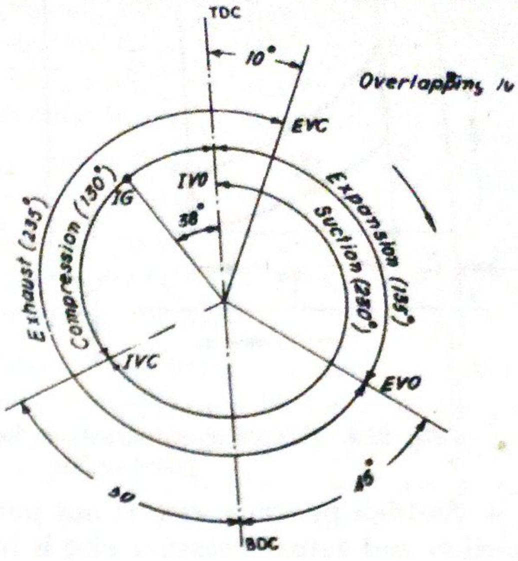

Fig. 22.6 (*b*) Actual valve timing diagram for high speed 4-stroke spark ignition engine.

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Higher the speed of the engine, the inlet valve closing is delayed longer to take advantage of ram effect.

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22.4.4. Working of 4-Stroke Cycle Diesel Engine

The working cycle of the engine is completed in four-strokes and diesel oil is used as fuel, therefore, it is known as four stroke diesel engine. The working of the engine is described as follows.

1. **Suction stroke.** The suction is similar to that in petrol engine except that only air is taken into the cylinder.

2. **Compression stroke.** Compression is also similar, but near the end of compression, pressure and temperature of the air is about 60 bar and 600°C respectively.

3. **Expansion stroke.** During this stroke, the inlet and exhaust valves are closed and fuel valve opens just before the beginning of the third stroke. The supply of fuel is continued during a small part of the expansion stroke. The temperature of the air at the end of compression stroke is sufficient to ignite the fuel. The combustion of fuel is continued at constant pressure as long as the fuel valve is open. The high pressure and high temperature gases push the piston down even after the fuel valve is closed.

The exhaust valve opens when the piston reaches BDC.

4. **Exhaust stroke.** During this stroke, the inlet and fuel valves remain closed and exhaust valve remains open. The piston moves up in the cylinder and pushes out the burned gases. The piston reaches the TDC completing the exhaust and is ready for the next cycle.

The working of the engine is shown in Fig. 22.7.

22.4.5. Theoretical and Actual p-v diagram of 4-Stroke Diesel Engine

The following assumptions are made during the 4-strokes of the cycle discussed above.

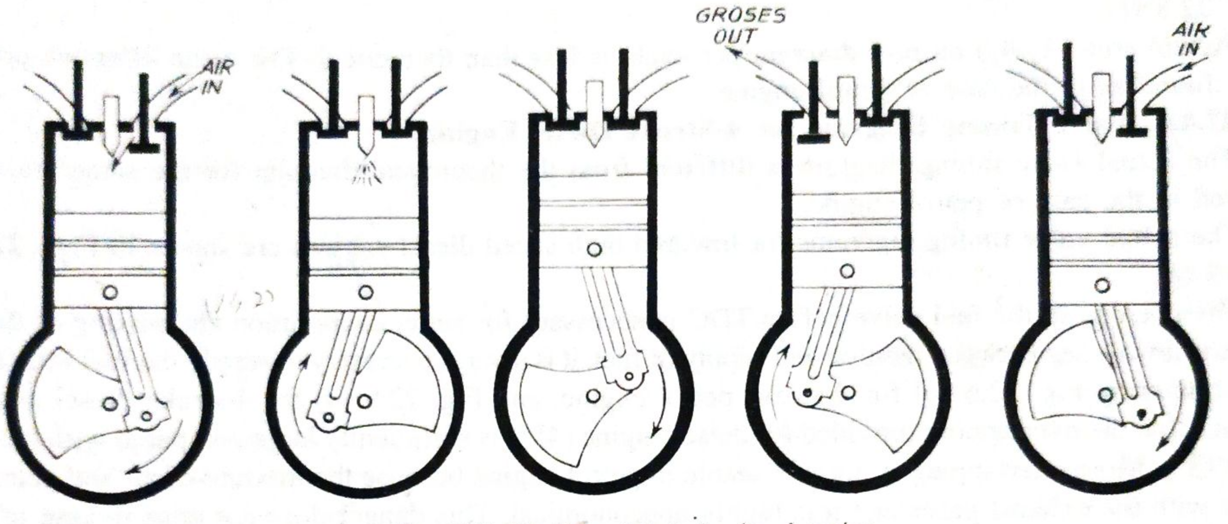

Fig. 22.7. Working of 4-stroke diesel engine.

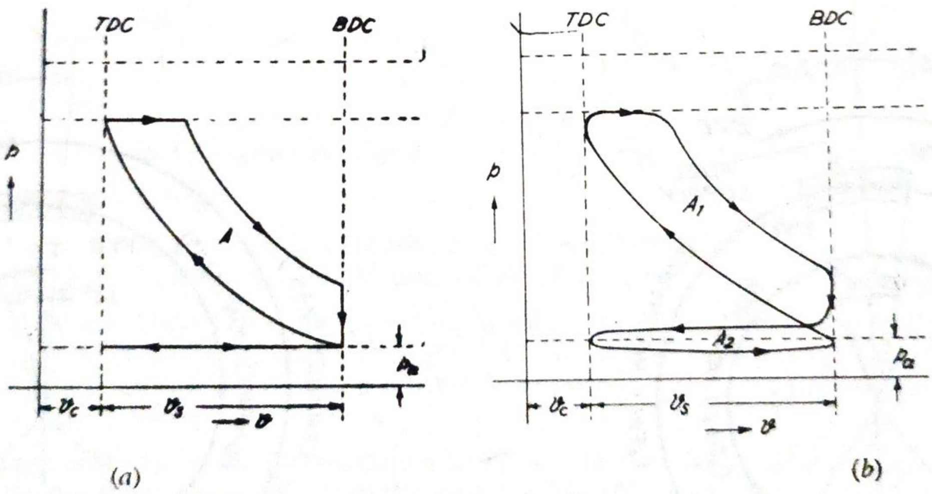

Fig. 22.8. Theoretical and actual *p-v* diagrams for 4-stroke diesel engine.

1. Suction and exhaust take place at atmospheric pressure.
2. Suction and exhaust take place during 180° of crank rotation.
3. Compression and expansion also take place during 180° rotation of crank.
4. Compression and expansion are isentropic.
5. The combustion takes place at constant pressure during a small part of expansion stroke.
6. Pressure suddenly falls to atmospheric pressure at the end of expansion stroke.

With the above assumptions, the working cycle can be represented on *p-v* diagram as shown in Fig. 22.8 (*a*) and it is similar to the theoretical Diesel cycle.

But in practice, the actual conditions differ from the ideal as described below.

1. The suction of the air inside the cylinder is possible only if the pressure inside the cylinder is below atmospheric.
2. Exhausting of gases is possible only if the pressure of the exhaust gases is above atmospheric pressure.

3. The compression and expansion do not follow the isentropic process, as there are heat and pressure losses.

4. The combustion at constant pressure is not possible as the fuel will not burn as it is introduced into the cylinder.

5. The sudden pressure release after the opening of expansion valve is not possible and it takes place through some crank rotation.

The operations of the cycle, taking the modifications into account are represented on $p-v$ diagram in Fig. 22.8 (*b*).

Actual area (A_1-A_2) on $p-v$ diagram per cycle is less than theoretical. The mean effective pressure can be found as in the case of petrol engine.