Mechanical Engineering

Internal Combustion Engines

Comprehensive Theory

with Solved Examples and Practice Questions

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Internal Combustion Engines

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Contents

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Chapter 5

CHAPTER 01

Basics and Air Standard Cycles

1.1 INTRODUCTION

The internal combustion I.C.engine is a heat engine that converts the chemical energy of a fuel into mechanical energy, usually mechanical energy available on a rotating output shaft. Chemical energy of the fuel is first converted to thermal energy by means of combustion of fuel with air inside the engine. This thermal energy raises the temperature and pressure of the gases inside the engine, and the high pressure gas then expands against the mechanical mechanism of the engine. This expansion of gas is converted by the mechanical linkage of the engine to a rotating crankshaft, which is the output of the engine.

1.2 Classification of IC Engines

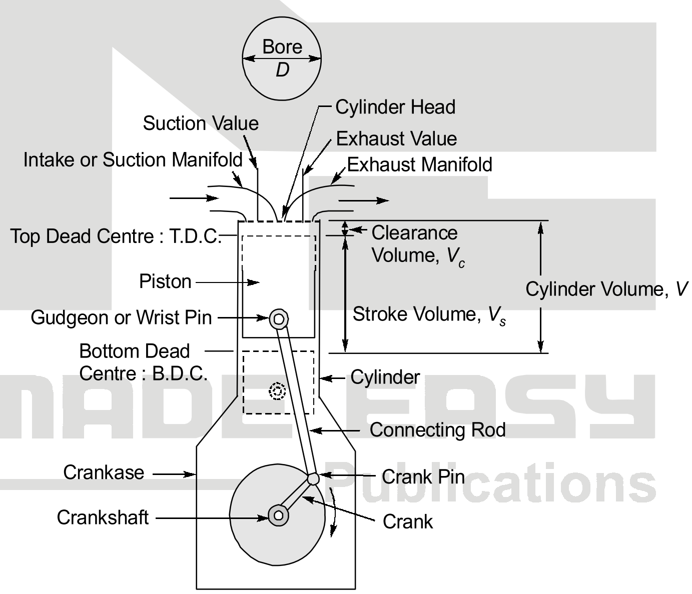


Figure 1.1

The Internal combustion engines are usually of reciprocating type. The reciprocating internal combustion engines are classified on the basis of the thermodynamic cycle and mechanical method of operation, type of fuel used, type of ignition, type of cooling system and cylinder arrangement, etc. The detailed classification is given below :

1. According to piston strokes in the working cycle
   (a) Four stroke engine (b) Two-stroke engine
2. According to fuel used in the cycle
   (a) Petrol engine (b) Diesel engine
   (c) Gas engine (d) Multi-fuel engine
3. According to method of ignition
   (a) Spark ignition (b) Compression ignition
4. According to fuel-feeding system
   (a) Carburetted engine (b) Engine with fuel injection
5. According to charge feeding system
   (a) Naturally aspirated engine (b) Supercharged engine
6. According to cooling system
   (a) Air-cooled engine (b) Water-cooled engine
7. According to number of cylinders
   (a) Single cylinder engine (b) Multi-cylinder engine
8. According to speed of the engine
   (a) Low-speed engine (b) Medium-speed engine (c) High-speed engine
9. According to number of cylinders
   (a) Horizontal engine (b) Vertical engine (c) V-engine

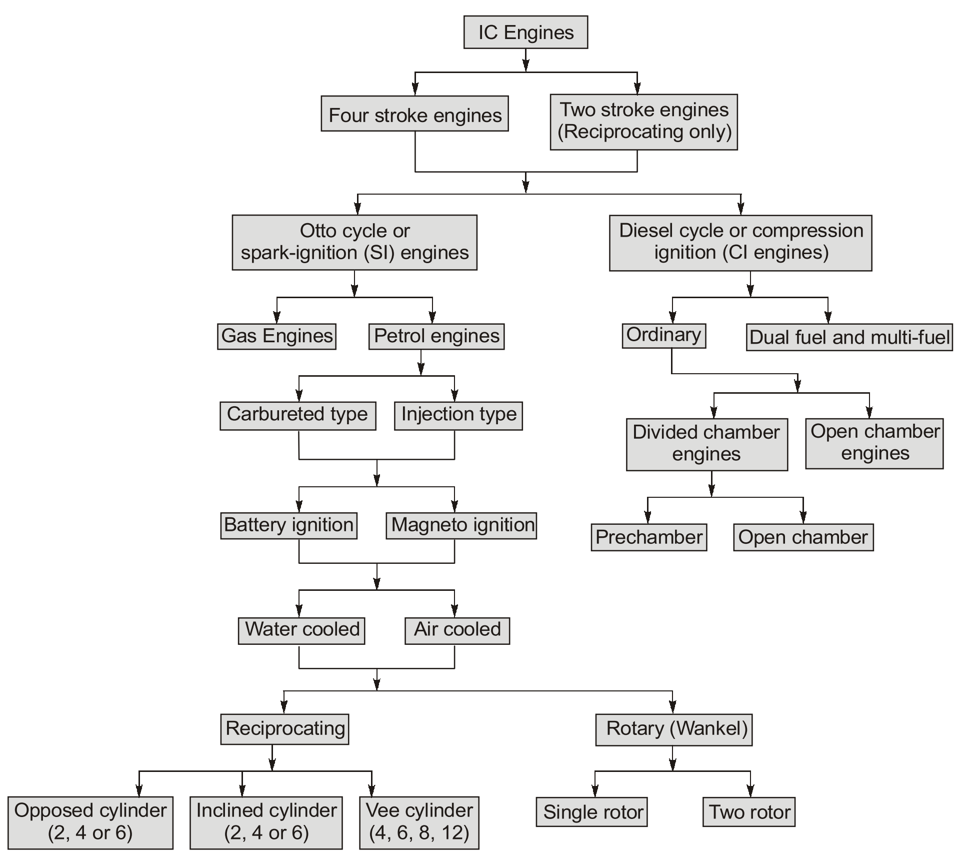


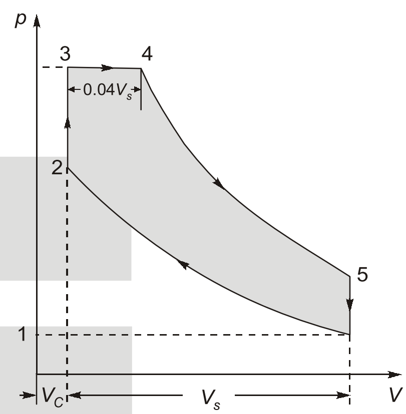
Figure 1.2

Example 1.26 The compression ratio for a single-cylinder engine operating on dual cycle is 9. The maximum pressure in the cylinder is limited to 60 bar. The pressure and temperature of the air at the beginning of the cycle are 1 bar and 30°C. Heat is added during constant pressure process upto 4 percent of the stroke. Assuming the cylinder diameter and stroke length as 250 mm and 300 mm respectively, determine :

(i) The air standard efficiency of the cycle.

(ii) The power developed if the number of working cycles are 3 per second.

Take for air c_v = 0.71 kJ/kgK and c_p = 1.0 kJ/kgK



Solution :

Cylinder diameter, D = 250 mm = 0.25 m

Compression ratio, r = 9

Stroke length, L = 300 mm = 0.3 m

Initial pressure, p_1 = 1 bar

Initial temperature, T_1 = 30°C = 30 + 273 = 303 K

Maximum pressure, $p_3 = p_4$ = 60 bar

cut-off = 4% of stroke volume

Number of working cycles/sec. = 3

(i) Air standard efficiency :

Now, swept volume, $$V_s = \frac{\pi}{4}D^2L = \frac{\pi}{4}\times 0.25^2 \times 0.3 = 0.0147 \text{ m}^3$$

Also, compression ratio, $$r = \frac{V_s + V_c}{V_c}$$

$$9 = \frac{0.0147 + V_c}{V_c}$$

$$\therefore \quad V_c = \frac{0.0147}{8} = 0.0018 \text{ m}^3$$

$$\therefore \quad V_1 = V_s + V_c = 0.0147 + 0.0018 = 0.0165 \text{ m}^3$$

For the adiabatic (or isentropic) process 1 – 2,

$$p_1V_1^{\gamma} = p_2V_2^{\gamma}$$

$$p_2 = p_1 \times \left(\frac{V_1}{V_2}\right)^{\gamma} = 1\times(r)^{\gamma} = 1\times(9)^{1.4} = 21.67 \text{ bar}$$

Also, $$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$= (r)^{\gamma} - 1 = (9)^{1.4-1} = (9)^{0.4} = 2.408$$

$$\therefore \quad T_2 = T_1 \times 2.408 = 303 \times 2.408 = 729.6 \text{ K}$$

For the constant volume process 2 – 3,

$$\frac{T_3}{p_3} = \frac{T_2}{p_2}$$

$\therefore \quad T_3 = T_2 \cdot \frac{p_3}{p_2} = 729.6 \times \frac{60}{21.67} = 2020 \text{ K}$

Also, $\quad \frac{\rho - 1}{r - 1} = \frac{4}{100} \approx 0.04$

$\therefore \quad \frac{\rho - 1}{9 - 1} = 0.04 \text{ or } \rho = 1.32$

For the constant pressure process 3 – 4,

$$\frac{V_4}{T_4} = \frac{V_3}{T_3}$$

or $\quad \frac{T_4}{T_3} = \frac{V_4}{V_3} = \rho$

$\therefore \quad T_4 = T_3 \times \rho = 2020 \times 1.32 = 2666.4 \text{ K}$

Also expansion ratio, $\quad \frac{V_5}{V_4} = \frac{V_5}{V_2} \times \frac{V_2}{V_4} = \frac{V_1}{V_2} \times \frac{V_3}{V_4} = \frac{r}{\rho} \quad [\because V_5 = V_1 \text{ and } V_2 = V_3]$

For adiabatic process 4 – 5, $\quad \frac{T_5}{T_4} = \left(\frac{V_4}{V_5}\right)^{\gamma-1} = \left(\frac{\rho}{r}\right)^{\gamma-1}$

$\therefore \quad T_5 = T_4 \times \left(\frac{\rho}{r}\right)^{\gamma-1} = 2666.4 \times \left(\frac{1.32}{9}\right)^{1.4-1} = 1237 \text{ K}$

Also $\quad p_4 V_4^{\gamma} = p_5 V_5^{\gamma}$

$$p_5 = p_4 \cdot \left(\frac{V_4}{V_5}\right)^{\gamma} = 60 \times \left(\frac{r}{\rho}\right)^{\gamma} = 60 \times \left(\frac{1.32}{9}\right)^{1.4} = 4.08 \text{ bar}$$

Heat supplied, $\quad Q_s = c_v(T_3 - T_2) + c_p(T_4 - T_3)$

$= 0.71(2020 - 729.6) + 1.0(2666.4 - 2020)$

$= 1562.58 \text{ kJ/kg}$

Heat rejected, $\quad Q_R = c_v(T_5 - T_1)$

$= 0.71\,(1237 - 303) = 663.14 \text{ kJ/kg}$

$$\eta_{\text{air-standard}} = \frac{Q_s - Q_R}{Q_s} = \frac{1562.85 - 663.14}{1562.58}$$

$= 0.5756 = 57.56\%$

(ii) Power developed by the engine, P:

Mass of air in cycle is given by, $\quad m = \frac{p_1 V_1}{R T_1} = \frac{1 \times 10^5 \times 0.0165}{287 \times 303} = 0.0189 \text{ kg}$

$\therefore$ Work done per cycle $= m(Q_s - Q_R) = 0.0189\,(1562.58 - 663.14) = 16.999$ kJ

Power developed = Work done per cycle × number of cycles per second

$= 16.999 \times 3 =$ **50.99 ≈ 51 kW**

Objective Brain Teasers

Q.1 Brake thermal efficiency of the three basic types of reciprocating engines commonly used in road vehicles are given in the increasing order as
(a) 2 stroke SI engine, 4 stroke SI engine, 4 stroke CI engine
(b) 2 stroke SI engine, 4 stroke CI engine, 4 stroke SI engine
(c) 4 stroke SI engine, 2 stroke SI engine, 4 stroke CI engine
(d) 4 stroke CI engine, 4 stroke SI engine, 2 stroke SI engine

Q.2 With increasing temperature of intake air, IC engine efficiency
(a) decreases
(b) increases
(c) remains same
(d) depends on other factors

Q.3 The silencer of an internal combustion engine
(a) reduces noise
(b) decreases brake specific fuel consumption (*bsfc*)
(c) increases *bsfc*
(d) has no effect on its efficiency

Q.4 A diesel engine develop a Brake power of 4.5 kW. Its indicated thermal efficiency is 30% and the mechanical efficiency is 85%. Take the calorific value of the fuel as 40000 kJ/kg the indicated specific fuel consumption in kg/kWhr is
(a) 0.4 (b) 0.5
(c) 0.2 (d) 0.3

Q.5 A Diesel engine is usually more efficient than a spark ignition engine because
(a) diesel being a heavier hydrocarbon, releases more heat per kg than gasoline
(b) the air standard efficiency of diesel cycle is higher than the Otto cycle, at a fixed compression ratio
(c) the compression ratio of a diesel engine is higher than that of an SI engine
(d) self-ignition temperature of diesel is higher than that of gasoline

Q.6 An automobile engine operates at a fuel air ratio of 0.05, volumetric efficiency of 90% and indicated thermal efficiency of 30%. Given that the calorific value of the fuel is 45 MJ/kg and the density of air at intake is 1 kg/m^3, the indicated mean effective pressure for the engine is
(a) 6.075 bar (b) 6.75 bar
(c) 67.5 bar (d) 243 bar

Q.7 Piston compression rings are made of which one of the following?
(a) Cast iron (b) Bronze
(c) Aluminum (d) White metal

Q.8 A 4 stroke, four cylinder spark ignition engine having bore 7 cm and stroke 9 cm develops 20 kW at 3000 rpm. If the clearance volume in each cylinder is 50 cm^3, the brake thermal efficiency is 50% of air standard efficiency and the calorific value of the fuel is 43 MJ/kg, the fuel consumption in kg/hr is
(a) 4.24 (b) 7.33
(c) 5.94 (d) 3.56

Linked Data (Q.9-Q.10)
A single cylinder, 4 stroke diesel engine running at 1800 rpm has a bore of 85 mm and a stroke of 110 mm. It takes 0.56 kg of air per minute and develops a brake power output of 6 kW while the air fuel ratio is 20:1. The calorific value of the fuel used is 42550 kJ/kg and the ambient air density is 1.18 kg/m^3.

Q.9 The volumetric efficiency in % is
(a) 66.67 (b) 84.47
(c) 74.56 (d) 56.86

Q.10 Brake specific fuel consumption in kg/kWhr
(a) 0.14 (b) 0.32
(c) 0.28 (d) 0.40

Q.11 A mechanic has an engine from a 1970 model car which works on the basis of Otto cycle. The engine displaces 1.8 liters, has a compression ratio of 10.2 : 1 and has six cylinders. The pistons in the original engine are 120 mm in diameter. The mechanic bores the cylinder and replaces the piston with new pistons that are 2 mm larger in diameter than the originals. Keeping all other factors same, the percentage change in power output will be

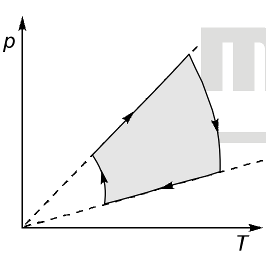
(a) 4.36 (b) 3.36
(c) 5.45 (d) 2.54

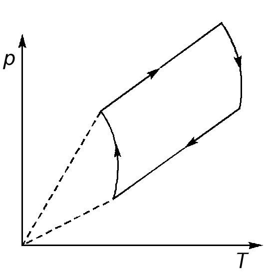
Q.12 **Assertion (A):** For a given compression ratio, the thermal efficiency of the Diesel cycle will be higher than that of the Otto cycle.

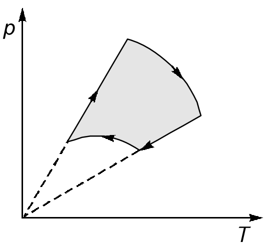
Reason (R): In the Diesel cycle, work is also delivered during heat addition.

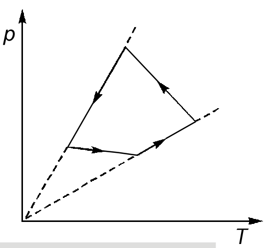
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Q.13 Which one of the following p-T diagrams illustrates the Otto cycle of an ideal gas?

(a)


(b)


(c)


(d)


Answers

1. (a)	2. (a)	3. (a)	4. (d)	5. (c)
6. (a)	7. (a)	8. (c)	9. (b)	10. (c)
11. (b)	12. (d)	13. (a)		

Hints and Explanations:

4. (d)

$$bp = 4.5 \text{ kW}$$
$$\eta_{i,th} = 30\% = 0.30$$
$$\eta_m = 85\% = 0.85$$
$$C.V. = 40000 \text{ kJ/kg}$$
$$\eta_m = \frac{bp}{ip}$$
$$0.85 = \frac{4.5}{ip}$$

or
$$ip = 5.29 \text{ kW}$$
$$\eta_{i,th} = \frac{ip}{m_f \times C.V.}$$
$$0.30 = \frac{5.29}{m_f \times 40000}$$

or
$$m_f = 4.408 \times 10^{-4} \text{ kg/s}$$
$$= 4.408 \times 3600 \times 10^{-4} \text{ kg/hr}$$
$$= 1.586 \text{ kg/hr}$$

Indicated specific fuel consumption,
$$isfc = \frac{m_f}{ip} \text{ kg/kWhr}$$

CHAPTER 03

Fuels

3.1 Requirement for an IC Engine Fuel

- It should take very little time for combustion
- It should have high energy density
- Low deposit forming tendency.

3.2 The Constituents of Crude Petroleum and their Properties

- Paraffins (C_n H_{2n+2}) like methane, propane, Iso-octane, n-Heptane. They are saturated and stable compound. Branch chain or isoparaffins are highly knock resistant in SI engine than straight chain paraffins.
- Olefins (C_n H_{2n}) like ethylene, propylene. They are unsaturated and unstable compound. They cause gummy deposit after oxidation.
- Napthenes (C_nH_{2n}) like cyclo butane, cyclo hexane. They are cyclic and saturated compound. They are more stable than olefins.
- Aromatics. They have ring structure of benzene (C_6H_6) as central structure. They are highly active or even explosive (Like Toluene)

3.3 Important Products of Refining Process of Crude Petroleum

- Natural Gas. They are paraffinic compound mainly Methane.
- Liquified Petroleum Gas (LPG). These are also paraffinic compound propane and butane. They can be liquified in ambient condition by applying pressure.
- Gasoline or Petrol. It is the highest liquid petroleum fraction. All liquid fraction having boiling point upto 200°C are gasoline. Its specific gravity is 0.70 to 0.78.
- Kerosene. These have boiling range 150°C to 300°C and specific gravity 0.78 to 0.85. These are heavier than petrol.
- Diesel. These have 200°C-370°C boiling range and wide range of specific gravity. These are having more specific gravity than petrol

3.4 Effect of Volatility on Petrol Engine Performance

- Volatility is the tendency of fuel to go from a liquid to a gaseous state on slow heating of fuel. Quantity of fuel evaporated with temperature is measured which is called distillation and this is a measure of volatility of the fuel.
- Front end volatility (0-20% evaporation)

  Cold starting, hot starting and vapour lock are three important performance characteristics which are affected by the front end volatility of the gasoline used.

  1. **Cold starting:** High front end volatility is required for easy starting of engine.
  2. **Hot starting:** If the front end volatility is very high, it will create problem in hot starting as more and more vapours will be present in the combustion chamber making the mixture too rich to ignite.
  3. **Vapour lock**: Low front end volatility is required so that sufficient amount of liquid fuel could be pumped as more vapourization makes air fuel mixture lean because of less quantity of vapour and liquid fuel.
- **Mid range volatility (20%-80% evaporation)**
  1. **Engine warm up, acceleration, smoothness and fuel economy:** The mid range volatility should be sufficient enough to get all these performances of the engine.
  2. **Carburetor icing:** A low mid range volatility is required to prevent carburettor icing. More volatile fuel evaporates rapidly, lowering the temperature of carburettor body. With high humidity content, water vapour in the fuel condense and freezes.
- **Tail end volatility (80%-100% evaporation)**

  High tail end volatility causes less crankcase dilution, less engine deposits, gum formation and spark fouling.

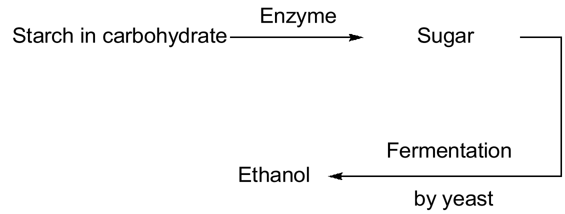
  - Aldehydes and peroxides formed after oxidation of unsaturated hydrocarbon are knock inducing compounds. So Alphanaphthol is used as antioxidant.
  - Sulphur in fuel causes corrosion, odour and poor explosion characteristic in petrol.

3.5 Octane Number

- It is percentage of iso-octane in the fuel containing iso-octane and n-Heptane that gives the same knocking intensity as that of the fuel whose octane number is calculated. Octane number 80 means the fuel is equivalent to 100% mixture of iso-octane and n-Heptane where iso-octane is 80% and n-Heptane is 20%.
- Octane number of a fuel can be increased by adding Tetra ethyl lead (TEL).
- TEL causes spark plug fouling so ethylene dibromide is used to avoid lead deposits for spark plug fouling.

3.6 Requirement of Diesel Fuel

- **Flash point:** It is the temperature at which a visible flame occurs for less than 5 seconds. It should be high.
- **Fire point:** It is the temperature at which the flame can sustain for more than, 5 seconds. It should be high.
- **Cloud point:** It is the temperature at which the wax content of the diesel separates out in the form of solid. It should be low.
- **Pour point:** it is the temperature below which the entire fuel freeze. It should also be very low.



- Vegetable oil particularly sunflower oil can be blended with diesel to reduce the consumption of diesel.

CNG (Compressed Natural Gas)

- It is a mixture of 90% Methane and remaining Ethane.
- It is a good SI engine fuel due to high Octane number.
- Fuel availability is large.
- It is cheap, odourless and safe in operation.
- Low engine emissions.

Summary

- It is percentage of iso-octane in the fuel containing iso-octane and n-Heptane that gives the same knocking intensity as that of the fuel whose octane number is calculated. Octane number 80 means the fuel is equivalent to 100% mixture of iso-octane and n-Heptane where iso-octane is 80% and n-Heptane is 20%.
- Octane number of a fuel can be increased by adding Tetra ethyl lead (TEL).
- It is the percentage by volume of cetane ($C_{16}H_{34}$) in a mixture of cetane and a-methyl napthalene ($C_{10}H_7CH_3$) that has the same performance in the standard test engine as that of the fuel whose cetane number is calculated. So if a fuel is equivalent to 100% mixture of cetane and a-methyl naphthalene where cetane is 85% and a-pmethyl naphthalene is 15% then cetane number of the fuel is 85.
- High cetane number of Diesel engine fuel reduce its knocking tendency.

Objective Brain Teasers

Q.1 For determining the ignition quality of compression ignition engine fuels, the reference fuels used are
(a) Iso-octane and n-heptane
(b) Cetane and α-methylnapthalene
(c) Hexadecane and n-heptane
(d) Cetane and iso-octane

Q.2 Alcohols are unsuitable at diesel engine fuels because
(a) The cetane number of a alcohol fuels is very low which prevents their ignition by compression
(b) The cetane number of alcohol fuels is very high which prevents their ignition by compression
(c) The octane number of alcohol fuels is very low which prevents their ignition by compression
(d) None of the above

Q.3 Methane burns with stoichiometric quantity of air. The air-fuel ratio by weight is
(a) 4 (b) 14.7
(c) 15 (d) 17.16

Q.4 Match **List-I** (Fuels) with **List-II** (Characteristics/ usages) and select the correct answer using the codes given below the lists:

List-I

A. Semi-bituminous coal
B. High-speed dieseloil
C. Biogas
D. LPG

List-II

1. Methane and carbon dioxide
2. Propane and butane
3. Calorific value of 10,600 kcal/kg
4. Power plants

Codes:

	A	B	C	D
(a)	3	4	1	2
(b)	4	3	2	1
(c)	3	4	2	1
(d)	4	3	1	2

Q.5 In a petrol engine car, which one of the following performance characteristic is affected by the front-end volatility gasoline used?
(a) Hot starting and vapour lock
(b) Engine warm-up and spark plug fouling
(c) Spark plug fouling and hot starting
(d) Vapour lock, engine warm-up and spark plug fouling

Q.6 Consider the following statements:
1. Motor gasoline is a mixture of various hydrocarbons with a major proportional being aromatic hydrocarbons.
2. Compressed natural gas is a mainly composed of methane.
3. Producer gas has a Predominant component of hydrogen with lesser proportion of carbon monoxide.
4. Cetane number of fuel used in diesel engines in India is in the range of 80 to 90.

Which of these statements are correct?
(a) 1 and 2 (b) 1 and 3
(c) 2, 3 and 4 (d) 1, 2, 3 and 4

Q.7 Which one of the following fuels can be obtained by fermentation of vegetable matter?
(a) Benzene (b) Diesel
(c) Gasoline (d) Alcohol

Answers

1. (a) **2.** (a) **3.** (d) **4.** (d) **5.** (a) **6.** (a) **7.** (d)

Student's Assignments

Q.1 Discuss the important qualities of a SI engine fuel.

Q.2 What is vapour lock?

Q.3 What do you mean by ignition quality of a fuel?

Q.4 Discuss the basic qualities of a good CI engine fuel.

Q.5 Briefly discuss the rating of CI engine fuels.

Chapter 04

Ignition, Engine Friction, Lubrication and Cooling

4.1 Introduction

In a SI engine, the combustion process is initiated by an electrical discharge between the spark plug electrodes when the piston is close to the end of compression process. The ignition system carries the electric current to the spark plug where the spark necessary to ignite the fuel-air mixture is produced. The high temperature plasma kernel created by the spark develops into a self-sustaining and propagating flame front, a thin reaction sheet, where the exothermic chemical reactions occur. The ignition Initiates this flame propagation process in a repeatable manner cycle-by-cycle, under all operating conditions of load and speed, and at the appropriate point in the engine cycle.

Times the sole objective of the ignition system is to initiate the combustion process and it is not associated with the gross behaviour of combustion phenomena. Therefore, the ignition system should be considered from the standpoint of the beginning of the combustion process that it initiates.

4.2 Energy Requirement

The development of a high compression ratio engine led to the development of a system which can product a light-tension spark across a short fixed gap in the combustion chamber for the ignition of the charge. A spark can be produced from one plug electrode to other only if a sufficiently high voltage is applied. In a typical spark discharge, the electrical potential across the electrode gap is increased until the breakdown of the intervening mixture occurs. This breakdown voltage (preceded by arc and (low discharge) is the critical voltage below which there can be no spark. About 0.2 mJ of energy is required to ignite a quiescent stoichiometric fuel-air mixture at normal engine conditions by means of a spark. If the mixture is rich or lean, the energy required Is about 3 mJ. It has been found that the critical spark energy required to ignite a given mixture decreases rapidly as the sparking voltage is increased. Thus, in a typical instance, for a mixture strength of 12.5 : 1, the spark energy required to ignite this charge was 5 mJ at 5 kV, 2 mJ at 6 kV and 0.7 mJ at 7 kV. Figure shows the minimum spark energy required for different air-fuel (gasoline) ratios.

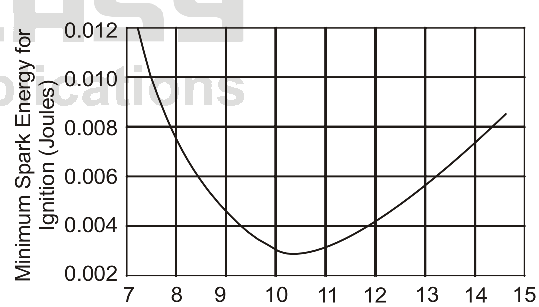


Figure 4.1 Ratio of air to Gasoline

The conventional ignition system delivers about 30 mJ of electrical energy to the spark. Thus a small fraction of the energy supplied to the spark gap is transmitted to the gas mixture and the rest of the energy is lost as heat energy.

It may be mentioned that the mixture in the spark gap is never entirely homogeneous-it may be very rich or may be a lean mixture and sometimes it may contain a few droplets of fuel or oil. Therefore, the practical picture of ignition to suit all conditions not only demands that energy be furnished quickly, but also requires a definite duration of spark. The conventional ignition systems deliver 30 to 50 mJ of electrical energy to the spark and the duration is longer than 0.5 ms to ignite the charge and initiate the combustion process.

4.3 Requirements of An Ignition System

The requirements of a smooth and reliable ignition system can be listed as following :

1. The system must provide sufficient voltage across the spark plug electrodes to produce a spark discharge.
2. The system should supply sufficient energy during spark discharge to ignite the combustible mixture adjacent to the plug electrodes under all operating conditions.
3. The spark should be produced at the appropriate point during the compression process and in a repeatable manner cycle-by-cycle. The duration of the voltage pulse should be sufficient to ensure ignition.
4. The system should have the means for automatically changing the spark timing with changes in load and engine speed.
5. The peak voltage produced by the system must be safe so that there is no damage to the spark plug electrodes.

Since the ignition system should have a source of electrical energy and that can be obtained either by a battery or by a generator or magnets, three methods have been generally employed to produce the necessary high voltage, and they are based on the principles of mutual electromagnetic induction. These are :

(a) Battery Ignition System, (b) Magnet Ignition System, and
(c) Electronic Ignition System.

4.3.1 Battery Ignition System

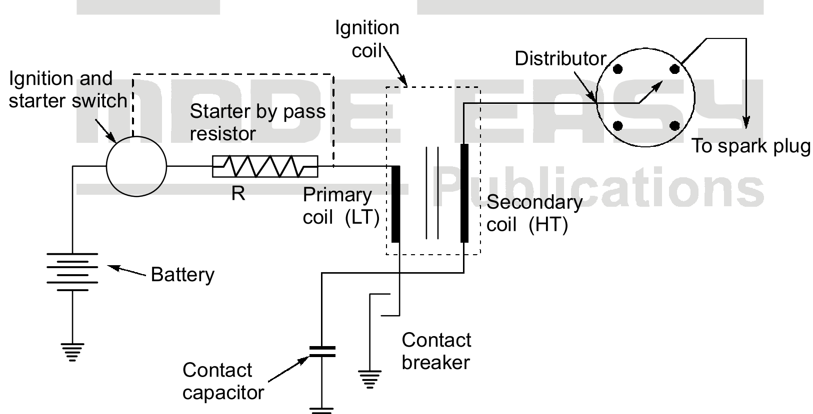


Figure 4.2 Mechanically Operated Battery Ignition System

The components of a conventional battery system shown in figure are a 12 V battery, an ignition switch, an ignition coil, a resistor, a distributor (which houses the breaker points, cam condenser, rotor and advance mechanism), spark plugs, and low and high-tension wiring.

Battery : The storage battery is an electrochemical device which converts chemical energy into electrical energy. The main functions of a battery are : (i) to supply a high current (upto 200 amperes) to the starter motor and a low current to the ignition system, (iii) to supply current to the electrical units when the total demand

Objective Brain Teasers

Q.1 The method of determination of indicated power of multicylinder SI engine is by the use of
(a) Morse test (b) Prony brake test
(c) Motoring test (d) Heat balance test

Q.2 In a Morse test for a 2-cylinder, 2-stroke, spark ignition engine, the brake power was 9 kW whereas the brake powers of individual cylinders with spark cut-off were 4.25 kW and 3.75 kW respectively. The mechanical efficiency of the engine is
(a) 90% (b) 80%
(c) 45.5% (d) 52.5%

Q.3 Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

List-I
A. Air standard efficiency of Otto cycle
B. Morse test
C. Constant volume cycle
D. Constant pressure heat addition

List-II
1. Mechanical efficiency
2. Diesel cycle
3. Brake thermal efficiency
4. Otto cycle
5. $1-\frac{1}{r^{\gamma-1}}$

Codes:

	A	B	C	D
(a)	5	1	4	2
(b)	3	5	2	4
(c)	3	5	4	2
(d)	5	1	2	4

Common Data Question (Q.4-Q.5)

In a test on a four cylinder spark ignition engine the following power and fuel consumption measurements were made

with all cylinders firing	30.00 kW
with cylinder 1 only not firing	20.75 kW
with cylinder 2 only not firing	20.50 kW
with cylinder 3 only not firing	20.50 kW
with cylinder 4 only not firing	20.75 kW

The time taken to consume 250 ml of fuel is 85 seconds. Specific gravity of fuel = 0.85. Calorific value of fuel is 40 MJ/kg.

Q.4 The mechanical efficiency of the engine is
(a) 67% (b) 80%
(c) 90% (d) 95%

Q.5 The brake thermal efficiency of the engine is
(a) 25% (b) 40%
(c) 35% (d) 30%

Common Data (Q.6-Q.7)

The Willan's line measured for a four-stroke, four-cylinder is expressed as: FC = 0.15 + 0.03 × BP., where FC is the rate of fuel consumption in gm/s and BP is the brake power in kW. The bore of each cylinder is 75 mm and stroke is 90 mm and the speed is 3000 rpm. If the engine develops brake power of 20 kW

Q.6 Mechanical efficiency is
(a) 0.6 (b) 0.7
(c) 0.8 (d) 0.9

Q.7 Indicated mean effective pressure in kPa is
(a) 628.76 (b) 314.38
(c) 512.14 (d) 678.48

Q.8 Consider the following statements relevant to the ignition system of SI engine:
1. Too small a dwell angle will lead to the burning of condenser and contact points.
2. Too small a dwell angle will result in misfiring.
3. Too large a dwell angle will result in burning of condenser and contact points.
4. Too large a dwell will result in misfiring.

Which of these statements are correct?
(a) 1 and 2 (b) 2 and 3
(c) 3 and 4 (d) 4 and 1

Answers

1. (a)	2. (a)	3. (a)	4. (b)	5. (d)
6. (c)	7. (a)	8. (b)		

Hints and Explanations:

2. (a)

$$(IP)_n = (BP)_n + FP$$
$$(IP)_{n-1} = (BP)_{n-1} + FP$$
$$(IP)_{1st} = (BP)_{n\ cylinder} - (BP)_{n-1}$$
$$= 9 - 4.25 = 4.75\text{ kW}$$
$$(IP)_{2nd} = 9 - 3.75 = 5.25\text{ kW}$$
$$\text{Total IP} = 4.75 + 5.25 = 10\text{ kW}$$
$$\therefore \quad \eta_m = \frac{BP}{IP} = \frac{9}{10} \times 100 = 90\%$$

Student's Assignments

Q.1 What is ignition? How does it differ from combustion?

Q.2 Explain, with a neat sketch, the working principles of a battery ignition system.

Q.3 Describe, with a neat sketch, the working of magneto ignition system.

Q.4 State the properties of a good lubricant.

Q.5 Why cooling of an IC engine is necessary?

Q.6 Compare the merit and demerits of air and water cooling system.

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