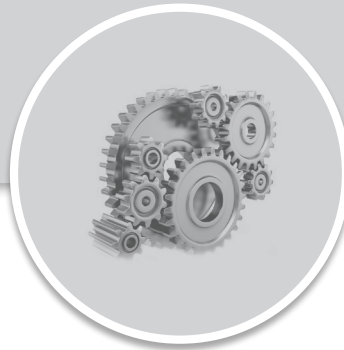


MECHANICAL ENGINEERING

Internal Combustion Engine



Comprehensive Theory
with Solved Examples and Practice Questions





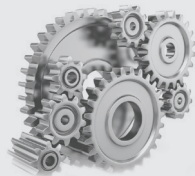
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Internal Combustion Engine

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CONTENTS

Internal Combustion Engine

CHAPTER 1

Basics and Air Standard Cycles..... 1-35

1.1	Introduction.....	1
1.2	Classification of IC Engines.....	1
1.3	Components of Engines.....	3
1.4	Basic Terminology.....	4
1.5	Petrol Engine.....	5
1.6	Diesel Engine.....	10
1.7	Air standard cycles.....	14
1.8	Comparison among Otto, Diesel and Dual Cycles.....	22
1.9	Comparison of four stroke and Two-stroke engines.....	26
1.10	Comparison of Petrol Engine and Diesel engine.....	26
	<i>Objective Brain Teasers</i>	31
	<i>Conventional Brain Teasers</i>	32

CHAPTER 2

Combustion in IC Engines..... 36-62

2.1	Introduction.....	36
2.2	Combustion in spark ignition engines.....	36
2.3	Stages of Combustion in spark ignition engines.....	38
2.4	Factors affecting the flame speed.....	40
2.5	Rate of Pressure Rise.....	42
2.6	Abnormal combustion.....	42
2.7	Knocking in SI Engine.....	43
2.8	Combustion in compression ignition engines.....	48
2.9	Spray Characteristics.....	49
2.10	Stages of Combustion in diesel engines.....	50
2.11	Physical Factors Affecting Delay Period.....	51
2.12	Rate of Pressure Rise.....	55
2.13	Knocking in CI Engine.....	56
2.14	Comparison of Knocking Phenomenon in SI Engine and CI Engine.....	57

2.15	Combustion Chamber Design Principle.....	58
2.16	CI Engine Combustion Chamber.....	58
	<i>Objective Brain Teasers</i>	59
	<i>Conventional Brain Teasers</i>	61

CHAPTER 3

Fuels 63-71

3.1	Introduction.....	63
3.2	Characteristics of a good IC Engine fuel.....	63
3.3	Classification of fuels.....	63
3.4	Chemical structure of petroleum fuels.....	64
3.5	Important Products of Refining Process of Crude Petroleum.....	65
3.6	Octane number.....	65
3.7	Cetane number.....	65
3.8	Important qualities of IC Engine fuels.....	66
3.9	Alternative fuels in IC Engines.....	69
	<i>Objective Brain Teasers</i>	70

CHAPTER 4

Carburetion, Fuel Injection and Ignition..... 72-81

4.1	The simple carburetor.....	72
4.2	Carburetion.....	74
4.3	Fuel injection.....	76
4.4	Ignition.....	78

CHAPTER 5

Engine Friction, Lubrication and Cooling..... 82-99

5.1	Introduction.....	82
5.2	Components of Engine Friction.....	82
5.3	Total Friction Work.....	83

5.4	Mechanical Friction	85
5.5	Blowby Losses	86
5.6	Effect of Engine Variables on Friction	86
5.7	Lubrication	87
5.8	Properties of Lubricants	88
5.9	Lubricating Systems.....	90
5.10	Cooling System	94
5.11	Types of Cooling System	95
	<i>Objective Brain Teasers</i>	99

CHAPTER 6

Supercharging 100-109

6.1	Supercharging	100
6.2	Methods of Supercharging	101
6.3	Thermodynamic Cycle With Supercharging	102
6.4	Supercharging of Spark-Ignition Engine.....	105
6.5	Supercharging of Compression-Ignition Engine.....	106
6.6	Advantages of Supercharging Over High Compression.....	106
6.7	Effects of Supercharging	107
6.8	Supercharging Limits	108
	<i>Objective Brain Teasers</i>	109

CHAPTER 7

Engine Performance and Testing..... 110-131

7.1	Introduction.....	110
7.2	Engine Power.....	110
7.3	Mean Effective Pressure.....	111
7.4	Basic Measurements	112
7.5	Heat Balance Sheet	118
7.6	Variation of Efficiency with Speed	120
7.7	Variation of Various Mean Effective Pressures (m.e.p.) with Speed	120
7.8	Variation of Torque, Mean Effective Pressure (m.e.p.), b.p. & Specific Fuel Consumption with Speed.....	121
	<i>Objective Brain Teasers</i>	124
	<i>Conventional Brain Teasers</i>	128

CHAPTER 8

IC Engine Emissions 132-141

8.1	Introduction.....	132
8.2	Exhaust Emissions.....	132
8.3	Methods of Exhaust Emission Control	136
8.4	Non-Exhaust Emissions.....	140
	<i>Objective Brain Teasers</i>	141



Basics and Air Standard Cycles

1.1 INTRODUCTION

Engine is a machine used for converting one form of energy into another form. Engine generally converts thermal energy into mechanical work and therefore they are called heat engines. When fuel burns in presence of air, a tremendous amount of heat energy is released. This energy is converted into useful work by means of heat engine. Heat engines are broadly classified into:

- (a) **External Combustion Engine:** In external combustion engines, the combustion of fuel takes place outside the engine. For example in steam engine, heat generated due to combustion of fuel is used to generate high pressure steam which is used as working fluid in steam engine. A steam turbine is a good example of external combustion engine.
- (b) **Internal Combustion Engine :** In internal combustion engine, combustion take place inside the engine. In this engine chemical energy of 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

The internal combustion engines are usually of reciprocating type. The reciprocating internal combustion engines are classified on the basis of the thermodynamic cycle, 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 number of strokes in the working cycle :**
 - (a) **Four Stroke Engine :** In this engine, the thermodynamic cycle is completed in four strokes of piston.
 - (b) **Two Stroke Engine :** In this engine, thermodynamic cycle is completed in two strokes of piston.
- 2. **According to fuel used :**
 - (a) **Petrol Engine :** It uses petrol and needs a spark plug to ignite petrol.
 - (b) **Diesel Engine :** It uses diesel and self ignition occurs in the combustion chamber due to high temperature of air.

- (c) **Gas Engine :** These engine use fuel like CNG, LPG, biogas. Gaseous fuels are better compared to liquid fuels because of reduced ignition delay.
 - (d) **Multi fuel Engine :** In these engines a gaseous fuel is supplied along with air during initial part of compression and other fuel is injected into combustion space at end of compression stroke.
3. **According to method of ignition :**
- (a) **Spark Ignition Engines :** These engines requires an external source of energy for initiation of spark and thereby the combustion process starts.
 - (b) **Compression Ignition Engines :** In these engines there is no need for an external means to produce ignition. They have high compression ratio which results in high temperature at end of compression process which is sufficient to self ignite the fuel.
4. **According to charge feeding system :**
- (a) **Naturally Aspirated Engines :** In these engines admission of air or air-fuel mixture is at atmospheric pressure.
 - (b) **Supercharged Engines :** In these engines admission of air or air-fuel mixture is at pressure that is above atmospheric pressure.
5. **According to cooling system :**
- (a) **Air Cooled Engine :** These engines uses fins to dissipate heat to surrounding to keep the engine within operating temperature.
 - (b) **Water Cooled Engines :** In these engines water is circulated continuously by means of a external pump which absorbs the engine heat and rejects it to surrounding by using radiator.
6. **According to cylinder arrangements :** To classify engines according to cylinder arrangement two terms must be defined.
- (i) **Cylinder Row :** In this arrangement centreline of crankshaft journal is perpendicular to plane containing centreline of engine cylinder.
 - (ii) **Cylinder Bank :** In this arrangement the centreline of crankshaft journal is parallel to plane containing centreline of engine cylinder.
- (a) **In-Line Engine :** In these engines all cylinders are arranged linearly and transmit power to single crankshaft.
 - (b) **V-Engine :** In these engines there are two banks of cylinders inclined at an angle to each other with one crankshaft.
 - (c) **Opposed Cylinder Engine :** These engines has two cylinder banks located in same plane on opposite side of crankshaft.
 - (d) **Radial Engine :** These engines has more than two cylinders in each row and are equally spaced around crankshaft.

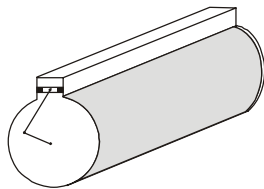


Figure: Inline cylinder Engine

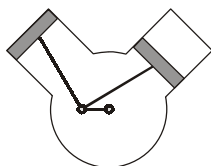


Figure: V engine

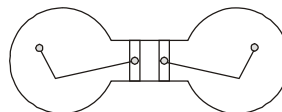


Figure: Opposed cylinder engine

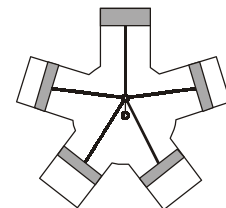


Figure: Radial engine

1.3 COMPONENTS OF ENGINES

An internal combustion engine consists of a large number of parts and each part has its own function. A few of them are shown in figure and listed below.

1. **Cylinder :** It is the heart of the engine. The piston reciprocates in the cylinder. It has to withstand high pressure and temperature, and thus it is made strong. Generally, it is made from cast iron. It is provided with a cylinder liner on the inner side and a cooling arrangement on its outer side. For two-stroke engines, it houses exhaust and transfer port.
2. **Cylinder Head :** The top cover of the cylinder, towards TDC, is called cylinder head. It houses the spark plug in petrol engines and fuel injector in Diesel engines. For four stroke cycle engines, the cylinder head is the housing of inlet and exhaust valves.
3. **Piston :** It is the reciprocating member of the engine. It reciprocates in the cylinder. Its top surface is called piston crown and bottom surface is called piston skirt. Its top surface is made flat for four-stroke engines and deflected for two-stroke engines.
4. **Piston Rings :** Two or three piston rings are provided on the piston. The piston rings seal the space between the cylinder liner and piston in order to prevent leakage (blow by losses) of high-pressure gases, from cylinder to crank case.
5. **Crank :** It is a rotating member. It makes circular motion in the crank case (its housing). Its one end is connected with a shaft called crank-shaft and the other end is connected with a connecting rod.
6. **Crank Case :** It is the housing of the crank and body of the engine to which cylinder and other engine parts are fastened. It also acts as a ground for lubricating oil.
7. **Connecting Rod :** It is a link between the piston and crank. Its one end is connected with a crank while other end with a piston. It transmits power developed on the piston to a crank shaft through crank. It is usually made of medium carbon steel.
8. **Crank Shaft :** It is the shaft, a rotating member, which connects the crank. The power developed by the engine is transmitted outside through this shaft. It is made of medium carbon or alloy steels.
9. **Cooling Fins or Cooling Water Jackets :** During combustion, the engine releases a large amount of heat. Thus the engine parts may be subjected to a temperature at which engine parts may not sustain their properties such as hardness, etc. In order to keep the engine parts within safe temperature limits, the cylinder and the cylinder head are provided with a cooling arrangement. The cooling fins are provided on light duty engines, while a cooling water jacket is provided on medium and heavy duty engines.
10. **Cam Shaft :** It is provided on four-stroke engines. It carries two cams, for controlling the opening and closing of inlet and exhaust valves.
11. **Inlet Valve :** This valve controls the admission of charge into the engine during a suction stroke.
12. **Exhaust Valve :** The removal of exhausted gases after doing work on the piston is controlled by exhaust valve.

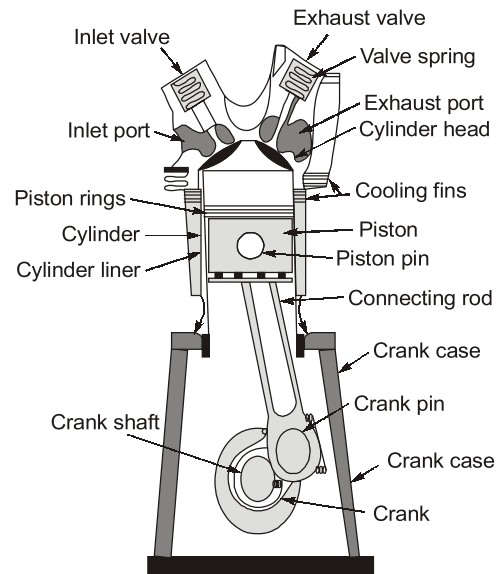


Figure : Components of an internal combustion engine

Assumptions :

(i) The petrol engine works on air standard Otto cycle.

(ii) The ratio of specific heats $\gamma = 1.4$ for air

Analysis :

(i) Air standard efficiency of Otto cycle,

$$\eta_{\text{Otto}} = 1 - \frac{1}{r^{\gamma-1}} = 1 - \frac{1}{(6)^{1.4-1}} = 0.511 = 51.1\%$$

(ii) Indicated mean effective pressure,

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

$$25 \text{ kW} = \frac{p_{mi} \times (0.15 \text{ m}) \times (\pi/4) \times (0.1 \text{ m})^2 \times 2000 \times 4}{60 \times 2}$$

or

$$p_{mi} = 318.3 \text{ kPa} = \mathbf{3.183 \text{ bar}}$$

(iii) Fuel consumption per hour

We have

$$\eta_{ith} = \frac{IP}{\dot{m}_f \times CV}$$

or

$$\begin{aligned} \dot{m}_f &= \frac{IP}{\eta_{ith} CV} = \frac{25 \text{ kW}}{0.511 \times 42 \times 10^3 \text{ kJ/kg}} \\ &= 1.984 \times 10^{-3} \text{ kg/s} = \mathbf{7.14 \text{ kg/h}} \end{aligned}$$

EXAMPLE : 1.5

The compression ratio for the maximum work to be done per kg of air in an Otto cycle between upper and lower limits of absolute temperatures T_3 and T_1 is given by:

(a) $r = \left(\frac{T_1}{T_3} \right)^{\frac{1}{2(\gamma-1)}}$

(b) $r = \left(\frac{T_3}{T_1} \right)^{\frac{1}{2(\gamma-1)}}$

(c) $r = \left(\frac{T_3}{T_1} \right)^{\frac{1}{\gamma-1}}$

(d) None of these

Solution: (b)

\therefore

\Rightarrow

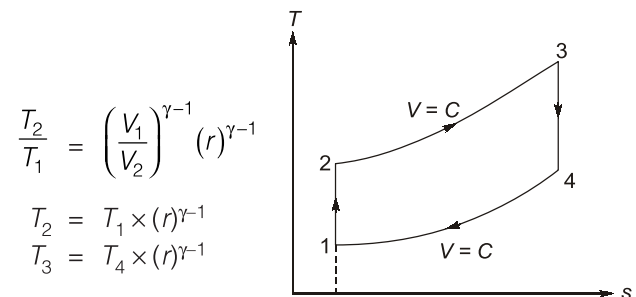
and

\therefore Work done per kg of fluid:

\Rightarrow

\therefore

From W_{max} ,



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

$$T_2 = T_1 \times (r)^{\gamma-1}$$

$$T_3 = T_4 \times (r)^{\gamma-1}$$

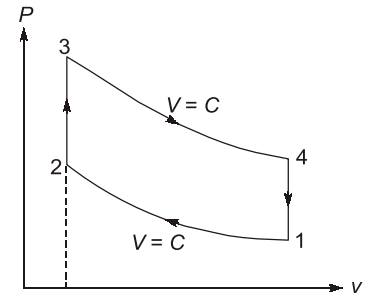
$W = \text{Heat supplied} - \text{Heat rejected}$

$$W = C_V(T_3 - T_2) - C_V(T_4 - T_1)$$

$$W = C_V \left[T_3 - T_1(r)^{\gamma-1} - \frac{T_3}{(r)^{\gamma-1}} + T_1 \right]$$

$$\frac{dW}{dr} = 0$$

$$\Rightarrow \begin{aligned} -T_1 (\gamma - 1) \times (r)^{\gamma-2} &= T_3 (r)^{-\gamma} \times (1 - \gamma) = 0 \\ T_1 \times (r)^{\gamma-2} &= T_3 \times (r)^{-\gamma} \\ \frac{r^{(\gamma-2)}}{r^{(-\gamma)}} &= \frac{T_3}{T_1} \\ r^{(2\gamma-2)} &= \frac{T_3}{T_1} \\ r^{2(\gamma-1)} &= \frac{T_3}{T_1} \\ r &= \left(\frac{T_3}{T_1} \right)^{\frac{1}{2(\gamma-1)}} \end{aligned}$$



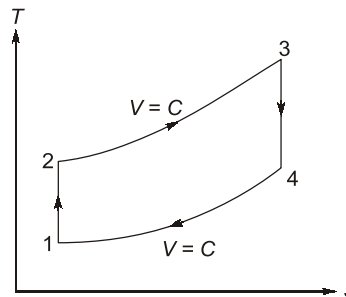
EXAMPLE : 1.6

If an engine works on Otto cycle between temperature limits 1450 K and 310 K, find the maximum power developed by the engine assuming circulation per minute as 0.38 kg.

- (a) 114.6 kW (b) 0.031 kW
(c) 1.9 kW (d) 2.65 kW

Solution: (c)

Given: $T_1 = 310 \text{ K}$, $T_3 = 1450 \text{ K}$, $m = 0.38 \text{ kg}$



$$\therefore W = C_V [(T_3 - T_2) - (T_4 - T_1)]$$

For maximum power,

$$T_2 = T_4 = \sqrt{T_1 T_3} = \sqrt{310 \times 1450} = 670.45 \text{ K}$$

$$\therefore W_{\max} = 0.72 [(1450 - 670.45) - (670.45 - 310)]$$

$$= 301.75 \text{ kJ/kg}$$

$$\therefore \text{Maximum power, } P_{\max} = 307.75 \times \frac{0.38}{60} = 1.9 \text{ kW}$$

EXAMPLE : 1.7

The stroke and cylinder diameter of a compression ignition engine are 250 mm and 150 mm respectively. If the clearance volume is 0.0004 m³ and fuel injection takes place at constant pressure for 5 percent of the stroke determine the efficiency of the engine. Assume the engine working on the diesel cycle.

Solution:

Length of stroke,

$$L = 250 \text{ mm} = 0.25 \text{ m}$$

Diameter of cylinder,

$$D = 150 \text{ mm} = 0,15 \text{ m}$$

Clearance volume, $V_2 = 0.0004 \text{ m}^3$

Swept volume, $V_s = \frac{\pi}{4} D^2 L = \frac{\pi}{4} \times 15^2 \times 0.25 = 0.004418 \text{ m}^3$

Total cylinder volume = Swept volume + Clearance volume

$$= 0.004418 + 0.0004 = 0.004818 \text{ m}^3$$

Volume at point of cut-off, $V_3 = V_2 + \frac{5}{100} V_s$

$$= 0.0004 + \frac{5}{100} \times 0.004418 = 0.000621 \text{ m}^3$$

\therefore Cut-off ratio, $\rho = \frac{V_3}{V_2} = \frac{0.000621}{0.0004} = 1.55$

Compression ratio, $r = \frac{V_1}{V_2} = \frac{V_s + V_2}{V_2} = \frac{0.004418 + 0.0004}{0.0004} = 12.04$

Hence,
$$\eta_{\text{diesel}} = 1 - \frac{1}{\gamma(r)^{\gamma-1}} \left[\frac{\rho^\gamma - 1}{\rho - 1} \right]$$
$$= 1 - \frac{1}{1.4 \times (12.04)^{1.4-1}} \left[\frac{(1.55)^{1.4} - 1}{1.55 - 1} \right]$$
$$= 1 - 0.264 \times 1.54 = \mathbf{0.593 \text{ or } 59.3 \%}$$

EXAMPLE : 1.8

Calculate the percentage loss in the ideal efficiency of a diesel engine with compression ratio 14 if the fuel cut-off is delayed from 5% to 8%.

Solution:

Let the clearance volume (V_2) be unity.

Then, compression ratio, $r = 14$

Now, when the fuel is cut-off at 5%, we have

$$\frac{\rho - 1}{r - 1} = \frac{5}{100} \quad \text{or} \quad \frac{\rho - 1}{14 - 1} = 0.05$$

or $\rho - 1 = 13 \times 0.05 = 0.65$

$\therefore \rho = 1.65$

$$\eta_{\text{diesel}} = 1 - \frac{1}{\gamma(r)^{\gamma-1}} \left[\frac{\rho^\gamma - 1}{\rho - 1} \right]$$
$$= 1 - \frac{1}{1.4 \times (14)^{1.4-1}} \left[\frac{(1.65)^{1.4} - 1}{1.65 - 1} \right]$$
$$= 1 - 0.248 \times 1.563 = 0.612 = 61.2\%$$

When the fuel is cut-off at 8%, we have

$$\frac{p-1}{r-1} = \frac{8}{100} \quad \text{or} \quad \frac{p-1}{14-1} = \frac{8}{100} = 0.08$$

∴

$$p = 1 + 1.04 = 2.04$$

$$\eta_{\text{diesel}} = \frac{1}{\gamma(r)^{\gamma-1}} \left[\frac{p^{\gamma}-1}{p-1} \right]$$

$$= 1 - \frac{1}{1.4 \times (14)^{1.4-1}} \left[\frac{(2.04)^{1.4}-1}{2.04-1} \right]$$

$$= 1 - 0.248 \times 1.647 = 0.591 = 59.1\%$$

Hence percentage loss in efficiency due to delay in fuel cut-off = $61.2 - 59.1 = 2.1\%$

EXAMPLE : 1.9

An oil engine working on the dual combustion cycle has a compression ratio 14 and the explosion ratio obtained from an indicator card is 1.4. If the cut-off occurs at 6 percent of stroke, find the ideal efficiency. Take γ for air = 1.4.

Solution :

Compression ratio, $r = 14$

Explosion ratio, $\beta = 1.4$

If p is the cut-off ratio, then $\frac{p-1}{r-1} = \frac{6}{100}$

or $\frac{p-1}{14-1} = 0.06$

∴ $p = 1.78$

Ideal efficiency is given by

$$\eta_{\text{ideal or dual}} = 1 - \frac{1}{(r)^{\gamma-1}} \left[\frac{(\beta p^{\gamma}-1)}{(\beta-1) + \beta\gamma(p-1)} \right]$$

$$= 1 - \frac{1}{(14)^{1.4-1}} \left[\frac{1.4 \times (1.78)^{1.4}-1}{(1.4-1) + 1.4 \times 1.4(1.78-1)} \right]$$

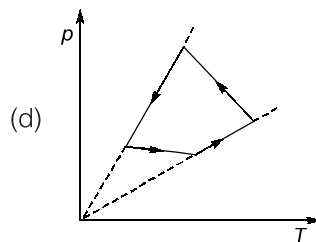
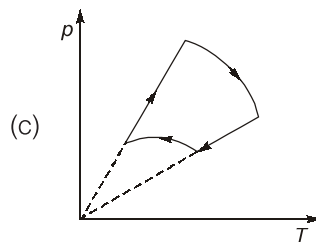
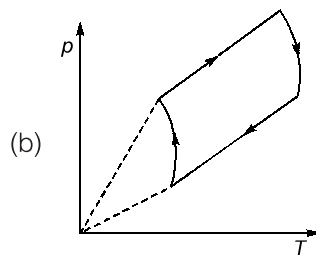
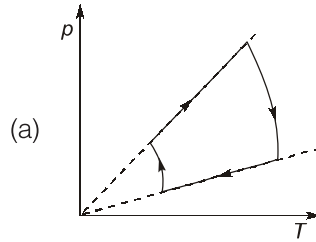
$$= 1 - 0.348 \left[\frac{3.138-1}{0.4+1.528} \right] = 0.614 = 61.5\%$$

■■■■



**OBJECTIVE
BRAIN TEASERS**

- Q.1** With increasing temperature of intake air, IC engine efficiency
(a) decreases
(b) increases
(c) remains same
(d) depends on other factors
- Q.2** 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.3** 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.4** Piston compression rings are made of
(a) Cast iron (b) Bronze
(c) Aluminum (d) White metal
- Q.5** **Statement (I):** For a given compression ratio, the thermal efficiency of the Diesel cycle will be higher than that of the Otto cycle.
Statement (II): In the Diesel cycle, work is also delivered during heat addition.
(a) Both Statement (I) and Statement (II) are true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are true but Statement (II) is not a correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.
- Q.6** Which one of the following p-T diagrams illustrates the Otto cycle of an ideal gas?



ANSWER KEY

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



CONVENTIONAL BRAIN TEASERS

Q.1 In an engine working on Dual cycle, the temperature and pressure at the beginning of the cycle are 90°C and 1 bar respectively. The compression ratio is 9. The maximum pressure is limited to 68 bar and total heat supplied per kg of air is 1750 kJ.

Determine:

- Pressure and temperature at all salient points
- Air standard efficiency
- Mean effective pressure.

Solution:

Initial pressure, $p_1 = 1 \text{ bar}$
 Initial temperature, $T_1 = 90^\circ = 363 \text{ K}$
 Compression ratio, $r = 9$
 Maximum pressure, $p_3 = p_4 = 68 \text{ bar}$
 Total heat supplied = 1750 kJ/kg

(i) Pressures and temperatures at salient points:

For the isentropic process 1-2,

$$p_1 V_1^\gamma = p_2 V_2^\gamma$$

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

Also,
$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{\gamma-1} = (r)^{\gamma-1} = (9)^{1.4-1} = 2.408$$

$\therefore T_2 = T_1 \times 2.408 = 363 \times 2.408 = 874.1 \text{ K}$
 $p_3 = p_4 = 68 \text{ bar}$

For the constant volume process 2-3,

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

$\therefore T_3 = T_2 \times \frac{p_3}{p_2} = 874.1 \times \frac{68}{21.67} = 2742.9 \text{ K}$

Heat added at constant volume = $c_v(T_3 - T_2) = 0.71(2742.9 - 874.1)$
 $= 1326.8 \text{ kJ/kg}$

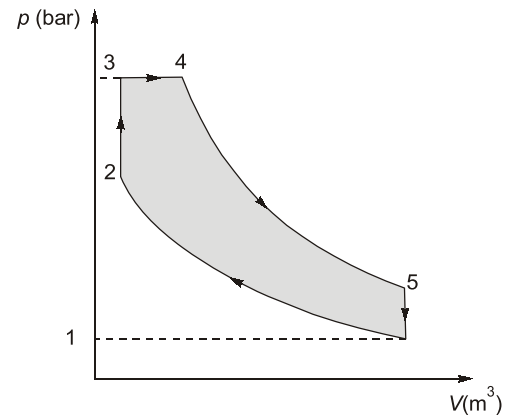
\therefore Heat added at constant pressure = Total heat added – Heat added at constant volume
 $= 1750 - 1326.8 = 423.2 \text{ kJ/kg}$

$\therefore c_p(T_4 - T_3) = 423.2$

or $1.0(T_4 - 2742.9) = 423.2$

$\therefore T_4 = 3166 \text{ K}$

For constant pressure process 3-4,
$$\rho = \frac{V_4}{V_3} = \frac{T_4}{T_3} = \frac{3166}{2742.9} = 1.15$$



For adiabatic (or isentropic) process 4–5,

$$\frac{V_5}{V_4} = \frac{V_5}{V_2} \times \frac{V_2}{V_4} = \frac{V_1}{V_2} \times \frac{V_3}{V_4} = \frac{r}{\rho} \quad \left(\because \rho = \frac{V_4}{V_3} \right)$$

Also

$$p_4 V_4^\gamma = p_5 V_5^\gamma$$

\therefore

$$\begin{aligned} p_5 &= p_4 \times \left(\frac{V_4}{V_5} \right)^\gamma \\ &= 68 \times \left(\frac{\rho}{r} \right)^\gamma = 68 \times \left(\frac{1.15}{9} \right)^{1.4} = \mathbf{3.81 \text{ bar}} \end{aligned}$$

Again,

$$\frac{T_5}{T_4} = \left(\frac{V_4}{V_5} \right)^{\gamma-1} = \left(\frac{\rho}{r} \right)^{\gamma-1} = \left(\frac{1.15}{9} \right)^{1.4-1} = 0.439$$

\therefore

$$T_5 = T_4 \times 0.439 = 3166 \times 0.439 = \mathbf{1389.9 \text{ K}}$$

(ii) Air standard efficiency :

Heat rejected during constant volume process 5–1,

$$Q_R = c_v(T_5 - T_1) = 0.71(1389.8 - 363) = 729 \text{ kJ/kg}$$

\therefore

$$\begin{aligned} \eta_{\text{air-standard}} &= \frac{\text{Work done}}{\text{Heat supplied}} = \frac{Q_s - Q_R}{Q_s} \\ &= \frac{1750 - 729}{1750} = \mathbf{0.5834 = 58.34\%} \end{aligned}$$

(iii) Mean effective pressure, p_m :

$$p_m = \frac{\text{Work done per cycle}}{\text{Stroke volume}}$$

or

$$p_m = \frac{1}{V_s} \left[p_3(V_4 - V_3) + \frac{p_4 V_4 - p_4 V_5}{\gamma - 1} - \frac{p_2 V_2 - p_1 V_1}{\gamma - 1} \right]$$

$$V_1 = V_5 = rV_c, V_2 = V_3 = V_c, V_4 = \rho V_c,$$

$$V_s = (r - 1)V_c$$

\therefore

$$r = \frac{V_s + V_c}{V_c} = 1 + \frac{V_s}{V_c}$$

\therefore

$$V_s = (r - 1)V_c$$

\therefore

$$p_m = \frac{1}{(r - 1)V_c} \left[p_3(\rho V_c - V_c) + \frac{p_4 \rho V_c - p_5 \times r V_c}{\gamma - 1} - \frac{p_2 V_c - p_1 r V_c}{\gamma - 1} \right]$$

$$r = 9, \rho = 1.15, \gamma = 1.4$$

$$p_1 = 1 \text{ bar}, p_2 = 21.67 \text{ bar},$$

$$p_3 = p_4 = 68 \text{ bar}, p_5 = 3.81 \text{ bar}$$

Substituting the above values in the above equation, we get

$$\begin{aligned} p_m &= \frac{1}{(9 - 1)} \left[68(1.15 - 1) + \frac{68 \times 1.15 - 3.81 \times 9}{1.4 - 1} - \frac{21.67 - 9}{1.4 - 1} \right] \\ &= \frac{1}{8} (10.2 + 109.77 - 31.67) = \mathbf{11.04 \text{ bar}} \end{aligned}$$

Q.2 The volume ratios of compression and expansion for a diesel engine as measured from an indicator diagram are 15.3 and 7.5 respectively. The pressure and temperature at the beginning of the compression are 1 bar and 27°C.

Assuming an ideal engine, determine the mean effective pressure, the ratio of maximum pressure to mean effective pressure and cycle efficiency.

Also find the fuel consumption per kWh if the indicated thermal efficiency is 0.5 of ideal efficiency, mechanical efficiency is 0.8 and the calorific value of oil 42000 kJ/kg.

Assume for air : $c_p = 1.005$ kJ/kgK; $c_v = 0.718$ kJ/kgK, $\gamma = 1.4$

Solution:

Given:

$$\frac{V_1}{V_2} = 15.3$$

$$\frac{V_4}{V_3} = 7.5$$

$$p_1 = 1 \text{ bar}; T_1 = 27^\circ\text{C} = 300 \text{ K}$$

$$\eta_{\text{th(I)}} = 0.5 \times \eta_{\text{air-standard}};$$

$$\eta_{\text{mech}} = 0.8; C V = 42000 \text{ kJ/kg.}$$

The cycle is shown in figure, the subscripts denote the respective points in the cycle.

Mean effective pressure, p_m :

$$p_m = \frac{\text{Work done by the cycle}}{\text{Swept volume}}$$

$$\text{Work done} = \text{Heat added} - \text{Heat rejected}$$

$$\text{Heat added} = mc_p(T_3 - T_2), \text{ and}$$

$$\text{Heat rejected} = mc_v(T_4 - T_1)$$

Now assume air as a perfect gas and mass of oil in the air-fuel mixture is negligible and is not taken into account.

Process (1-2) is an adiabatic compression process, thus

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

or

$$T_2 = T_1 \times \left(\frac{V_1}{V_2}\right)^{1.4-1} \quad (\text{since } \gamma = 1.4)$$

or

$$T_2 = 300 \times (15.3)^{0.4} = 893.3 \text{ K}$$

Also,

$$p_1 V_1^\gamma = p_2 V_2^\gamma$$

\Rightarrow

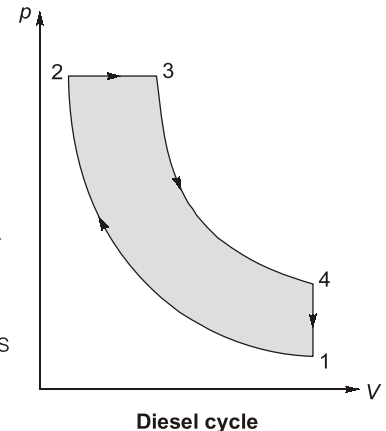
$$p_2 = p_1 \times \left(\frac{V_1}{V_2}\right)^\gamma = 1 \times (15.3)^{1.4} = 45.56 \text{ bar}$$

Process (2 - 3) is a constant pressure process, hence

$$\frac{V_2}{T_2} = \frac{V_3}{T_3}$$

\Rightarrow

$$T_3 = \frac{V_3 T_2}{V_2} = 2.04 \times 893.3 = 1822.3 \text{ K}$$



Diesel cycle