INTERNAL COMBUSTION ENGINES

3RD YEAR SEM-1 BTECH MECHANICAL ENGINEERING (R18A0313)

MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

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COURSE OBJECTIVES

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UNIT - 1	CO1: To recall air standard cycles and compare with actual cycles, classification and working principles of air standard and actual cycles.
UNIT - 2	CO2: Understand the process of combustion of IC engines and deal with practical challenges in combustion process.
UNIT - 3	CO3: Evaluate the performance parameters of IC engines by conducting the performance tests.
UNIT - 4	CO4: Understand the classification of air compressors of positive displacement and rotodynamic.
UNIT - 5	CO5: Evaluate and analyze the performance of centrifugal and axial flow compressors.

UNIT 1

Actual Cycles and their Analysis

CO1: To recall air standard cycles and compare with actual cycles, classification and working principles of air standard and actual cycles.

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UNIT – I (SYLLABUS)

ELEMENTS OF CUTTING PROCESS

Introduction, Comparison of Air Standard and Actual Cycles, Time Loss Factor, Heat Loss Factor, Exhaust Blow down-Loss due to Gas exchange process, Volumetric Efficiency. Loss due to Rubbing Friction, Actual and Fuel-Air Cycles of CI Engines.

UNIT – 1

NO OF LECTURE HOURS: 18

LECTURE	LECTURE TOPIC	KEY ELEMENTS	LEARNING OBJECTIVES (2 to 3 objectives)
1.	Introduction to IC engines	Heat engines, Energy conversion, Concept of automotive force	Understanding (2)
2.	Comparison of Air Standard and Actual Cycles	General comparison based on working	Understanding (2)
3.	Time Loss Factor, Heat Loss Factor	Heat Loss Factor	Analyzing (4)
4.	Exhaust Blow down-Loss due to Gas exchange process	Exhaust Blow down-Loss	Analyzing (4)
5.	Volumetric Efficiency. Loss due to Rubbing Friction	Volumetric Efficiency	Understanding (2)
6.	Actual and Fuel-Air Cycles of CI Engines	Actual and Fuel-Air Cycles	Understanding (2)
7.	IC engines classification	classification	Remembering (1)

COURSE OUTLINE

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Bloom's Taxonomy - Cognitive

1 Remember

Behavior: To recall, recognize, or identify concepts

2 Understand

Behavior: To comprehend meaning, explain data in own words

3 Apply

Behavior: Use or apply knowledge, in practice or real life situations

4 Analyze

Behavior: Interpret elements, structure relationships between individual components

5 Evaluate

Behavior: Assess effectiveness of whole concepts in relation to other variables

6 Create

Behavior: Display creative thinking, develop new concepts or approaches

LECTURE 1

AIR-STANDARD CYCLES AND THEIR ANALYSIS

INTRODUCTION

- The operating cycle of an internal combustion engine can be broken down into a sequence of separate processes viz., intake, compression, combustion, expansion and exhaust.
- The internal combustion engine does not operate on a thermodynamic cycle as it involves an open system i.e., the working fluid enters the system at one set of conditions and leaves at another.
- However, it is often possible to analyze the open cycle as though it were a closed one by imagining one or more processes that would bring the working fluid at the exit conditions back to the condition of the starting point.
- The accurate analysis of internal combustion engine processes is very complicated.

FUEL–AIR CYCLES AND THEIR ANALYSIS

- The analysis was based on highly simplifying assumptions. Because of this, the estimated engine performance by air-standard cycle analysis is on the higher side compared to the actual performance.
- For example, the actual indicated thermal efficiency of an SI engine, say with a compression ratio of 8:1, is of the order of 28% whereas the air-standard efficiency is 56.5%.
- This large deviation may to some extent be attributed to progressive burning of the fuel, incomplete combustion and valve operation etc.
- However, the main reasons for this may be attributed to the over simplified assumptions made in the analysis.

FACTORS AFFECTING THE FUEL-AIR CYCLE

The following factors affect the analysis of the fuel-air cycle:

1 Composition of Cylinder Gases

In an actual operation of an engine, the air/fuel ratio may vary for different operating conditions. This affects the composition of the cylinder gases before and after combustion. Before combustion the cylinder gases are a mixture of air, fuel and residual gases in the clearance space from the previous cycle. The products of combustion may be CO_2, CO, H_2O, O_2, and N_2. The amount of exhaust gases in the clearance volume varies with the speed and the load on the engine. In order to avoid laborious and time-consuming calculations by hand, the fuel-air cycles are analysed with the help of combustion charts. Separate charts are used for unburned and burned mixtures for each fuel/air ratio of interest. However, with the availability of fast digital computers, it is now possible to analyse the fuel-air cycle by means of suitable numerical techniques, which may produce fast and accurate results.

.2 Variation of Specific Heats

All gases, except monatomic gases, show an increase in specific heats with increase in temperature. The specific heat is the amount of heat required to raise the temperature of a unit mass by one degree. As the temperature is raised, larger fractions of the input heat go to produce motion of the atoms within the molecules. Since temperature is the result of motion of the molecules, the energy which goes into moving the atoms does not contribute to the temperature rise, so the final temperature and pressure are lowered. Since at high temperatures, a given amount of heat results in a smaller increase in temperature, therefore the specific heats increase with temperature.

The variation of specific heats with temperature does not follow any specific law. Figure 4.1 shows the variation of specific heat at constant pressure c_p versus temperature for a few ideal gases. Specific heat at constant volume c_v can be obtained from the relation $c_v = c_p - R$, where R is the gas constant.

Variation of Specific Heats

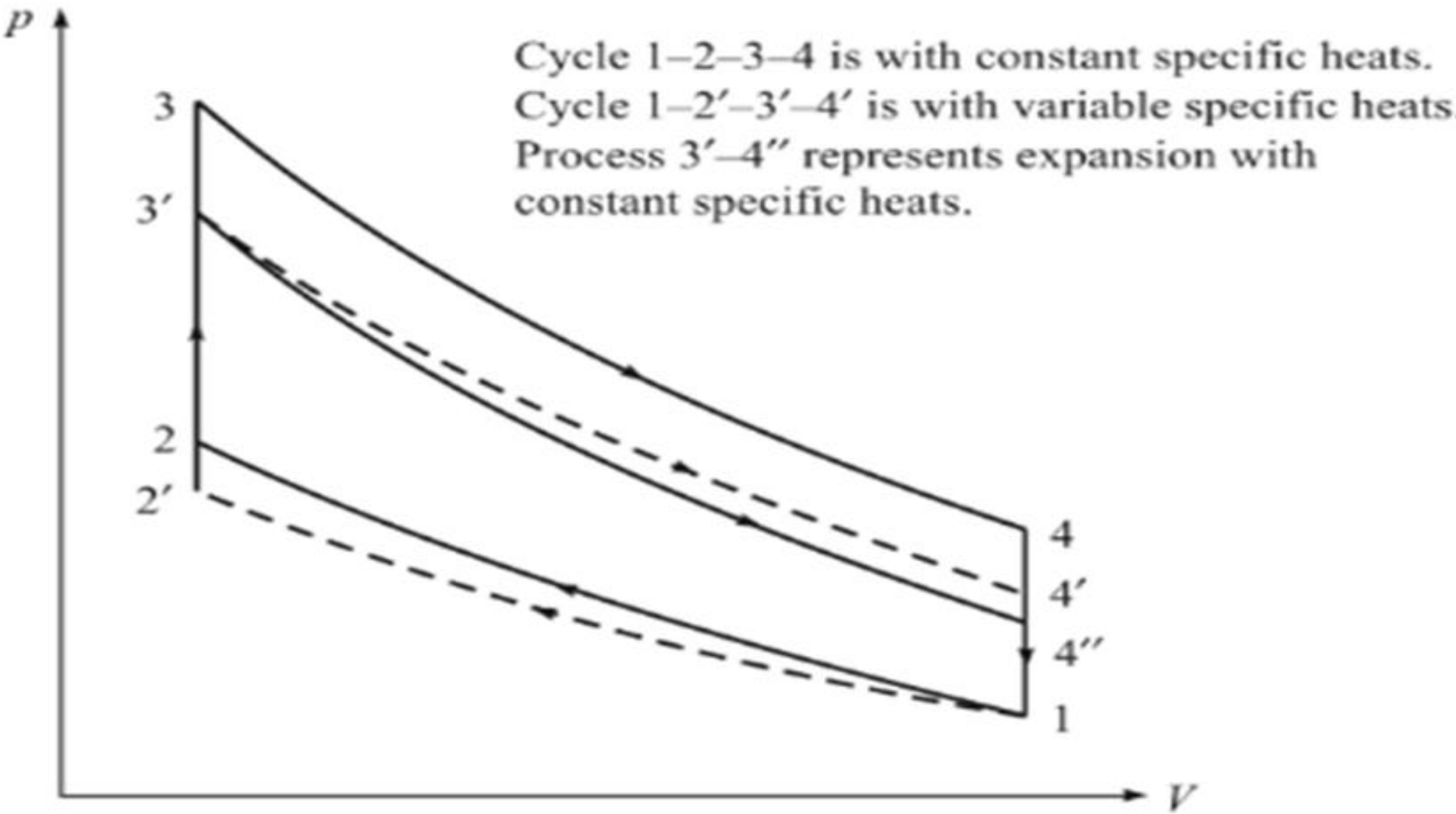


Figure 4.1 Effect of variation of specific heats on Otto cycle.

Source – ICE by GANESHAN

3 Effect of Dissociation

Dissociation is a process of disintegration of combustion products at high temperatures. If a mixture of a hydrocarbon fuel and excess air is ignited and the temperature does not exceed 1600 K under certain conditions, the reaction will be completed and the products of combustion will contain CO_2, H_2O, O_2, and N_2. However, in IC engines the temperatures of the products are very high. Even though excess air is present, incomplete combustion of fuel results because of dissociation, which may result in the formation of H_2O, H_2, OH, H, N_2, NO, N, CO_2, CO, O_2, O, A (argon), hydrocarbons, etc. In other words, an equilibrium is established between the uncombined fuel, air, and the combustion products. The incomplete combustion of fuel and air at high temperatures results in lower values of temperature and pressure after the combustion process than would otherwise be expected, since during combustion heat is liberated and whereas during dissociation heat is absorbed.

The dissociation of CO_2 into CO and O_2 starts commencing around 1000 °C and the reaction equation can be written as

$$CO_2 \rightleftharpoons 2CO + O_2$$

Similarly, the dissociation of H_2O occurs at temperatures above 1300 °C and is written as

$$H_2O \rightleftharpoons 2H_2 + O_2$$

4 EFFECT OF NUMBER OF MOLES

As already mentioned the number of molecules present in the cylinder after combustion depends upon the fuel-air ratio, type and extend of reaction in the cylinder. According to the gas law

$$pV = N\bar{R}T$$

the pressure depends on the number of molecules or moles present. This has direct effect on the amount of work the cylinder gases can impart on the piston.

Comparison of Air-Standard & Fuel-Air cycles

- Working fluid considered as air in air standard cycle but in actual there is always mixture of air and fuel.
- Because of air is considered as constant there is heat capacity value like Cp & Cv are standard for air but it changes in actual cycle.
- Also Cp & Cv change with temperature in actual but taken as constant in air standard cycle.
- In air standard cycle we assume cylinder as insulated but in actual there is a heat transfer.
- There is loss of work because of friction and because of leakage in actual but in air standard it's neglected.

ACTUAL CYCLES

- The actual cycles for IC engines differ from the fuel-air cycles and air-standard cycles in many respects. The actual cycle efficiency is much lower than the air-standard efficiency due to various losses occurring in the actual engine operation.
- The major losses are due to:
- Variation of specific heats with temperature
- Dissociation of the combustion products
- Progressive combustion
- Incomplete combustion of fuel
- Heat transfer into the walls of the combustion chamber

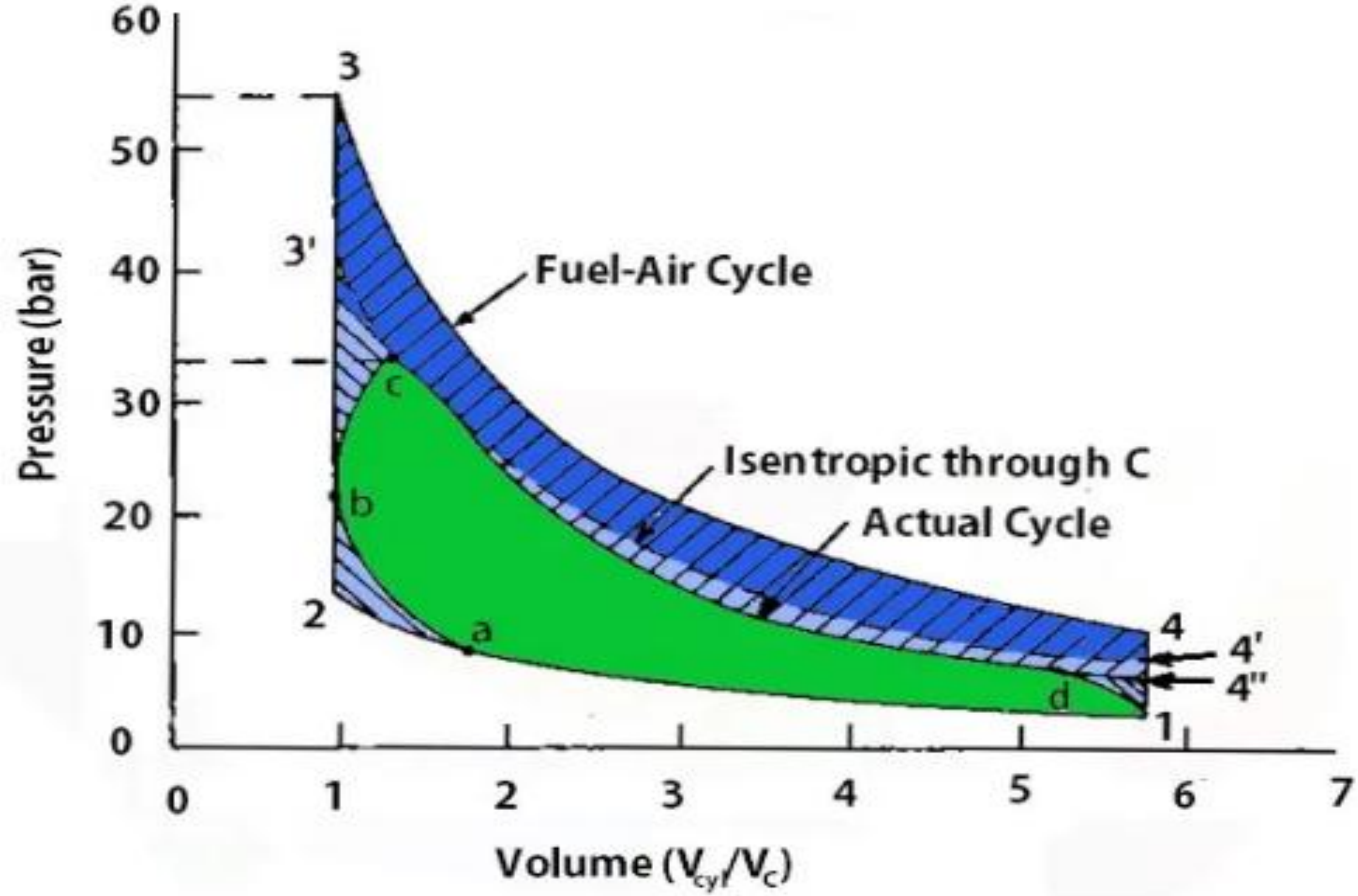
COMPARISON OF AIR-STANDARD AND ACTUAL CYCLES

- The actual cycles for internal combustion engines differ from air-standard cycles in many respects. These differences are mainly due to:
- The working substance being a mixture of air and fuel vapour or finely atomized liquid fuel in air combined with the products of combustion left from the previous cycle.
- The change in chemical composition of the working substance.
- The variation of specific heats with temperature.
- The change in the composition, temperature and actual amount of fresh charge because of the residual gases.
- The progressive combustion rather than the instantaneous combustion

Time Loss Factor

- In Air-standard cycles, the combustion (Heat addition) assumed to be instantaneous,
- But in actual cycles, it will take a definite period of time. Approximately the crankshaft will turn about 30° to 40° of rotation during the overall combustion process (Spark creation to till complete combustion).
- This is the time loss due to progressive combustion.
- Following is the P-V diagram for the Internal Combustion engine.
- Represented with the fuel-air cycle and the Actual cycle

Time Loss Factor



Time losses representation with P-V diagram

Cycle Performance at Various Ignition Timing

Cycle	Ignition advance	Max. cycle pressure bar	*mep* bar	efficiency %	$\frac{\text{Actual } \eta}{\text{Fuel cycle } \eta}$
Fuel-air cycle	0°	44	10.20	32.2	1.00
Actual cycle	0°	23	7.50	24.1	0.75
"	17°	34	8.35	26.3	0.81
"	35°	41	7.60	23.9	0.74

HEAT LOSS FACTOR

- Heat loss during combustion will naturally have the maximum effect on the cycle efficiency while heat loss just before the end of the expansion stroke can have very little effect because of its contribution to the useful work is very little.
- The heat lost during the combustion does not represent a complete loss because, even under ideal conditions assumed for air-standard cycle, only a part of this heat could be converted into work (equal to $Q \times \eta_{th}$) and the rest would be rejected during the exhaust stroke.
- During the combustion process and the subsequent expansion stroke the heat flows from the cylinder gases through the cylinder walls and cylinder head into the water jacket or cooling fins.

EXHAUST BLOWDOWN

- The cylinder pressure at the end of exhaust stroke is about 7 bar depending on the compression ratio employed.
- If the exhaust valve is opened at the bottom dead centre, the piston has to do work against high cylinder pressures during the early part of the exhaust stroke.
- If the exhaust valve is opened too early, a part of the expansion stroke is lost.
- The best compromise is to open the exhaust valve 40◦ to 70◦ before BDC thereby reducing the cylinder pressure to halfway (say 3.5 bar) before the exhaust stroke begins.

EXHAUST BLOWDOWN (Source – ICE by Ganeshan)

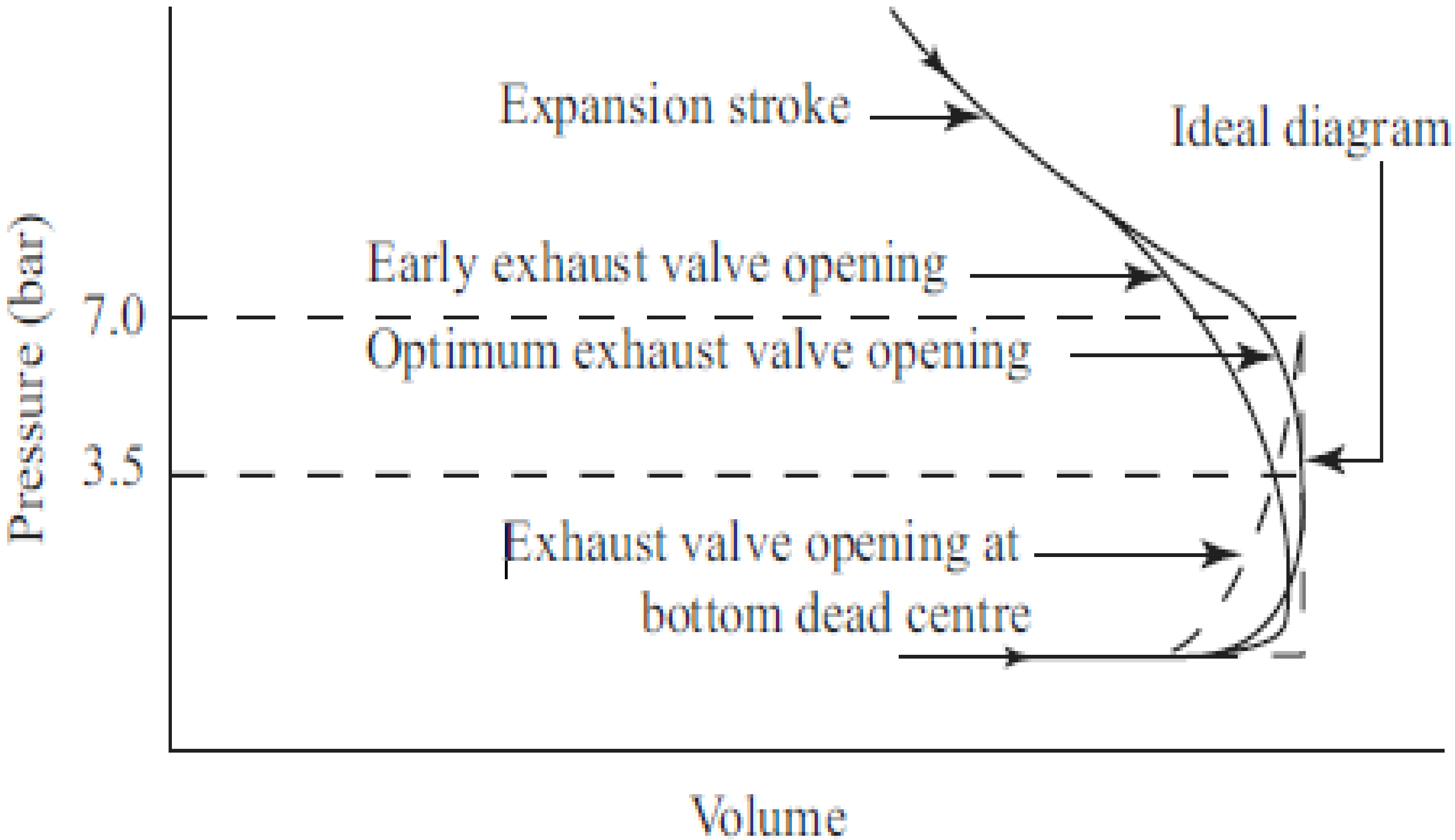


Fig. 4.9 Effect of exhaust valve opening time on blowdown

Loss due to gas exchange process:

- The difference of work done in expelling the exhaust gases and the work done by the fresh charge during the suction stroke is called as Pumping work.
- In other words loss due to the gas exchange process is due to pumping gas from lower inlet pressure Pi to higher exhaust pressure Pe.
- The pumping loss increase by increasing the throttling process because of the throttling process reduces the inlet pressure in suction.
- Pumping loss also increases with speed. The gas exchange process largely effects volumetric efficiency of the engine.

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LECTURE 2

INTERNAL COMBUSTION ENGINES

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INTRODUCTION

- **CLASSIFICATION OF INTERNAL COMBUSTION ENGINES**

- According to the *type of fuel* used
  - Petrol engines, b) Diesel engines, and c) Gas engines.
- According to the *method of igniting* the fuel
  - Spark ignition engines, and b) Compression ignition engines.
- According to the *number of strokes* per cycle
  - Four stroke cycle engines, and b) Two stroke cycle engines.
- According to the *cycle of operation*
  - Otto cycle engines, b) Diesel cycle engines, and c) Dual cycle engines.
- According to the *speed of the engine*
- a) Slow speed engines, b) Medium speed engines, and c) High speed engines.
- According to the *cooling system*
- a) Air-cooled engines, and b) Water-cooled engines.

Constructional details of I.C. Engines

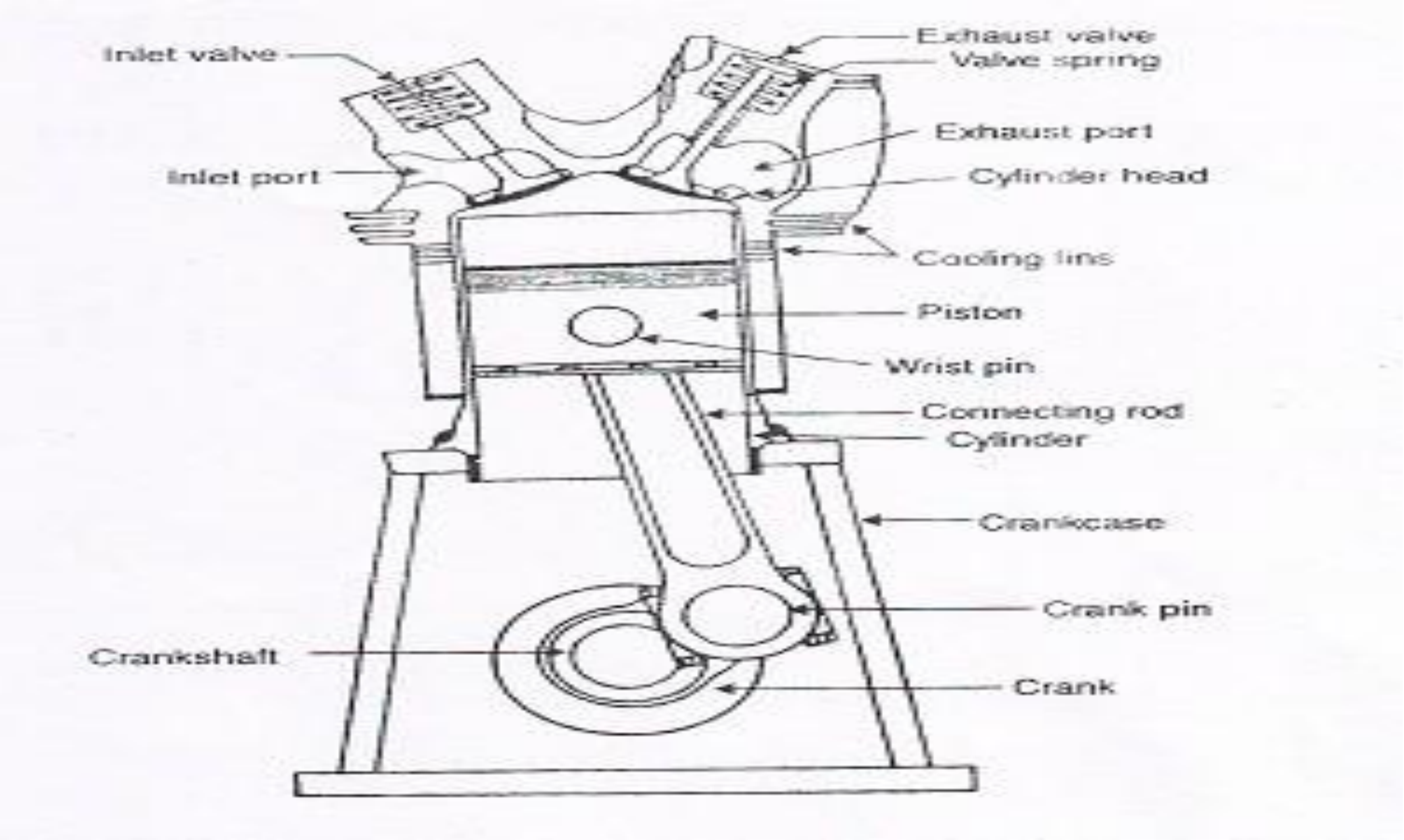


Fig 1.2   Source – ICE by GANESHAN

Basic components and terminology of IC engines

- − Even though reciprocating internal combustion engines look quite simple, they are highly complex machines. There are many components which have to perform their functions effectively to produce output power.
- − There are two types of engines, viz., spark-ignition (SI) and compression-ignition (CI) engine.
- **Engine Components**
- − A cross section of a single cylinder spark-ignition engine with overhead valves is shown in Fig.1.2. The major components of the engine and their functions are briefly described below.

Basic components and terminology of IC engines

- **a) Cylinder block**
- − The cylinder block is the main supporting structure for the various components. The cylinder of a multi cylinder engine are cast as a single unit, called cylinder block. The cylinder head is mounted on the cylinder block. The cylinder head and cylinder block are provided with water jackets in the case of water cooling or with cooling fins in the case of air cooling.
- **b) Cylinder**
- − As the name implies it is a cylindrical vessel or space in which the piston makes a reciprocating motion. The varying volume created in the cylinder during the operation of the engine is filled with the working fluid and subjected to different thermodynamic processes. The cylinder is supported in the cylinder block.

Basic components and terminology of IC engines

- **c) Piston**
- − It is a cylindrical component fitted into the cylinder forming the moving boundary of the combustion system. It fits perfectly (snugly) into the cylinder providing a gas-tight space with the piston rings and the lubricant. It forms the first link in transmitting the gas forces to the output shaft.
- **d) Combustion chamber**
- − The space enclosed in the upper part of the cylinder, by the cylinder head and the piston top during the combustion process, is called the combustion chamber. The combustion of fuel and the consequent release of thermal energy results in the building up of pressure in this part of the cylinder.

Basic components and terminology of IC engines

- **e) Inlet manifold**
- − The pipe which connects the intake system to the inlet valve of the engine and through which air or air-fuel mixture is drawn into the cylinder is called the inlet manifold.
- **f) Exhaust manifold**
- − The pipe which connects the exhaust system to the exhaust valve of the engine and through which the products of combustion escape into the atmosphere is called the exhaust manifold.

Terminologies used in IC engine

- − **Cylinder Bore (d):** The nominal inner diameter of the working cylinder is called the cylinder bore and is designated by the letter d and is usually expressed in millimeter (mm).
- − **Piston Area (A):** The area of a circle of diameter equal to the cylinder bore is called the piston area and is designated by the letter A and is usually expressed in square centimeter (cm2).
- − **Stroke (L):** It is the linear distance traveled by the piston when it moves from one end of the cylinder to the other end. It is equal to twice the radius of the crank. It is designated by the letter L and is expressed usually in millimeter (mm).

Terminologies used in IC engine

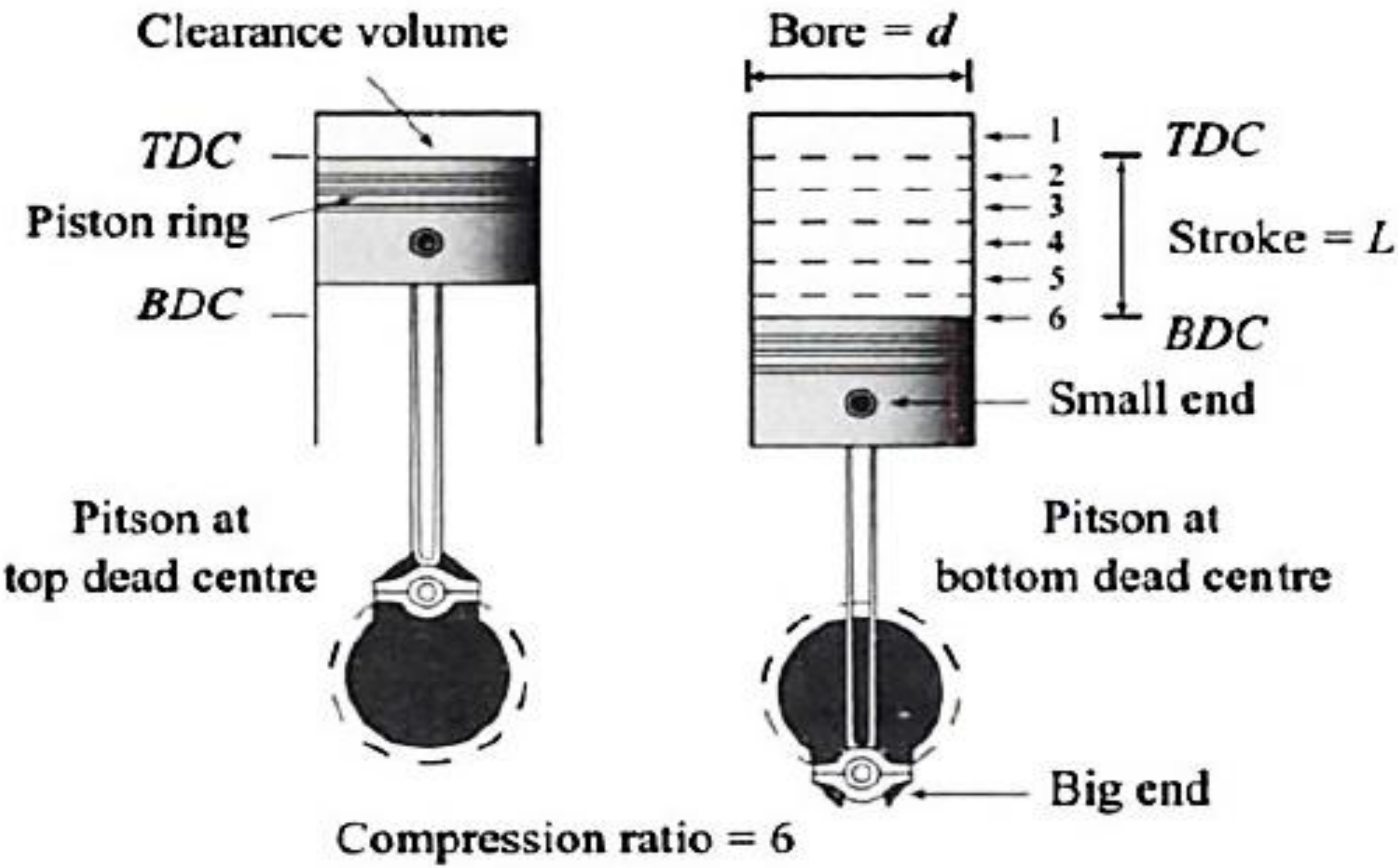


Fig 1.3 IC Engine nomenclature

Terminologies used in IC engine

- **Stroke to Bore Ratio (L/d):** L / d ratio is an important parameter in classifying the size of the engine.
- − If $d < L$, it is called under-square engine.
- − If $d = L$, it is called square engine.
- − If $d > L$, it is called over-square engine.
- An over-square engine can operate at higher speeds because of larger bore and shorter stroke.
- − **Dead Centre:**
- In the vertical engines, top most position of the piston is called Top Dead Centre (TDC). When the piston is at bottom most position, it is called Bottom Dead Centre (BDC).
- In horizontal engine, the extreme position of the piston near to cylinder head is called Inner Dead Centre (IDC.) and the extreme position of the piston near the crank is called Outer Dead Centre (O.D.C.).

Working Principle of Four Stroke Spark-Ignition Engine

- − In a four-stroke engine, the cycle of operations is completed in four strokes of the piston or two revolutions of the crankshaft.
- − During the four strokes, there are five events to be completed, viz., suction, compression, combustion, expansion and exhaust. Each stroke consists of 180° of crankshaft rotation and hence a four-stroke cycle is completed through 720° of crank rotation.
- − The cycle of operation for an ideal four-stroke SI engine consists of the following four strokes: (i) suction or intake stroke; (ii) compression stroke; (iii) expansion or power stroke and (iv) exhaust stroke.
- The details of various processes of a four-stroke spark-ignition engine with overhead valves are shown in Fig. 1.4 (a-d). When the engine completes all the five events under ideal cycle mode, the pressure-volume (p-V) diagram.

Working Principle of Four Stroke Spark-Ignition Engine

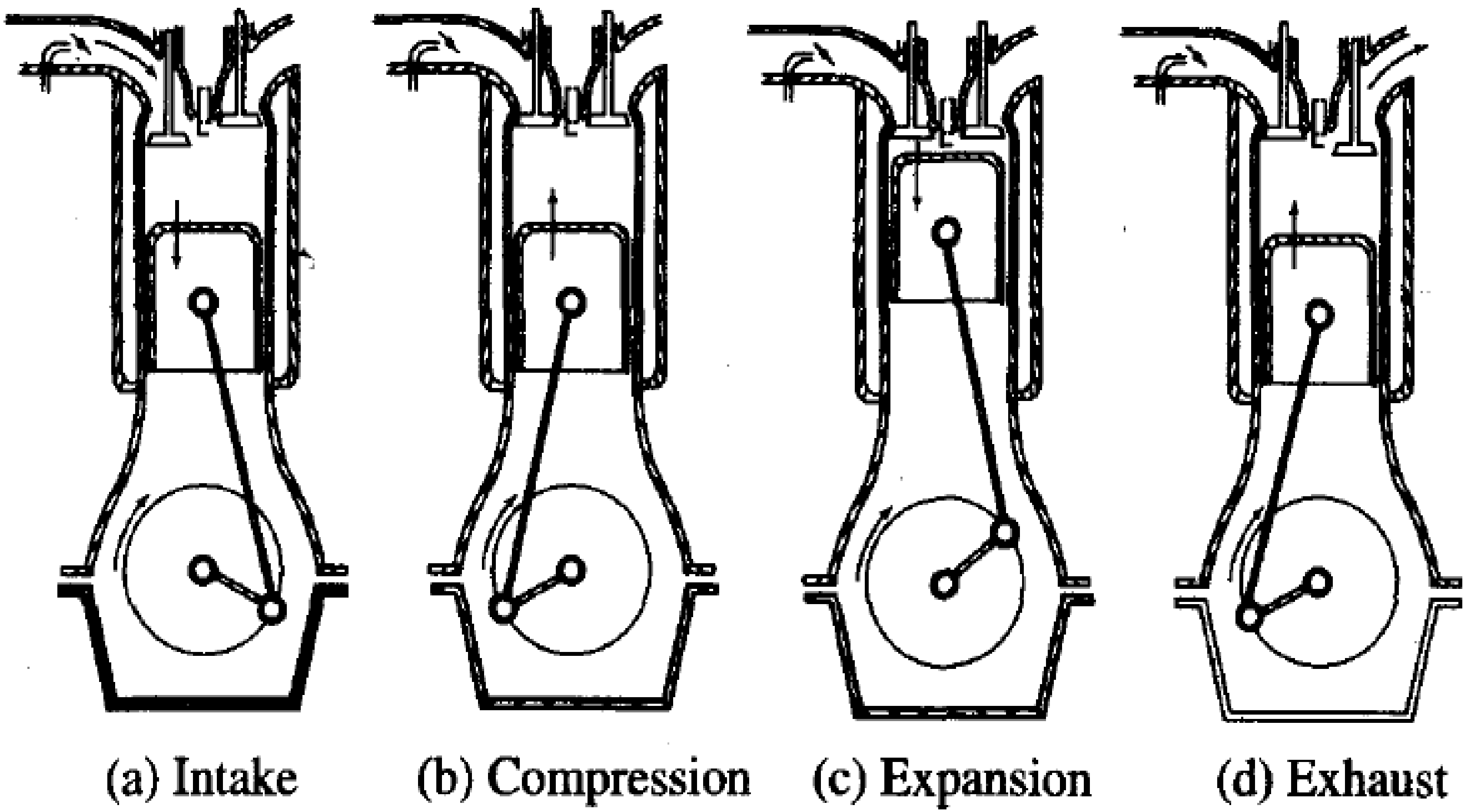


Fig. 1.4 Working principle of a four-stroke SI engine

Working Principle of Four Stroke Spark-Ignition Engine

- **a) Suction or Intake Stroke:** Suction stroke 0→1 starts when the piston is at the
- top dead centre and about to move downwards. The inlet valve is assumed to open instantaneously and at this time the exhaust valve is in the closed position, Fig.1.4
- − Due to the suction created by the motion of the piston towards the bottom dead centre, the charge consisting of fuel-air mixture is drawn into the cylinder. When the piston reaches the bottom dead centre the suction stroke ends and the inlet valve closes instantaneously.

Working Principle of Four Stroke Spark-Ignition Engine

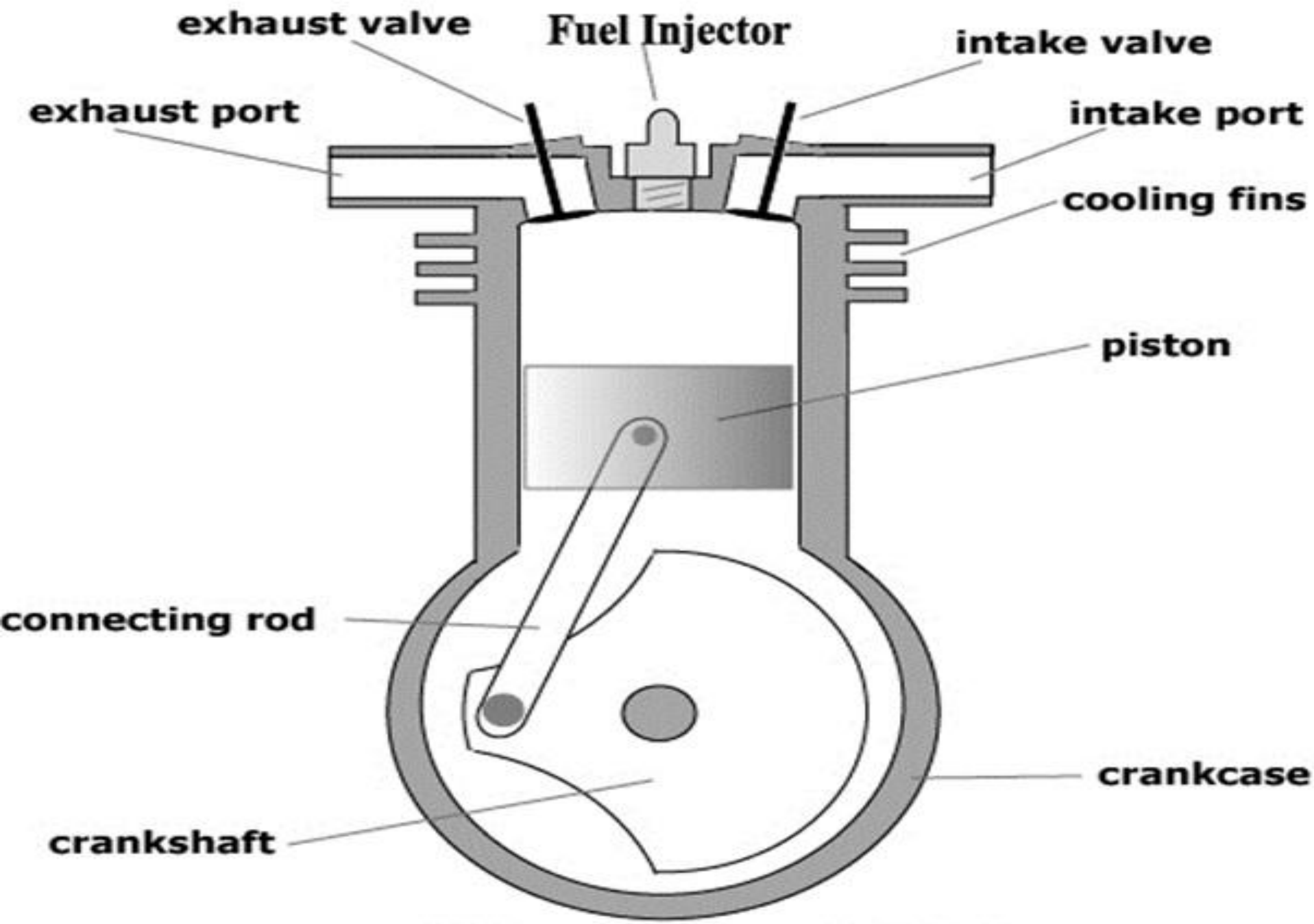
- **b) Compression Stroke:** The charge taken into the cylinder during the suction stroke is compressed by the return stroke of the piston 1→2, (Fig.1.4). During this stroke both inlet and exhaust valves are in closed position,
- − The mixture which fills the entire cylinder volume is now compressed into the clearance volume. At the end of the compression stroke the mixture is ignited with the help of a spark plug located on the cylinder head.
- **c) Expansion or Power Stroke:** The high pressure of the burnt gases forces the piston towards the BDC, (stroke 3→4)
- Both the valves are in closed position, Of the four-strokes only during this stroke power is produced. Both pressure and temperature decrease during expansion.

Working Principle of Four Stroke Spark-Ignition Engine

- **d) Exhaust Stroke:** At the end of the expansion stroke the exhaust valve opens instantaneously and the inlet valve remains closed, Fig. 1.4. The pressure falls to atmospheric level a part of the burnt gases escape. The piston starts moving from the bottom dead centre to top dead centre (stroke $5 \rightarrow 0$), and sweeps the burnt gases out from the cylinder almost at atmospheric pressure. The exhaust valve closes when the piston reaches TDC.
- − Thus for one complete cycle there is only one power stroke while the crankshaft makes two revolutions. For getting higher output from the engine the heat addition (process $2 \rightarrow 3$) should be as high as possible and the heat rejection (process $3 \rightarrow 4$) should be as small as possible. Hence, one should be careful in drawing the ideal p - V diagram which should represent the processes correctly

Working Principle of Four Stroke Compression-Ignition Engine

- The four-stroke CI engine is similar to the four-stroke SI engine but it operates at a much higher compression ratio. The compression ratio of an SI engine is between 6 and 10 while for a CI engine it is from 16 to 20.
- − In the CI engine during suction stroke, air, instead of a fuel-air mixture, is inducted. Due to higher compression ratios employed, the temperature at the end of the compression stroke is sufficiently high to self-ignite the fuel which is injected into the combustion chamber.
- − In CI engines, a high pressure fuel pump and an injector are provided to inject the fuel into the combustion chamber. The carburetor and ignition system necessary in the SI engine are not required in the CI engine.



4 STROKE DIESEL ENGINE

https://autoelectronicsembedded.blogspot.com/2016/09/diesel-engine.html

Working Principle of Four Stroke Compression-Ignition Engine

- **a) Suction Stroke:** In the suction stroke piston moves from TDC to BDC. Air alone is inducted during the suction stroke. During this stroke inlet valve is open and exhaust valve is closed.
- **b) Compression Stroke:** In this stroke piston moves from BDC to TDC. Air inducted during the suction stroke is compressed into the clearance volume. Both valves remain closed during this stroke.
- **c) Expansion Stroke:** Fuel injection starts nearly at the end of the compression stroke. The rate of injection is such that combustion maintains the pressure constant in spite of the piston movement on its expansion stroke increasing the volume. Heat is assumed to have been added at constant pressure.

Working Principle of Four Stroke Compression-Ignition Engine

- **d) Exhaust Stroke:** The piston travelling from BDC to TDC pushes out the products of combustion. The exhaust valve is open and the intake valve is closed during this stroke.
- − Due to higher pressures in the cycle of operations the CI engine has to be sturdier than a SI engine for the same output. This results in a CI engine being heavier than the SI engine. However, it has a higher thermal efficiency on account of the high compression ratio (of about 18 as against about 8 in SI engines) used.

Comparison of SI and CI Engines

- The detailed comparison of SI and CI engine is given in table 1.2

Table 1.2 Comparison of SI and CI Engines

Description	SI Engine	CI Engine
Basic cycle	Works on Otto cycle or constant volume heat addition cycle.	Works on Diesel cycle or constant pressure heat addition cycle.
Fuel	Gasoline, a highly volatile fuel. Self-ignition temperature is high.	Diesel oil, a non-volatile fuel. Self-ignition temperature is comparatively low
Introduction of fuel	A gaseous mixture of fuel-air is introduced during the suction stroke. A carburetor and an ignition system are necessary. Modern engines have gasoline injection.	Fuel is injected directly into the combustion chamber at high pressure at the end of the compression stroke. A fuel pump and injector are necessary.
Load control	Throttle controls the quantity of fuel-air mixture to control the load.	The quantity of fuel is regulated to control the load. Air quantity is not controlled.

Two-Stroke Engine

- **Two-Stroke Engine**
- − In two-stroke engines the cycle is completed in one revolution of the crankshaft. The main difference between two-stroke and four-stroke engines is in the method of filling the fresh charge and removing the burnt gases from the cylinder.
- − In the four-stroke engine these operations are performed by the engine piston during the suction and exhaust strokes respectively.
- − In a two- stroke engine, the filling process is accomplished by the charge compressed in crankcase or by a blower. The induction of the compressed charge moves out the product of combustion through exhaust ports. Therefore, no separate piston strokes are required for these two operations.

Two-Stroke Engine

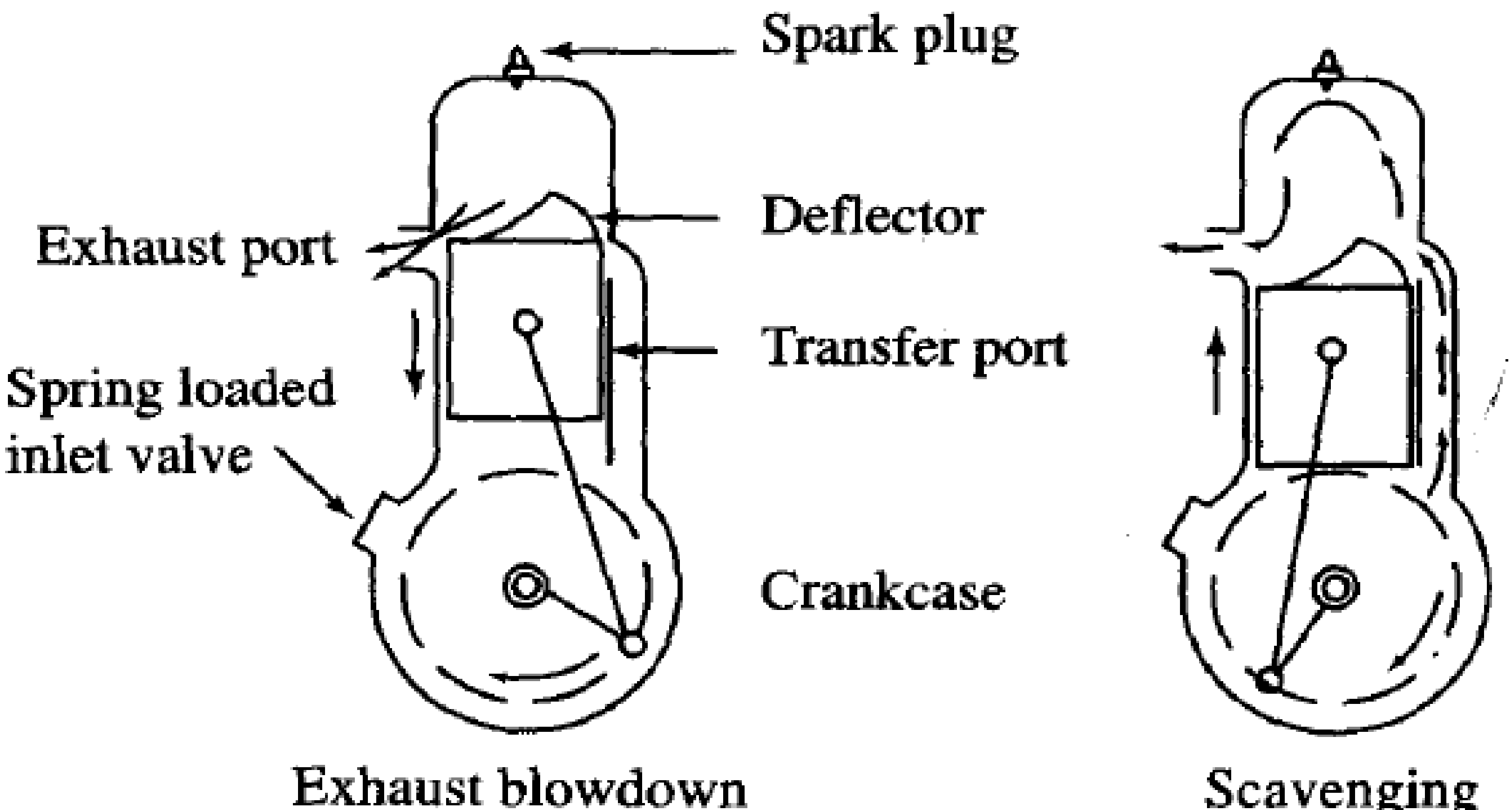


Fig. 1.8 Crankcase scavenged two-stroke SI engine

Two-Stroke Engine

- Two strokes are sufficient to complete the cycle, one for compressing the fresh charge and the other for expansion or power stroke. It is to be noted that the effective stroke is reduced.
- − Figure 1.8 shows one of the simplest two-stroke engines, viz., the crankcase scavenged engine.
- − The air-fuel charge is inducted into the crankcase through the spring loaded inlet valve when the pressure in the crankcase is reduced due to upward motion of the piston during compression stroke. After the compression and ignition, expansion takes place in the usual way.

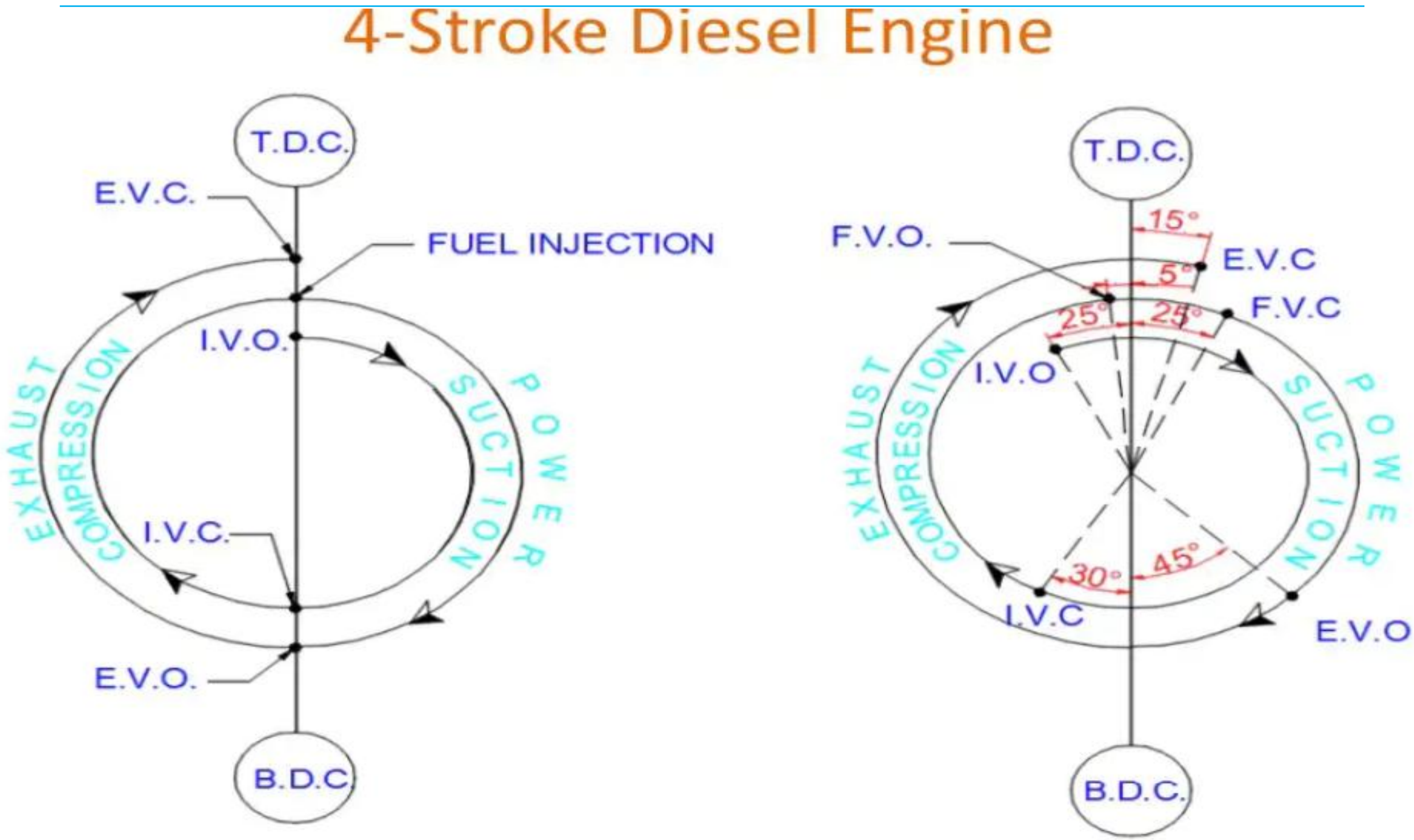
Two-Stroke Engine

- − During the expansion stroke the charge in the crankcase is compressed. Near the end of the expansion stroke, the piston uncovers the exhaust ports and the cylinder pressure drops to atmospheric pressure as the combustion products leave the cylinder.
- The piston top usually has a projection to deflect the fresh charge towards the top of the cylinder preventing the flow through the exhaust ports. This serves the double purpose of scavenging the combustion products from the upper part of the cylinder and preventing the fresh charge from flowing out directly through the exhaust ports.

Table 1.3 Application of Engines

IC Engine		EC Engine	
Type	Application	Type	Application
Gasoline engines	Automotive, Marine, Aircraft	Steam Engines	Locomotives, Marine
Gas engines	Industrial power	Stirling Engines	Experimental Space Vehicles
Diesel engines	Automotive, Railways, Power, Marine	Steam Turbines	Power, Large Marine
Gas turbines	Power, Aircraft, Industrial, Marine	Close Cycle Gas Turbine	Power, Marine

Theoretical and Actual Valve Timing Diagrams



Actual Valve Timing For 4-Stroke Diesel Engine

I.V.O. → 25° Before T.D.C.

I.V.C. → 30° After B.D.C.

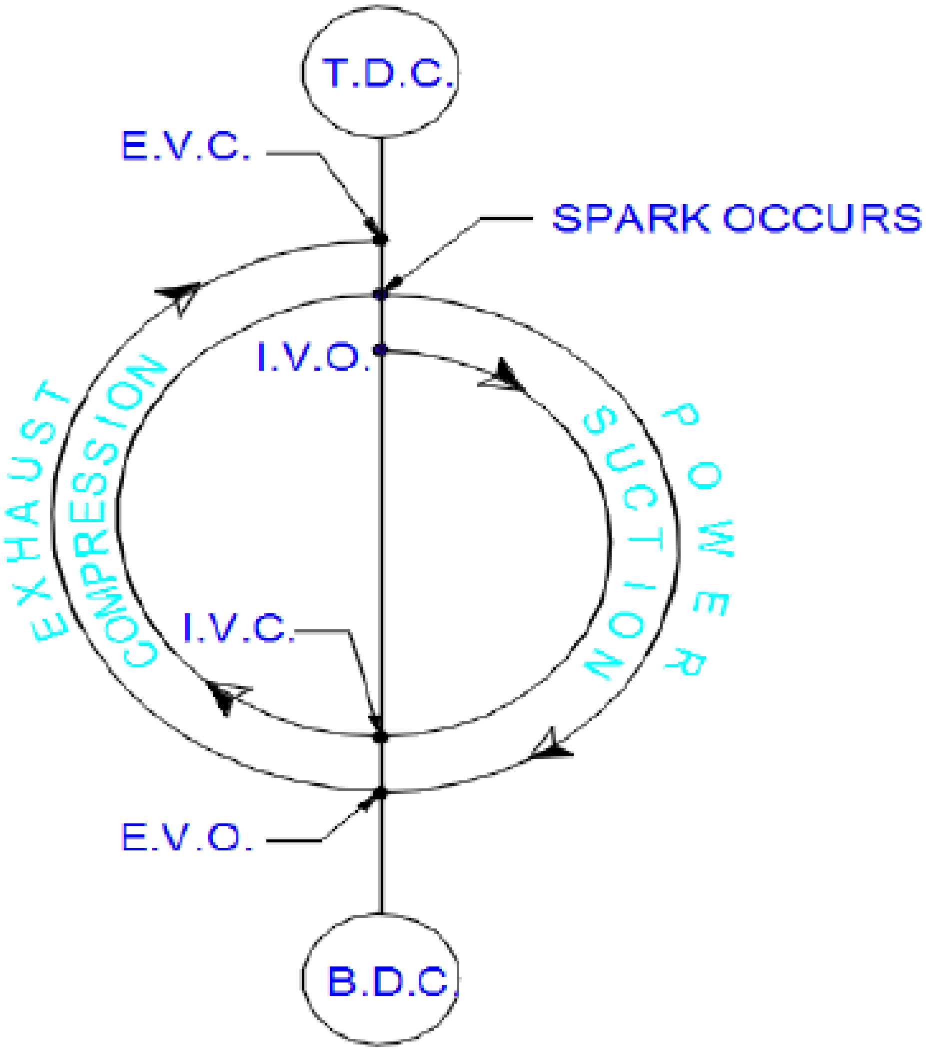
F.V.O. → 5° Before T.D.C.

F.V.C. → 25° After T.D.C.

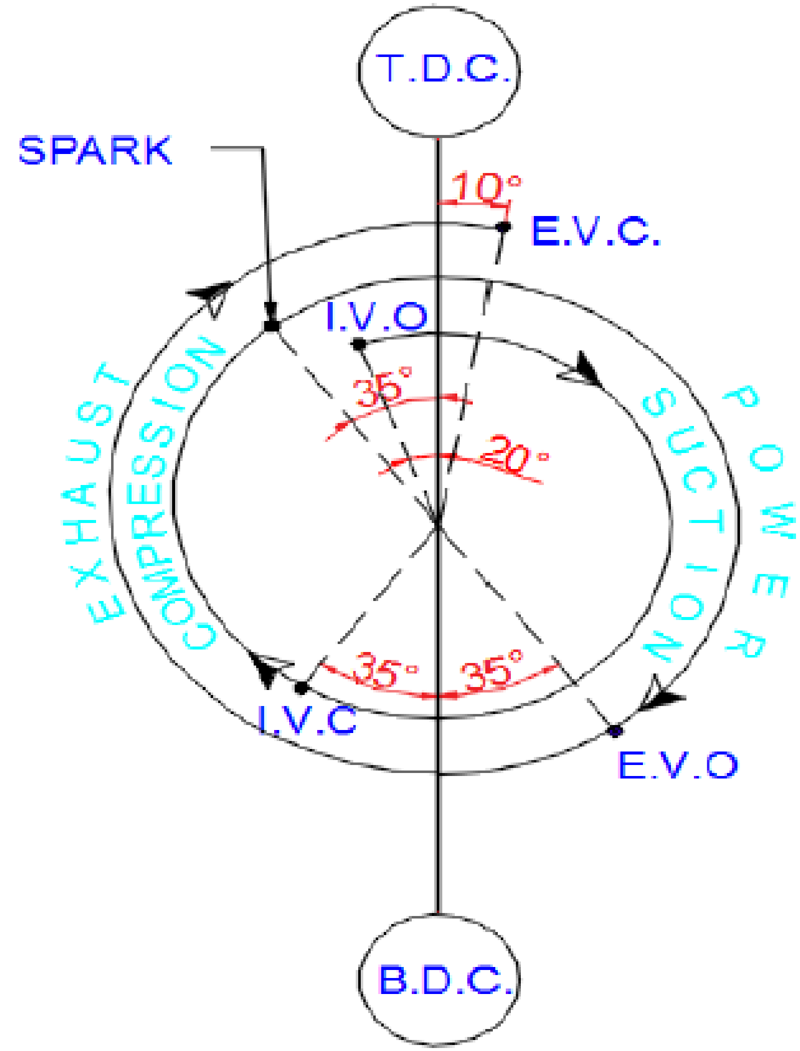
E.V.O. → 45° Before B.D.C.

E.V.C. → 15° After T.D.C.

Theoretical & Actual Valve Timing Diagram For 4-Stroke Petrol Engine



Theoretical Valve Timing Diagram



Actual Valve Timing Diagram

Actual Valve Timing For 4-Stroke Petrol Engine

I.V.O. → 20° Before T.D.C.

I.V.C. → 35° After B.D.C.

F.V.O. → 35° Before T.D.C.

E.V.O. → 35° Before B.D.C.

E.V.C. → 10° After T.D.C.

Valve Overlap → 30°

2-Stroke Petrol & Diesel Engine

- There is mainly two stroke in 2-stroke engine:
- 1. Expansion Stroke
- 2. Compression Stroke
- **First stroke**
- At the beginning of the first stroke piston is at the TDC as shown in fig. A. Piston moves from TDC to BDC.
- The electric spark ignites the compressed charge in petrol engine & Diesel spray in diesel engine when compression stroke is about complete . The combustion of the charge will release the hot gases which increase the temperature and pressure in cylinder. The high pressure combustion engine to force piston downward

First stroke

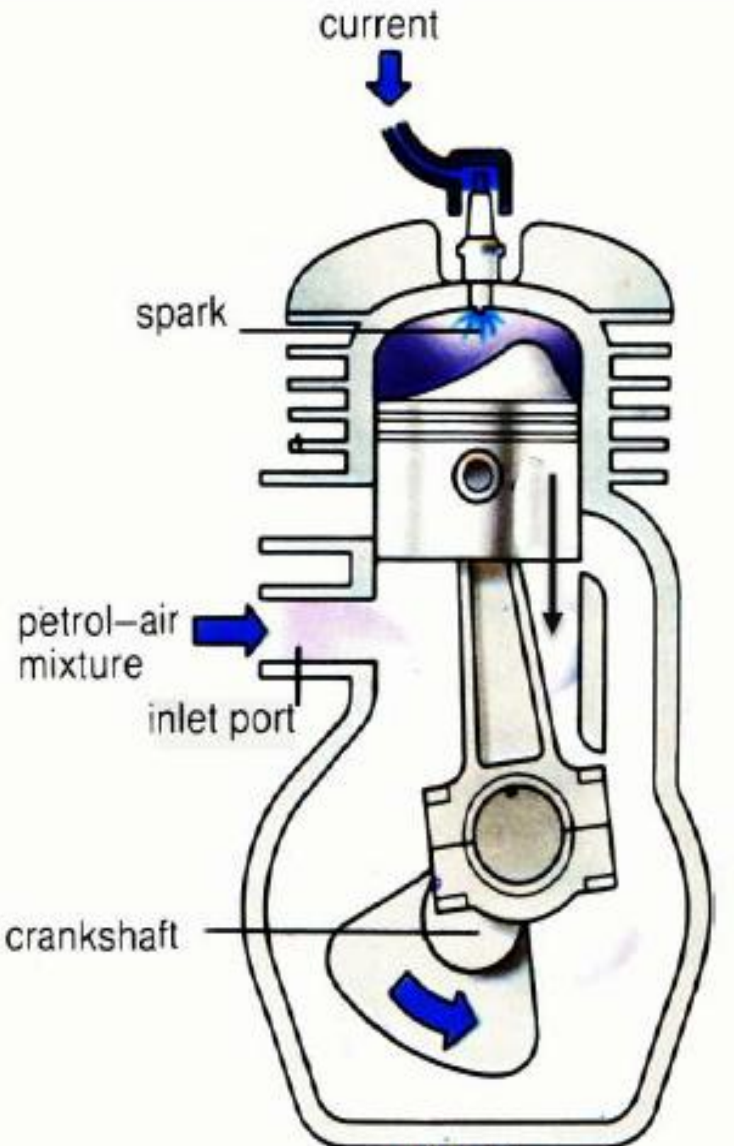


Fig. A

Beginning of the first stroke

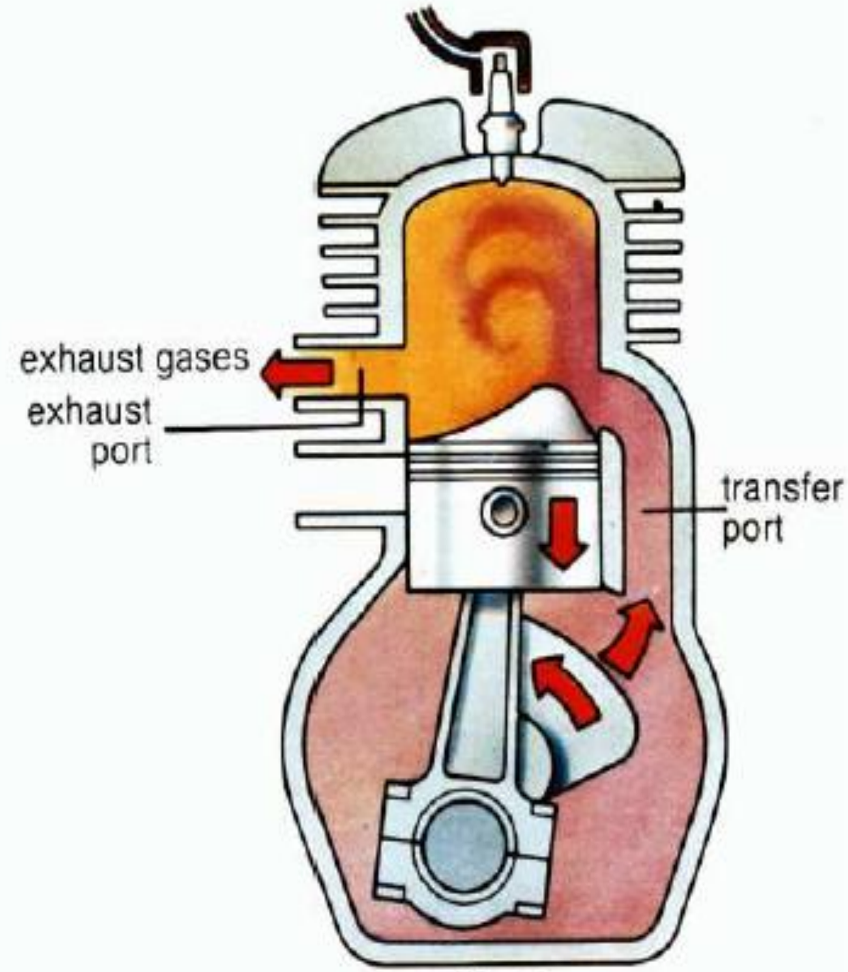


Fig. B

Piston uncovers transfer port
During first stroke

2-Stroke Petrol & Diesel Engine

- **Second Stroke**
- In this stroke piston moves from BDC to TDC.
- When it covers the transfer port in fig. C. , the supply of charge is stopped and then when it moves further up it covers the exhaust port completely in fig. D stop the scavenging.
- Further upward motion of the piston will compressed the charge in the cylinder.
- After the piston reaches TDC the first stroke repeats again.

Second Stroke

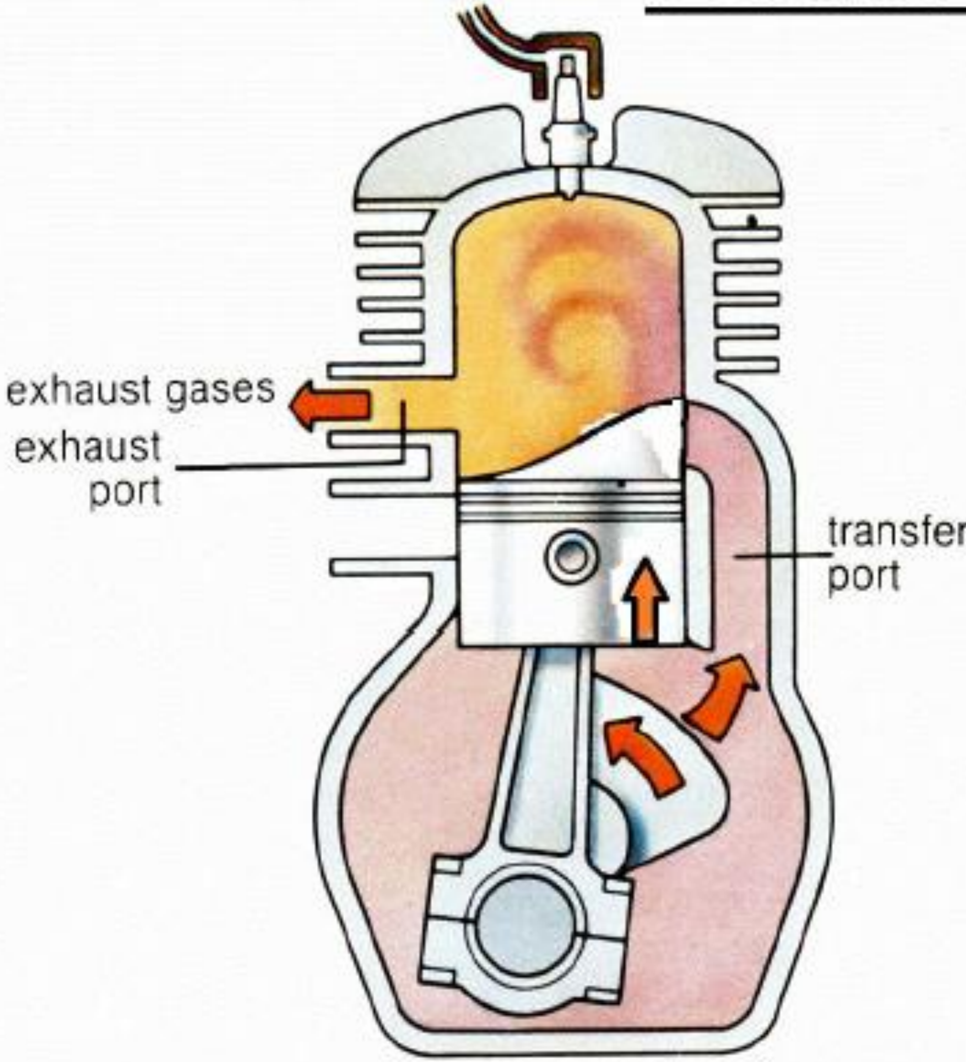


Fig. C.

Transfer port covered

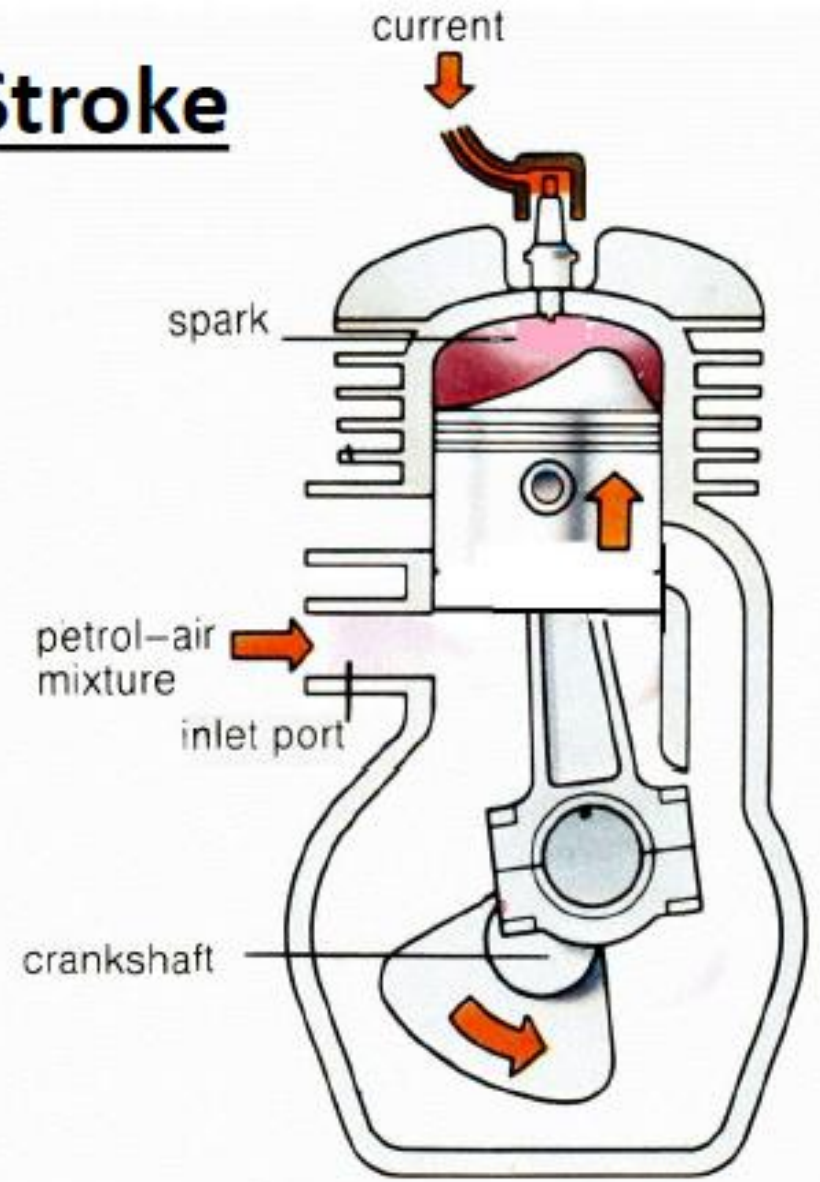
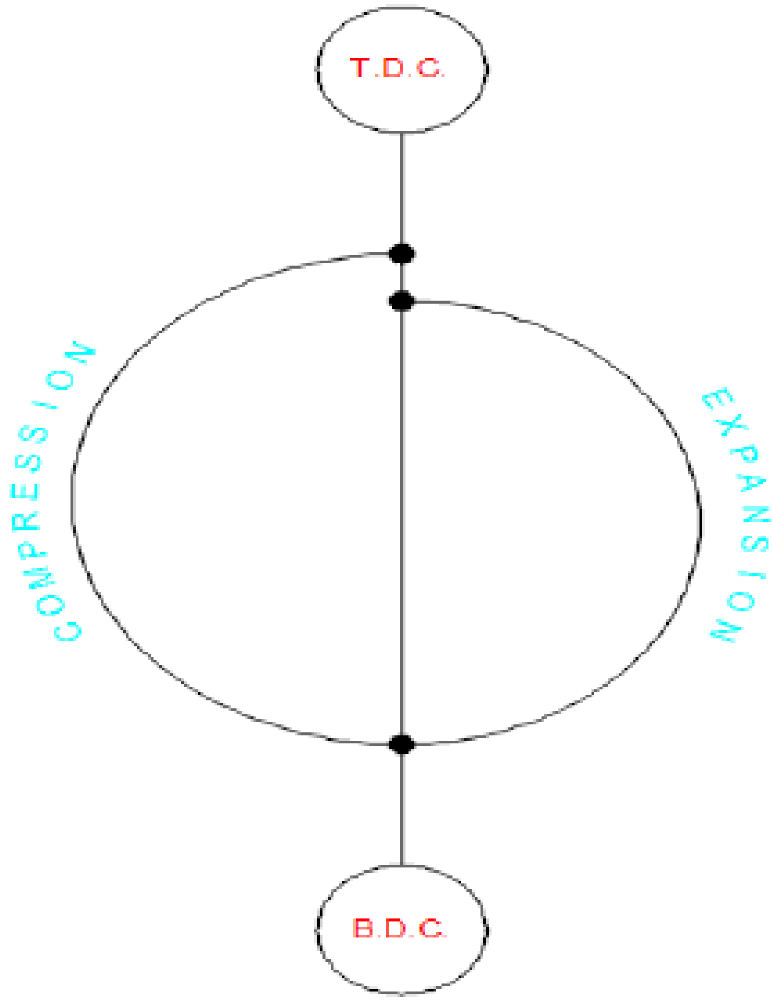


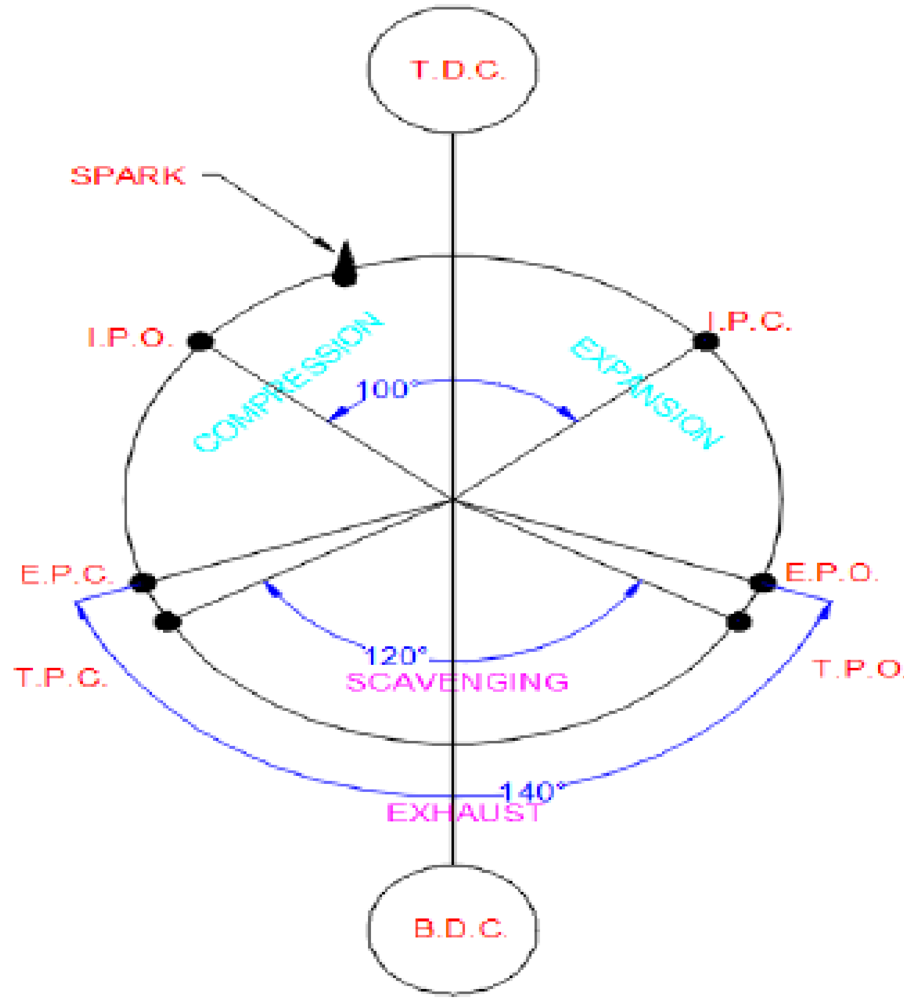
Fig. D.

Compression commenced

Theoretical & Actual Valve Timing Diagram For 2-Stroke Petrol Engine



Theoretical Valve Timing Diagram



Actual Valve Timing Diagram

CARBURETION

The process of preparation of combustible mixture by mixing the proper amount of fuel with air before admission to the engine cylinder is called *carburetion*. A device which atomises the fuel and mixes it with air and prepares the charge for Otto cycle engine is called carburetor.

Source : TE by Mahesh

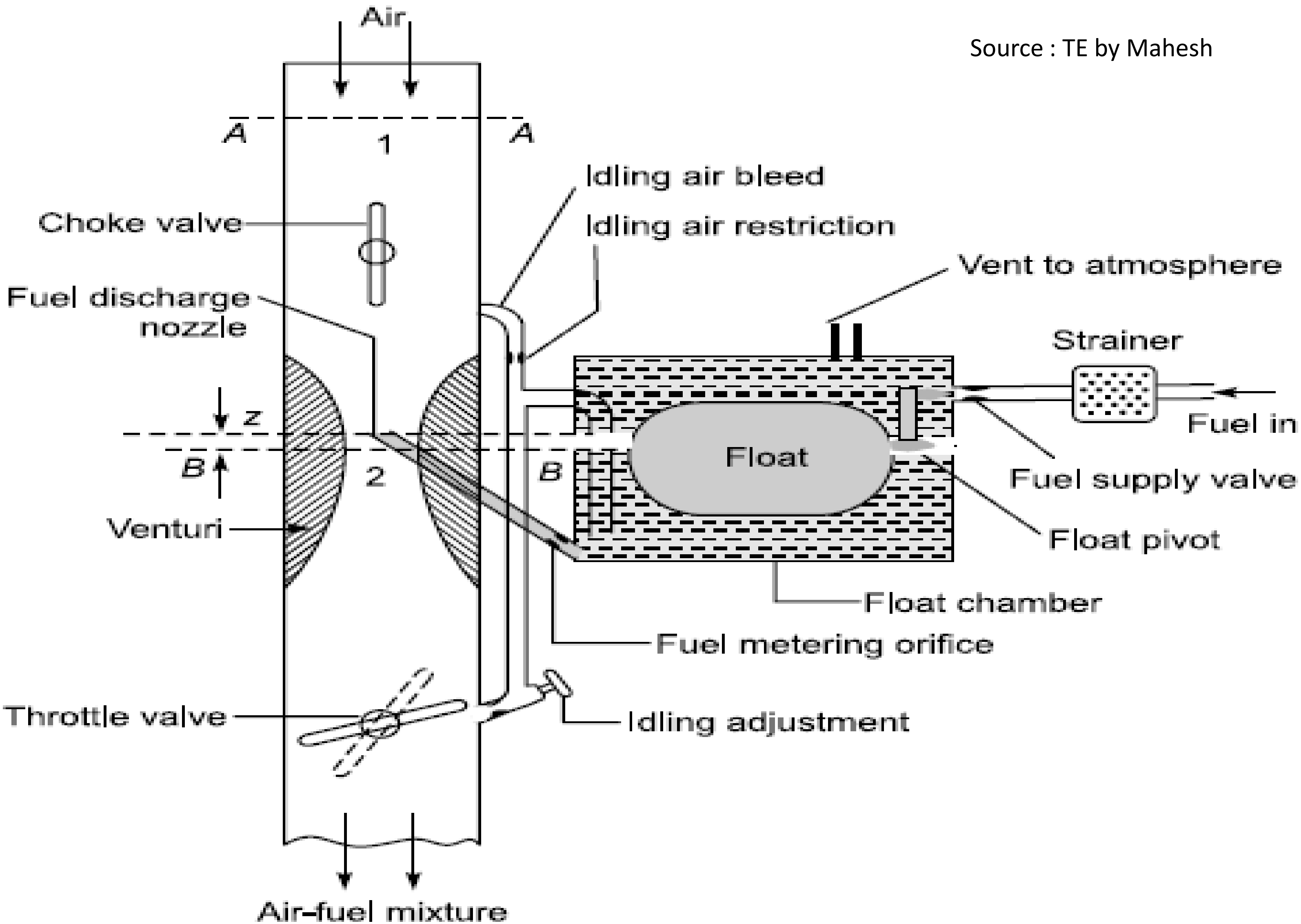


Fig. 2.7 *Simple Carburetor*

Working

- The basic carburetor as shown in Fig. 2.7 is built around a hollow tube called a throat venturi.
- The downward motion of the piston creates a partial vacuum inside the cylinder that draws air into the carburetor’s throat and past a nozzle that sprays fuel. The mixture of air and fuel produced inside the carburetor is delivered to the cylinder for combustion.
- A throttle valve at the base of the carburetor controls the amount of charge sucked through the engine by the partial vacuum in the cylinder.
- The driver opens the throttle valve by pressing down the accelerator.

Working

- The venturi is a gradually decreasing cross-sectional hollow tube. The venturi is the narrowing passage of the carburetor's throat.
- Air rushing through the narrow part speeds up.
- The fuel that enters the carburetor is stored in a reservoir called a float chamber or float bowl. A float and needle valve system maintains a constant level of gasolene in the float chamber.
- In addition to the main nozzle in the venturi portion of the carburetor, two other nozzles, or ports, deliver fuel to the engine.
- The choke is a device that can partially block air from entering into the carburetor.
- The throttle valve is almost closed and
- when the choke is applied (closed), the vacuum from
- the engine is strong enough inside the carburetor

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Working

- The throttle valve is almost closed and when the choke is applied (closed), the vacuum from the engine is strong enough inside the carburetor to draw more fuel from all the nozzles.
- carburetor can be adjusted to mix larger or smaller amounts of air with the fuel.
- A lean mixture produces a cleaner, hotter combustion for normal speeds, but not enough fuel for starting the engine efficiently or allowing it to produce more power.

Limitations

- It can only provide required A/F ratio at one throttle position at constant speed. As speed or throttle position changes, the mixture is either richer or leaner.
- At a wider open throttle, the air flow rate increases at the venturi throat, the air density and the pressure of air decrease, while the fuel density remains constant.
- Thus, a simple carburetor provides a progressively rich mixture with increasing throttle opening or speed of engine.

Fuel Injection Pump

- The basic principle of a fuel-injection system can be understood with the help of Fig. 2.25.
- It consists of a spring loaded, plunger-type pump.
- The plunger is activated through a push rod from the cam shaft.
- When the follower on the push rod is at the minimum lift position of the cam, the spring forces the plunger for its lowest position.
- Thus a suction is created in the barrel and the fuel from the main tank flows into the barrel through the fuel filter.
- When the cam rotates and reaches its maximum lift, the plunger is lifted upwards, the inlet valve closes and the fuel is forced through the delivery valve.

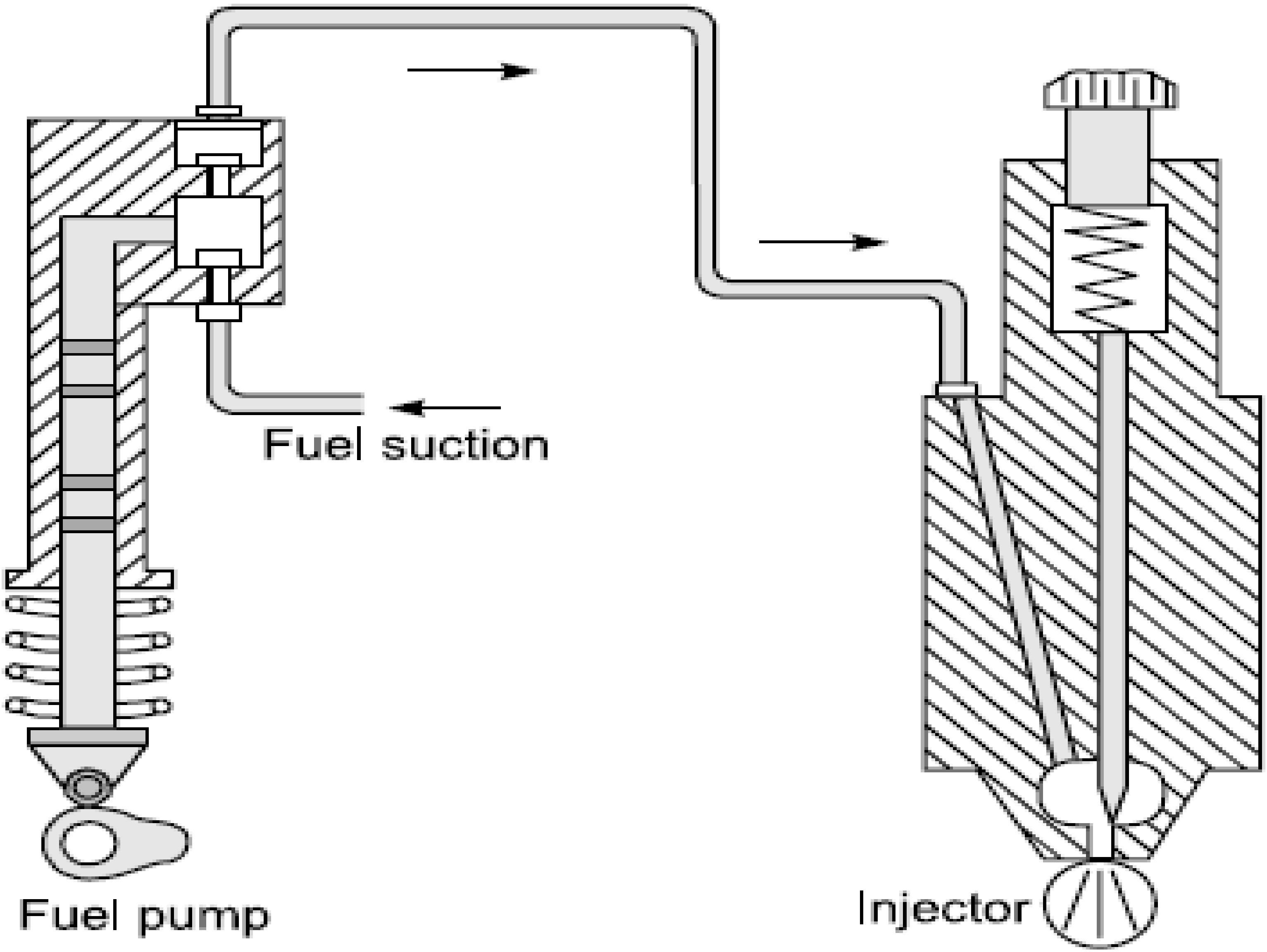


Fig. 2.25 *Schematic diagram of a fuel feed pump*

Fuel Injector

- The fuel pump in its effective stroke supplies the fuel to the fuel injector.
- The fuel injector delivers the fuel under pressure into the combustion chamber.
- The fuel injector serves to fulfil the following tasks:
- It atomizes the fuel into fine droplets.
- It distributes the fuel uniformly by proper spray pattern.
- It prevents the injection of fuel on the cylinder walls and piston top.
- It controls the start and stop of fuel instantaneously.

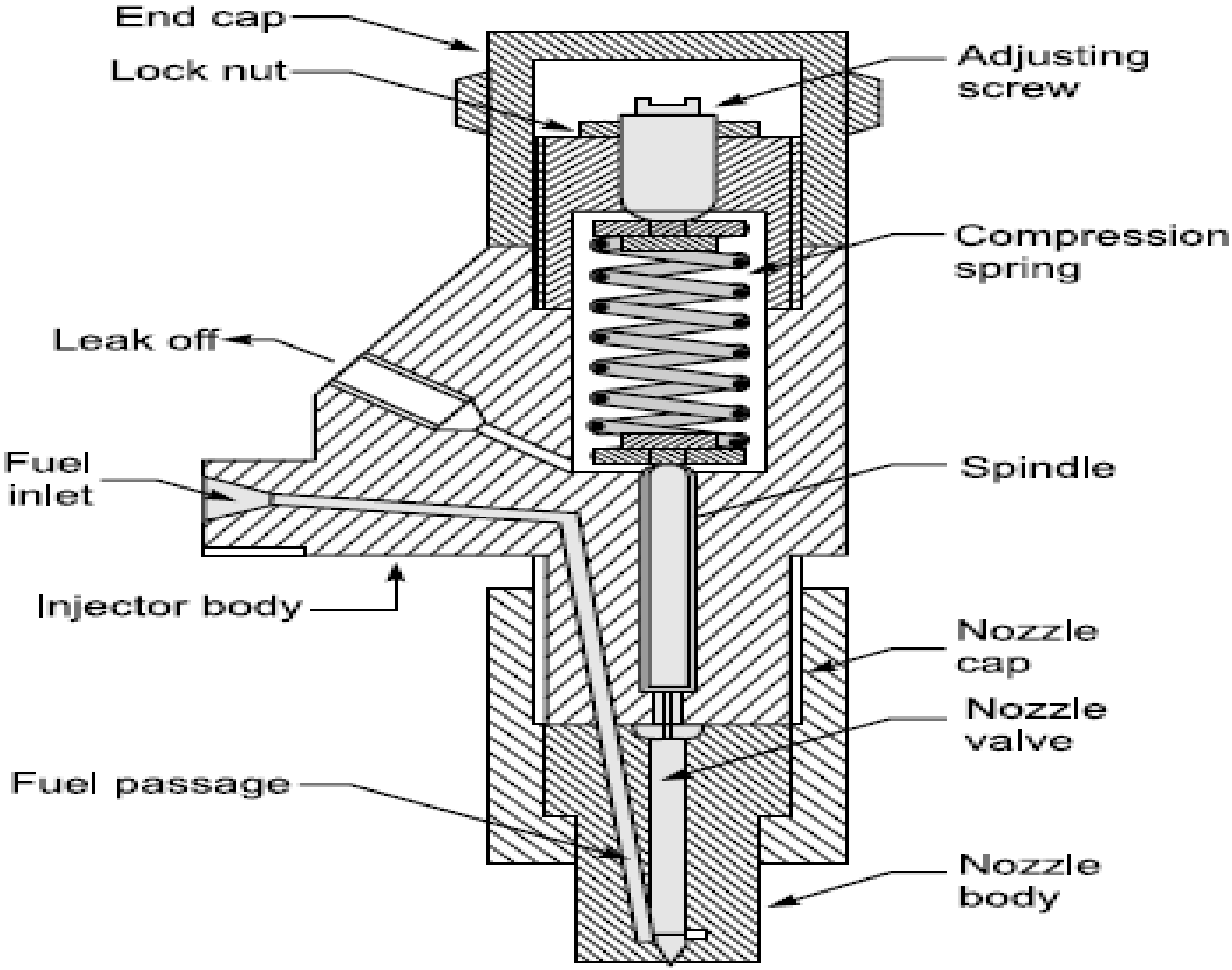
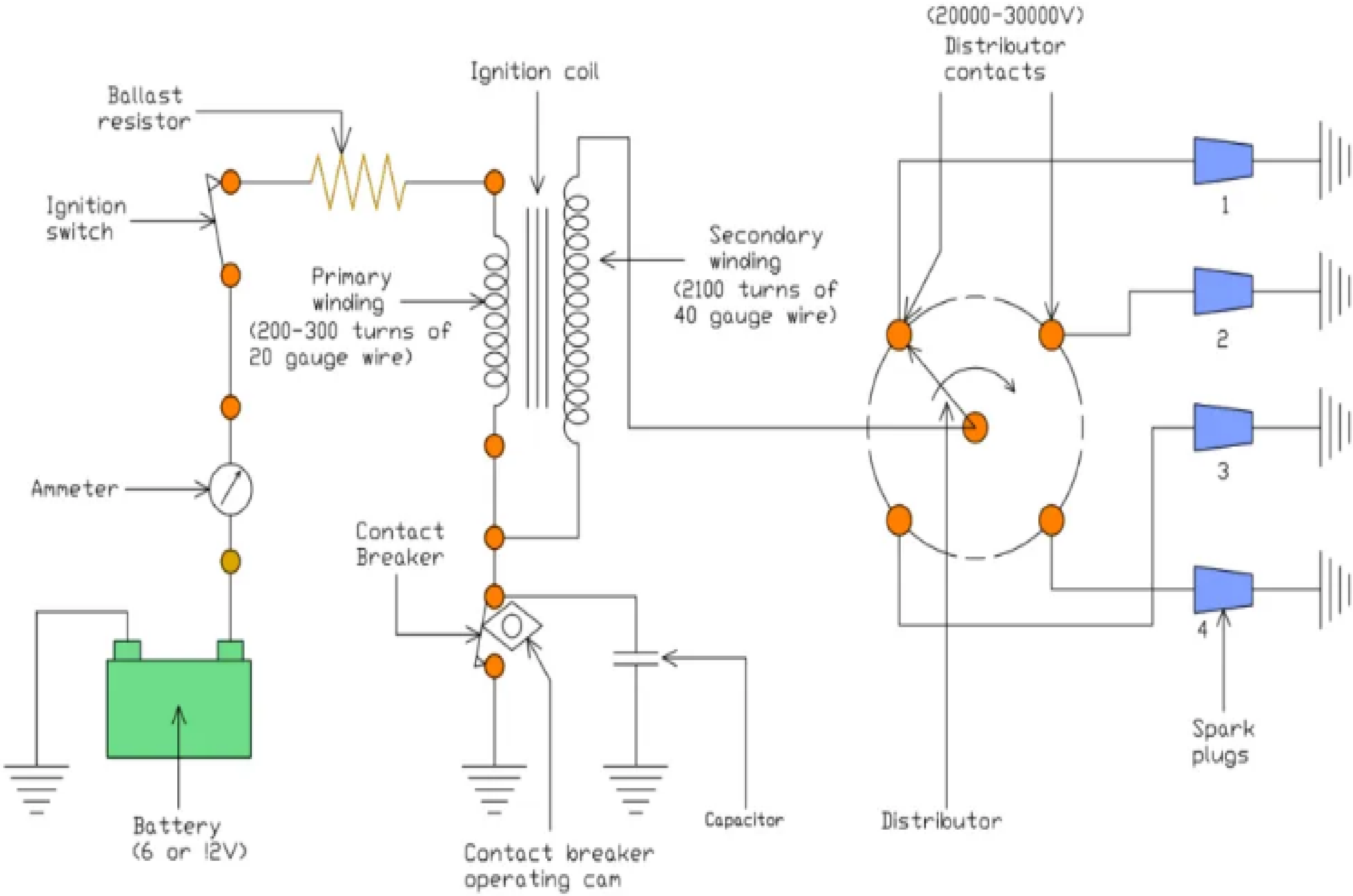


Fig. 2.28 *Fuel injector*

Fuel Injector

- The compression spring exerts the force on the nozzle valve through the spindle to close it.
- When the fuel is supplied under high pressure by a fuel pump, as it overcomes the spring force, the nozzle valve lifts and the fuel is sprayed into the combustion chamber in finely atomized particles.
- As the fuel pressure falls, the nozzle valve is pushed on its seat by a spring force.
- The amount of fuel injected is regulated by the duration of open period of the nozzle valve.



https://learnmechanical.com/battery-ignition-system/

Diagram of Battery Ignition System, *Learn Mechanical*

MAGNETO IGNITION SYSTEM

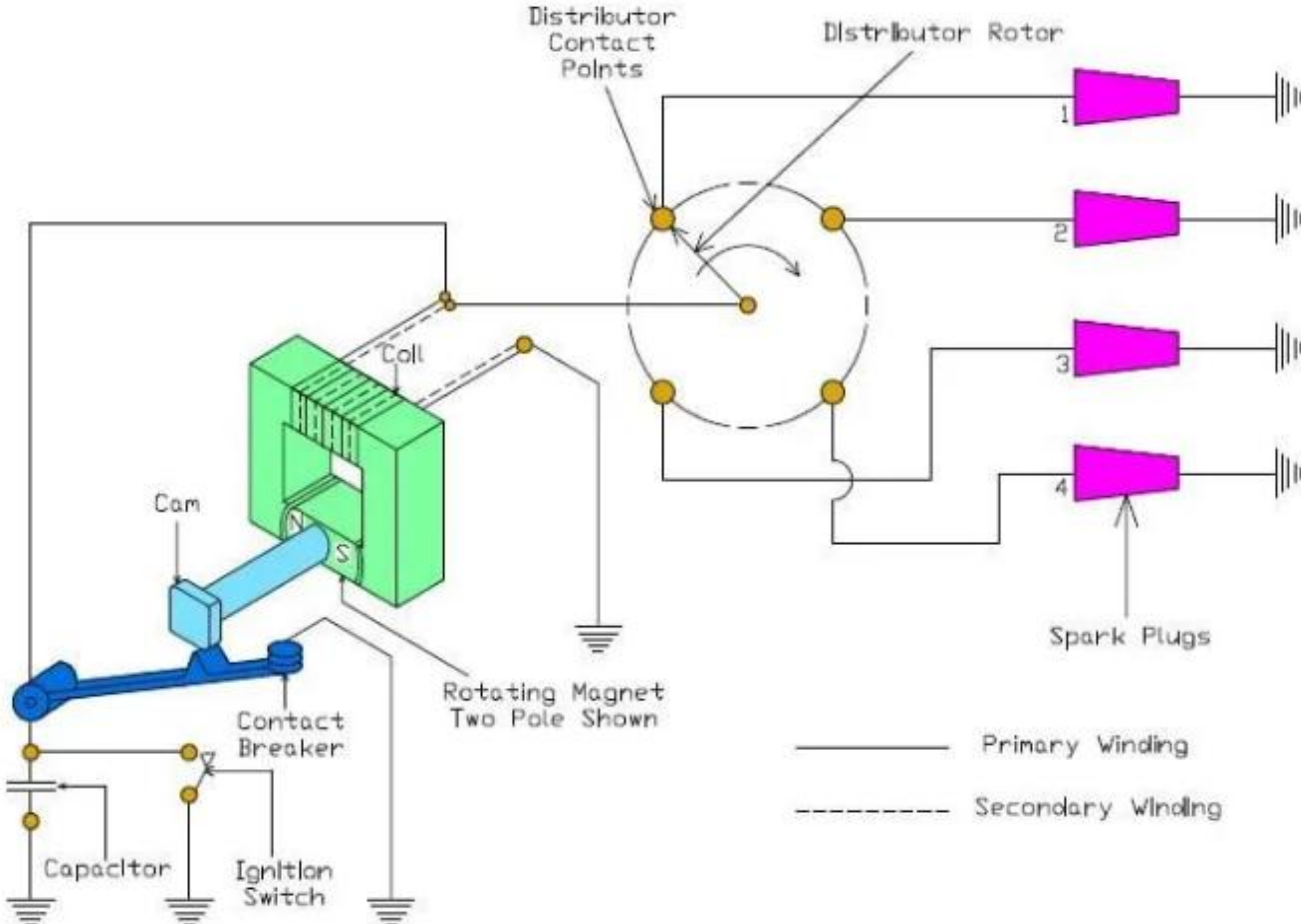
A magneto is an electric generator that provides the current for ignition in systems that do not have batteries. It is mounted to the engine. When engine is started, it supplies kinetic energy to the magneto. The magneto then converts this energy to electrical energy. The schematic of magneto ignition system is shown in Fig. 2.30.

The difference between battery and magneto ignition systems is in the source of electrical energy, all other components being the same. A magneto system is popular on motorcycles, racing cars, and a variety of small engines.

ENGINE LUBRICATION

The lubrication is the supply of oil between two surfaces having relative movement. The objectives of lubrication are

1. To minimize the friction between the parts having relative motion.
2. To reduce the wear and tear of moving parts.
3. To cool the surfaces by carrying away the heat generated due to friction.
4. To seal the space between piston rings and cylinder liner.
5. To absorb the shocks between bearings and other parts and consequently, reduce noise.
6. To act as cleaning agent and remove dirt, grit and any deposits that might be present between the moving parts.



Magneto Ignition System

https://learnmechanical.com/magneto-ignition-system/

(i) Splash Lubrication System It is used on small, stationary four-stroke engines. In this system, the cap of the big end bearing on the connecting rod is provided with a scoop which strikes and dips into the oil-filled troughs at every revolution of the crank shaft and oil is splashed all over the interior of crank case into the piston and over the exposed portion of the cylinder as shown in Fig. 2.41. A hole is drilled through the connecting rod cap through which the oil passes to the bearing surface. Oil pockets are provided to catch the splashed oil over all the main bearings and also the cam shaft bearing. From these pockets, oil passes to the bearings through drilled hole. The surplus oil dripping from the cylinder flows back to the oil sump in the crank case.

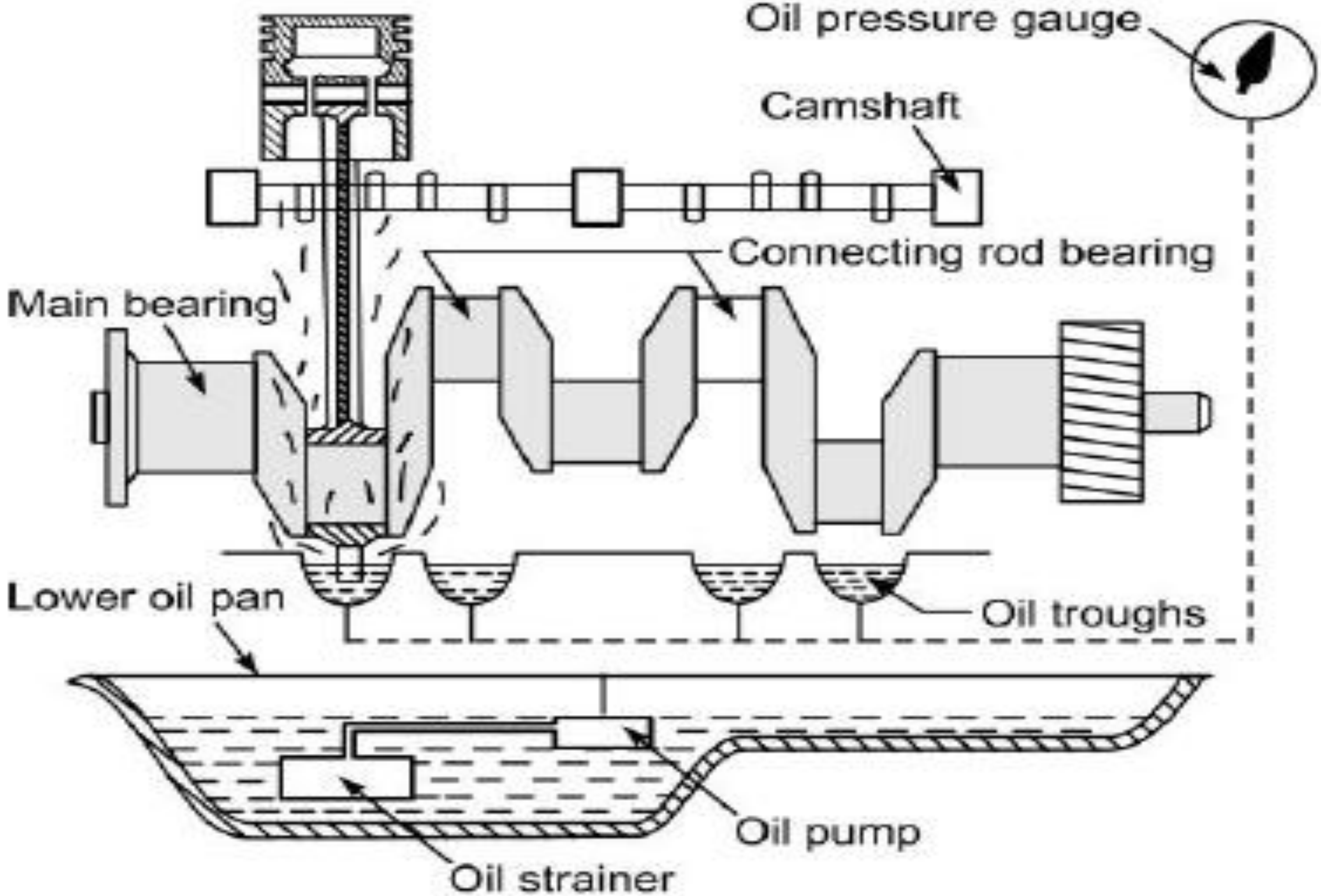


Fig. 2.41 *Splash lubrication system*

(*iii*) *Pressurized Lubrication System* In this system, the lubricating oil is supplied by a pump under pressure to all parts requiring lubrication as shown in Fig. 2.43. The oil under the pressure is supplied to main bearings of the crank shaft and camshaft. Holes drilled through the main crank shaft bearing journals, communicate oil to big end bearing and small end bearings through a hole drilled in the connecting rod. A pressure gauge is provided to confirm the circulation of oil to various parts.

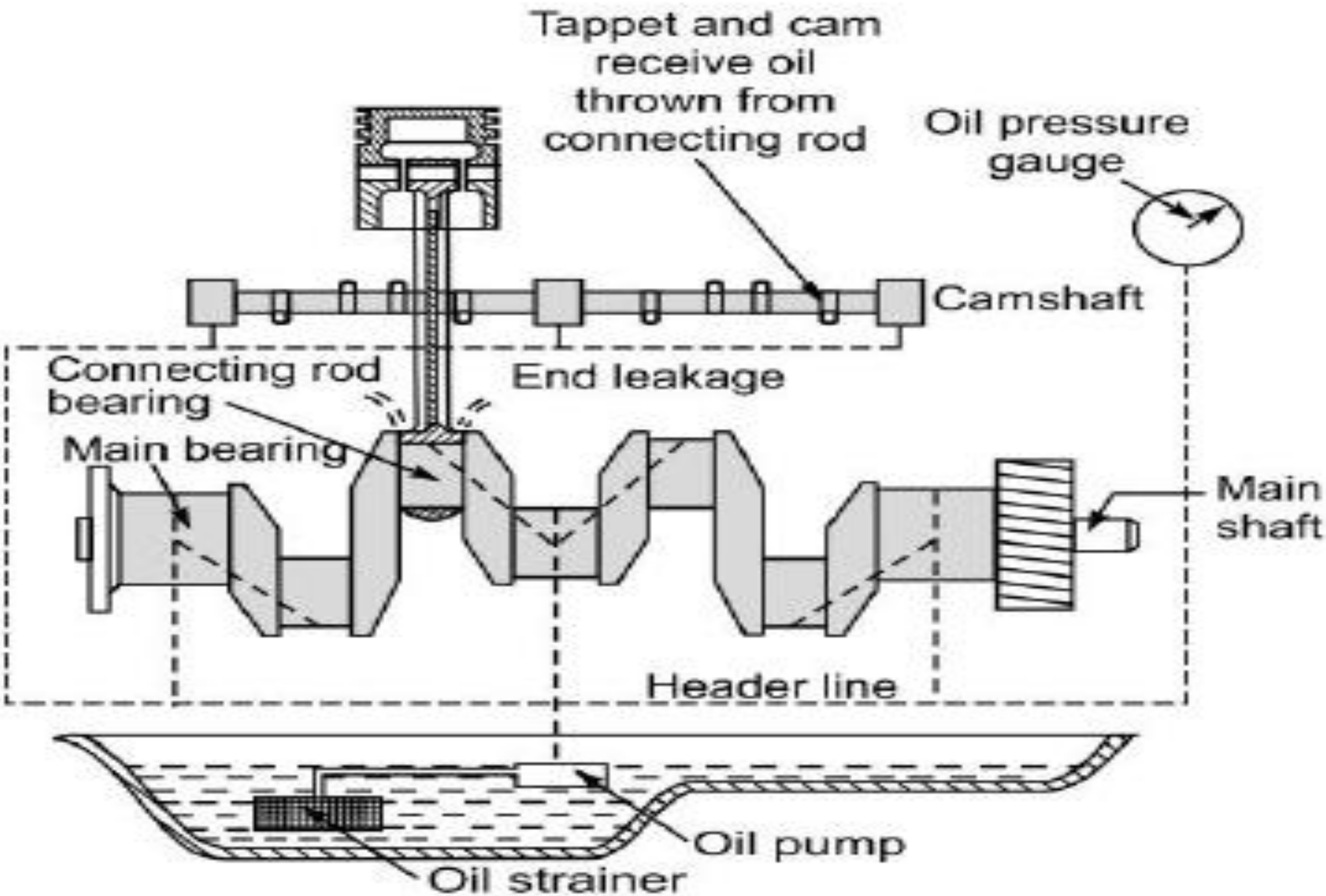


Fig. 2.43 *Pressurized lubrication system*

Air Cooled System

Air cooled system is generally used in small engines say up to 15-20 kW and in aero plane engines.

In this system fins or extended surfaces are provided on the cylinder walls, cylinder head, etc. Heat generated due to combustion in the engine cylinder will be conducted to the fins and when the air flows over the fins, heat will be dissipated to air.

The amount of heat dissipated to air depends upon :

(a) Amount of air flowing through the fins.

(b) Fin surface area.

(c) Thermal conductivity of metal used for fins.

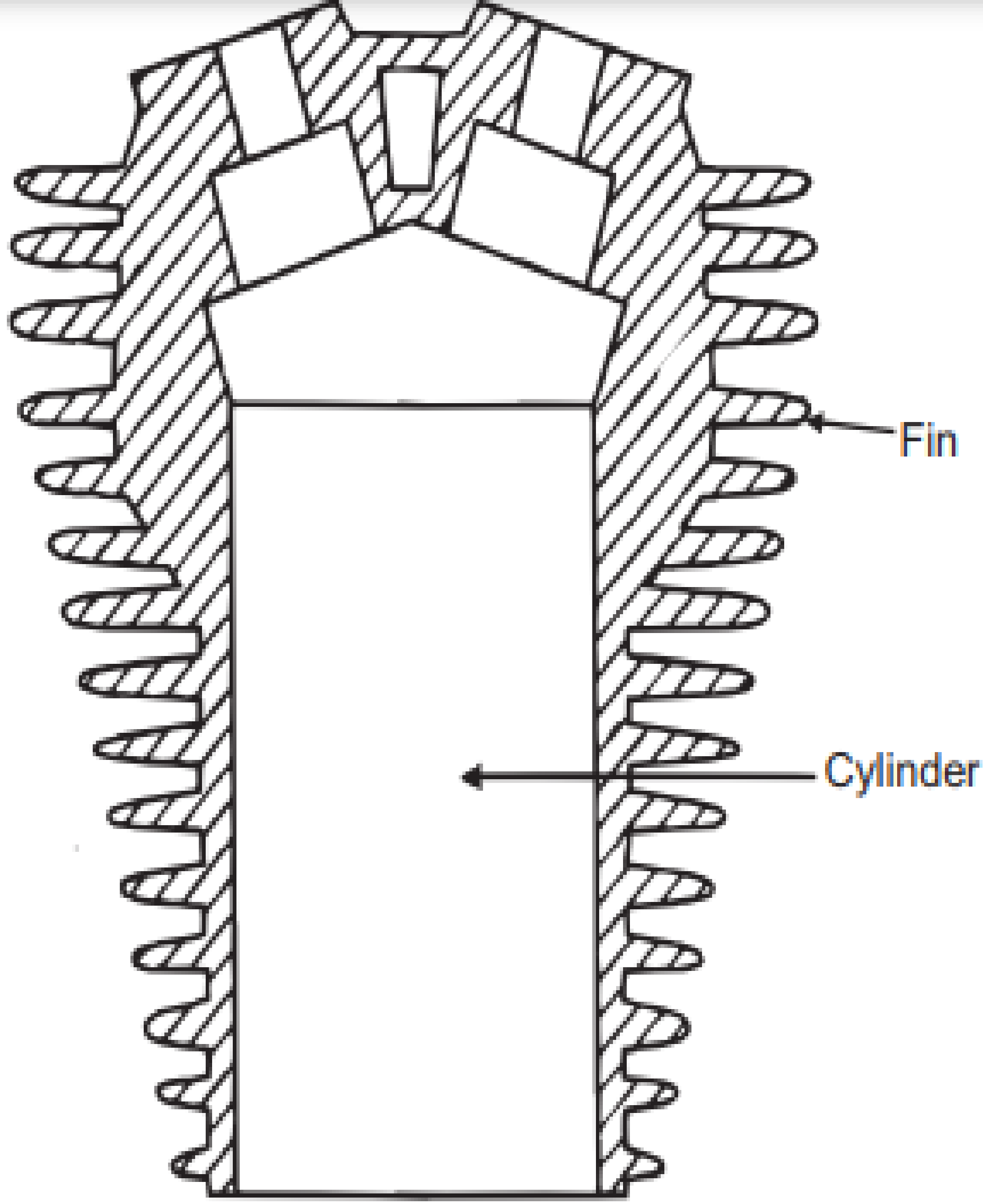


Figure 5.1 : Cylinder with Fins

Advantages of Air Cooled System

Following are the advantages of air cooled system :

(a) Radiator/pump is absent hence the system is light.

(b) In case of water cooling system there are leakages, but in this case there are no leakages.

(c) Coolant and antifreeze solutions are not required.

(d) This system can be used in cold climates, where if water is used it may freeze.

Disadvantages of Air Cooled System

(a) Comparatively it is less efficient.

(b) It is used in aero planes and motorcycle engines where the engines are exposed to air directly.

http://www.ignou.ac.in/upload/unit-5.pdf

2.25.5 Liquid-Cooling System

The liquid cooling system is explained with the help of block diagram Fig. 2.38 and operational diagram Fig. 2.39. The water-cooling system mainly consists of a radiator, fan water pump and thermostat.

The water or other coolant solutions flow through the water jacket around the cylinder and cylinder head to absorb the heat. The hot liquid coming out

1. Pump The pump maintains the water circulation through the water jacket around the engine. The bottom side of the radiator is connected to the suction side of the pump. The pump is mounted on the engine chassis and driven by a crank shaft with a fan belt.

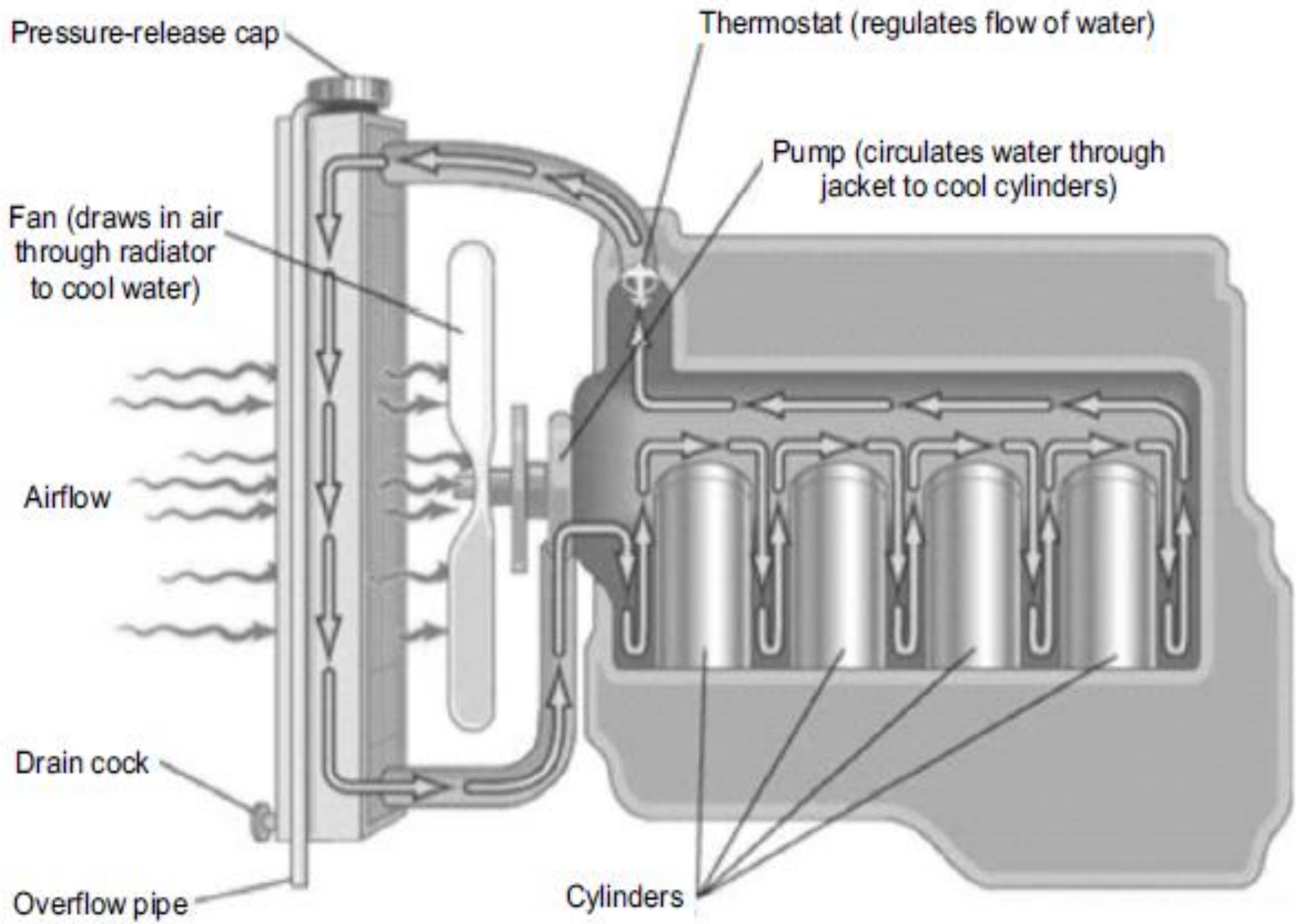


Fig. 2.39 *Components of water cooling system*

2. Fan The fan is mounted in front of the radiator and is driven by a belt-pulley arrangement. The fan draws air through the spaces between the radiator tube and fins, thus bringing down the temperature of the water flowing in the tubes.

3. Water Jacket The water passages between the double walls of the cylinder and cylinder head are called the water jacket. The water jacket is usually cast as an integral part of the cylinder block and head. The jacket covers the entire length of the stroke in order to avoid unequal thermal expansion of cylinder and to prevent the breakdown of lubricating oil film by excessive temperature.

4. Radiator The radiator is basically a compact heat exchanger. It is provided with a large surface area for effective heat transfer. It consists of an upper header and lower header. Between these headers, there is a core of the radiator, which consists of a large number of elliptical or circular brass tubes, pressed into a large number of brass fins. As hot water flows from top to down in the radiator core, it transfers its heat to the radiator fins from where the heat is picked up by circulating air.

5. Thermostat The lower cylinder temperature results into poor performance and rough operation of the engine. In cold starting, if water is circulated through the radiator, as the engine starts, the circulation of cold water in the water jacket brings down the cylinder temperature continuously and the engine will take a long time to reach the safe operating temperature.

Assignment Questions

Unit-2

Combustion in SI Engines

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UNIT 2

Combustion in SI Engines

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UNIT – II (SYLLABUS)

Combustion in SI Engines

- Normal Combustion and abnormal combustion – Importance of flame speed and effect of engine variables – Type of Abnormal combustion, pre-ignition and knocking (explanation of) – Fuel requirements and fuel rating, anti knock additives – combustion chamber – requirements, types.

II - UNIT

Combustion in SI Engines

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Introduction

Combustion is a chemical reaction in which certain elements of the fuel like hydrogen and carbon combine with oxygen liberating heat energy and causing an increase in temperature of the gases. The conditions necessary for combustion are the presence of combustible mixture and some means of initiating the process. The theory of combustion is a very complex subject and has been a topic of intensive research for many years. In spite of this, not much knowledge is available concerning the phenomenon of combustion.

The process of combustion in engines generally takes place either in a homogeneous or a heterogeneous fuel vapour-air mixture depending on the type of engine.

Homogeneous Mixture

In spark-ignition engines a nearly homogeneous mixture of air and fuel is formed in the carburettor. Homogeneous mixture is thus formed outside the engine cylinder and the combustion is initiated inside the cylinder at a particular instant towards the end of the compression stroke. The flame front spreads over a combustible mixture with a certain velocity. In a homogeneous gas mixture the fuel and oxygen molecules are more or less, uniformly distributed.

Heterogeneous Mixture

In a heterogeneous gas mixture, the rate of combustion is determined by the velocity of mutual diffusion of fuel vapours and air and the rate of chemical reaction is of minor importance. Self-ignition or spontaneous ignition of fuel-air mixture, at the high temperature developed due to higher compression ratios, is of primary importance in determining the combustion characteristics.

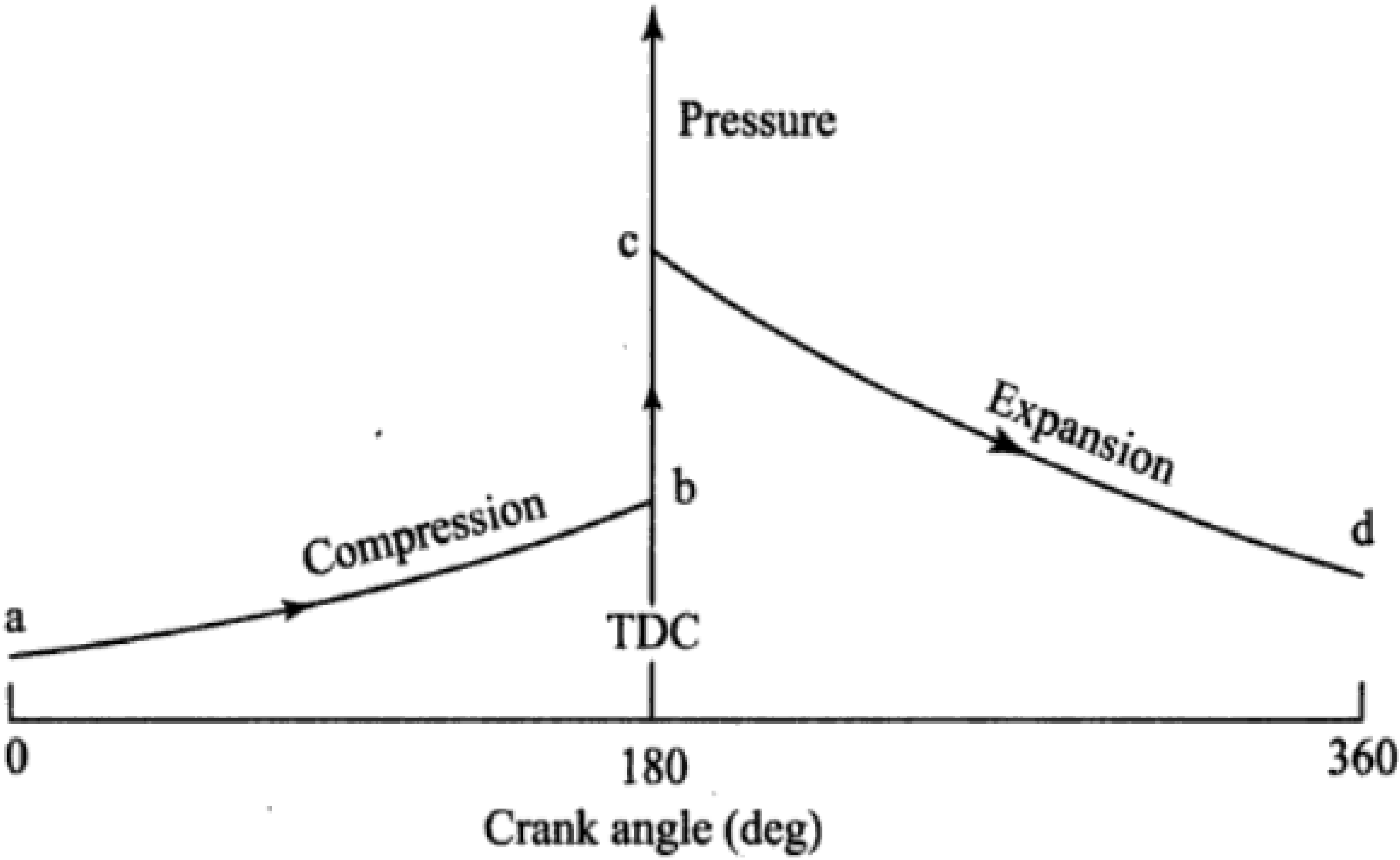
Combustion – SI Engines

As already mentioned, in a conventional spark-ignition engine, the fuel and air are homogeneously mixed together in the intake system, inducted through the intake valve into the cylinder where it mixes with residual gases and is then compressed. Under normal operating conditions, combustion is initiated towards the end of the compression stroke at the spark plug by an electric discharge. A turbulent flame develops following the ignition and propagates through this premixed charge of fuel and air, and also the residual gas in the clearance volume until it reaches the combustion chamber walls. Combustion in the SI engine may be broadly divided into two general types, viz., normal combustion and abnormal combustion.

Stages of Combustion – SI Engines

A typical theoretical pressure-crank angle diagram, during the process of compression (a→b), combustion (b→c) and expansion (c→d) in an ideal four-stroke spark-ignition engine is shown in Fig.12.1. In an ideal engine, as can be seen from the diagram, the entire pressure rise during combustion takes place at constant volume i.e., at TDC. However, in an actual engine this does not happen. The detailed process of combustion in an actual SI engine is described below.

Sir Ricardo, known as the father of engine research, describes the combustion process in a SI engine as consisting of three stages:



Theoretical p-θ Diagram

The pressure variation due to combustion in a practical engine is shown in Fig.12.2. In this figure, A is the point of passage of spark (say $20° bTDC$), B is the point at which the beginning of pressure rise can be detected (say $8°\ bTDC$) and C the attainment of peak pressure. Thus AB represents the first stage and BC the second stage and CD the third stage.

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First Stage – Ignition Lag or Preparation Phase

The *first stage* (A→B) is referred to as the ignition lag or preparation phase in which growth and development of a self propagating nucleus of flame takes place. This is a chemical process depending upon both temperature and pressure, the nature of the fuel and the proportion of the exhaust residual gas. Further, it also depends upon the relationship between the temperature and the rate of reaction.

Propagation of Flame(B-C)

The *second stage* (B→C) is a physical one and it is concerned with the spread of the flame throughout the combustion chamber. The starting point of the second stage is where the first measurable rise of pressure is seen on the indicator diagram i.e., the point where the line of combustion departs from the compression line (point B). This can be seen from the deviation from the motoring curve.

- Heat transfer to the cylinder wall is low
- Rate of heat release depends upon the turbulence intensity and reaction rate

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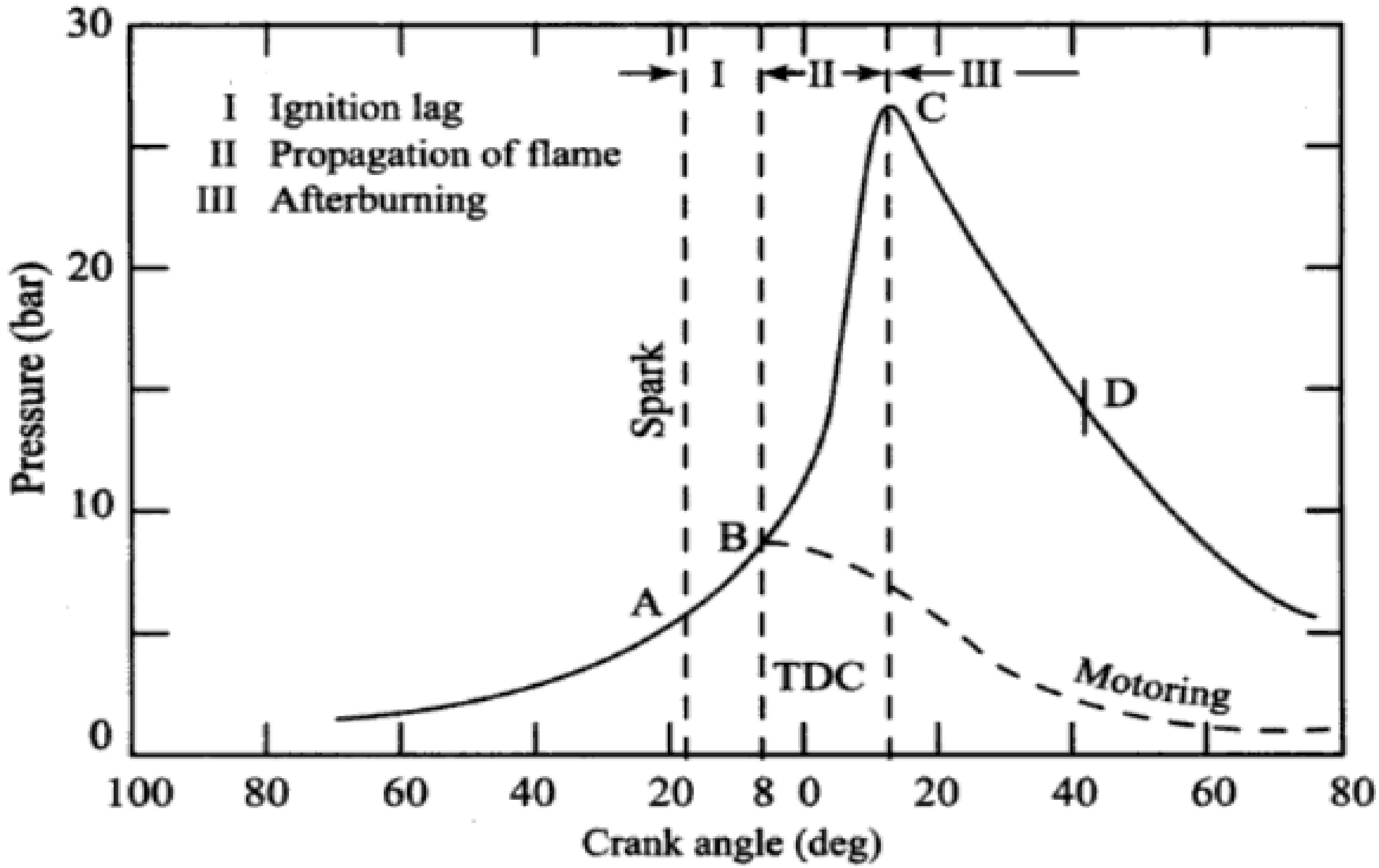

Stages of Combustion in an SI Engine

During the second stage the flame propagates practically at a constant velocity. Heat transfer to the cylinder wall is low, because only a small part of the burning mixture comes in contact with the cylinder wall during this period. The rate of heat-release depends largely on the turbulence intensity and also on the reaction rate which is dependent on the mixture composition. The rate of pressure rise is proportional to the rate of heat-release because during this stage, the combustion chamber volume remains practically constant (since piston is near the top dead centre).

After Burning (C-D):

The starting point of the *third stage* is usually taken as the instant at which the maximum pressure is reached on the indicator diagram (point C). The flame velocity decreases during this stage. The rate of combustion becomes low due to lower flame velocity and reduced flame front surface. Since the expansion stroke starts before this stage of combustion, with the piston moving away from the top dead centre, there can be no pressure rise during this stage.

- No pressure rise during this period

Effect of Engine Variables on Ignition Lag

- Ignition lag in terms of crank angle is 10^o to 20^o and in terms of seconds, 0.0015 second or so. Duration depends on the following factors:

Initial temperature and pressure:

Rate of reaction depends on increasing the intake temperature and pressure, increasing the compression ratio, chemical reaction rate and retarding the spark all reduce the ignition lag.

Electrode gap:

- Lower the compression ratio and higher the electrode gap is desirable -voltage required at the spark plug electrode to produce spark is found to increase with decrease in fuel-air ratio and with increase in compression ratio and engine load.

Turbulence:

- Turbulence is directly proportional to engine speed –
- engine speed does not affect much ignition lag measured in milliseconds but ignition lag increases linearly with engine speed when measured in degree crank angle
- -spark advance is desirable in higher engine speed
- -Excessive turbulence of the mixture in the area of spark plug is harmful


Crown
Ring
Grooves
Piston
Skirt
Piston
Pin Hole
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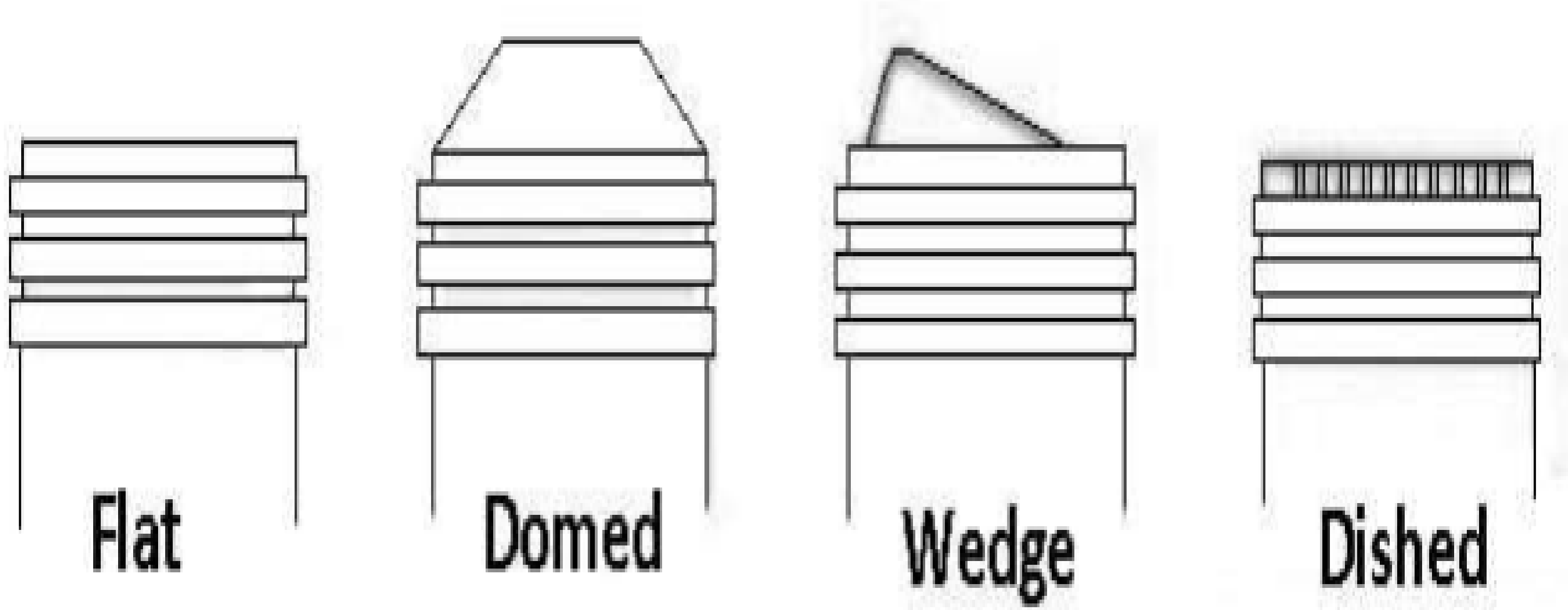
Flat
Domed
Wedge
Dished

Effect of Engine Variables on Flame Propagation

- Rate of flame propagation affects the combustion process in SI engines.
- Higher combustion efficiency and fuel economy can be achieved by higher flame propagation velocities.
- Unfortunately flame velocities for most of fuel range between 10 to 30 m/second.

- **The factors which affect the flame propagations are**

- Air – Fuel ratio
- Compression ratio
- Intake temp. and press.
- Load on engine
- Turbulence and engine speed
- Engine Size

Air – Fuel Ratio

- The mixture strength influences the rate of combustion and amount of heat generated.
- The maximum flame speed for all hydrocarbon fuels occurs at nearly 10% rich mixture.
- Flame speed is reduced both for lean and as well as for very rich mixture.
- Lean mixture releases less heat resulting lower flame temperature and lower flame speed.
- Very rich mixture results incomplete combustion and also results in production of less heat and flame speed remains low.

Compression ratio:

- The higher compression ratio increases the pressure and temperature of the mixture and also decreases the concentration of residual gases.
- All these factors reduce the ignition lag and help to speed up the second phase of combustion.
- The maximum pressure of the cycle as well as mean effective pressure of the cycle with increase in compression ratio.

Load on Engine:

- With increase in load, the cycle pressures increase and the flame speed also increases.
- -In S.I. engine, the power developed by an engine is controlled by throttling.
- At lower load and higher throttle, the initial and final pressure of the mixture after compression decrease and mixture is also diluted by the more residual gases.
- This reduces the flame propagation and prolongs the ignition lag. This is the reason, the advance mechanism is also provided with change in load on the engine.

Load on Engine:

- This difficulty can be partly overcome by providing rich mixture at part loads but this definitely increases the chances of afterburning.
- The after burning is prolonged with richer mixture.
- In fact, poor combustion at part loads and necessity of providing richer mixture are the main disadvantages of SI engines which causes wastage of fuel and discharge of large amount of CO with exhaust gases.

Engine Speed

- The turbulence of the mixture increases with an increase in engine speed.
- For this reason the flame speed almost increases linearly with engine speed.
- If the engine speed is doubled, flame to traverse the combustion chamber is halved (in milliseconds).
- Double the original speed and half the original time give the same number of crank degrees for flame propagation.

- The crank angle required for the flame propagation, which is main phase of combustion will remain almost constant at all speeds.
- This is an important characteristic of all petrol engines.
- If speed is doubled, first stage will be doubled in terms of crank angle but constant in terms of milliseconds

Engine Size

- Engines of similar design generally run at the same piston speed.
- This is achieved by using small engines having larger RPM and larger engines having smaller RPM.
- Due to same piston speed, the inlet velocity, degree of turbulence and flame speed are nearly same in similar engines regardless of the size.
- However, in small engines the flame travel is small and in large engines large.
- Therefore, *if the engine size is doubled the time required for propagation of flame through combustion space is also doubled. But with lower RPM of large engines the time for flame propagation in terms of crank would be nearly same as in small engines. In other words, the number of crank degrees required for flame travel will be about the same irrespective of engine size provided the engines are similar.*

Assignment Questions

Assignment Questions

Combustion in C.I. Engines

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UNIT 2

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UNIT – II (SYLLABUS)

Combustion in C.I. Engines

Four stages of combustion – Delay period and its importance – Effect of engine variables – Diesel Knock– Need for air movement, suction, compression and combustion induced turbulence – open and divided combustion chambers and nozzles used – fuel requirements and fuel rating.

LECTURE 2

Combustion in C.I. Engines

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4 Stages of combustion in CI engine

- Combustion is a process of the rapid chemical reaction between fuel and the air.
- This process results in the generation of heat and light. In IC Engine, there are different stages of combustion for different engines.
- In this post, we are going to focus on stages of combustion in CI engine. Stages of combustion in SI engine are completely different than the CI engines.
- In CI or compression ignition engine, in the compression stroke, only air is compressed at very high pressure and temperature. The compression ratio used is in the range of 12 to 120.

- The temperature of the air becomes higher than the temperature of the fuel which is diesel in the CI engine.
- Then diesel fuel is injected in the combustion chamber under very high pressure about 120 to 210 bar.
- The temperature of this fuel is around 20° to 35° before TDC (Top Dead Center).

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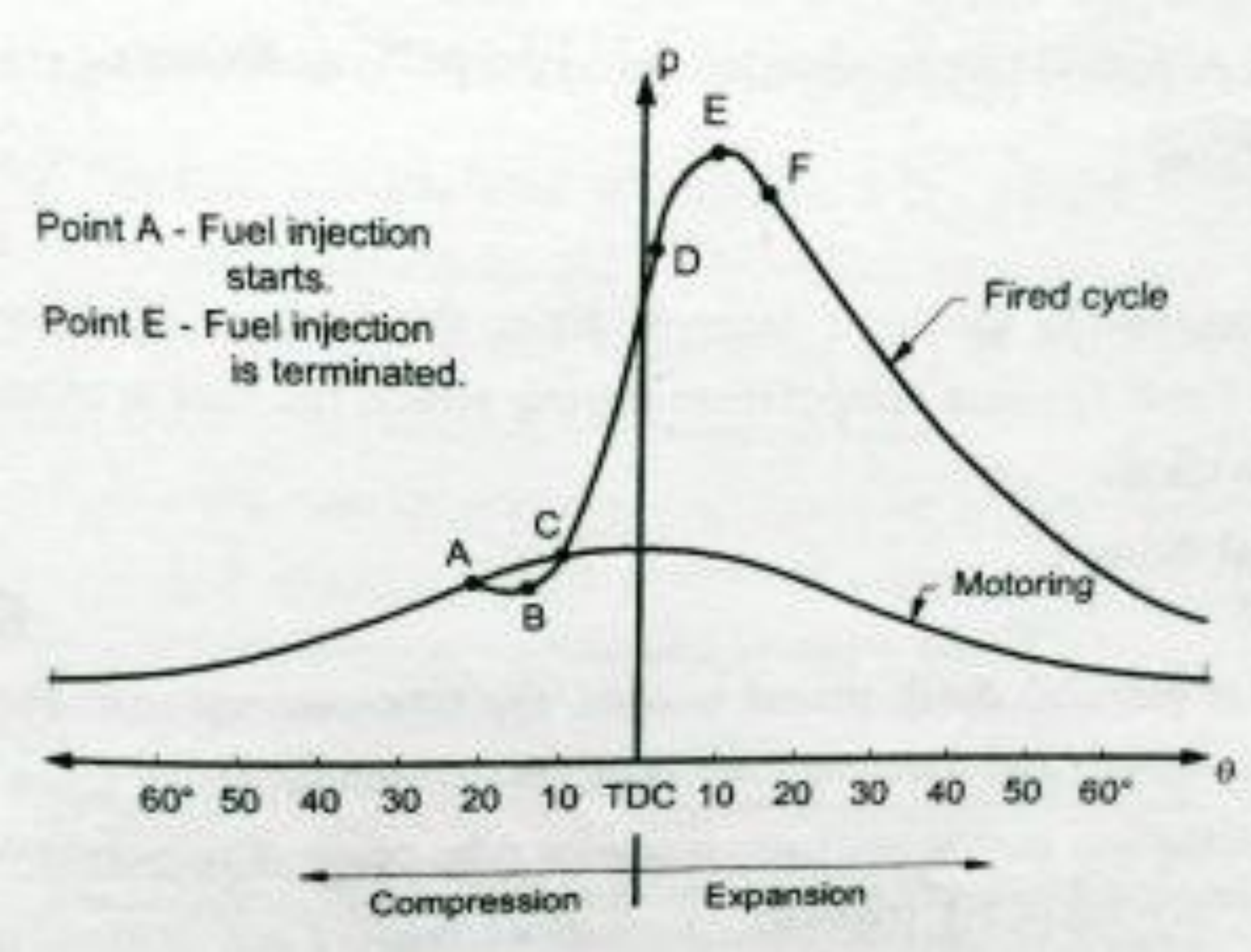


https://www.enggstudy.com/stages-of-combustion-in-ci-engine/

Stages of Combustion in CI engine:

- There are four different stages of combustion in CI engine where proper combustion of air and fuel takes place as follows:

➢ Ignition Delay Period

➢ Period of Uncontrolled Combustion

➢ Period of Controlled Combustion

➢ After Burning

1. Ignition Delay Period

- At this first stage of combustion in the CI engine, the fuel from the injection system sprayed in the combustion chamber in the form of a jet. Due to atomization and vaporization, this fuel disintegrates at the core which is surrounded by a spray of air and fuel particles.

Stages of Combustion in CI engine:

- After completion of the vaporization process, the *preflame reaction* of the mixture in the combustion chamber starts. During the preflame reaction, pressure into the cylinder starts increasing with the release of energy at a slow rate.
- This time interval between the starting of the fuel injection and the beginning of the combustion is called the **delay period**.
- Preflame reaction we discussed above is taking place during the chemical delay.
- Due to the complex process of combustion is a CI engine, it's difficult to separate these two delay periods.

2. Period of Uncontrolled Combustion

- This is the second stage of combustion in the CI engine. After the above-mentioned delay period is over, the air and fuel mixture will auto-ignite as they have achieved their self-ignition temperature.
- The mixture of air and fuel in CI engines is heterogeneous unlike homogeneous in the SI engines. Due to this heterogeneous mixture, flames appear at more than one location where the concentration of the mixture is high.
- When the flame formed the mixture in the other low concentration starts burning by the propagation of flames or due to auto-ignition, because of the process of heat transfer.

3. Period of Controlled Combustion

- When the accumulated fuel during the delay period completely burned in the period uncontrolled combustion, the temperature and pressure of the mixture in the cylinder are so high that new injected fuel from the nozzle will burn rapidly due to the presence of sufficient oxygen in the combustion chamber.
- That’s the reason we can control the rise of pressure into the cylinder by controlling the fuel injection rate.
- Therefore, this period of combustion is called a period of controlled combustion.

4. After Burning

- This is the last stage out of the four stages of combustion in CI engine.
- Naturally, the combustion process is completed at the point when the maximum pressure is obtained in the combustion chamber at point E as shown in the figure.
- Practically, the burning of the fuel in the combustion chamber remains to continue during the expansion stroke.
- The main reason behind it is the reassociation of dissociated gases and unburnt fuel.

Knock in C.I. Engines (Abnormal Combustion)

- In C.I engine as delay period increases, the amount of fuel injected and accumulated in combustion chamber increases.
- A very high temperature and pressure is generated by combustion of this large amount of fuel is known as knocking or detonation in C.I engine.
- “Accumulation of fuel during large delay period creates very high pressure, it is known as knocking in C.I. engine.”
- This high rate of pressure rise creates pulsating combustion which produces heavy noise.
- In C.I. engine knocking occurs during initial phase of combustion i.e. as delay period is completed and uncontrolled combustion starts.

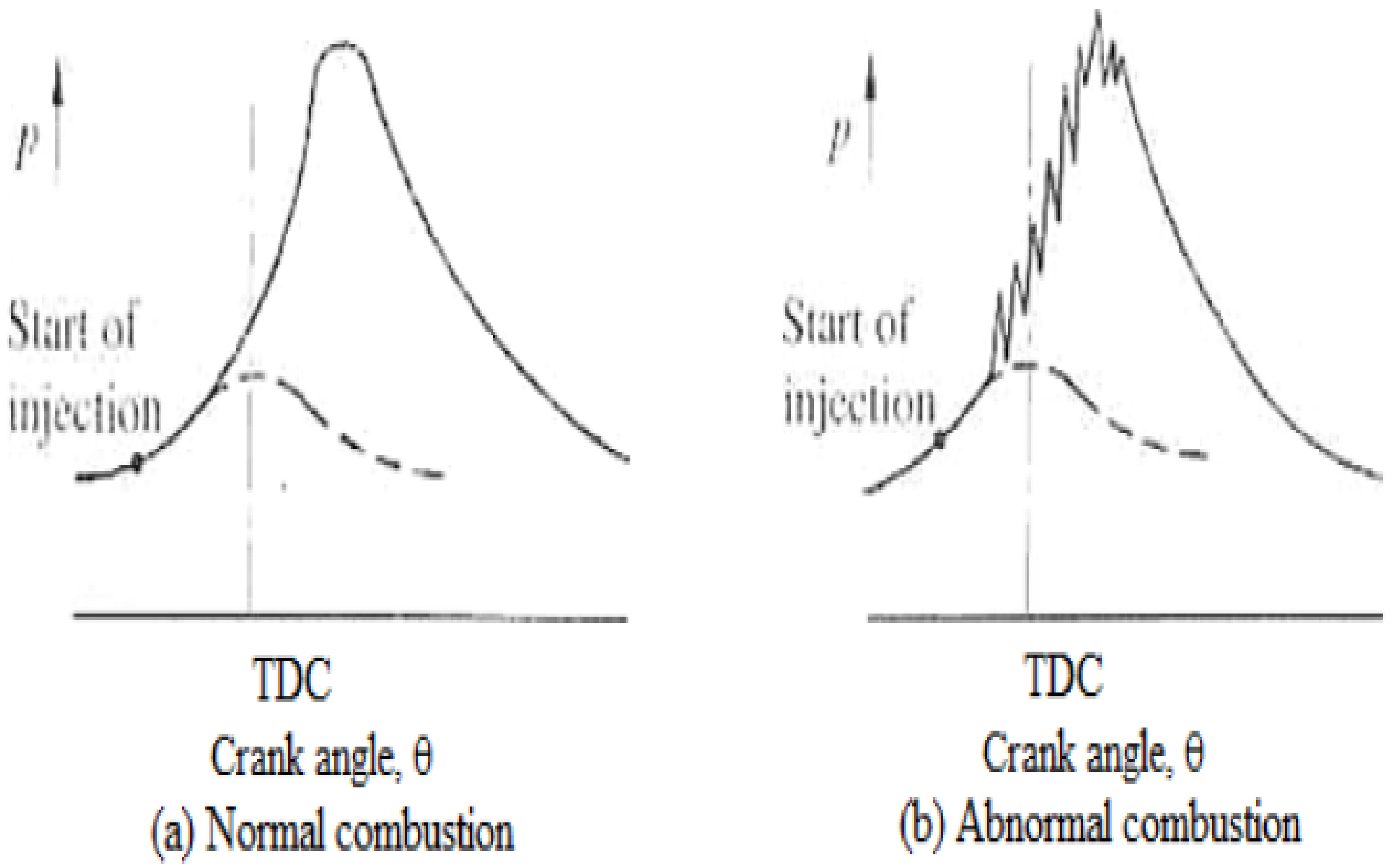


Fig.7. 20 p - θ diagram of C.I. engine with and without Knocking

Knock in C.I. Engines (Abnormal Combustion

- As ignition delay is longer , the actual burning of first few droplets is delayed and accumulation of greater quantity of fuel take place.
- When actual burning take place under such conditions the rate of pressure rise increases as shown in fig. –
- If ignition delay is quite large and the actual burning is substantially delayed and the accumulation of fuel is high when actual burning
- take place the rate of pressure rise is almost instantaneous the knocking begins as shown in fig.
- -

- **Knocking is characterized by extreme pressure differentials and violent gas vibrations evidenced by audible knock.**
- **- In CI engines knocking occurs in the beginning of combustion.**
- **- In order to decrease knocking the actual burning should start as early as possible after the fuel injection begins.**
- **Low ignition temp., ignition delay & speed reduce knock as also higher CR, Inlet Temp. & press., comb. wall temp. cylinder size.**

Air Motion

- **Fuel - Air Mixing and Combustion :**
- **-The air motion so organized inside the combustion**
- **chamber and the turbulence of the air passes across the fuel jet tears it into fine particles.**
- **- A mixture of air and fuel forms at some location in the spray envelope and oxidation starts**
- **- The liquid fuel droplets initially evaporate and then get heated up , and A/F ratio (local) within combustible range , autoignite.**

Combustion Chamber Design for C.I. Engines

Objectives

- In the C.I engine during induction, suction, and compression only air is there and fuel is injected at the end of compression. The time available for vaporization and mixing with air is very limited. Also for better mixing and better combustion air swirl is required which gives better combustion.
- For better combustion atomization, vaporization and proper mixing with air is required in minimum time and result of all these give high power, better efficiency, smooth and noiseless engine running, and shorter delay period which reduces probability of knocking.
- To achieve all of the above advantages the design of C.I engine combustion chamber becomes more complicated and swirl is very important in the C.I engine.

- **Air Swirl:**
- For proper mixing of fuel and air in the combustion chamber the various methods of air movement are employed called air swirl. Various types of air swirl are being discussed below :
- **Induction Swirl**
- In this method swirl is provided to incoming air to the cylinder during suction, that's why it is known as induction swirl.
- Different methods of giving swirl to incoming air are shown in fig 7.22 in which air enters at some angle and gets the swirl.
- Fig. 7.22 (b) shows a masking or shrouding one side of the inlet valve, so that air enters only around the part of periphery of the valve and air swirl is produced. The angle of mask used usually varies from 90° to 140°.

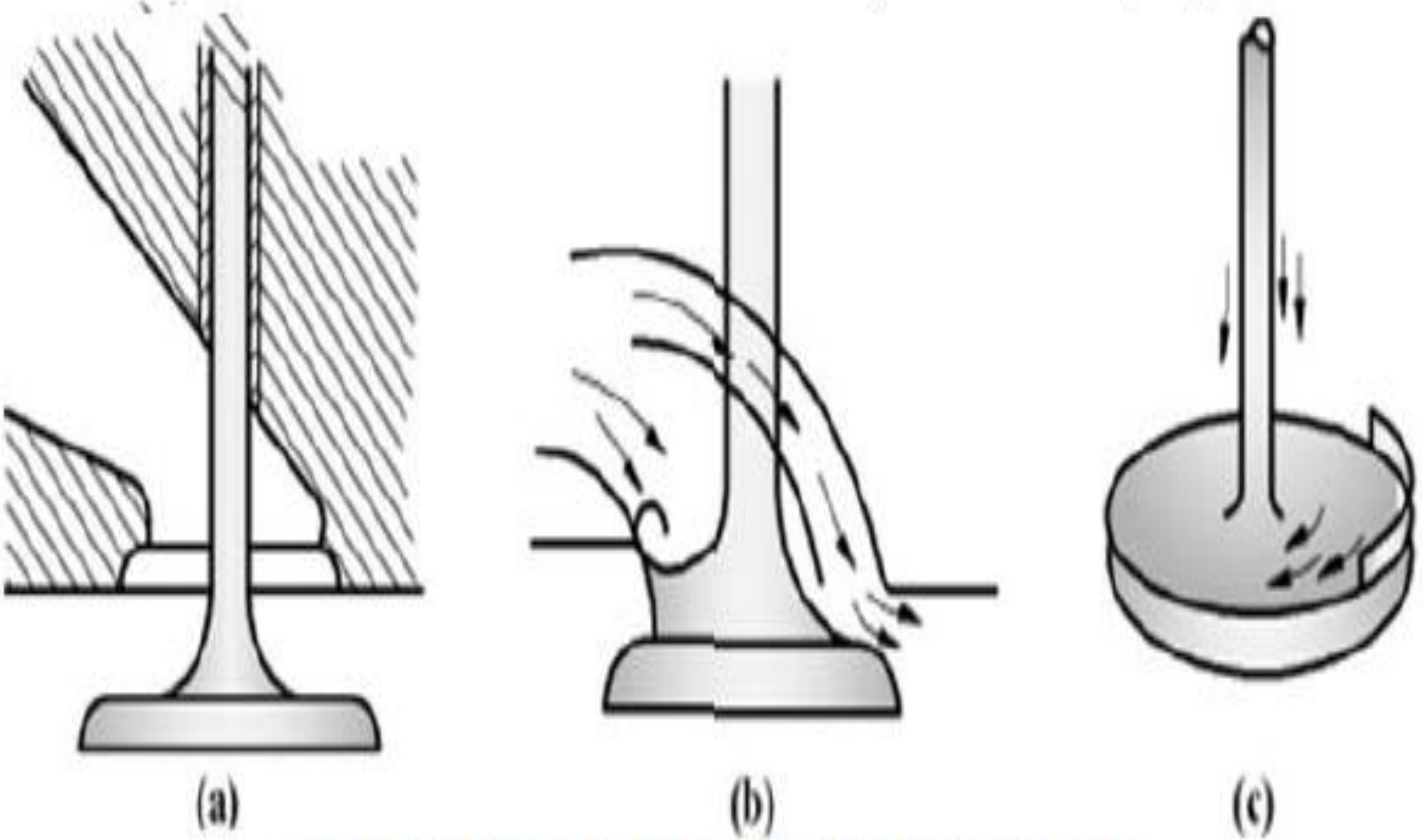


Fig.7. 22 Different methods of achieve induction swirl

Fig.7. 22 Different methods of achieve induction swirl

2. Compression Swirl

- In this method air swirl is produced during compression stroke. At the top of the piston different types of cavity is formed which gives different type of swirl during compression. It is shown in Fig. 7.23 (a) and (b).

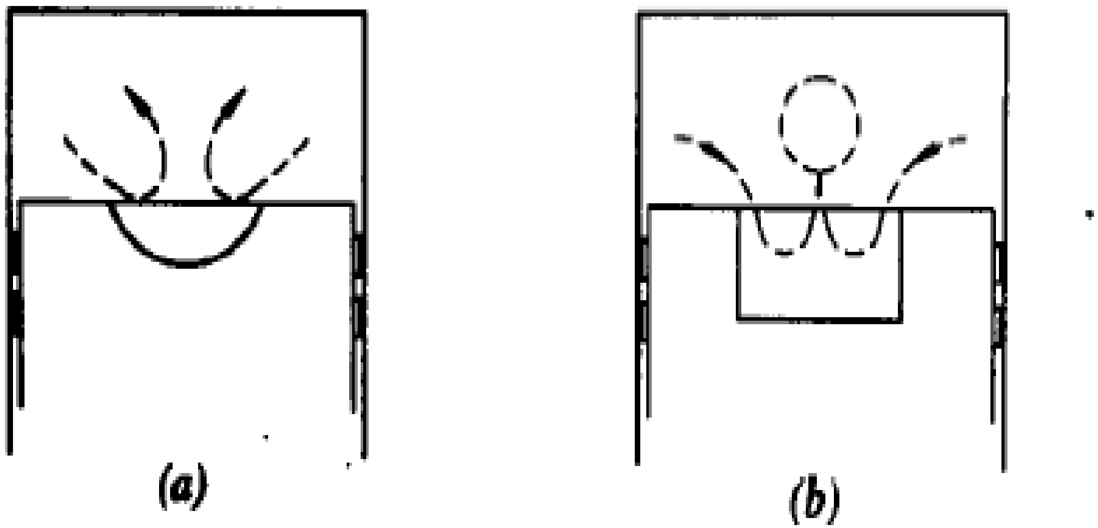


Fig.7. 23 Compression Swirl

3. Combustion Induced Swirl

- In this method swirl is produced by high pressure generated during first part of combustion of fuel. The piston head have different types of design which help to generate the swirl during combustion. This method is employed in pre-combustion and air cell combustion chamber designs.

7.19. Classification of Combustion Chambers for C.I. Engines

– The combustion chamber for the C.I. engines are classified as follows:

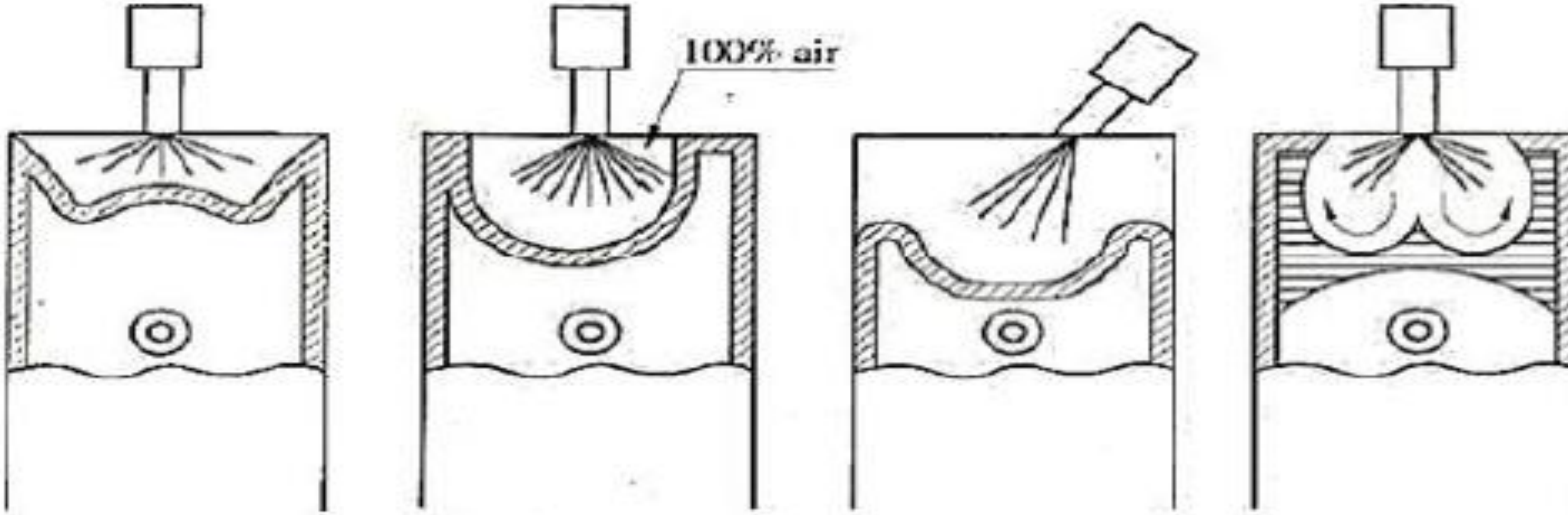
   a. Open combustion chamber or Direct injection (D.I.) combustion chambers.
   b. Pre-combustion chamber.
   c. Turbulent combustion chamber or Indirect injection combustion chamber.
   d. Special combustion chambers.

1. Open or Direct Injection (DI) Combustion Chambers

In an open combustion chamber the space between the piston and cylinder head is open i.e. no restriction in between. Therefore, all air is contained in single space between the piston and cylinder head. The fuel is directly injected inside this space that's why it is also known as direct injection engine or in short D.I. engine.

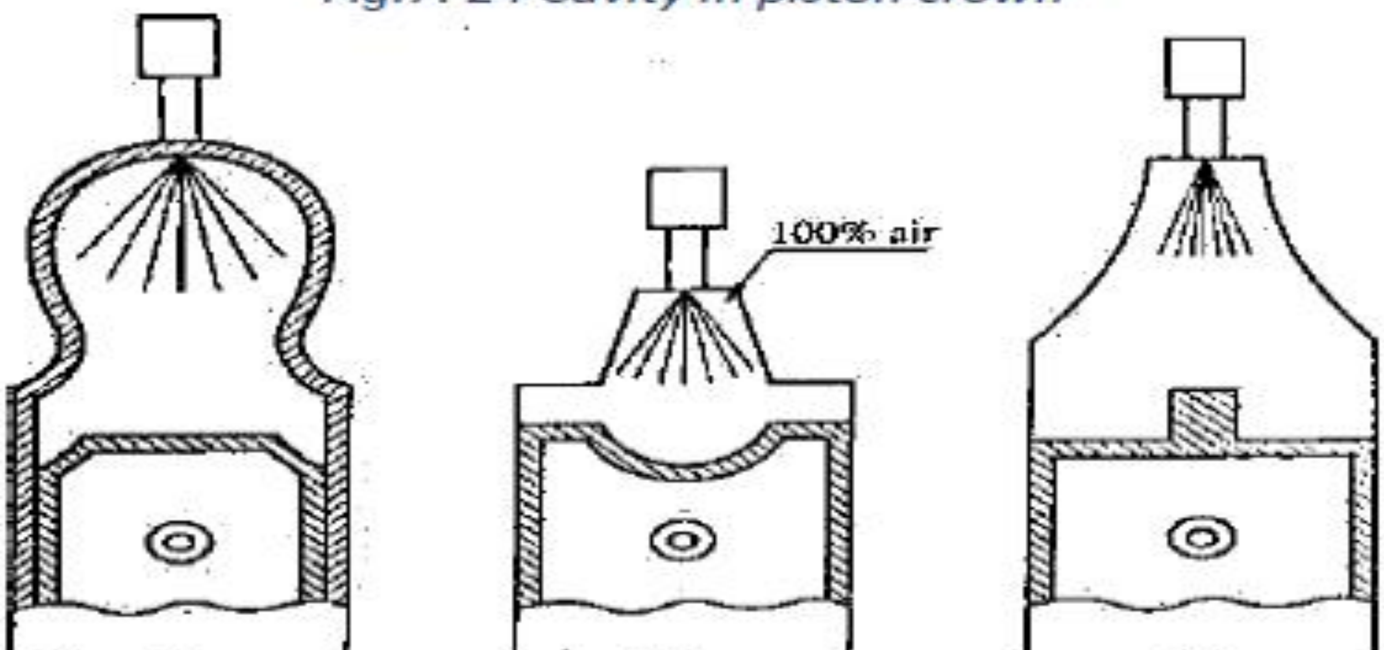
To achieve better combustion and swirl different types of cavity are formed in piston crown and cylinder head.

In some cases, the shape of cylinder head provides a cavity to create favourable conditions for better mixing and better burning.



(a) Shallow depth (b) Hemispherical (c) Cylindrical (d) Truncated cone

Fig.7. 24 Cavity in piston crown



(a) (b) (c)

Source – ICE by GANESHAN

Fig.7. 25 Cavity in piston crown

- Advantages and disadvantages of this type of combustion chambers are as follows :

- Advantages:

1. The thermal efficiency is high because heat transfer losses are less.
2. Easier starting because heat transfer losses are less.
3. Simple in construction.
4. In case of slow speed engines less costly fuels with longer delay can be used.

Disadvantages:

1. Engine size becomes large for generating same power due to large excess air required.
2. Due to less turbulence, high injection pressure is required with multiple hole nozzle.
3. Maintenance cost is higher.

Pre-Combustion Chamber

- A small additional chamber called as pre-combustion chamber is connected with main combustion chamber where fuel is injected in this pre-combustion chamber. Both these chambers are connected with small holes.
- As fuel is injected, combustion starts at pre-combustion chamber and products of combustion rush out through small holes to main combustion chamber with very high velocity, thus it generates turbulence as well as swirl which produces bulk combustion in the main combustion chamber. About 80% of energy is released in main combustion chamber.

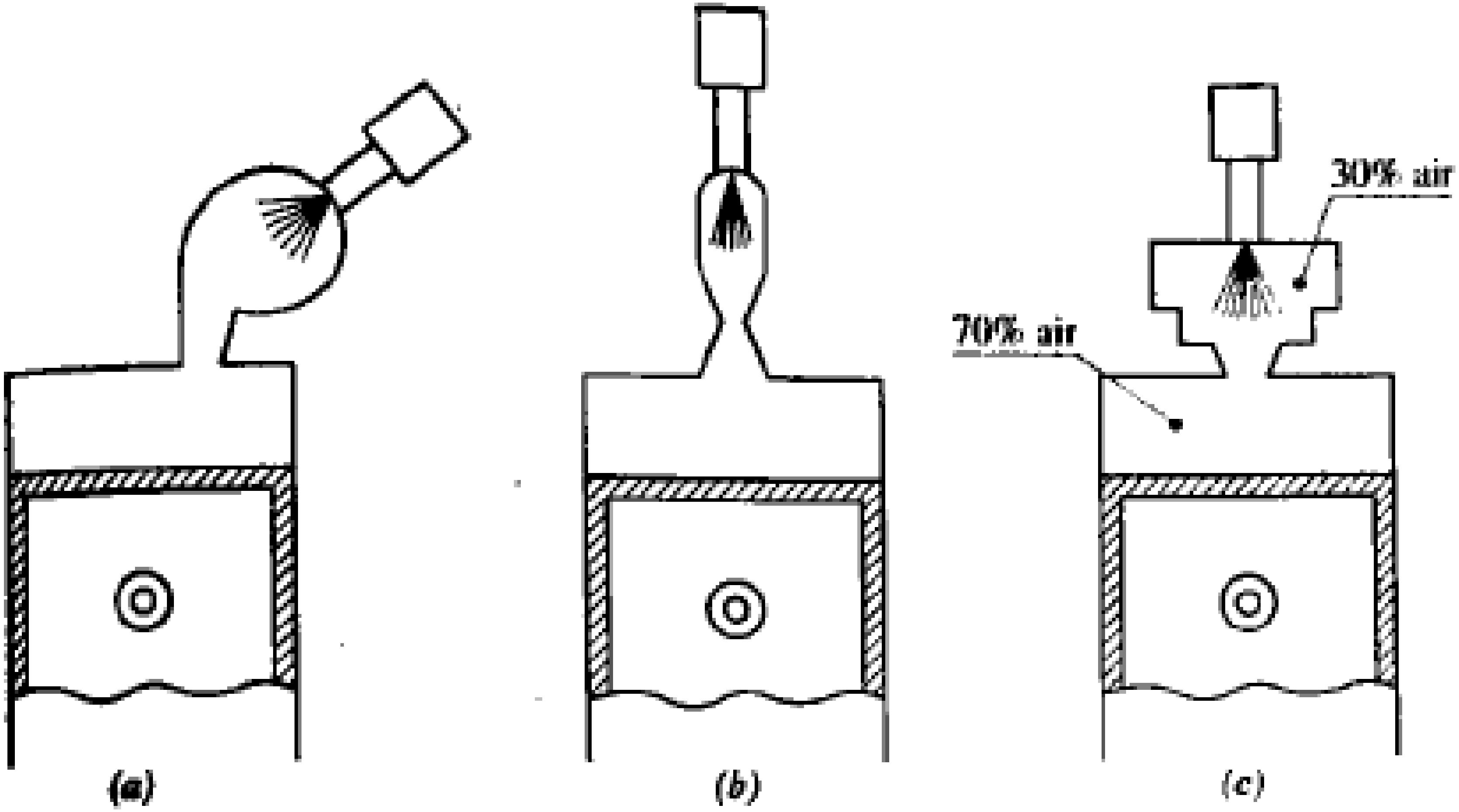


Fig.7. 26 Precombustion chamber

- Advantages:

1. Fuel with wide range of Cetane No. can be used.
2. As injection pressure is low, simple fuel nozzle can be used.
3. Smoother running of engine.
4. Engine can be run at high speed.
5. As delay period in main combustion chamber is very small, knocking tendency is very less. Also engine can run with higher compression ratio.

Disadvantages:

1. Engine design becomes complicated due to pre-combustion chamber.
2. Heat loss from pre-combustion chamber is high.

- **Turbulent or Indirect Injection (IDI) Combustion Chambers**

- **These combustion chambers are similar as that of pre-combustion chamber. The difference is that in pre-combustion chamber only 20 to 25% of total air enters while in these type 80 to 90% of total air circulates in pre-chamber.**
- **As high rate of "swirl" produces in this type, it is also known as swirl combustion chamber. During compression stroke most of the air from main combustion chamber enters to pre-combustion chamber, where high rate of swirl is produced.**

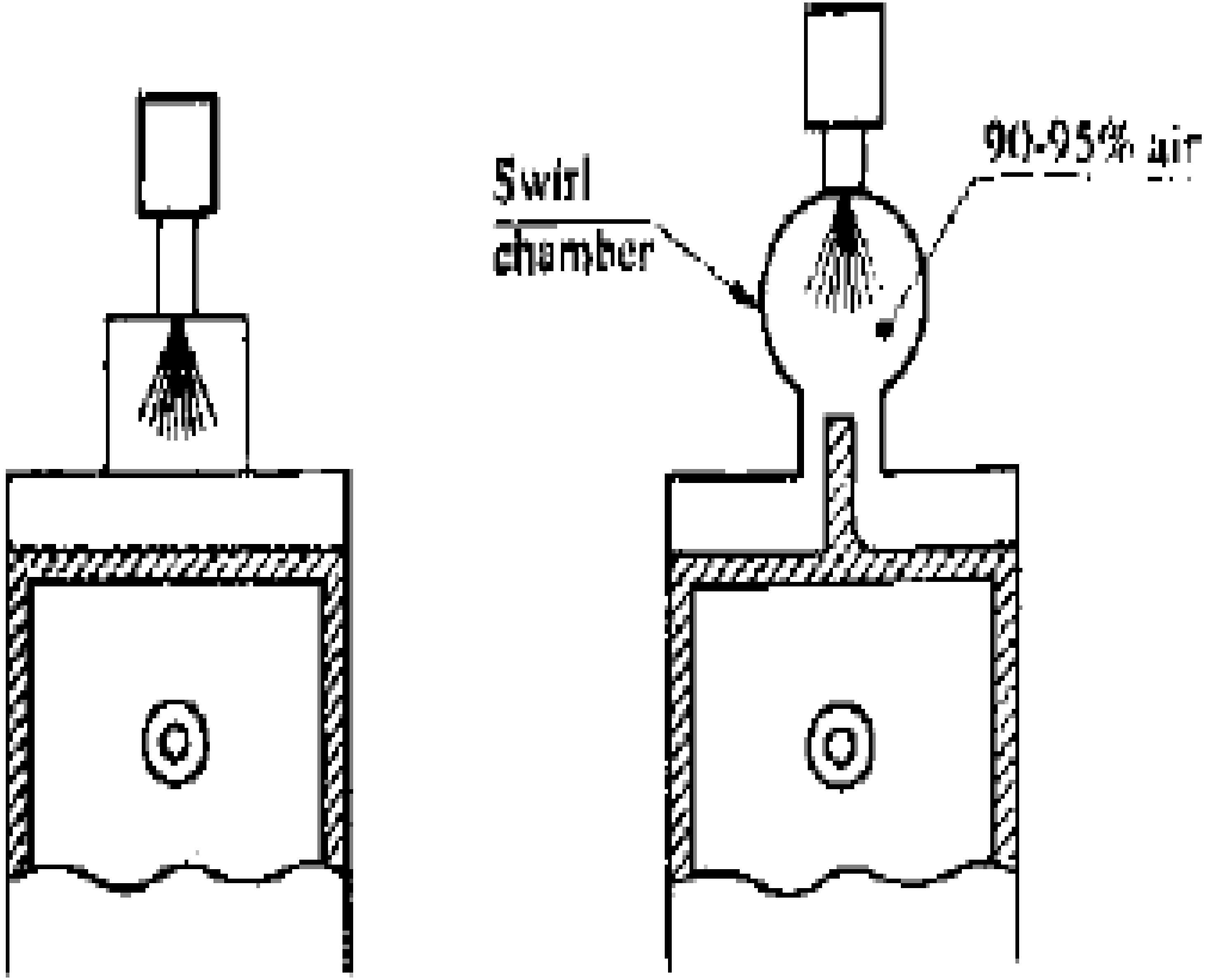


Fig.7. 27 Turbulent or Indirect Injection (IDI) Combustion Chambers

Assignment Questions

1. State and explain different combustion stages in SI engine?
2. State and explain different combustion stages in CI engine?
3. Explain knocking, properties and its effects in CI engine?
4. Explain different types of combustion chambers in SI and CI engines?
5. Explain the need for air motion and types?

IC Engines

3RD YEAR SEM-1 BTECH MECHANICAL ENGINEERING (R18A0313)

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UNIT 3

Testing and Performance of IC Engines

CO3: Evaluate the performance parameters of IC engines by conducting the performance tests.

UNIT – III (SYLLABUS)

Testing and Performance of IC Engines

Parameters of performance - measurement of cylinder pressure, fuel consumption, air intake, exhaust gas composition, Brake power – Determination of frictional losses and indicated power – Performance test – Heat balance sheet and chart.

COURSE OBJECTIVES

COURSE OBJECTIVES

UNIT - 1	CO1: To recall air standard cycles and compare with actual cycles, classification and working principles of air standard and actual cycles.
UNIT - 2	CO2: Understand the process of combustion of IC engines and deal with practical challenges in combustion process.
UNIT - 3	CO3: Evaluate the performance parameters of IC engines by conducting the performance tests.
UNIT - 4	CO4: Understand the classification of air compressors of positive displacement and rotodynamic.
UNIT - 5	CO5: Evaluate and analyze the performance of centrifugal and axial flow compressors.

Introduction

- The basic task in the design and development of I.C.Engines is to reduce the cost of production and improve the efficiency and power output.
- In order to achieve the above task, the engineer has to compare the engine developed by him with other engines in terms of its output and efficiency.
- Hence he has to test the engine and make measurements of relevant parameters that reflect the performance of the engine.
- In general the nature and number of tests to be carried out depend on a large number of factors. In this chapter only certain basic as well as important measurements and tests are described.

Important performance parameters of ic engine

- Important performance parameters of ic engine are as follow:
- i. Friction power
- ii. Indicated power
- iii. Brake power
- iv. Fuel consumption
- v. Air flow
- vi. Speed
- vii. Exhaust and coolant temperature
- viii. Emissions

Indicated Power (I.P.)

- The indicated power of an engine is the power developed within the cylinder.
- Knowing the speed and type of engine the rate of work developed can be evaluated.
- The apparatus used for drawing actual (p-V) diagram is called engine indicator.
- In order to estimate the indicated power of an engine the following methods are usually followed.

1. Using the indicator diagram
2. By adding two measured quantities viz. brake power and friction power
3. From morse test

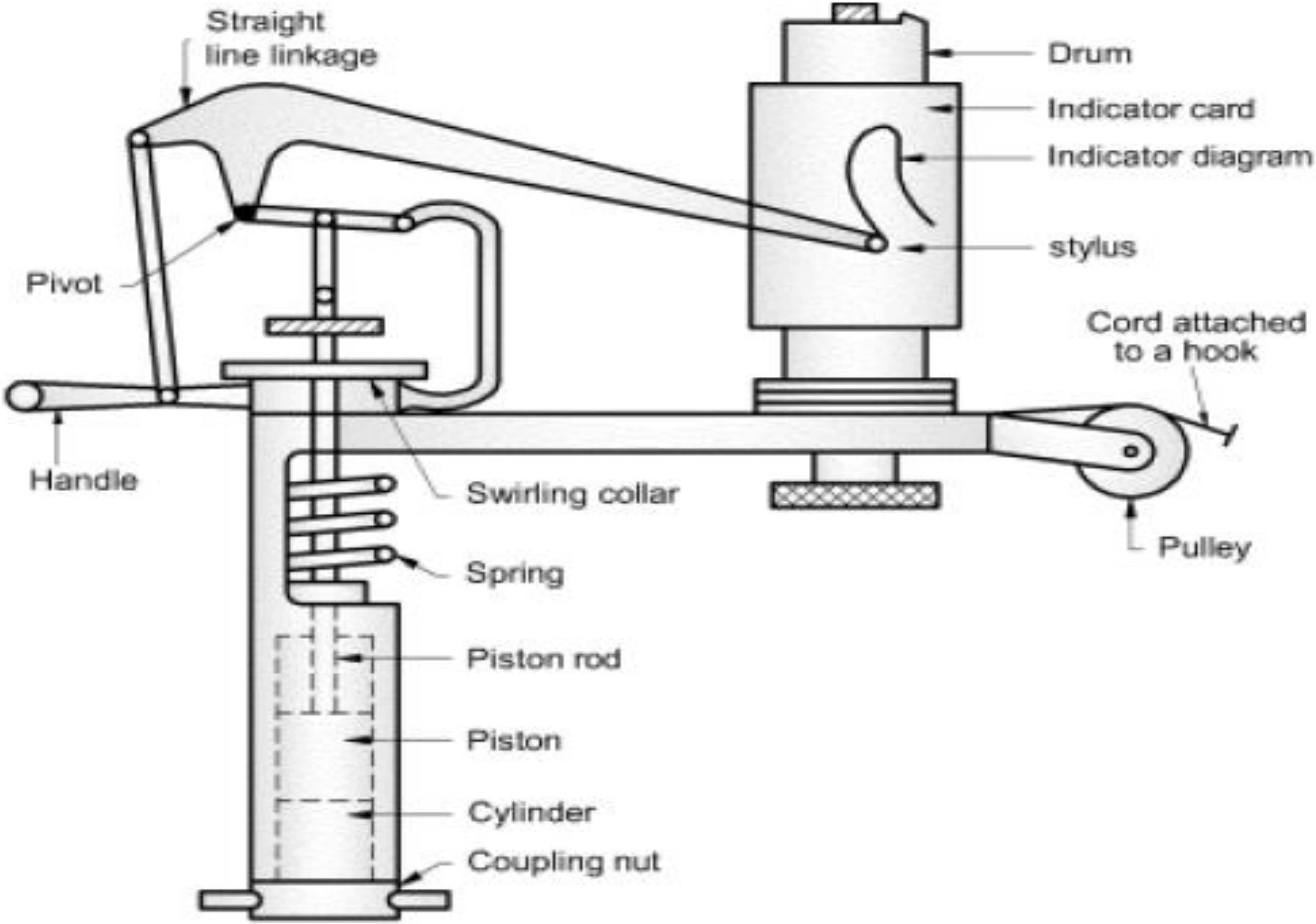

Fig. 9. 1 Engine indicator (Mechanical type)

- The gas tap connects through passages both to the cylinder of indicator and to the combustion chamber of the engine cylinder.
- The piston slides in the cylinder and the piston rod is connected to straight line linkage through a spring of proper stiffness.
- The straight line linkage is mounted on a swinging collar which can rotate on the top of the indicator cylinder.
- The spring controls the movement of the piston according to the pressure of engine cylinder.
- A stylus (pencil) is attached at the end of straight line linkage so that it moves in a vertical line in proportion to the movement of piston by magnifying its movement.

- A drum, to which a paper or indicator card can be fixed, is mounted on a vertical spring and shaft.
- It is rotated by a cord wound round it, the other end of which is attached to a point on the engine whose motion is same as that the piston of the engine cylinder.
- The vertical movement of the stylus and the horizontal movement of the cord combines to produce a closed figure known as indicator diagram.
- The area enclosed on the indicator diagram measures the work developed during a stroke to a definite scale.

Indicated Mean Effective Pressure (I.M.E.P.)

- It represents that constant pressure which if it is acted over the full length of the stroke would produce the same amount of work done by the piston as is actually produced by the engine cylinder during a cycle.

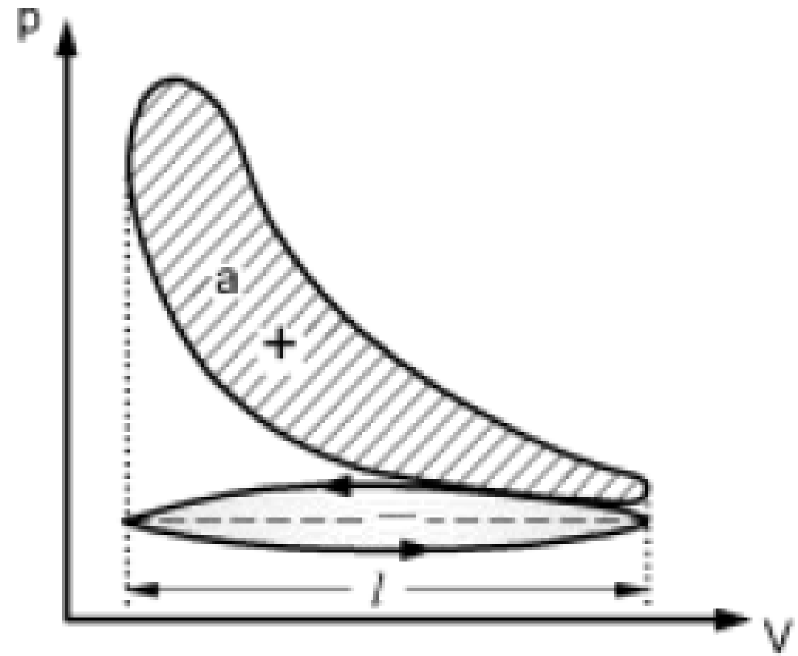

Fig. 9. 1 Indicator diagram

- i.m.e.p. can be determined with the help of indicator diagram shown in Fig. 9.2. The area of indicator diagram can be measured with the help of planimeter.

Let, a = Net area of indicator diagram (cm^2)

l = Length of indicator diagram (cm)

K = Spring constant, $N/cm^2/cm$

Therefore,

$$Mean\ height\ of\ diagram = \frac{a}{l}$$

$$i.m.e.p. = \frac{a}{l} \times K\ (N/cm^2)$$

Indicated power (I.P.):

Let, p_m = Indicated mean effective pressure (N/cm^2)

$$A = \text{Cross} - \text{sectional area of piston } (\text{cm}^2) = \frac{\pi}{4}(d)^2$$

Where,

d = Diameter of piston or bore (cm)

L = Length of stroke (m)

n = Number of power strokes per minute

N = Speed of the engine (r.p.m.)

n = Power stroke /min

= N/2 for 4 S engine as one power stroke per 2 rev &

= N for 2S engine

$$\text{Force on piston} = p_m \times \text{A (Newtons)}$$

$$I.P. = p_m A L n \ (Nm / min)$$

$$I.P. = p_m A L \frac{n}{60} \ (Nm/s \ \text{or} \ W)$$

$$I.P. = \frac{p_m A L n}{60000} \ (kW)$$

Measurement of Brake Power (B.P.)

- Measurement of brake power is an important test carried out in the test schedule of an engine.
- It involves the determination of the torque and the angular speed of the engine output shaft. The torque measuring device is called a dynamometer.

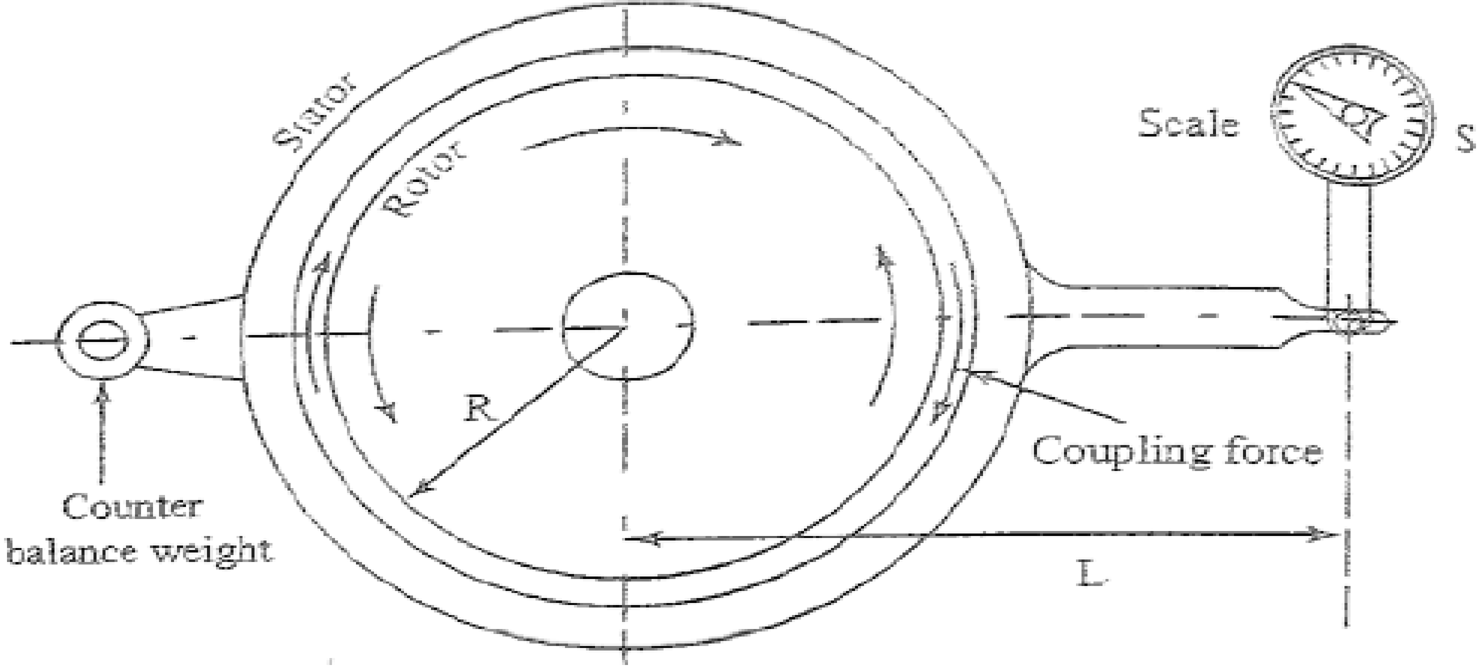

Fig. 9. 2 Principle of a dynamometer

- Figure shows the basic principle of a dynamometer. A rotor driven by the engine under test, is mechanically, hydraulically or electromagnetically coupled to a stator. For every revolution of the shaft, the rotor periphery moves through a distance $2\pi R$ against the coupling force, F. Hence the work done per revolution is

$$W = 2\pi RF$$

- The external moment or torque is equal to S x L , where S is the scale reading and L is the arm length. This moment balances the turning moment R x F, i.e.,

$$S \times L = R \times F$$

Therefore

$$\text{Work done/revolution} = 2\pi SL$$

$$\text{Work done/minute} = 2\pi SLN$$

- Hence brake power is given by

$$bp = 2\pi NT \ Watts$$

Prony Brake Dynamometer:

– One of the simplest methods of measuring power output of an engine is to attempt to stop the engine by means of a mechanical brake on the flywheel and measure the weight which an arm attached to the brake will support, as it tries to rotate with the flywheel. This system is known as the prony brake and from its use, the expression brake power has come. The prony brake consists of a frame with two brake shoes gripping the flywheel

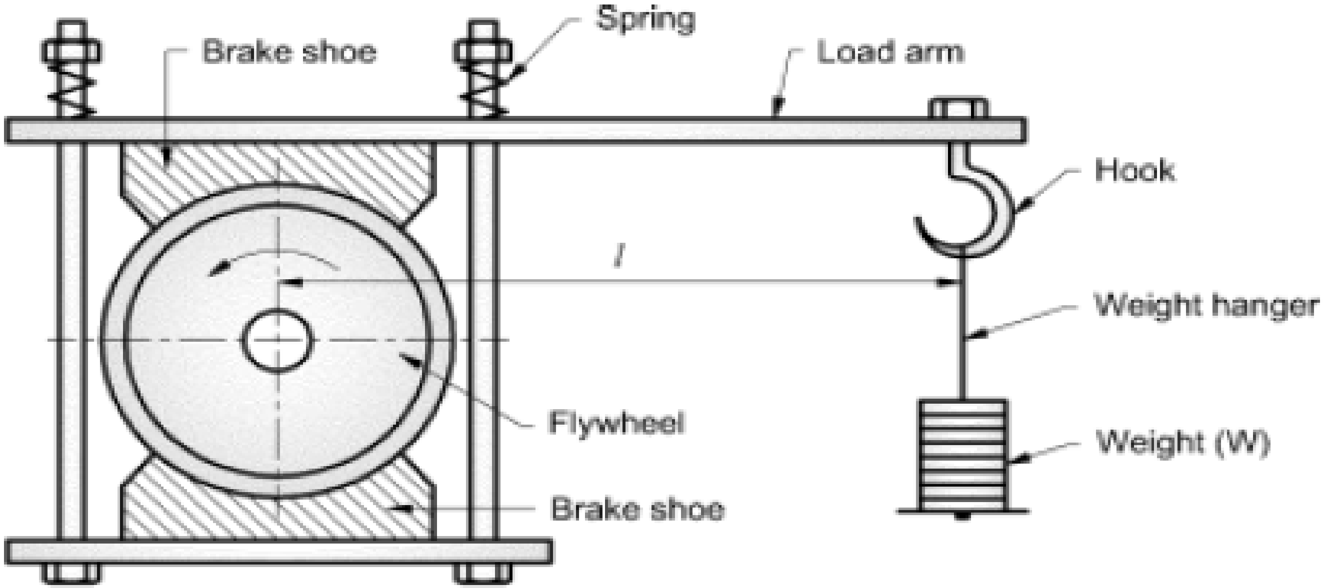

Fig. 9. 3 Prony Brake Dynamometer

– The pressure of the brake shoes on the fly wheel can be varied by the spring loaded using nuts on the top of the frame. The wooden block when pressed into contact with the rotating drum opposes the engine torque and the power is dissipated in overcoming frictional resistance. The power absorbed is converted into heat and hence this type of dynamometer must be cooled.

Let, W = Weight on hanger (N)

L = Distance from centre to flywheel to the hanger called load arm (m)

N = Speed (rpm)

Torque = W × L

$$B.P. = \frac{(W \times L)2\pi N}{60000}\ kW$$

Rope brake Dynamometer:

– The rope brake as shown in Fig. is another simple device for measuring bp of an engine. It consists of a number of turns of rope wound around the rotating drum attached to the output shaft.

– One side of the rope is connected to a spring balance and the other to a loading device. The power absorbed is due to friction between the rope and the drum. The drum therefore requires cooling.

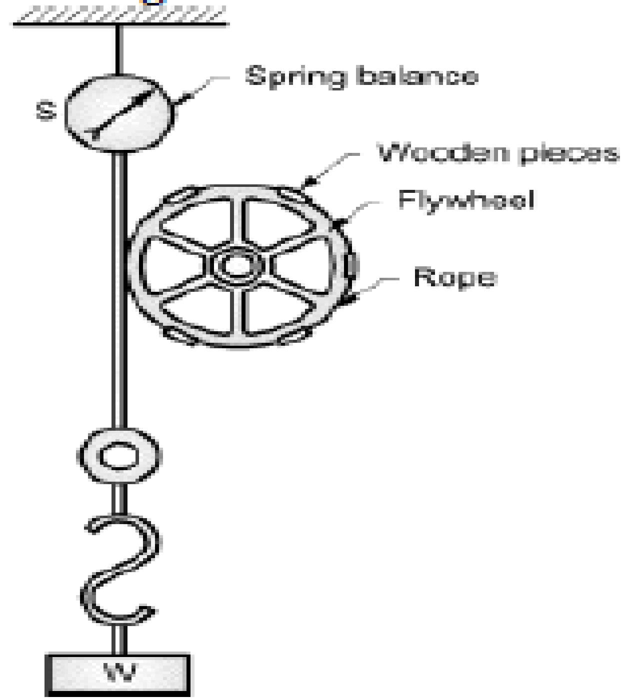

Fig. 9. 4 Rope Brake Dynamometer

Rope brake is quite cheaper and can be easily fabricated but not very accurate because of changes in the friction coefficient of the rope with temperature.

Let, W = Dead weight (Newtons)

S = Spring balance reading (Newtons)

$$\text{Rb} = \text{Radius of brake drum or flywheel (effective)} = \frac{D + d}{2}$$

Where, D = Brake drum diameter, and

d = Rope diameter

N = Speed in r.p.m.

Brake load or net load = (W – S)

Braking torque = (W – S) Rb

$$Brake\ Power = \frac{(W - S)R_b \times 2\pi N}{60000} kW$$

With the help of brake power, the brake mean effective pressure (b.m.e.p.) can be

Hydraulic Dynamometer:

- The hydraulic dynamometer was developed by Froude in 1877. This dynamometer is useful for measuring brake power over wide range of power and speeds.
- These are accurate, simple in construction, and free from vibration and maintenance.

Fig. shows the part of a hydraulic dynamometer. It consists of a shaft supported in shaft bearings. The casing is carried by the anti-friction trunions so that it is free to swirl about the same axis as the axis of the shaft.

The shaft carries a rotor in the form of semi-elliptical cross-section divided one from another by means of oblique vanes.

The internal faces of the casing are provided with liners which are pocketed in the same way.

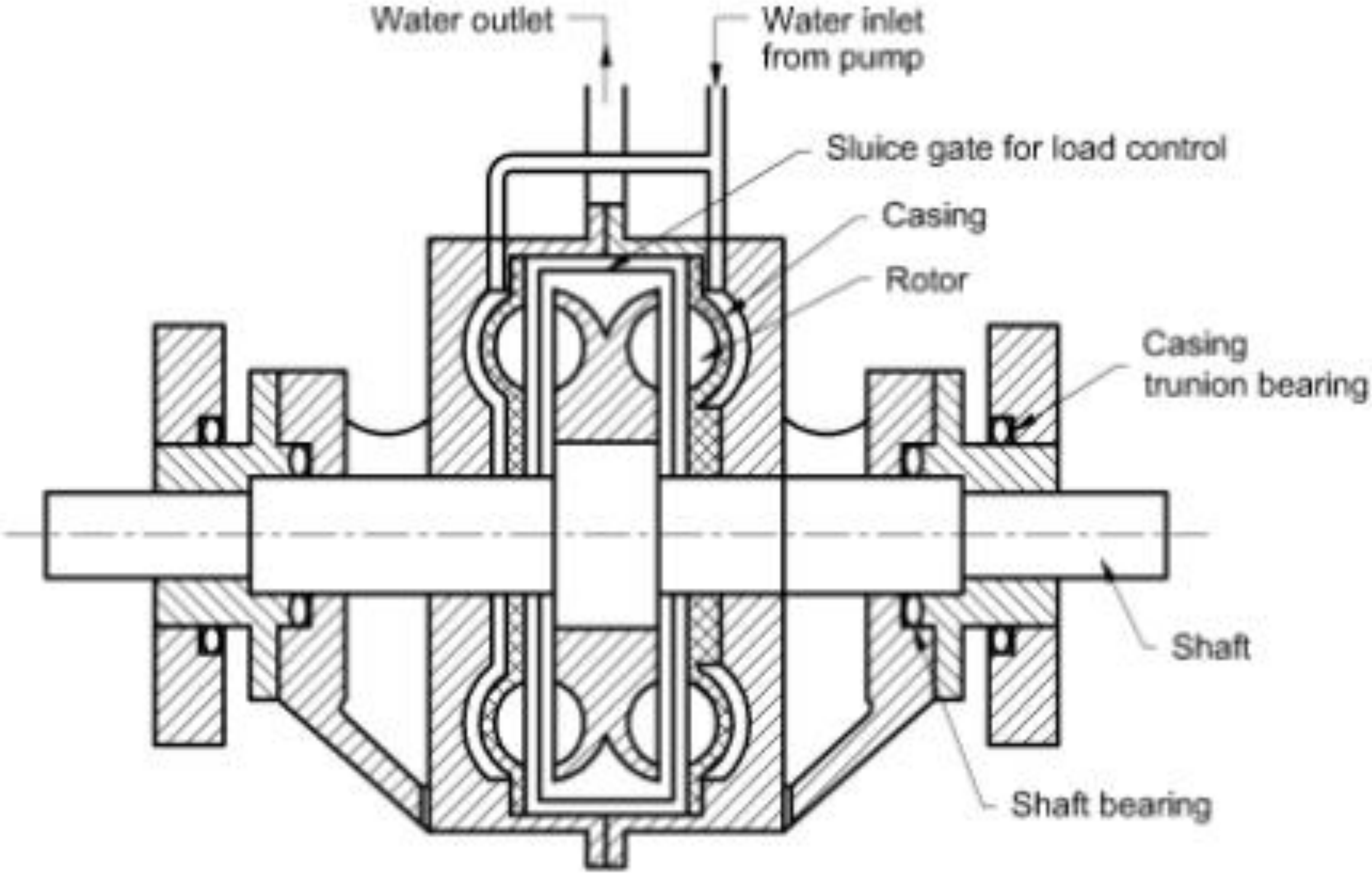

Fig. 9. 5 Hydraulic Dynamometer

Willan's line method

- In Willan's line method, gross fuel consumption vs. BP at a constant speed is plotted and the graph is extrapolated back to zero fuel consumption as illustrated in Figure. The point where this graph cuts the BP axis in an indication of the friction power of the engine at that speed. This negative work represents the combined loss due to mechanical friction, pumping and blow by.
- In petrol engine, we keep the air-fuel mixture constant and vary the amount of the mixture intake for required torque or power. This is called quantitative governing. In diesel engine, we draw a constant volume of air (compressed) and vary the fuel injected. Technically, we alter the quality of the air - fuel mixture, this is called qualitative governing.
- In SI engine, at low speeds, the air mixture intake is very low (quantitative governing). Hence, there will be a low pressure region created inside the cylinder due to which, there will be pumping losses. Therefore, there will be more friction power than actual, we get erroneous output if we use Willan's line test for SI engine.
- If we use the same test for CI engines, there is qualitative governing and hence, there will be fixed amount of air entering the cylinder and no negative pressure and pumping losses occurs. So, we get a relatively closer value of friction power, the errors are greatly minimized.

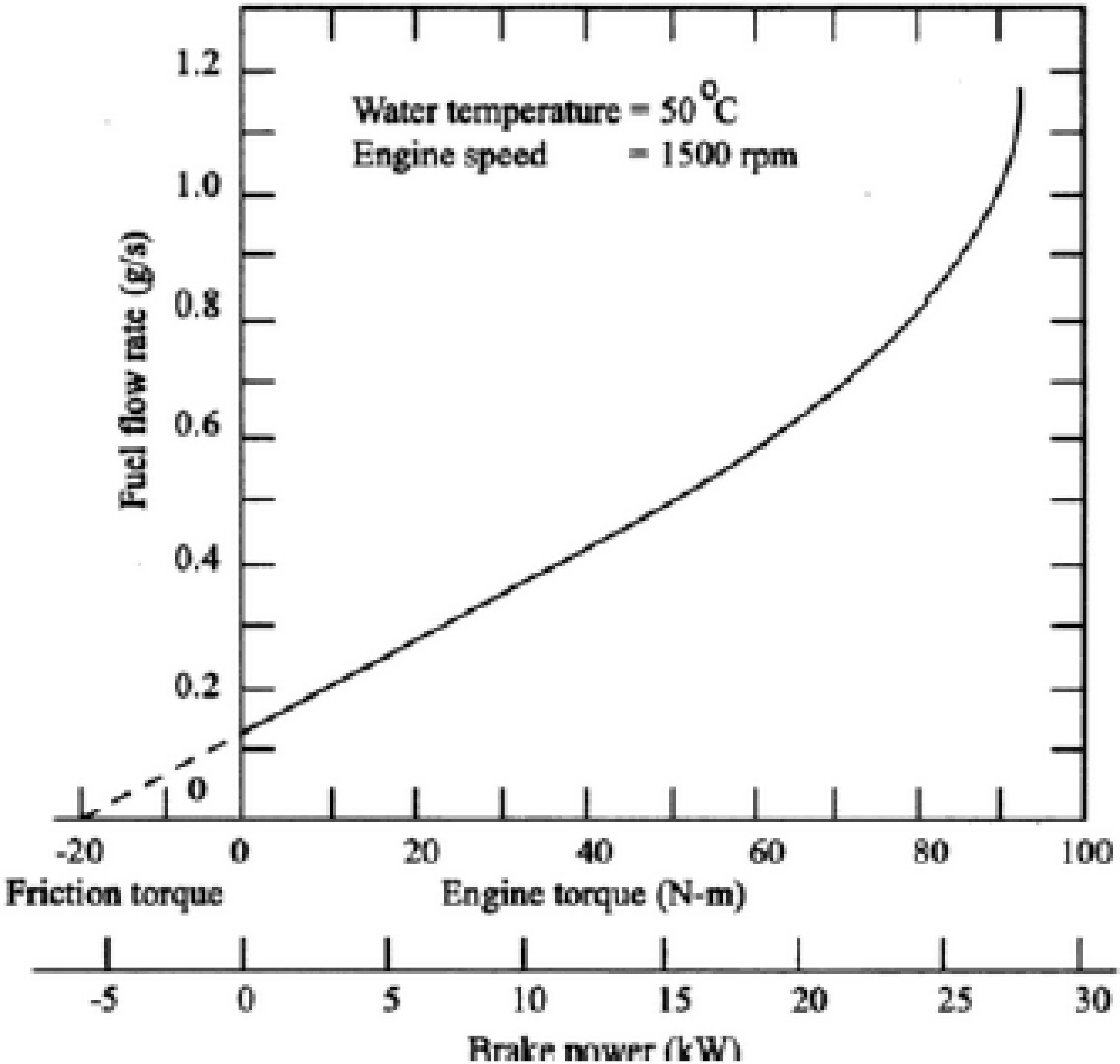

Fig. 9. 8 Willan's line method

- The main drawback of this method is the long distance to be extrapolated from data measured between 5 and 40% load towards the zero line of fuel input.

Morse test

- The indicated power (ip) of multi cylinder engine can be found out by this method, is not possible to find ip for single cylinder that is the limitation of this method. Also, in the method the indicator or indicator diagram is not required. For multi cylinder engine, power developed in any one cylinder is cut off and output power (bp) is measured. In case of petrol (S.I.) engines, each cylinder in turn is rendered inoperative by shorting the spark plug of the cylinder and in case of diesel (C.I.) engines by cutting off the fuel supply to cylinders successively.
- Consider a four cylinder spark ignition engine coupled to a dynamometer. Throughout the test the engine is run at constant speed of N r.p.m. It is assumed that the pumping and mechanical friction losses are the same whether the cylinder is working or not. Also, the throttle position is kept constant throughout the test.
- Let :

  B = B.P. of the engine when all the four cylinders are working

  B_1 = B.P. of the engine when cylinder - 1 is cut - off

  B_2 = B.P. of the engine when the cylinder - 2 is cut-off

  B_3 = B.P. of the engine when cylinder - 3 is cut-off

  B_4 = B.P. of the engine when cylinder - 4 is cut-off.

  I_1, I_2, I_3 and I_4 be the indicated power (I.P.) developed by cylinder numbers 1, 2, 3 and 4 respectively and their corresponding friction power (F.P) be F_1, F_2, F_3 and F_4.

Total brake power (B) = $(I_1 + I_2 + I_3 + I_4) - (F_1 + F_2 + F_3 + F_4)$

$B_1 = (I_2 + I_3 + I_4) - (F_1 + F_2 + F_3 + F_4)$

On subtracting Equation

$B - B_1 = I_1$

Similarly, we could write the equations when the other cylinders are cut-off in turn as follows:

$B - B_2 = I_2$

$B - B_3 = I_3$

$B - B_4 = I_4$

On adding Equations

Total indicated power, $I = I_1 + I_2 + I_3 + I_4 = 4B - (B_1 + B_2 + B_3 + B_4)$

Frictional power, $F = I - B$

F.P. = I.P. – B.P

Measurement of Air Consumption

Air Flow Meter:

- The air flow meter is shown in Fig. for measurement of air consumption in a laboratory. It consists of a surge tank of capacity (400-600) times to the displacement volume of the engine so as to reduce pulsations. The surge tank is connected to the intake side of the engine with an orifice of cross-sectional area A and of known coefficient of discharge Cd.
- The pressure difference causing the air flow is measured with the help of a water manometer.
- Let $(\Delta H)_w$ be the pressure difference measured in cm of water and $(\Delta H)_{air}$ the corresponding pressure difference in cm of air. Based on unit area of manometer, the head in terms of meters of air is given by,

$$(\Delta p) = (\Delta H)_w \times 1 \times \rho_w = (\Delta H)_{air} \times 1 \times \rho_{air}$$

$$(\Delta H)_{air} = \frac{\rho_w}{\rho_{air}} \times (\Delta H)_w$$

where , $\rho_w = 1000 \text{ kg} / m^3$

- The volume flow rate of air is given by,

$$V = C_d \times A \times \sqrt{2g(\Delta H)_{air}}$$

$$V = C_d \times A \times \sqrt{2g \frac{\rho_w}{\rho_{air}} \times (\Delta H)_w}$$

$$m_{air} = V.\rho_a$$

$$m_{air} = C_d \times A \times \sqrt{2g.\rho_w.\rho_a(\Delta H)_w}$$

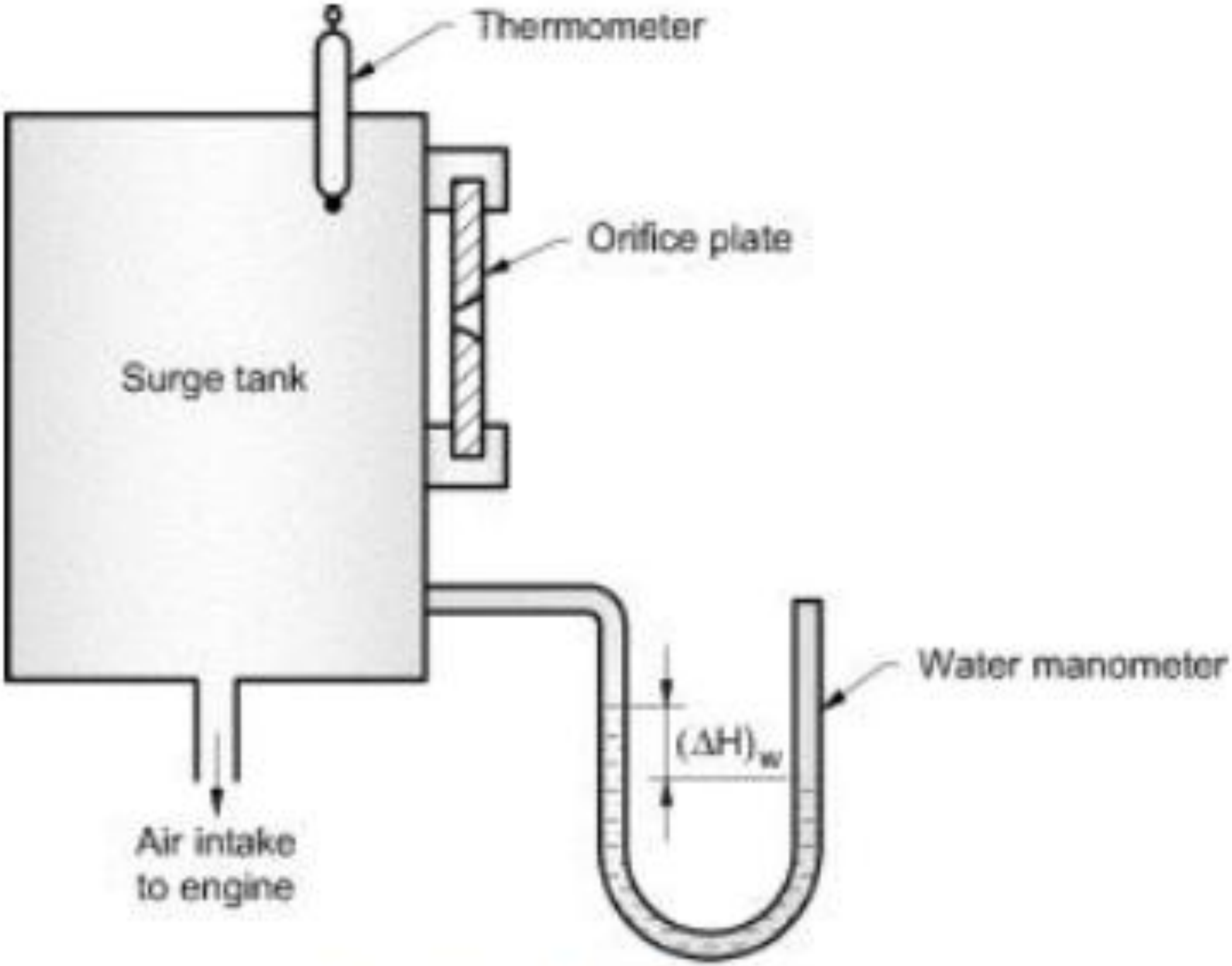

Fig. 9. 12 Air flow meter

Heat Balance Sheet or Energy Balance

Heat balance sheet represents an account of the heat supplied in fuel and released in combustion and its utilization in the engine. Necessary information concerning the performance of the engine is obtained from the heat balance sheet.

In order to draw a heat balance sheet, a complete test on the engine must be carried out while the engine is run at constant load.

Heat supplied: Energy is supplied to the engine in the form of fuel supplied to the engine, its heat being released during combustion.

$$Heat\ supplied = m_f \times C.V.\,(kJ/min)$$

here, m_f= mass flow rate of fuel (kg/min)

C.V. = Calorific value of fuel in kJ/kg

Heat expenditure / Heat utilised:

– Heat energy of the fuel is partly converted into useful work equivalent to its B.P. and the remainder is carried away by cooling water, exhaust gases and some of heat is lost in radiation, incomplete combustion, lubricating oil, which remains unaccounted for.

Note: Frictional power is not accounted in the heat calculations since friction work is converted into heat which in turn is transferred partly to cooling water and remainder is carried away by exhaust gases.

Calculations for expenditure of heat are as follows:

a) Heat equivalent to B.P.:

– Heat equivalent to brake power per min = B.P. × 60 (kJ/min)

b) Heat rejected to cooling water:

– Heat carried away by cooling water per minute

$$= m_w \times C_{pw} \times (t_{wo} - t_{wi})$$

Where, m_w = mass of cooling water circulated in kg/min

C_{pw} = specific heat of water = 4.187 kJ/kg K

t_{wi} = cooling water inlet temperature (°C)

t_{wo} = cooling water outlet temperature (°C)

Heat carried away by exhaust gases:

– Heat carried away by exhaust gases per minute

$$= m_g \times C_{pg} \times (t_g - t_o)$$

Heat balance sheet

Table 9. 2 Heat balance sheet

Heat supplied	kJ/min	%	Heat Expenditure	kJ/min	%
Heat supplied by Combustion of fuel = $\dot{m}_f \times C.V.$	–	100	(a) Heat in B.P. = B.P. × 60	–	–
			(b) Heat rejected to cooling water $= \dot{m}_w \times C_{pw} \times (t_{c2} - t_{c1})$	–	–
			(c) Heat carried away by exhaust gases $= \dot{m}_g \times C_{pg} \times (t_g - t_0)$	–	–
			(d) Heat unaccounted due to radiation etc. (by difference)	–	–
Total	–	100%	Total	–	100%

Exhaust Gas Composition

- Internal combustion engines, converts chemical energy contained in the fuel into mechanical power.
- IC Engine fuel is a mixture of hydrocarbons which—during an ideal combustion process—would produce only carbon dioxide (CO_2) and water vapor (H_2O). Indeed, exhaust gases are primarily composed of CO_2, H_2O and the unused portion of engine charge air.
- The volumetric concentrations of these gases in diesel exhaust are typically in the following ranges:
- CO_2 - ... 12%
- H_2O - ... 12%
- O_2 - ... 17%
- N_2 - balance.

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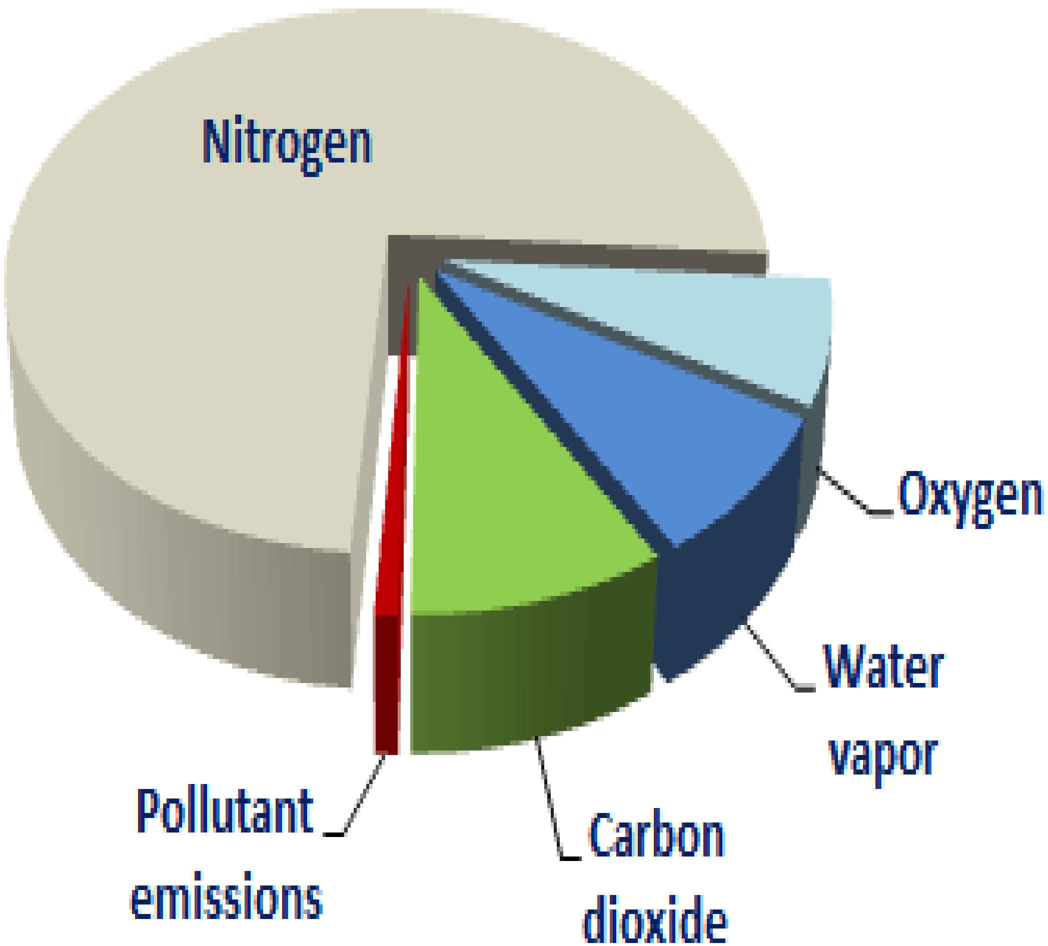
Exhaust Gas Composition

- The concentrations depend on the engine load, with the content of CO_2 and H_2O increasing and that of O_2 decreasing with increasing engine load. None of these principal diesel emissions (with the exception of CO_2 for its greenhouse gas properties) have adverse health or environmental effects.
- Diesel emissions include also pollutants that can have adverse health and/or environmental effects.
- Most of these pollutants originate from various non-ideal processes during combustion, such as incomplete combustion of fuel, reactions between mixture components under high temperature and pressure, combustion of engine lubricating oil and oil additives as well as combustion of non-hydrocarbon components of diesel fuel, such as sulfur compounds and fuel additives.



Relative concentration of pollutant emissions in diesel exhaust gas

Representative for diesel engines before the introduction of advanced aftertreatment

Exhaust Gas Composition

- Common pollutants include unburned hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx) or particulate matter (PM).
- Total concentration of pollutants in diesel exhaust gases typically amounts to some tenths of one.
- Much lower, “near-zero” levels of pollutants are emitted from modern diesel engines equipped with emission after treatment devices such as NOx reduction catalysts and particulate filters.
- There are other sources that can contribute to pollutant emissions from internal combustion engines—usually in small concentrations, but in some cases containing material of high toxicity.

Exhaust Gas Composition

- These additional emissions can include metals and other compounds from engine wear or compounds emitted from emission control catalysts (via catalyst attrition or volatilization of solid compounds at high exhaust temperatures).
- Formation of new species—normally not present in engine exhaust—can also be facilitated by catalysts.
- This seems to be especially the case when catalysts are introduced into the combustion chamber.
- For example, some fuel additives—so-called “fuel-borne catalysts”—used to support the regeneration of diesel particulate filters have been linked to emissions of highly toxic dioxins.

Example 4.1 *A rope-brake dynamometer was used to measure the brake power of a single cylinder, four-stroke cycle petrol engine. It was found that the torque due to brake load was 175 Nm and the engine makes 500 rpm. Determine the brake power developed by the engine.*

Solution

Given A single-cylinder, four-stroke petrol engine with a rope-brake dynamometer

$$k = 1$$

$$T = 175 \text{ Nm} \qquad N = 500$$

To find Brake power

Analysis The brake power is given by

$$BP = \frac{2\pi N T}{60{,}000} = \frac{2\pi \times 500 \times 175}{60{,}000} = \mathbf{9.16\ kW}$$

Example 4.2 *A four-cylinder, four-stroke petrol engine develops indicated power of 14.7 kW at 1000 rpm. The mean effective pressure is 5.5 bar. Calculate the bore and stroke of the engine, if the stroke is 1.5 times the bore.*

Solution

Given A four-cylinder, four-stroke cycle petrol engine

$$k = 4 \qquad n = \frac{N}{2}$$

$$IP = 14.7 \text{ kW} \qquad N = 1000 \text{ rpm}$$

$$p_m = 5.5 \text{ bar} = 550 \text{ kPa}$$

$$L = 1.5\, d$$

To find (i) Bore (ii) Stroke

Analysis The power of an engine is given by

$$IP = p_m \frac{L\, A\, n\, k}{60}$$

$$14.7 = 550 \times \frac{(1.5\, d)}{60} \times \left(\frac{\pi}{4} d^2\right) \times \frac{1000}{2} \times 4$$

$$d^3 = 6.806 \times 10^{-4} \text{ m}^3$$

Bore, $d = 0.08796$ m or **87.96 mm**

Stroke $L = 1.5\, d =$ **131.94 mm.**

1. *A four cylinder diesel engine of 4-stroke type has stroke to bore ratio as 1.2 and the cylinder diameter is 12 cm. Estimate indicated power of the engine using the indicator diagram arrangement. Indicator card shows the diagram having area of 30 cm^2 and length as half of stroke. Indicator spring constant is 20 × 10^3 kN/m^2 and engine is running at 2000 rpm. Also find out mechanical efficiency of engine if 10% of power is lost in friction and other losses.*

Solution:

From stroke to bore ratio i.e. $\frac{L}{D}$ = 1.2 and cylinder diameter = bore, i.e. D = 12 cm, so L = 14.4 cm

Area of indicator diagram = 30 cm^2 = 30×10^{-4} m^2

$$\text{Length of indicator diagram} = \frac{1}{2} \times \text{stroke}$$

$$= 7.2 \text{ cm or } 7.2 \times 10^{-2} \text{ m}$$

$$\text{Mean effective pressure} = \frac{30\times10^{-4}\times20\times10^{3}\times10^{3}}{7.2\times10^{-2}}$$

$$\text{m.e.p.} = 8333.333 \times 10^{2} \text{ N/m}^2$$

$$\text{Cross-sectional area of piston} = \frac{\pi}{4}D^2 = 0.01131 \text{ m}^2$$

For one cylinder indicated power

$$= \frac{8333.333 \times 10^2 \times 0.01131 \times 14.4 \times 10^{-2} \times 2000}{2 \times 60}$$

$$= 22619.9 \text{ W}$$

For four cylinders total indicated power $= 90479.6$ W

Frictional power loss $= 0.10 \times 90479.6 = 9047.96$ W

Brake power available $=$ Indicated power $-$ Frictional power

$$= (90479.6 - 9047.96)$$

$$= 81431.64 \text{ W}$$

Therefore, mechanical efficiency of engine $= \dfrac{\text{brake power}}{\text{indicated power}}$

$$= \frac{81431.64}{90479.6}$$

$$= 0.90$$

Indicated power	= **90479.6 W**
Mechanical efficiency	= **90%**

Ans.

Example 4.3 *A four-cylinder, two-stroke cycle petrol engine develops 30 kW at 2500 rpm. The mean effective pressure on each piston is 8 bar and mechanical efficiency is 80%. Calculate the diameter and stroke of each cylinder, if the stroke to bore ratio is 1.5. Also calculate the fuel consumption of the engine, if the brake thermal efficiency is 28%. The calorific value of the fuel is 43900 kJ/kg.*

Solution

Given A four-cylinder, two-stroke cycle petrol engine

$k = 4$ $BP = 30$ kW

$N = 2500$ rpm $n = N$

$\eta_{mech} = 0.8$ $L = 1.5d$

$\eta_{bth} = 0.28$ $CV = 43900$ kJ/kg

$p_m = 8$ bar $= 800$ kPa

To find

(i) Bore of cylinder,

(ii) Stroke of pistion, and

(iii) Fuel consumption rate ($Bsfc$).

Analysis The mechanical efficiency is given as

$$\eta_{mech} = \frac{BP}{IP}$$

$$\therefore \quad IP = \frac{30 \text{ kW}}{0.8} = 37.5 \text{ kW}$$

(i) The indicated power is expressed as

$$IP = \frac{p_m L A n k}{60}$$

$$\text{or} \quad 37.5 = \frac{800 \times (1.5d) \times \left(\frac{\pi}{4} d^2\right) \times 2500 \times 4}{60}$$

$$\text{or} \quad d^3 = 0.000238 \text{ m}^3$$

$$\text{Bore} \quad d = 0.062 \text{ m} \quad \text{or} \quad \mathbf{62 \text{ mm}}$$

(ii) $$\text{Stroke} \quad L = 1.5d = \mathbf{93 \text{ mm}}$$

(iii) The brake thermal efficiency is given by

$$\eta_{bth} = \frac{BP}{\dot{m}_f CV}$$

$$\text{or} \quad \dot{m}_f = \frac{30 \text{ kW}}{0.28 \times (43900 \text{ kJ/kg})}$$

$$= 0.00244 \text{ kg/s} \quad \text{or} \quad 8.78 \text{ kg/h}$$

The brake specific fuel consumption

$$Bsfc = \frac{\dot{m}_f(\text{kg/h})}{BP(\text{kW})} = \frac{8.78}{30}$$

$$= \mathbf{0.293\ kg/kWh}$$

Example 4.4 *The following results were obtained from a test on a single-cylinder, four-stroke Diesel engine. Diameter of the cylinder is 30 cm, stroke of the piston is 45 cm, indicated mean effective pressure is 540 kPa and engine speed is 2400 rpm. Calculate the indicated power of the engine.*

Solution

Given A single-cylinder, four-stroke Diesel engine

$d = 30\text{ cm} = 0.3\text{ m}$ $L = 45\text{ cm} = 0.45\text{ m}$

$p_{mi} = 540\text{ kPa}$ $N = 2400\text{ rpm}$

$k = 1$

$$n = \frac{N}{2} = 1200 \text{ working stroke per minute}$$

Analysis The cross-sectional area of the cylinder

$$A = \frac{\pi}{4} d^2 = \frac{\pi}{4} \times (0.3)^2 = 0.07068 \text{ m}^2$$

Indicated power (IP)

$$IP = \frac{p_{mi} \ L \ A \ n \ k}{60}$$

$$= \frac{(540 \text{ kPa}) \times (0.45 \text{ m}) \times (0.07068 \text{ m}^2) \times 1200 \times 1}{60}$$

$$= \mathbf{343.53 \text{ kW}}$$

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4. An eight cylinder diesel engine of two stroke type has specific fuel consumption of 0.25 kg/kWh. The brake mean effective pressure of each cylinder is 1.5 MPa and engine run at 100 rpm. The bore and stroke of cylinder are 85 cm and 220 cm respectively. Considering the calorific value of diesel as 43 MJ/kg determine the brake power of engine, fuel consumption in kg/hr and brake thermal efficiency of engine.

Solution:

$$\text{Brake power of engine} = P_{b\,\text{mep}} \times L \times A \times N$$

$$= \frac{1.5\times10^{3}\times(2.2)\times\left(\frac{\pi}{4}\times(0.85)^{2}\right)\times100}{60}$$

$$= 3120.97 \text{ kW or } 31.21 \text{ MW}$$

$$\boxed{\text{Brake power} = \mathbf{31.21\ MW}} \quad \textbf{Ans.}$$

$$\text{The fuel consumption in kg/hr} = 0.25 \times 3120.97 = 780.24 \text{ kg/hr}$$

In order to find out brake thermal efficiency the heat input from fuel per second is required.

$$\text{Heat from fuel, kJ/s} = \frac{780.24\times43\times10^{3}}{3600} = 9319.53 \text{ kJ/s}$$

$$\text{Energy to brake power} = 3120.97 \text{ kW}$$

$$\text{Brake thermal efficiency} = \frac{3120.97}{9319.53} = 0.33488 \text{ or } 33.49\%$$

$$\boxed{\text{Fuel consumption} = 780.24 \text{ kg/hr, Brake thermal efficiency} = \mathbf{33.49\%}} \quad \textbf{Ans.}$$

Example 4.22 *A full-load test was conducted on a two-stroke engine and the following results were obtained:*

Speed	= 500 rpm
Brake load	= 500 N
imep	= 3 bar
Oil consumtion	= 5 kg/h
Jacket water temperature rise	= 35°C
Jacket water flow rate	= 7 kg/min.
A/F ratio by mass	= 30
Exhaust gas temperature	= 350°C
Room temperature	= 25°C
Atmospheric pressure	= 1 bar
Cylinder diameter	= 22 cm
Stroke	= 28 cm
Brake diameter	= 1.6 m
CV of fuel	= 42000 kJ/kg
Proportion of H_2 by mass in fuel	= 15%
Specific heat of exhaust gas	= 1.0 kJ/kg · K
Specific heat of dry steam	= 2.0 kJ/kg · K

Calculate

(a) indicated thermal efficiency,

(b) *Specific fuel consumtion, and*

(c) *Volumetric efficiency based on atmospheric conditions.*

Draw up a heat balance sheet for test.

Solution

Given A single-cylinder, two-stroke Diesel engine:

$n = N = 500$ rpm	$A/F = 30$
$d = 22$ cm $= 0.22$ m	$L = 28$ cm $= 0.28$ m
$p_{mi} = 3$ bar $= 300$ kPa	$\dot{m}_f = 5$ kg/h
$CV = 42000$ kJ/kg	$W_{brake} = 500$ N
$D_{brake} = 1.6$ m	$\dot{m}_w = 7$ kg/min
$T_g = 350°C$	$(\Delta T)_w = 35°C$
$T_a = 25°C = 298$ K	$p_a = 1$ bar $= 100$ kPa
$C_{pg} = 1.0$ kJ/kg · K	$C_{ps} = 2.0$ kJ/kg · K

H2 % by mass in fuel = 15%

Analysis The swept volume rate

$$\dot{V}_s = \frac{\pi}{4} d^2 L n k = \frac{\pi}{4} \times (0.22)^2 \times 0.28 \times \frac{500}{60} \times 1$$

$$= 0.0887 \text{ m}^3/\text{min}$$

(i) *Indicated power*

$$IP = p_{mi} \dot{V}_s = 300 \times 0.0887 = 26.6 \text{ kW}$$

Heat supplied by fuel

$$\dot{Q}_{in} = \dot{m}_f CV = 5 \times 42000$$

$$= 210000 \text{ kJ/h} = 58.33 \text{ kW}$$

Indicated thermal efficiency

$$\eta_{ith} = \frac{IP}{Q_{in}} = \frac{26.6 \text{ kW}}{(58.33 \text{ kJ/s})}$$

$$= 0.456 \quad \text{or} \quad \mathbf{45.6\%}$$

(ii) *Specific fuel consumption*

The brake drum radius

$$R_{brake} = \frac{D_{brake}}{2} = \frac{1.6}{2} = 0.8 \text{ m}$$

Brake torque T = Load × Effective brake radius

$$= W_{brake}\, R_{brake}$$

$$= 500 \times 0.8 = 400 \text{ N-m}$$

Brake power

$$BP = \frac{2\pi\, N\, T}{60,000} = \frac{2\pi \times 500 \times 400}{60000}$$

$$= 20.94 \text{ kW}$$

The brake-specific fuel consumtion

$$Bsfc = \frac{\dot{m}_f}{BP} = \frac{(5 \text{ kg/h})}{(20.94 \text{ kW})}$$

$$= \mathbf{0.238\ kg/kWh}$$

(iii) *Volumetric efficiency*

Actual mass flow rate of air into engine

$$\dot{m}_a = (\text{A/F})\ \dot{m}_f = 30 \times 5 = 150 \text{ kg/h}$$

$$= 0.4167 \text{ kg/s}$$

Actual volume flow rate of air;

$$\dot{V}_a = \frac{\dot{m}_a R T_a}{p_a} = \frac{0.4167 \times 0.287 \times 298}{100}$$

$$= 0.03563 \text{ m}^3/\text{s}$$

The volumetric efficiency

$$\eta_{vol} = \frac{\dot{V}_a}{\dot{V}_s} = \frac{0.03563}{0.0887}$$

$$= 0.4017 \quad \text{or} \quad \mathbf{40.17\%}$$

Heat Balance sheet: On minute basis;

Heat supplied per minute by fuel

$$\dot{Q}_{in} = \dot{m}_f CV = \left(\frac{5}{60} \text{ kg/min}\right) \times 42000$$

$$= 3500 \text{ kJ/min}$$

(a) Heat equivalent to BP

$$\dot{Q}_1 = BP \times 60 = 20.96 \times 60$$

$$= 1257.6 \text{ kJ/min}$$

(b) Heat lost to cooling water

$$\dot{Q}_2 = \dot{m}_w C_{pw}(\Delta T) = 7 \times 4.187 \times 35$$

$$= 1025.81 \text{ kJ/min}$$

Heat lost to exhaust gases

Mass of exhaust gases formed/kg of fuel

$$m_{ex} = \dot{m}_f \times \frac{A}{F} = \left(\frac{5}{60}\ \text{kg/ min}\right) \times 30$$

$$= 2.5\ \text{kg/min}$$

Mass of H_2O formed during combustion

$$m_{ex} = 9H_2 \times \text{Mass of fuel used per minute}$$

$$= 9 \times 0.15 \times \frac{5}{60} = 0.1125\ \text{kg/min}$$

Mass of dry exhaust gases per minute

$$m_g = \text{Mass of wet exhaust} - \text{Mass of } H_2O \text{ formed}$$

$$= 2.5 - 0.1125 = 2.3875\ \text{kg/min}$$

(c) Heat lost to dry exhaust gases

$$\dot{Q}_3 = \dot{m}_g C_{pg} (\Delta T)_g$$

$$= 2.3875 \times 1.0 \times (350 - 25)$$

$$= 775.93\ \text{kJ/min}$$

(d) H_2O formed exit in superheated state at 350°C, thus heat carried away by steam

$$\dot{Q}_4 = \dot{m}_{H_2O} (C_{pw} (T_{sat} - T_a) + h_{fg} + C_{ps} (T_g - T_{sat}))$$

$$= 0.1125\ [(4.187 \times (100 - 25) + 2257 + 2.0 \times (350 - 100)]$$

$$= 345.5\ \text{kJ/min}$$

(e) Unaccounted heat loss rate

$$\dot{Q}_5 = 3500 - (1257.6 + 1025.81 + 775.93 + 345.5)$$

Heat Balance Sheet

Particulars	*Quntity*	*Percentage*
Credit (input) *Heat supplied by fuel*	*3500 kJ/min*	*100%*
Debit (output)		
Heat equivalent to BP	1257.6 kJ/min	35.93%
Heat carried by coolant	1025.81 kJ/min	29.3%
Heat carried away by dry flue gases	775.93 kJ/min	22.17%
Heat carried away by steam	345.5 kJ/min	9.87%
Unaccounted heat lost	95.16 kJ/min	2.71%

Assignment Questions

1. Explain the Morse test ?
2 What is willan's line .how do you measure frictional power using this.
3 Discuss different types of dynamometers.
4 Write short notes on Exhaust gas analysis
5 Describe briefly about Heat Balance Sheet