SREENIVASA INSTITUTE OF TECHNOLOGY AND MANAGEMENT STUDIES, CHITTOOR.

(Autonomous)

DEPARTMENT of MECHANICAL ENGINEERING
(NBA & NAAC Accredited)

THERMAL ENGINEERING-I (18MEC221)

COURSE MATERIAL

FACULTY INCHARGE
Mr.R.SATHEESH
Asso.Prof.,
Dept. of Mechanical Engg.

PROGRAM OUTCOMES (PO's)

PO1. Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution of complex engineering problems.

PO2. Problem analysis: Identify, formulate, review research literature and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences.

PO3. Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety and the cultural, societal and environmental considerations.

PO4. Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data and synthesis of the information to provide valid conclusions.

PO5. Modern tool usage: Create, select and apply appropriate techniques, resources and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO6. The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO7. Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts and demonstrate the knowledge of and need for sustainable development.

PO8. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO9. Individual and team work: Function effectively as an individual and as a member or leader in diverse teams and in multidisciplinary settings.

PO10. Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations and give and receive clear instructions.

PO11. Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO12. Life-long learning: Recognize the need for and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

II B.Tech II Semester	**L T P C**
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18MEC221 THERMAL ENGINEERING - I	

Course Educational Objectives:

- To acquire knowledge on analysis of stages in gas power cycles.
- To introduce the principles, working and various systems of IC engines.
- To analyze the combustion of SI engines and CI engines.
- To analyze the performance parameters of IC engines.
- To analyze the performance of air compressors.

UNIT – 1: GAS POWER CYCLES

Otto, Diesel cycle analysis - MEP, efficiency calculations - Comparison of air standard and fuel-air cycles - Causes for deviation of fuel-air cycle from air standard cycle - Comparison of air standard and actual cycles - Time loss factor, head loss factors, blowdown loss and rubbing friction factors.

UNIT – 2: INTERNAL COMBUSTION ENGINES

Introduction of IC Engines: Classification of IC engines - Components and their function - Valve timing diagram and port timing diagram - Comparison of two stroke and four stroke engines, S.I and C.I engines. Fuel Systems: S.I. Engine: Carburetor - Mechanical and electrical fuel pump - C.I. Engine: Fuel injection pump - Fuel injector - Types of fuel injector nozzles. Cooling Systems: Cooling requirements - Air cooling and water cooling (thermosyphon and forced circulation system). Lubrication Systems: Petroil, splash, pressurized and mist lubrication. Ignition Systems: Function of an ignition system - Battery coil, magneto coil and electronic ignition system using contact breaker and contact triggers.

UNIT – 3: COMBUSTION IN IC ENGINES

S.I. Engine: Normal and abnormal combustion - Importance of flame speed and effect of engine variables - Type of abnormal combustion, pre ignition and knocking (concept only) - Fuel requirements and fuel rating, antiknock additives - Combustion chambers. C.I. Engine: Stages of combustion - Delay period and its importance - Effect of engine variables - Diesel knock - Combustion chambers - Fuel requirements and fuel rating.

UNIT – 4: TESTING AND PERFORMANCE OF IC ENGINES

Performance parameters - 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.

UNIT – 5: AIR COMPRESSOR

Classification of air compressor - Reciprocating compressor - Workdone by single stage reciprocating air compressor with and without clearance volume - Efficiencies of reciprocating compressor - Multistage air compressor and inter cooling - Types of rotary air compressors (basics only) - Comparison between reciprocating and rotary air compressors.

Course Outcomes:

On successful completion of the course, students will be able to:

Course Outcomes		POs related to COs
CO1	Acquire knowledge on gas power cycles and analysis on it.	PO1, PO2, PO3, PO4
CO2	Know the basic knowledge of an engine, identify the types, components of IC engines and explain the functions of each.	PO1
CO3	Demonstrate the basic knowledge and analyze the types and stages of combustion in SI and CI engines.	PO1
CO4	Investigation on IC engines for performance improvement and emission reduction to environment.	PO1, PO2, PO3, PO4, PO7
CO5	Demonstrate the basic knowledge of an air compressor in developing the analytical models.	PO1, PO2, PO3, PO4

Text Books:

1. **Thermal Engineering, R.K Rajput, 8/e, Laxmi Publications (P) Ltd, New Delhi, 2010.**
2. **Internal Combustion Engines, V. Ganesan, 4/e, Tata McGraw-Hill Education Pvt. Ltd., Noida, 2012.**

Reference Books:

1. **IC Engines, Mathur and Sharma, 1/e, Dhanpat Rai Publishing Company (P) Ltd., New Delhi, 2010.**
2. **A course in thermal Engineering, C.P. Kothandaraman, S.Domkundwar and A.V.Domkundwar, 5/e, Dhanpat Rai & sons, 2002.**
3. **Thermal Engineering, Rudramoorthy, 15/e, Tata McGraw-Hill Education Pvt.Ltd, Noida, 2012.**
4. **I .C. Engines, Heywood, 1/e, Tata McGraw-Hill Education Pvt.Ltd., Noida, 1998.**
5. **Thermal Engineering, R.S.Khurmi and J.K.Gupta, 5/e, S Chand & Company Pvt. Ltd., New Delhi, 2008.**

UNIT – 1: GAS POWER CYCLES

Otto, Diesel cycle analysis - MEP, efficiency calculations - Comparison of air standard and fuel-air cycles - Causes for deviation of fuel-air cycle from air standard cycle - Comparison of air standard and actual cycles - Time loss factor, head loss factors, blowdown loss and rubbing friction factors.

Course Outcomes:
On successful completion of this unit, students will be able to:

Course Outcomes		POs related to COs
CO1	Acquire knowledge on gas power cycles and analysis on it.	PO1, PO2, PO3, PO4

WEB SOURCE REFERENCES:

1	https://nptel.ac.in/courses/112106133/2
2	http://en.wikipedia.org/wiki/mechanical
3	http://en.wikipedia.org/wiki/Applied_Thermal_Engineering
4	https://www.brighthubengineering.com/thermodynamics/4125-air-standard-cycle-part-one/
5	www.sciencedirect.com
6	www.journals.elseier.com

ADDITIONALRESOURCES:

1. **Anna university tutorials**
2. **Thermal engineering Books (PDF Formats)**
3. **Online Objective Questions (GATE, IES, NPTEL etc.,)**
4. **Videos Materials if any (You tube)**

Gas Power Cycle's (or Thermodynamic Air Cycle's

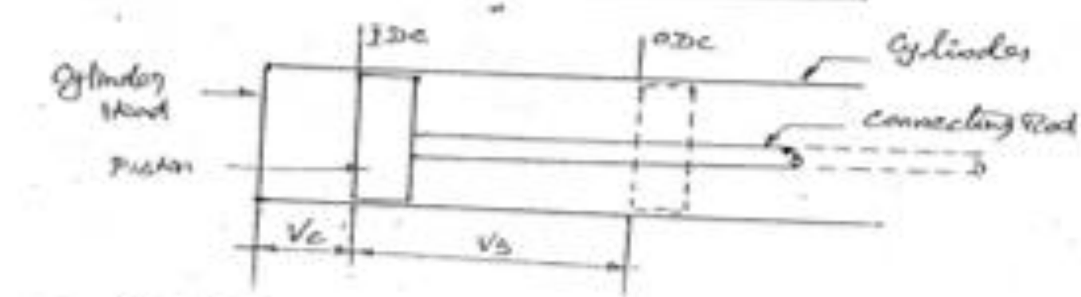
Introduction: A thermodynamic cycle is a series of thermodynamic processes during which a working substance undergoes a change in properties (P, V & T etc) & finally the working substance returns to its initial state.

These processes can be plotted on a P-V & T-S diagram.

Heat Engine: Any machine designed to carry out a thermodynamic cycle to convert heat energy supplied to it, into mechanical energy is called a heat engine.

The cycle on which a heat engine works is known as a heat engine cycle. A cycle requiring two complete revolutions of the crank [or 4 strokes of the piston] is known as 4-stroke cycle. A cycle requiring one complete revolution of the crank [or 2 strokes of the piston] is known as 2-stroke cycle.

Terms used in thermodynamic cycle:



→ **Cylinder Bore:** This is the diameter of the cylinder in which the piston moves.

→ **Stroke length:** The piston moves in the cylinder due to the rotation of the crank. (L)
It means : distance b/t. (IDC to ODC) (or (TDC to BDC).

Efficiency of a Cycle:- (η) (or) Air Standard Efficiency (ASE)

$$\eta \text{ (or) } ASE = \frac{\text{Workdone per cycle}}{\text{Heat supplied}} = \frac{W}{Q_s}$$

where; W = heat supplied − heat rejected.

$$\therefore \eta = \frac{Q_S - Q_R}{Q_S}$$

$$\text{Relative efficiency} = \frac{\text{Actual Thermal efficiency}}{\text{Theoretical Thermal efficiency}}$$

Classification of Thermodynamic Cycles:

(a) Reversible cycle & (b) Irreversible cycle.

(a) Reversible Cycle:

A thermodynamic process which can be operated in a reversed direction is known as reversible process.

A thermodynamic cycle which consists of reversible process only is known as reversible cycle. At the end of the cycle, the initial conditions are restored.

An engine working on reversible cycle is most efficient one. Carnot cycle is reversible & hence most efficient. But it is impossible to construct an engine working on Carnot cycle.

(b) Irreversible Cycle:-

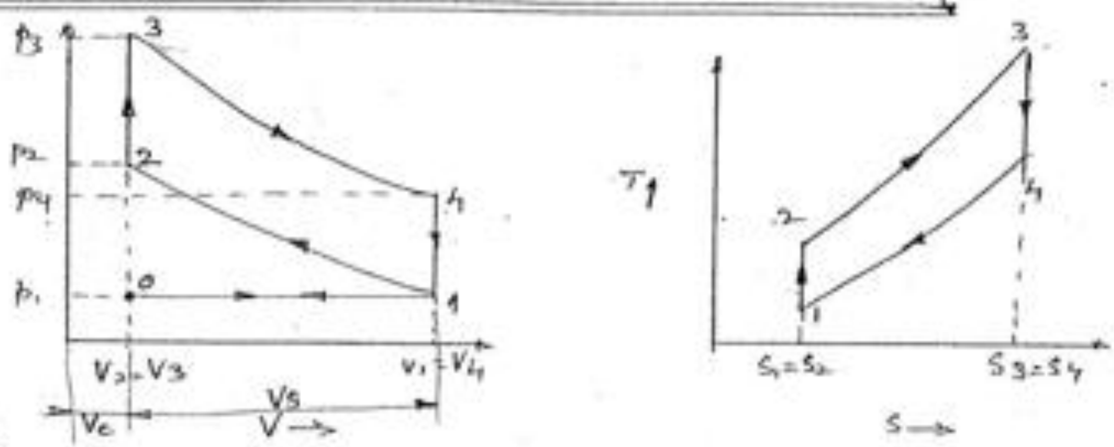
A thermodynamic process which cannot be operated in a reversed direction is known as irreversible process.

In actual practice, all processes are irreversible. A thermodynamic cycle is said to be irreversible cycle, if any of the process in the cycle is irreversible. At the end of the cycle, the initial conditions are not restored.

Types of Thermodynamic Cycles :-

1. Carnot cycle (1824) Nicolas Leonard Sadi Carnot -(French)
2. Otto cycle. [Const. volume cycle] (1876)
3. Brayton cycle [Const. pressure cycle] (or) Joule cycle.
4. Diesel cycle. (1892) Dr. Rudolph Diesel
5. Dual combustion cycle.
6. Stirling cycle (1827) Robert Stirling
7. Ericsson cycle (1850) & Joule cycle.

Otto cycle [Nikolaus A. Otto (German engineer)] :



In Fig's:

(1-2) : Adiabatic compression.
(2-3) : Heat addition at const. volume.
(3-4) : Adiabatic expansion.
(4-1) : Heat rejection at const. volume.

This is the theoretical cycle on which the petrol & gas engines work.

The cycle consists of two adiabatic & two constant volume process as shown in PV & T-S diagrams. This is also known as "Const. volume cycle" as heat is received at constant volume.

Working of otto cycle:

1. First stage (Adiabatic compression (1-2)):

The air is compressed adiabatically from temperature T_1 to T_2. In this process no heat is absorbed (or) rejected by the air.

2. Second stage (Const. volume of heat addition (2-3)):

The heat is supplied at const. volume. This increases the pr. P_2 to P_3 & the temp. T_2 to T_3.

$$Q_S = m.C_v(T_3 - T_2)$$

3. Third stage (Adiabatic Expansion (3-4)):-

At the end of heat addition, the air is expanded adiabatically by moving the piston from temp. T_3 to T_4 & P_3 to P_4. The volume increases from V_3 to V_4. No heat is absorbed (or) rejected by the air.

4. Fourth stage (Const. volume of heat rejection (4-1)):-

At the end of expansion, the heat is rejected from air at const. volume until the air is brought to its original condition P_1, V_1 & T_1.

$$Q_R = m.C_v(T_4 - T_1)$$

The cycle is thus repeated.

Air standard Efficiency of otto cycle:

$$\eta_{otto} = \frac{\text{Workdone}}{\text{Heat Supplied}} = \frac{Q_S - Q_R}{Q_S}$$

$$= \frac{mC_v(T_3 - T_2) - m.C_v(T_4 - T_1)}{m.C_v(T_3 - T_2)}$$

$$\eta = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)} \longrightarrow (A)$$

The above expression can be simplified by substituting the values of T_4 in terms of T_3 & T_1 in terms of T_2

From adiabatic expansion (3-4);

$$\boxed{\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1}} \rightarrow (1)$$

From adiabatic compression (1-2);

$$\boxed{\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}} \rightarrow (2)$$

WKT, $V_1 = V_4$; $V_2 = V_3$

$$\therefore \frac{T_2}{T_1} = \frac{T_3}{T_4} \Rightarrow \frac{T_4}{T_1} = \frac{T_3}{T_2} \Rightarrow \frac{T_4}{T_1} - 1 = \frac{T_3}{T_2} - 1$$

$$\Rightarrow \frac{T_4 - T_1}{T_1} = \frac{T_3 - T_2}{T_2}$$

$$\Rightarrow \frac{T_4 - T_1}{T_3 - T_2} = \frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1} \longrightarrow (B)$$

Sub (B) in (A);

we get;

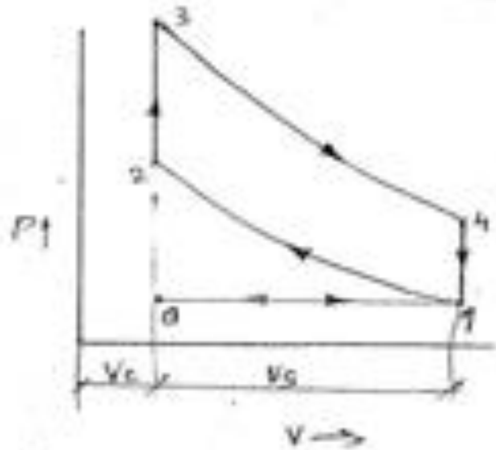
$$\eta_{otto} = 1 - \left(\frac{V_2}{V_1}\right)^{\gamma-1}$$

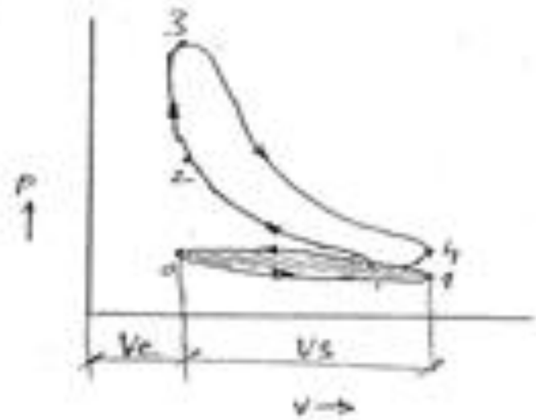
where; Compression ratio; $r = \frac{V_1}{V_2} = \frac{\text{vol. at the beginning of compression}}{\text{vol. at the end of compression}}$

$$\boxed{\therefore \eta_{otto} = 1 - \frac{1}{r^{\gamma-1}}}$$

"The efficiency of the air standard otto cycle is thus a function of the compression ratio only".

Ideal & Actual p-v diagrams of otto cycle:



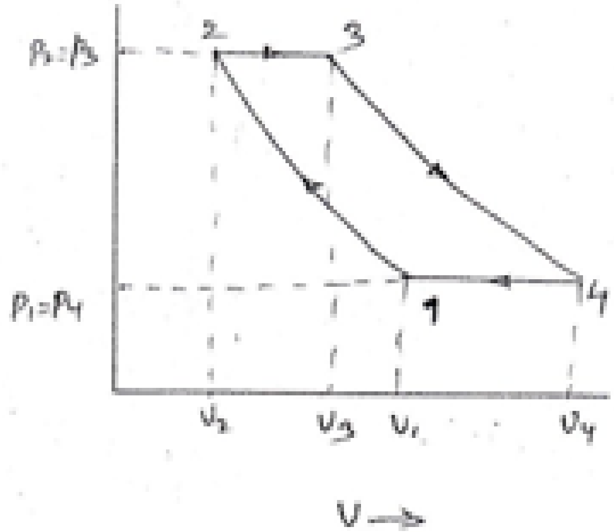


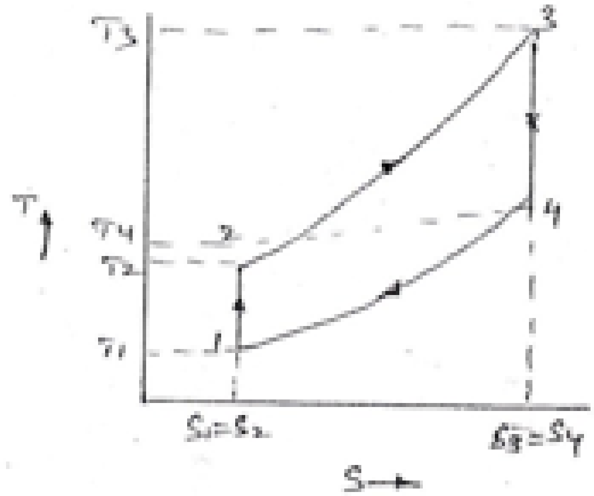
- In ideal cycle, the corners of p-v diagrams are sharp. But in actual p-v diagram, there is "rounding off" of the corners, because the closing & opening of the valves are not instantaneous but takes some time.
- Time lag between the time of ignition & combustion.
- There is no heat transfer during the adiabatic compression & expansion. But these are not possible in practice because the heat transfer to the metal surface's of cylinder & piston.

The total effect of all the above differences is that the thermal efficiency of the actual cycle is less than ideal (or) Air standard efficiency.

It can be seen from the actual p-v diagram that the area 1-2-3-4 is positive (Actual work developed) & area 4-0-1 is negative (work used for discharging gases to atmosphere) & is called negative power (or) Pumping power.

Brayton Cycle (or) Joule's cycle [Constant pressure cycle].





This is an ideal cycle for gas turbine plants. The cycle consists of two adiabatic processes & two constant pressure processes.

(1-2) : Adiabatic Compression.

(2-3) : Heat addition @ const. pressure : $Q_S = m.C_p(T_3 - T_2)$

(3-4) : Adiabatic expansion.

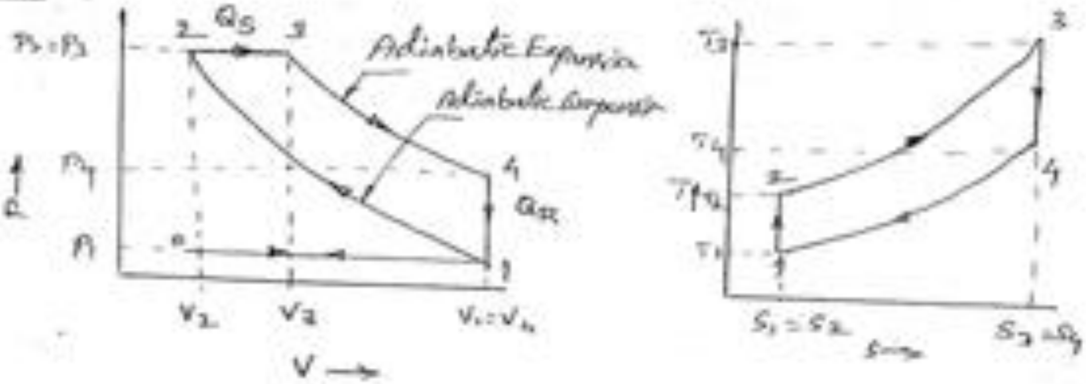
(4-1) : Heat rejection @ const. pressure : $Q_R = m.C_p(T_4 - T_1)$

$$\therefore \eta = \frac{W}{Q_S} = \frac{m.C_p(T_3-T_2) - m.C_p(T_4-T_1)}{m.C_p(T_3-T_2)}$$

$$\eta_{Bray} = 1 - \frac{T_4-T_1}{T_3-T_2} = 1 - \frac{1}{r^{\gamma-1}}$$

The efficiency of otto cycle is equal to efficiency of Brayton cycle due to same compression ratio.

Diesel Cycle:



This is an important cycle in practice on which all diesel engines work. The diesel engine works with high compression ratio & gives higher thermal efficiency than petrol engine working on otto cycle.

The cycle consists of two adiabatic process, one constant pressure process & one constant volume process.

Working :-

Stage - 1 : [Adiabatic compression] (1-2) :-

At point 1, the cylinder is full of air with volume V_1, pr. P_1 & temp. T_1. At the end of stroke the condition of air is represented by the point 2 on p-v diagram V_2, P_2 & T_2. No heat is absorbed/rejected by the air during this process.

Stage - 2 : [Heat Addition at Const. Pressure (2-3)] :-

At the point 2, heat is supplied to air at P=c. The piston moves outwards / downwards. At point 3, the supply of heat is stopped. This point is known as "point of cut-off".

$$Q_s = m \cdot C_p (T_3 - T_2)$$

Stage 3: [Adiabatic Expansion (3-4)]:-

From point 3, the air is expanded adiabatically by moving the piston outwards. The work is done on the piston. The Pr, & temp. drops from P_3 to P_4 & T_3 to T_4. The volume increases from V_3 to V_4. No heat is absorbed / rejected by the air.

Stage-4: [Heat Rejection at Constant Volume (4-1)]:-

At point 4, the heat is abstracted from air at V=C, until the air brought to its original condition P_1, V_1 & T_1.

$$Q_R = m \cdot C_V (T_4 - T_1)$$

The cycle is thus repeated.

Air standard efficiency = $\dfrac{\text{Workdone}}{\text{Heat Supplied}}$

$$\eta_{diesel} = \frac{m \cdot C_p (T_3 - T_2) - m \cdot C_V (T_4 - T_1)}{m \cdot C_p (T_3 - T_2)}$$

$$\eta_{diesel} = 1 - \frac{C_V}{C_p} \frac{(T_4 - T_1)}{(T_3 - T_2)}$$

$$\boxed{\eta_{diesel} = 1 - \frac{1}{\gamma} \frac{(T_4 - T_1)}{(T_3 - T_2)}} \longrightarrow ①$$

The above expression (eqn) can be simplified by substituting all temp's in terms of T_3.

Let compression ratio, $r = \dfrac{V_1}{V_2}$, ∴ Expansion ratio $= \dfrac{V_4}{V_3}$

Cut-off ratio, $\rho = \dfrac{V_3}{V_2}$

$$= \frac{V_4}{V_2} \cdot \frac{V_2}{V_3}$$

$$= \frac{V_1}{V_2} \cdot \frac{V_2}{V_3} \quad (\because V_4 = V_1)$$

$$\text{Exp. ratio} = \frac{r}{\rho} \longrightarrow ②$$

Process (2-3) [Q_S @ $P=C$];

$$\frac{P_2 V_2}{T_2} = \frac{P_3 V_3}{T_3} \quad (\because P_2 = P_3)$$

$$\therefore \frac{V_2}{T_2} = \frac{V_3}{T_3} \Rightarrow \frac{T_3}{T_2} = \frac{V_3}{V_2} = \rho$$

$$\therefore \boxed{T_2 = \frac{T_3}{\rho}} \longrightarrow (3)$$

Process (1-2) [Adiabatic Compression]:

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = r^{\gamma-1} \quad \therefore \boxed{T_1 = \frac{T_2}{r^{\gamma-1}}} \longrightarrow (4)$$

(3) in (4); we get;

$$\therefore \boxed{T_1 = \frac{T_3}{\rho . r^{\gamma-1}}} \longrightarrow (5)$$

Process (3-4) [Adiabatic Expansion]:

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = \left(\frac{r}{\rho}\right)^{\gamma-1} \quad \therefore \boxed{T_4 = T_3\left(\frac{\rho}{r}\right)^{\gamma-1}} \longrightarrow (6)$$

Substituting the values of T_2, T_1 & T_4 in eqn (1), we get;

$$\eta_{diesel} = 1 - \frac{1}{\gamma} \times \frac{\left[T_3\left(\frac{\rho}{r}\right)^{\gamma-1} - \frac{T_3}{\rho . r^{\gamma-1}}\right]}{\left[T_3 - \frac{T_3}{\rho}\right]}$$

$$= 1 - \frac{1}{\gamma} \times \frac{1}{r^{\gamma-1}}\left[\frac{\rho^{\gamma-1} - \frac{1}{\rho}}{1 - \frac{1}{\rho}}\right]$$

$$\boxed{\eta_{diesel} = 1 - \frac{1}{\gamma . r^{\gamma-1}}\left[\frac{\rho^{\gamma} - 1}{\rho - 1}\right]}$$

Comparison of OTTO & DIESEL Cycle:

Otto Cycle	Diesel Cycle
1. It is used in petrol engines	- It is used in diesel engines
2. The cycle consists of two adiabatic & two const. volume process.	It consists of two adiabatic, one const. Pr. & one const. volume process.
3. Heat added at const. volume.	- Heat added at const. Pr.
4. Compression ratio & expansion ratio are same.	- Not same. Expansion ratio is less than compression ratio.
5. η of the cycle depends on compression ratio. η increases with increase in compression ratio.	- η of the cycle depends on compression ratio & cut-off ratio. η increases with increase in compression ratio & with decrease in cut off ratio.
6. The compression ratio is limited from 6 to 9	- 12 to 18
7. For the same compression ratio & same heat input, the η_{otto} is more than that of diesel cycle.	- η_{diesel} is less than that of otto cycle for the same compression ratio & same heat input.
8. $\eta_{otto} = 1 - \frac{1}{r^{\gamma-1}}$	- $\eta_{diesel} = 1 - \frac{1}{\gamma \cdot r^{\gamma-1}}\left(\frac{\rho^{\gamma}-1}{\rho-1}\right)$

Comparison of efficiencies of otto & diesel cycle:

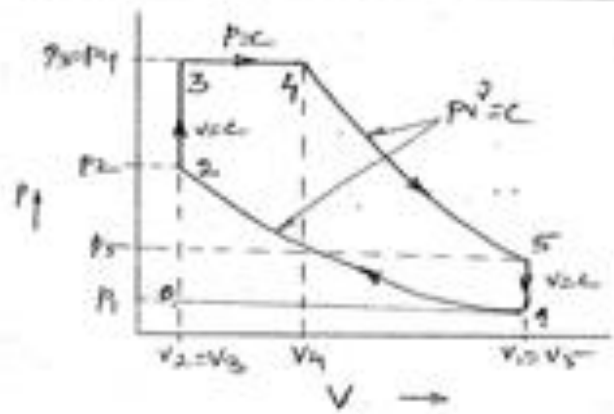
The air standard efficiency of:

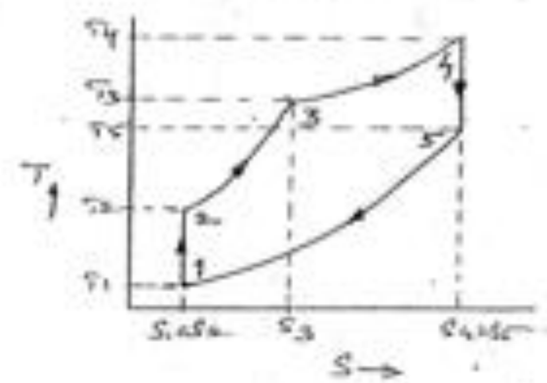
Otto cycle. $\eta = 1 - \frac{1}{r^{\gamma-1}}$

Diesel cycle. $\eta = 1 - \frac{1}{\gamma \cdot r^{\gamma-1}}\left(\frac{\rho^{\gamma}-1}{\rho-1}\right) = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{\rho^{\gamma}-1}{\gamma(\rho-1)}\right]$

In the efficiency eqn. of diesel cycle, the value of the factor $\left[\frac{\rho^{\gamma}-1}{\gamma(\rho-1)}\right]$ depends on the value of cut off ratio (ρ), which is always more than unity. Hence the value of this factor is greater than unity. Therefore for the same compression ratio, η_{diesel} is less than η_{otto}. $[\because \eta_{diesel} < \eta_{otto}]$. That is otto cycle is more efficient than diesel cycle.

Dual Combustion cycle [Limited Pr. Cycle / Mixed Cycle]:





This cycle is a combination of otto & Diesel cycles, in a way that heat is added partly at constt. volume & partly at constt. pr..

This cycle consists of two adiabatic process, two constt. volume process & one constt. pr. process.

I-stage (1-2): Adiabatic compression:

II-stage (2-3): Heat Addition at const. volume

$$Q_S = m.C_v(T_3-T_2)$$

III-stage (3-4): Heat Addition at constt. pressure.

$$Q_S = m.C_p(T_4-T_3)$$

IV stage (4-5) : Adiabatic Expansion

V-stage : (5-1) Heat rejection at constant volume.

$$Q_R = m.C_v(T_5 - T_1)$$

Air standard efficiency, $\eta_{dual} = \frac{W}{Q_S} = \frac{Q_S - Q_R}{Q_S}$

$$\eta_{dual} = \frac{[m.C_v(T_3-T_2) + m.C_p(T_4-T_3)] - m.C_v(T_5-T_1)}{[m.C_v(T_3-T_2) + m.C_p(T_4-T_3)]}$$

$$= 1 - \frac{C_v(T_5-T_1)}{C_v(T_3-T_2)+C_p(T_4-T_3)}$$

$$\boxed{\eta_{dual} = 1 - \frac{(T_5-T_1)}{(T_3-T_2)+\gamma(T_4-T_3)}} \rightarrow (1) \quad \left\{ \because \frac{C_p}{C_v} = \gamma \Rightarrow C_p = \gamma . C_v \right\}$$

The above eqn/. can be expressed in terms of the following ratios & all temp's/. in terms of T_4.

Compression ratio, $r = \frac{V_1}{V_2}$

expansion ratio, $r_e = \frac{V_5}{V_4} = \frac{V_1}{V_4}$ $[\because V_1 = V_5]$

Cut-off ratio, $\rho = \frac{V_4}{V_3} = \frac{V_4}{V_2}$ $[\because V_3 = V_2]$

Pressure ratio at const. volume, $\beta = \frac{P_3}{P_2}$
((or) Explosion ratio)

$\therefore$ Compression Ratio, $r = \frac{V_1}{V_2} = \frac{V_1}{V_4} \cdot \frac{V_4}{V_2} = r_e . \rho$

(or) Exp. ratio, $\boxed{r_e = \frac{r}{\rho}}$

Process : (3-4) :-

$$\frac{P_3V_3}{T_3} = \frac{P_4V_4}{T_4} \qquad P = C \; (\because P_3 = P_4)$$

$$\therefore \frac{V_3}{T_3} = \frac{V_4}{T_4} \Rightarrow \boxed{T_4 = T_3 \frac{V_4}{V_3} = T_3 . \rho \quad (or) \quad T_3 = \frac{T_4}{\rho}} \rightarrow (2)$$

Process (2 - 3) : $\frac{P_2 V_2}{T_2} = \frac{P_3 V_3}{T_3}$ $(\because V_2 = V_3)$

$$\Rightarrow \frac{P_2}{P_3} = \frac{T_2}{T_3} \Rightarrow T_2 = T_3 \cdot \frac{P_2}{P_3} = \frac{T_3}{\beta} \rightarrow (3)$$

eqn. (2) in (3);

$$\therefore \boxed{T_2 = \frac{T_4}{\rho . \beta}} \rightarrow (4)$$

Process (1-2):

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

$$\Rightarrow \boxed{T_1 = \frac{T_2}{r^{\gamma-1}} = \frac{T_4}{\rho . \beta . r^{\gamma-1}}} \rightarrow (5)$$

Process (4-5):

$$\frac{T_5}{T_4} = \left(\frac{V_4}{V_5}\right)^{\gamma-1} = \frac{1}{r_e^{\gamma-1}}$$

$$\Rightarrow \boxed{T_5 = \frac{T_4}{r_e^{\gamma-1}} = \frac{T_4 . \rho^{\gamma-1}}{r^{\gamma-1}}} \rightarrow (6)$$

Substitute T_3, T_2, T_1 & T_5 value's in eqn. (1); we get;

$$\eta_{Dual} = 1 - \frac{T_4 \cdot \frac{\rho^{\gamma-1}}{r^{\gamma-1}} - \frac{T_4}{\rho . \beta . r^{\gamma-1}}}{\left(\frac{T_4}{\rho} - \frac{T_4}{\rho . \beta}\right) + \gamma\left(T_4 - \frac{T_4}{\rho}\right)}$$

$$\boxed{\eta_{Dual} = 1 - \frac{1}{r^{\gamma-1}} \times \frac{\rho^{\gamma} . \beta - 1}{(\beta - 1) + \gamma \beta(\rho - 1)}}$$

The comparison of Otto, Diesel & Dual cycles for the

→ Same compression ratio & heat rejection;

$$\eta_{Otto} > \eta_{Dual} > \eta_{Diesel}.$$

→ Same maximum pressure & temperature & heat rejection also;

$$\eta_{Diesel} > \eta_{Dual} > \eta_{Otto}$$

The efficiency of an otto cycle is 60% & $\gamma = 1.5$. What is the compression ratio?

Soln:- $\eta = 60\% = 0.6$, $\gamma = 1.5$

$$\eta_{otto} = 1 - \frac{1}{r^{\gamma-1}} \Rightarrow 0.6 = 1 - \frac{1}{r^{1.5-1}}$$

$$\Rightarrow r = 6.25$$

An engine working on the otto cycle is supplied with air at 0.1 MPa, 35°c. The compression ratio is 8. Heat supplied is 2100 kJ/kg. Calculate the max. pressure & temp. of the cycle, the cycle efficiency & the Mean effective pr. (For air, $C_p = 1.005$ kJ/kg k, $C_v = 0.718$ kJ/kg k & $R = 0.287$ kJ/kg k)

Soln: $T_1 = 35°c = 308k$, $P_1 = 0.1 MPa = 100 kN/m^2$, $Q_s = 2100 kJ/kg$, $r = 8$, $\gamma = 1.4$.

$$\eta_{otto} = 1 - \frac{1}{r^{\gamma-1}} = 1 - \frac{1}{8^{1.4-1}} = 0.565 \text{ (or) } 56.5\%$$

Compression Ratio, $r = \frac{V_1}{V_2} \Rightarrow 8 = \frac{V_1}{V_2}$

$\because P_1V_1 = RT_1$ (for unit mass)

$\Rightarrow V_1 = \frac{R T_1}{P_1} = \frac{0.287 \times 308}{100}$

$V_1 = 0.884 \, m^3/kg$

$$\Rightarrow V_2 = \frac{V_1}{8} = \frac{0.884}{8}$$

$$\therefore V_2 = 0.11 \, m^3/kg$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = 8^{1.4-1} = 2.3$$

$$\Rightarrow T_2 = 2.3 \times T_1 = 2.3 \times 308 = 708.4 K$$

Heat Supplied;

$$Q_s = m c_v (T_3 - T_2)$$

for unit mass;

$$Q_s = C_v (T_3 - T_2)$$

$$2100 = 0.718 (T_3 - 708.4)$$

$$\Rightarrow T_3 = T_{max} = 3633 K$$

$$\frac{P_3 V_3}{T_3} = \frac{P_2 V_2}{T_2} \quad (\because V_2 = V_3)$$

$$\Rightarrow \frac{P_3}{P_2} = \frac{T_3}{T_2}$$

$$\Rightarrow P_3 = P_{max} = P_2 \times \frac{T_3}{T_2}$$

(1-2); $\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma} = 8^{1.4} = 18.37$

$\therefore P_2 = P_1 \times 18.37 = 100 \times 18.37 = 1837\ kN/m^2$

$P_2 = \underline{1.837\ MPa}$

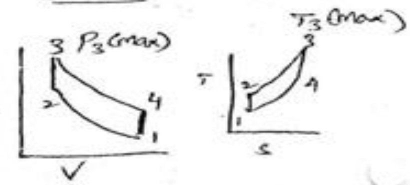
$\therefore P_3 = P_{max} = 1.837 \times \frac{3633.4}{708.4} = \underline{\underline{9.422\ MPa}}$

WKT,

$\eta = \frac{W_{net}}{Q_s} \Rightarrow W_{net} = \eta . Q_s = 0.565 \times 2100 = \underline{1186.5\ KJ/kg}.$

WKT, $W = p.dv$

$W = P_m(V_1 - V_2)$



$\Rightarrow$ Mean Effective pr. $\Rightarrow P_m = \frac{W}{(V_1 - V_2)}$

$\Rightarrow P_m, [m.e.p] = \frac{1186.5}{0.884 - 0.11} = 1533\ kPa = \underline{\underline{1.533\ MPa}}$

The minimum pr. & temp. in an otto cycle are 100kPa & 27°c. The amount of heat added to the air per cycle is 1500 kJ/kg. (i) Determine the pr. & temp. at all points of the air standard otto cycle, (ii) Also calculate the sp. work & thermal efficiency of the cycle for a compression ratio 8:1. Take for air; $C_v = 0.72\ kJ/kg.k$ & $\gamma = 1.4$.

<u>Soln:-</u> $p_1 = 100kPa = 1\ bar$, $T_1 = 27°c = 300k$, $\gamma = 1.4$

$Q_s = 1500\ kJ/kg$. $r = 8:1 = \frac{8}{1} = 8$, $C_v = 0.72\ kJ/kg.k$.

(Consider Unit mass):

(i)

<u>(1-2):</u> ($\because PV^{\gamma} = C$ process.)

$\left(\frac{T_2}{T_1}\right) = \left(\frac{V_1}{V_2}\right)^{\gamma - 1} = 8^{1.4-1} = 2.3$

$\Rightarrow T_2 = T_1 \times 2.3 = 300 \times 2.3 = \underline{689.2\ K}$

$\left(\frac{P_2}{P_1}\right) = \left(\frac{V_1}{V_2}\right)^{\gamma} = 8^{1.4} = 18.38$

$\Rightarrow P_2 = P_1 \times 18.38 = \underline{18.38}$ bar

<u>(2-3):-</u> ($\because V = C$)

$Q_s = C_v(T_3 - T_2)$

$1500 = 0.72(T_3 - 689.2) \Rightarrow T_3 = \underline{\underline{2772.5\ K}}$

(@ V=C) $\frac{P_2}{P_3} = \frac{T_2}{T_3} \Rightarrow P_3 = \frac{P_2 \times T_3}{T_2} = \frac{18.38 \times 2772.5}{} = 72.0..$

Also; (3-4) :- (process) $[PV^{\gamma}=C]$

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = r^{\gamma-1} = 2.3$$

$$\therefore T_4 = \frac{T_3}{2.3} = \frac{2772.5}{2.3}$$

$$T_4 = 1205.43 K$$

Also;

$$\frac{P_3}{P_4} = \left(\frac{V_4}{V_3}\right)^{\gamma} = 8^{1.4} = 18.38$$

$$\therefore P_4 = \frac{P_3}{18.38} = \frac{73.94}{18.38} = 4.023 \text{ bar}$$

(ii)

$$\eta_{otto} = \eta_{thermal} = 1 - \frac{1}{r^{\gamma-1}} = 1 - \frac{1}{8^{0.4}} = 0.565$$

$$\eta_{th} = 56.5\%$$

(iii) Specific Work, $W = Q_S - Q_R$

$$= C_v(T_3 - T_2) - C_v(T_4 - T_1)$$

$$= 0.72[T_3 - T_2 - T_4 + T_1]$$

$$= 0.72[2772.5 - 689.2 - 1205.43 + 300]$$

$$W = 848.1 \text{ kJ/kg}$$

In an air standard diesel cycle, the compression ratio is 16 & @ the beginning of isentropic compression, the temp. is 15°C & the pressure is 0.1 MPa. Heat is added until the temp. at the end of the constr. pr. process is 1480°C. Calculate (a) cut-off ratio, (b) the heat supplied per kg of air, (c) the cycle efficiency & (d) the M.E.P.

Soln: $r = \frac{V_1}{V_2} = 16$, $T_1 = 15°C = 288K$, $P_1 = 0.1 MPa$, $T_3 = 1480°C$,
$P_1 = 100 kN/m^2$, $T_3 = 1753K$

(1-2):- $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = 16^{0.4} = 3.03$

$\therefore T_2 = 3.03 \times 288 = 873K$

(2-3):- $\frac{P_2V_2}{T_2} = \frac{P_3V_3}{T_3}$ $(\because V_2 = V_3)$

(a)
$\Rightarrow$ Cut-off Ratio, $\rho = \frac{V_3}{V_2} = \frac{T_3}{T_2} = \frac{1753}{873} = 2.01$

(b) Heat Supplied, $Q_s = C_p(T_3 - T_2)$
$= 1.005(1753 - 873)$
$Q_s = 884.4 \ kJ/kg$

(c) Cycle Efficiency $= 1 - \frac{Q_R}{Q_S}$ $\left[\eta = \frac{W}{Q_S} = \frac{Q_S - Q_R}{Q_S}\right]$

$\Rightarrow Q_R = C_v(T_4 - T_1)$

$\therefore Q_R = 0.718(766 - 288)$

$Q_R = 343.2 \ kJ/kg$

$\therefore \eta = 1 - \frac{343.2}{884.4} = 0.612$
$= 61.2\%$

$\left[\because (3\text{-}4) \text{ process:-} \quad \frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = \left(\frac{r}{\rho}\right)^{\gamma-1} = \left(\frac{16}{2.01}\right)^{0.4}\right.$

$\frac{T_3}{T_4} = 2.29$

$\left.\therefore T_4 = \frac{1753}{2.29} = 766K\right]$

(d) M.E.P, $P_m \Rightarrow W_{net} = Q_S - Q_R$
$= 884.4 - 343.2 = 541.2 \ kJ/kg$

WKT, $W = P_m(V_1 - V_2)$

$\Rightarrow P_m = \frac{541.2}{0.825 - 0.0516}$

$P_m = 699.8 \ kPa$

$V_1 = \frac{RT_1}{P_1} = \frac{0.287 \times 288}{100}$
$= 0.8252 \ m^3/kg$

$V_2 = \frac{V_1}{16} = \frac{0.8252}{16} = 0.0512 \ m^3/kg$

An air standard dual cycle has a compression ratio of 16, & compression begins at 1 bar, 50°C. The max. pr. is 70 bar. The heat transferred to air at const. pr. is equal to that at const. volume. Estimate (a) the pr's & temp's at the cardinal points of the cycle. (b) the cycle efficiency & (c) M.E.P of the cycle. $C_v = 0.718$ kJ/kg-k, $C_p = 1.005$ kJ/kg-k.

Soln: $T_1 = 50°C = 323K$, $r = 16$, $P_1 = 1$ bar

(1-2): ($PV^\gamma = C$)

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \Rightarrow T_2 = 323 \times 16^{0.4} = 979.15\,K$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma} \Rightarrow P_2 = 1 \times 16^{1.4} = 48.5\text{ bar}$$

(2-3): ($V = C$);

$$\frac{P_2}{P_3} = \frac{T_2}{T_3} \Rightarrow T_3 = T_2\frac{P_3}{P_2} \qquad \frac{P_2V_2}{T_2} = \frac{P_3V_3}{T_3}\ (\because V_2 = V_3)$$

Given: $P_3 = 70$ bar

$$T_3 = 979.15 \times \frac{70}{48.5} = 1413\,K$$

$$Q_{2-3} = C_v(T_3 - T_2)$$

$$= 0.718\,[1413 - 979.15] = 312\text{ kJ/kg}$$

$$Q_{3-4} = Q_{2-3} = 312\text{ kJ/kg}$$

(3-4): ($P = C$)

$$\therefore Q_{3-4} = m\,C_p(T_4 - T_3)$$

$$312 = 1.005\,[T_4 - 1413] \Rightarrow T_4 = 1723\,K$$

$$\frac{V_4}{V_3} = \frac{T_4}{T_3} = \frac{1723}{1413} = 1.22$$

(5-1): ($V = C$):

$$\Rightarrow \frac{V_5}{V_4} = \frac{V_1}{V_4} \quad (\because V_1 = V_5)$$

$$= \frac{V_1}{V_2}\cdot\frac{V_2}{V_4} \quad (\because V_2 = V_3)$$

$$\frac{V_5}{V_4} = \frac{V_1}{V_2}\cdot\frac{V_3}{V_4} = \left(16 \times \frac{1}{1.22}\right) = 13.11$$

(4-5): ($PV^\gamma = C$)

$$\frac{T_5}{T_4} = \left(\frac{V_4}{V_5}\right)^{\gamma-1} \Rightarrow T_5 = T_4 \times \left(\frac{V_4}{V_5}\right)^{\gamma-1} = 1723 \times \frac{1}{(13.11)^{0.4}}$$

$$T_5 = 615.4\,K$$

(5-1): (V=C)

$$\frac{p_5}{p_1} = \frac{T_5}{T_1} \Rightarrow p_5 = p_1 \cdot \frac{T_5}{T_1}$$

$$p_5 = 1 \times \frac{615.4}{323} = \underline{1.91} \text{ bar} ✓$$

(4-5): ($pV^{\gamma} = C$)

$$\left(\frac{p_4}{p_5}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{T_4}{T_5}\right) \Rightarrow \frac{p_4}{p_5} = \left(\frac{T_4}{T_5}\right)^{\frac{\gamma}{\gamma-1}} = \left(\frac{1723}{615.4}\right)^{\frac{1.4}{0.4}}$$

$$\frac{p_4}{p_5} = 36.724$$

$$\therefore p_4 = p_5 \times 36.724 = 1.91 \times 36.724$$

$$p_4 = \underline{70.14} \text{ bar} ✓$$

(or)

$$p_3 = p_4 = 70 \text{ bar} ✓$$

(b) Cycle efficiency,

$$\eta_{Dual} = 1 - \frac{C_v(T_5 - T_1)}{C_v(T_3 - T_2) + C_p(T_4 - T_3)}$$

$$\eta_{Dual} = 1 - \frac{0.718(615.4 - 323)}{312 + 312}$$

$$= 0.6635 = \underline{66.35} \% ✓$$

(c) **M.E.P; p_m:**

$$W_{net} = Q_s \times \eta \qquad \left[\because \eta = \frac{W}{Q_s}\right]$$

$$W_{net} = 624 \times 0.6635 = \underline{414.1} \text{ kJ/kg}$$

$$p_1 V_1 = R T_1 \Rightarrow V_1 = \frac{R T_1}{p_1} = \frac{0.287 \times 323}{100} = \underline{0.927} \text{ m}^3/\text{kg}$$

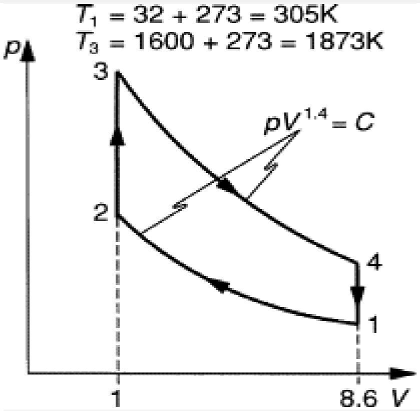
$$\frac{V_1}{V_2} = 16 \Rightarrow V_2 = \frac{0.927}{16} = \underline{0.058} \text{ m}^3/\text{kg}$$

WKT;

$$W = p_m(V_1 - V_2) \Rightarrow p_m = \frac{414.1}{0.927 - 0.058} = 476.5 \text{ kN/m}^2$$

$$\therefore p_m = \underline{4.76} \text{ bar} ✓$$

- **The ratio of compression of an engine working on the constant volume cycle is 8.6:1. At the beginning of compression the temperature is 32°C and at the end of heat supply the temperature is 1600°C. If the index of compression and expansion is 1.4, find: (a) the temperature at the end of compression; (b) the temperature at the end of expansion and (c) the air standard efficiency of the cycle.**



$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}, \quad \frac{T_2}{305} = \left(\frac{8.6}{1}\right)^{1.4-1}$$

$$T_2 = 305 \times 8.6^{0.4}$$

$$= \underline{721.3\,\text{K}} \text{ temperature at end of compression.}$$

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} \frac{T_4}{1873} = \left(\frac{1}{8.6}\right)^{0.4},$$

$$T_4 = 1873 \times 0.42$$

$$= \underline{792\,\text{K}} \text{ temperature at end of expansion.}$$

Air standard efficiency, η

$$= 1 - \frac{\text{heat rejected}}{\text{heat supplied}}$$

$$= 1 - \frac{m.c_v\,(T_4 - T_1)}{m.c_v\,(T_3 - T_2)} m \text{ and } c_v \text{ cancel}$$

$$= 1 - \frac{(792 - 305)}{(1873 - 721.3)} = 1 - \frac{487}{1151.7}$$

$$= 0.577 = \underline{57.7\%} \text{ air standard efficiency}$$

- **An engine of 250 mm bore and 375 mm stroke works on Otto cycle. The clearance volume is 0.00263 m^3. The initial pressure and temperature are 1 bar and 50°C. If the maximum pressure is limited to 25 bar, find the following:**

(i) The air standard efficiency of the cycle.

(ii) The mean effective pressure for the cycle. Assume the ideal conditions.

Given:

Bore of the engine, D = 250 mm = 0.25 m

Stroke of the engine, L = 375 mm = 0.375 m

Clearance volume, V_c = 0.00263 m^3

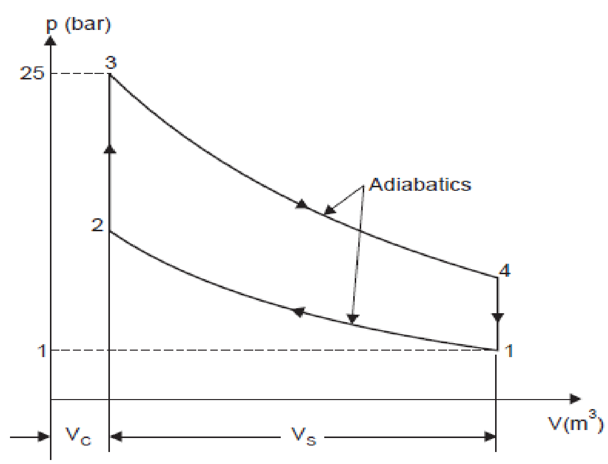
Initial pressure, p_1 = 1 bar

Initial temperature, T_1 = 50 + 273 = 323 K

To Find:

(i) The air standard efficiency of the cycle

(ii) The mean effective pressure for the cycle.



Solution:

Maximum pressure, $p_3 = 25$ bar

Swept volume, $V_s = \pi/4\ D^2L = \pi/4 \times 0.25^2 \times 0.375 = 0.0184\ m^3$

Compression ratio, $r = \frac{V_s + V_c}{V_c} = \frac{0.0184 + 0.00263}{0.00263} = 8.$

(*i*) **Air standard efficiency :**

The air standard efficiency of Otto cycle is given by

$$\eta_{Otto} = 1 - \frac{1}{(r)^{\gamma-1}} = 1 - \frac{1}{(8)^{1.4-1}} = 1 - \frac{1}{(8)^{0.4}}$$

$$= 1 - 0.435 = \mathbf{0.565} \text{ or } \mathbf{56.5\%}. \text{ (Ans.)}$$

(*ii*) **Mean effective pressure, p_m :**

For adiabatic (or isentropic) process 1-2

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

$$p_2 = p_1\left(\frac{V_1}{V_2}\right)^{\gamma} = 1 \times (r)^{1.4} = 1 \times (8)^{1.4} = 18.38 \text{ bar}$$

∴ Pressure ratio, $r_p = \frac{p_3}{p_2} = \frac{25}{18.38} = 1.36$

The mean effective pressure is given by

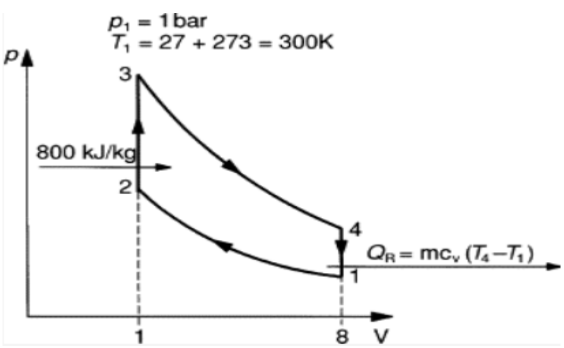
$$p_m = \frac{p_1 r[(r^{\gamma-1} - 1)(r_p - 1)]}{(\gamma - 1)(r - 1)} = \frac{1 \times 8\,[\{(8)^{1.4-1} - 1\}(1.36 - 1}{(1.4 - 1)(8 - 1)}$$

$$= \frac{8\,(2.297 - 1)(0.36)}{0.4 \times 7} = 1.334 \text{ bar}$$

Result:

Air standard efficiency η_{otto} = 56.5 % & Mean effective pressure P_m = 1.334 bar

- **In an air standard (Otto) constant volume cycle, the compression ratio is 8 to 1, and the compression commences at 1 bar, 27°C. The constant volume heat addition is 800 kJ per kg of air. Calculate: the thermal efficiency; and the indicated mean effective pressure, P_{mi}.**



$$R = c_p - c_v,\ R = 1005 - 718 = \underline{287 \text{J/kgK}}$$

$$p_1V_1 = \underline{m.R.T_1},\ V_1 = \frac{mRT_1}{p_1} = \frac{1 \times 287 \times 300}{1 \times 10^5}$$

$$= \underline{0.861\ m^3}$$

$$\frac{V_1}{V_2} = 8,\quad V_2 = \frac{0.861}{8} = \underline{0.1076\ m^3}$$

Swept volume = $V_2 - V_1 = 0.861 - 0.1076 = 0.7534 m^3$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1},\ \frac{T_2}{300} = \left(\frac{8}{1}\right)^{1.4-1}$$

$$T_2 = 300 \times 8^{0.4} = \underline{689.2\ K}$$

$$Q_{1-2} = m.c_v(T_3 - T_2)$$
$$T_3 = 689.2 + \frac{800\times10^3}{718} = \underline{1803.4k}\ (m = 1\,\text{kg})$$
$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{1.4-1} T_4 = 1803.4\left(\frac{1}{8}\right)^{0.4} = \underline{785\,\text{K}}$$
$$\text{Heat energy rejected} = Q_{4-1} = m.c_v(T_4 - T_1) = 718(785 - 300) = \underline{348.2\,\text{kJ}}$$
$$\text{Work} = \text{heat supplied} - \text{heat rejected} = 800 - 348.2 = \underline{451.8\,\text{kJ}}$$

$$\text{Air standred efficiency} = \eta = 1 - \frac{\text{heat rejected}}{\text{heat supplied}} = 1 - \frac{451.8}{800} = 1 - 0.5647 = 0.435 = \underline{43.5\%}$$
$$\text{Mean effective pressure, } P_{mi} = \frac{\text{area of diagram}}{\text{length}} = \frac{\text{work}}{\text{swept volume}} = \frac{451.8}{0.7534} = \underline{599.7\text{kN/m}^2}$$

➢ **The minimum pressure and temperature in an Otto cycle are 100 kPa and 27°C. The amount of heat added to the air per cycle is 1500 kJ/kg. Determine the pressures and temperatures at all points of the air standard Otto cycle. Also calculate the specific work and thermal efficiency of the cycle for a compression ratio of 8 : 1. Take for air: C_v = 0.72 kJ/kg K, and γ = 1.4.**

Given:

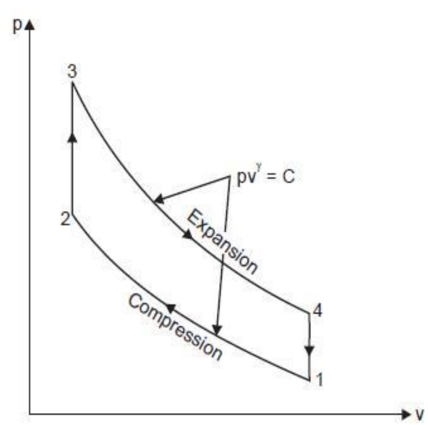
P_1 = 100 kPa = 105 N/m^2 or 1 bar
T1 = 27 + 273 = 300 K
Heat added Q_S= 1500 kJ/kg;
r = 8 : 1 ; C_v = 0.72 kJ/kg ; γ = 1.4.

To Find:

(i) Pressure and temperature at all points
(ii) η_{otto} and (iii) Specific work

Solution:

Consider 1 kg of air.



(*i*) **Pressures and temperatures at all points :**

Adiabatic compression process 1-2 :

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma - 1} = (r)^{\gamma - 1} = (8)^{1.4 - 1} = 2.297$$

$$\mathbf{T_2 = 300 \times 2.297 = 689.1\ K.} \quad \textbf{(Ans.)}$$

$$p_1 v_1^{\gamma} = p_2 v_2^{\gamma}$$

$$\frac{p_2}{p_1} = \left(\frac{v_1}{v_2}\right)^{\gamma} = (8)^{1.4} = 18.379$$

$$\mathbf{p_2 = 1 \times 18.379 = 18.379\ bar.} \quad \textbf{(Ans.)}$$

Constant volume process 2-3 :

Heat added during the process,

$$c_v\,(T_3 - T_2) = 1500$$

$$0.72\,(T_3 - 689.1) = 1500$$

$$\mathbf{T_3} = \frac{1500}{0.72} + 689.1 = \mathbf{2772.4\ K.} \quad \textbf{(Ans.)}$$

$$\frac{p_2}{T_2} = \frac{p_3}{T_3} \quad \Rightarrow \quad \mathbf{p_3} = \frac{p_2 T_3}{T_2} = \frac{18.379 \times 2772.4}{689.1} = \mathbf{73.94\ bar.}$$

Adiabatic Expansion process 3-4 :

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma - 1} = (r)^{\gamma - 1} = (8)^{1.4 - 1} = 2.297$$

$$\mathbf{T_4} = \frac{T_3}{2.297} = \frac{2772.4}{2.297} = \mathbf{1206.9\ K.} \quad \textbf{(Ans.)}$$

Also, $p_3 v_3^{\gamma} = p_4 v_4^{\gamma} \quad \Rightarrow \quad \mathbf{p_4} = p_3 \times \left(\frac{v_3}{v_4}\right)^{\gamma} = 73.94 \times \left(\frac{1}{8}\right)^{1.4} = \mathbf{4.023\ bar.}$ **(Ans.)**

(*ii*) **Specific work and thermal efficiency :**

Specific work = Heat added – heat rejected

$$= c_v\,(T_3 - T_2) - c_v(T_4 - T_1) = c_v\,[(T_3 - T_2) - (T_4 - T_1)]$$

$$= 0.72\,[(2772.4 - 689.1) - (1206.9 - 300)] = \mathbf{847\ kJ/kg.} \quad \textbf{(Ans.)}$$

Thermal efficiency, $\eta_{th} = 1 - \dfrac{1}{(r)^{\gamma - 1}}$

$$= 1 - \frac{1}{(8)^{1.4 - 1}} = \mathbf{0.5647 \ \ or \ \ 56.47\%.} \quad \textbf{(Ans.)}$$

Result:

Air standard efficiency, η_{otto} = 56.47

% Specific work = 847 KJ/Kg

- **An air standard Otto cycle has a volumetric compression ratio of 6, the lowest cycle pressure of 0.1MPa and operates between temperature limits of 27°C and 1569°C. (i) Calculate the temperature and pressure after the isentropic expansion (ratio of specific heats = 1.4). (ii) Since it is observed that values in (i) are well above the lowest cycle operating conditions, the expansion process was allowed to continue down to a pressure of 0.1 MPa. Which process is required to complete the cycle? Name the cycle so obtained. (iii) Determine by what percentage the cycle efficiency has been improved.**

Given:

$r = 6$; $P_1 = 0.1$ MPa = 1 bar; $T_1 = 27 + 273 = 300$ K; $T_3 = 1569 + 273 = 1842$ K; $\gamma = 1.4$.

To Find:

Temperature & Pressure and efficiency.

Solution:

(i) Temperature and pressure after the isentropic expansion, T_4, p_4 :

Consider 1 kg of air :

For *the compression process 1-2 :*

$$p_1 v_1^{\gamma} = p_2 v_2^{\gamma} \quad \Rightarrow \quad p_2 = p_1 \times \left(\frac{v_1}{v_2}\right)^{\gamma} = 1 \times (6)^{1.4} = 12.3 \text{ bar}$$

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma - 1} = (6)^{1.4-1} = 2.048$$

$$T_2 = 300 \times 2.048 = 614.4 \text{ K}$$

For *the constant volume process 2-3 :*

$$\frac{p_2}{T_2} = \frac{p_3}{T_3} \quad \Rightarrow \quad p_3 = \frac{p_2 T_3}{T_2} = 12.3 \times \frac{1842}{614.4} = 36.9 \text{ bar}$$

For *the expansion process 3-4 :*

$$\frac{T_3}{T_4} = \left(\frac{v_4}{v_3}\right)^{\gamma - 1} = (6)^{1.4-1} = 2.048$$

$$\mathbf{T_4} = \frac{T_3}{2.048} = \frac{1842}{2.048} = \mathbf{900\ K.}$$

$$p_3 v_3^{\gamma} = p_4 v_4^{\gamma} \quad \Rightarrow \quad p_4 = p_3 \times \left(\frac{v_3}{v_4}\right)^{\gamma}$$

$$\mathbf{p_4} = 36.9 \times \left(\frac{1}{6}\right)^{1.4} = \mathbf{3\ bar.}$$

(*ii*) **Process required to complete the cycle :**

Process required to complete the cycle is the *constant pressure scavenging.*

The cycle is called **Atkinson cycle** (Refer Fig. 13.9).

(*iii*) **Percentage improvement/increase in efficiency :**

$$\eta_{Otto} = 1 - \frac{1}{(r)^{\gamma - 1}} = 1 - \frac{1}{(6)^{1.4-1}} = 0.5116 \quad \text{or} \quad \mathbf{51.16\%.}$$

$$\eta_{Atkinson} = \frac{\text{Work done}}{\text{Heat supplied}} = \frac{\text{Heat supplied} - \text{Heat rejected}}{\text{Heat supplied}}$$

$$= \frac{c_v(T_3 - T_2) - c_p(T_5 - T_1)}{c_v(T_3 - T_2)} = 1 - \frac{c_p(T_5 - T_1)}{c_v(T_3 - T_2)} = 1 - \frac{\gamma(T_5 - T_1)}{(T_3 - T_2)}$$

$$\frac{T_5}{T_3} = \left(\frac{p_5}{p_3}\right)^{\frac{\gamma - 1}{\gamma}} \quad \text{or} \quad T_5 = 1842 \times \left(\frac{1.0}{36.9}\right)^{\frac{1.4-1}{1.4}} = 657\ \text{K}$$

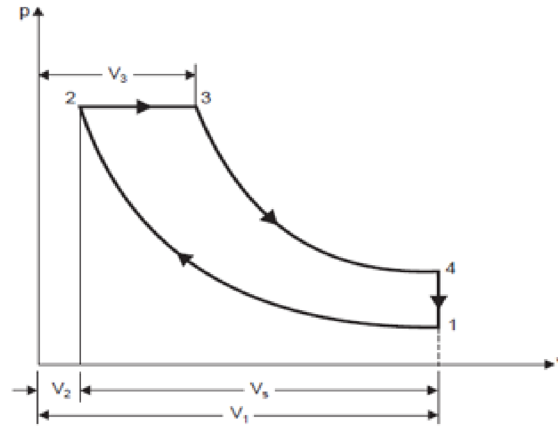
$$\eta_{Atkinson} = 1 - \frac{1.4(657 - 300)}{(1842 - 614.4)} = \mathbf{0.5929} \quad \textbf{or} \quad \mathbf{59.29\%.}$$

Improvement in efficiency = 59.29 – 51.16 = **8.13%.** (**Ans.**)

- **A diesel engine has a compression ratio of 15 and heat addition at constant pressure takes place at 6% of stroke. Find the air standard efficiency of the engine. Take γ for air as 1.4.**

Given data

r = 15, heat addition takes place 6% of stroke



To find

Air standard efficiency

Solution

Compression ratio, $r \left(= \frac{V_1}{V_2}\right) = 15$

γ for air = 1.4

Air standard efficiency of diesel cycle is given by

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

where ρ = cut-off ratio = $\frac{V_3}{V_2}$

But $V_3 - V_2 = \frac{6}{100} V_s$ (V_s = stroke volume)

$$= 0.06 (V_1 - V_2) = 0.06 (15 V_2 - V_2)$$
$$= 0.84 V_2 \text{ or } V_3 = 1.84 V_2$$

$$\therefore \quad \rho = \frac{V_3}{V_2} = \frac{1.84 V_2}{V_2} = 1.84$$

Putting the value in eqn. (*i*), we get

$$\eta_{diesel} = 1 - \frac{1}{1.4 (15)^{1.4-1}} \left[\frac{(1.84)^{1.4} - 1}{1.84 - 1}\right]$$
$$= 1 - 0.2417 \times 1.605 = \mathbf{0.612 \text{ or } 61.2\%.} \quad \text{(Ans.)}$$

Res
ult

Air standard efficiency = 61.2 %

- **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%.**

Given data

Let the clearance volume (V_2) be unity.

Then, compression ratio, r = 14

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

$$\frac{\rho - 1}{r - 1} = \frac{5}{100} \text{ or } \frac{\rho - 1}{14 - 1} = 0.05 \text{ or } \rho - 1 = 13 \times 0.05 = 0.65$$
$$\rho = 1.65$$

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

$$= 1 - 0.248 \times 1.563 = 0.612 \quad \text{or} \quad 61.2\%$$

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

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

$$\rho = 1 + 1.04 = 2.04$$

$$\eta_{diesel} = 1 - \frac{1}{\gamma (r)^{\gamma - 1}} \left[\frac{\rho^{\gamma} - 1}{\rho - 1} \right] = 1 - \frac{1}{1.4 \times (14)^{1.4 - 1}} \left[\frac{(2.04)^{1.4} - 1}{2.04 - 1} \right]$$

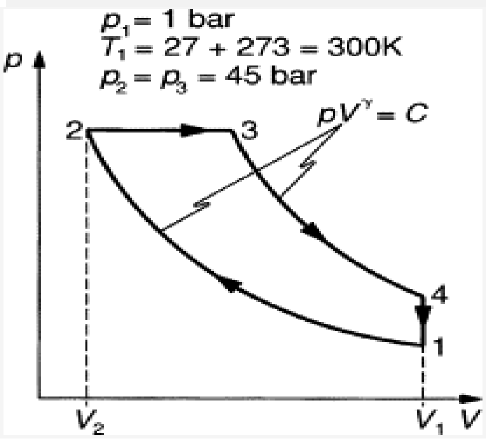
$$= 1 - 0.248 \times 1.647 = 0.591 \quad \text{or} \quad 59.1\%.$$

Hence percentage loss in efficiency due to delay in fuel cut off

$$= 61.2 - 59.1 = \mathbf{2.1\%}. \quad \textbf{(Ans.)}$$

Result: Percentage loss in efficiency = 2.1%

- **In an air standard diesel cycle, the compression commences at 1 bar, 27°C. Maximum pressure is 45 bar and the volume doubles during the constant pressure process. Calculate the air standard efficiency.**



Using a mass of 1 kg,

$$p_1 V_1 = m.R.T_1$$

$$V_1 = \frac{m.R.T_1}{P_1} = \frac{1 \times 287 \times (27 + 273)}{1 \times 10^5} = \underline{0.861 \text{ m}^3}$$

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma - 1}{\gamma}} T_2 = T_1 \left(\frac{p_2}{p_1}\right)^{\frac{\gamma - 1}{\gamma}}$$

$$T_2 = 300 \left(\frac{45}{1}\right)^{0.286} = \underline{891 \text{ K}}$$

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

$$V_2 = \frac{p_1 V_1 T_2}{p_2 T_1} = \frac{1 \times 0.861 \times 891}{45 \times 300} = \underline{0.0568 \text{m}^3}$$

$$\frac{p_2 V_2}{T_2} = \frac{p_3 V_3}{T_3}$$

$$T_3 = \frac{V_3 T_2}{V_2} = \frac{(0.0568 \times 2) \times 891}{0.0568} = \underline{1782 \text{ K}}$$

$$T_4 = T_3 \left(\frac{V_3}{V_4}\right)^{\gamma - 1} = 1780 \left(\frac{2 \times 0.0568}{0.861}\right)^{0.4} = \underline{791.7 \text{ K}}$$

$$\text{Air standard efficiency} = 1 - \frac{\text{heat rejected}}{\text{heat supplied}}$$

$$= 1 - \frac{m.c_v (T_4 - T_1)}{m.c_p (T_3 - T_2)} = 1 - \frac{718(791.7 - 300)}{1005(1780 - 891)}$$

$$= 0.605 = \underline{60.5\%} \text{ air standard efficiency.}$$

- **The stroke and cylinder diameter of a compression ignition engine are 250 mm and 150 mm respectively. If the clearance volume is 0.0004 m^3 and fuel injection takes place at constant pressure for 5 per cent of the stroke determine the efficiency of the engine. Assume the engine working on the diesel cycle.**

Given data

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, $V_s = \pi/4 \, D^2 L = \pi/4 \times 0.15^2 \times 0.25 = 0.004418 \text{ m}^3$

Total cylinder volume = Swept volume + clearance volume

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

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

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

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

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

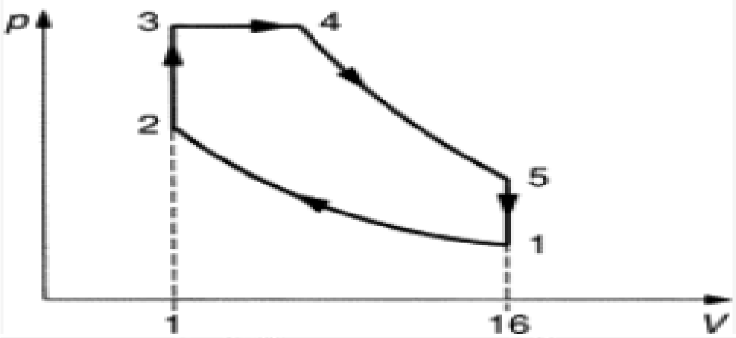
$$\eta_{diesel} = 1 - \frac{1}{\gamma (r)^{\gamma - 1}}\left[\frac{\rho^{\gamma} - 1}{\rho - 1}\right] = 1 - \frac{1}{1.4 \times (12.04)^{1.4 - 1}}\left[\frac{(1.55)^{1.4} - 1}{1.55 - 1}\right]$$

$$= 1 - 0.264 \times 1.54 = \mathbf{0.593 \text{ or } 59.3\%.} \quad \textbf{(Ans.)}$$

Result: Efficiency = 59.3%

- **A compression ignition engine working on the ideal dual combustion cycle has a compression ratio of 16:1. The pressure and temperature at the beginning of compression are 98 kN/m^2 and 30°C respectively. The pressure and temperature at the completion of heat supplied are 60 bar and 1300°C. Calculate the thermal efficiency of the cycle.**

$p_1 = 98$ kN/m^2
$T_1 = 30 + 273 = 303$K
$V_1 = V_5 = 16$
$V_2 - V_3 = 1$
$p_3 = p_4 = 60$ bar
$T_4 = 1300 + 273 = 1573$K



$$p_2 = p_1\left(\frac{V_1}{V_2}\right)^{\gamma} = 0.98\left(\frac{16}{1}\right)^{1.4} = \underline{47.53\,\text{bar}}$$

$$T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma - 1} = 303\left(\frac{16}{1}\right)^{0.4} = \underline{918\,\text{K}}$$

$$\frac{p_2 V_2}{T_2} = \frac{p_3 V_3}{T_3}, T_3 = \frac{60 \times 918}{47.53} = \underline{1159\,\text{K}}$$

$$\frac{p_3 V_3}{T_3} = \frac{p_4 V_4}{T_4}, V_4 = \frac{V_3 \times 1573}{1159} = \underline{1.358\,V_3}$$

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

$$p_5 = p_4 \left(\frac{V_4}{V_5}\right)^{\gamma} = 60\left(\frac{1.358\,V_3}{16\,V_3}\right)^{1.4} = \underline{1.899\,\text{bar}}$$

$$T_5 = T_4 \left(\frac{V_4}{V_5}\right)^{\gamma-1} = 1573\left(\frac{1.358\,V_c}{16\,V_c}\right)^{0.4} = \underline{586.5\,\text{K}}$$

$$\text{Heat energy supplied} = m.c_v\,(T_3 - T_2) + m.c_p\,(T_4 - T_3)$$

$$= 0.717\,(1159 - 918) + 1.004\,(1573 - 1159), \quad \text{using a ma}$$

$$= 173 + 416 = 589\ \text{kJ/kg}$$

$$\text{Heat energy rejected} = m.c_v\,(T_5 - T_1) = 0.717\,(586.5 - 303) = \underline{203.3\,\text{kJ/kg}}$$

$$\text{Air standard efficiency} = 1 - \frac{\text{heat rejected}}{\text{heat supplied}} = 1 - \frac{203.3}{589} = 0.6548 = \underline{65.48\%}$$

- **The swept volume of a diesel engine working on dual cycle is 0.0053 m^3 and clearance volume is 0.00035 m^3. The maximum pressure is 65 bar. Fuel injection ends at 5 % of the stroke. The temperature and pressure at the start of the compression are 80°C and 0.9 bar. Determine the air standard efficiency of the cycle. Take γ for air = 1.4.**

Given data

Swept volume, $V_s = 0.0053\ m^3$

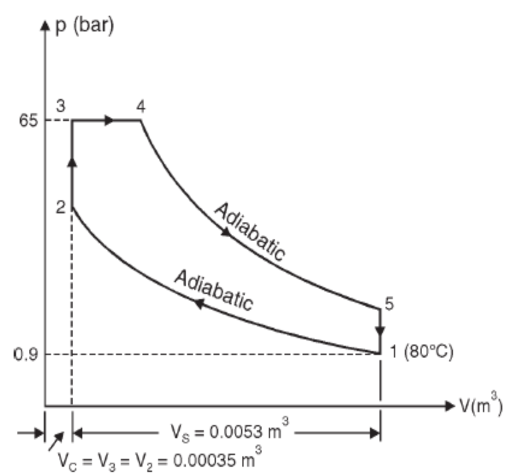
Clearance volume, $V_c = V_3 = V_2 = 0.00035\ m^3$

Maximum pressure, $p_3 = p_4 = 65$ bar

Initial temperature, $T_1 = 80 + 273 = 353$ K

Initial pressure, $p_1 = 0.9$ bar

$\eta_{dual} = ?$



To find

Efficiency

Solution

The efficiency of a dual combustion cycle is given by

$$\eta_{dual} = 1 - \frac{1}{(r)^{\gamma-1}}\left[\frac{\beta\,.\,\rho^{\gamma}-1}{(\beta-1)+\beta\gamma(\rho-1)}\right] \quad ...(i)$$

Compression ratio, $r = \frac{V_1}{V_2} = \frac{V_s + V_c}{V_c} = \frac{0.0053 + 0.00035}{0.00035} = 16.14$

$[\because \quad V_2 = V_c = \text{Clearance volume}]$

Cut-off ratio, $\rho = \frac{V_4}{V_3} = \frac{\frac{5}{100}V_s + V_3}{V_3} = \frac{0.05V_s + V_c}{V_c} \quad (\because \quad V_2 = V_3 = V_c)$

$$= \frac{0.05 \times 0.0053 + 0.00035}{0.00035} = 1.757 \text{ say } 1.76$$

Also during the *compression operation 1-2,*

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

$$\frac{p_2}{p_1} = \left(\frac{V_1}{V_2}\right)^{\gamma} = (16.14)^{1.4} = 49.14$$

$$p_2 = p_1 \times 49.14 = 0.9 \times 49.14 = 44.22 \text{ bar}$$

Pressure or explosion ratio, $\beta = \frac{p_3}{p_2} = \frac{65}{44.22} = 1.47$

Putting the value of r, ρ and β in eqn. (*i*), we get

$$\eta_{dual} = 1 - \frac{1}{(16.14)^{1.4-1}}\left[\frac{1.47 \times (1.76)^{1.4} - 1}{(1.47-1) + 1.47 \times 1.4\,(1.76-1)}\right]$$

$$= 7 - 0.328\left[\frac{3.243 - 1}{0.47 + 1.564}\right] = \mathbf{0.6383 \text{ or } 63.83\%.}$$

Result: Efficiency = 63.83 %

- **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 % of stroke, find the ideal efficiency. Take γ for air = 1.4.**

Given data

Compression ratio, $r = 14$

Explosion ratio, $\beta = 1.4$

If ρ is the cut-off ratio, then $\frac{\rho - 1}{r - 1} = \frac{6}{100}$ or $\frac{\rho - 1}{14 - 1} = 0.06$

$\therefore \quad \rho = 1.78$

Ideal efficiency is given by

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

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

$$= 1 - 0.348\left[\frac{3.138 - 1}{0.4 + 1.528}\right] = \mathbf{0.614 \text{ or } 61.4\%.}$$

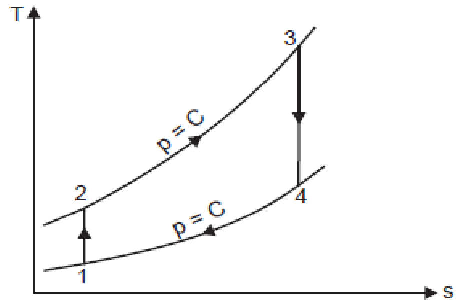
- **Air enters the compressor of a gas turbine plant operating on Brayton cycle at 101.325 kPa, 27°C. The pressure ratio in the cycle is 6. Calculate the maximum temperature in the cycle and the cycle efficiency. Assume $W_T = 2.5\ W_C$, where W_T and W_C are the turbine and the compressor work respectively. Take γ = 1.4.**

Given data

Pressure of intake air, P1 = 101.325 kPa

Temperature of intake air, T1 = 27 + 273 = 300 K , The pressure ratio in the cycle, Rp= 6

(i) Maximum temperature in the cycle, T_3:



$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} = (r_p)^{\frac{\gamma-1}{\gamma}} = (6)^{\frac{1.4-1}{1.4}} = 1.668$$

$$T_2 = 1.668\ T_1 = 1.668 \times 300 = 500.4\ \text{K}$$

$$\frac{T_3}{T_4} = (r_p)^{\frac{\gamma-1}{\gamma}} = (6)^{\frac{1.4-1}{1.4}} = 1.668$$

$$T_4 = \frac{T_3}{1.668}$$

$$W_T = 2.5\ W_C$$

$$mc_p\ (T_3 - T_4) = 2.5\ mc_p\ (T_2 - T_1)$$

(*ii*) **Cycle efficiency, η_{cycle} :**

$$T_4 = \frac{T_3}{1.668} = \frac{1251}{1.668} = 750\ \text{K}$$

$$\eta_{cycle} = \frac{\text{Net work}}{\text{Heat added}} = \frac{mc_p\ (T_3 - T_4) - mc_p\ (T_2 - T_1)}{mc_p(T_3 - T_2)}$$

$$= \frac{(1251 - 750) - (500.4 - 300)}{(1251 - 500.4)} = 0.4 \text{ or } 40\%. \quad \text{(Ans.)}$$

$$\left[\textit{Check};\ \eta_{cycle} = 1 - \frac{1}{(r_p)^{\left(\frac{\gamma-1}{\gamma}\right)}} = 1 - \frac{1}{(6)^{\frac{1.4-1}{1.4}}} = 0.4 \text{ or } 40\%. \quad \text{(Ans.)} \right]$$

$$T_3 - \frac{T_3}{1.668} = 2.5\ (500.4 - 300) = 501 \quad \text{or} \quad T_3\left(1 - \frac{1}{1.668}\right) = 501$$

$$T_3 = \frac{501}{\left(1 - \frac{1}{1.668}\right)} = 1251\ \text{K or } 978°\text{C}. \quad \text{(Ans.)}$$

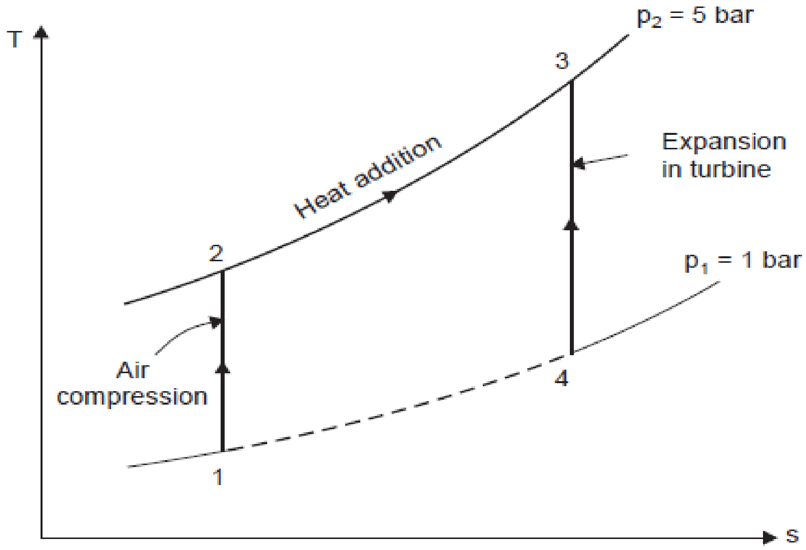
- **A gas turbine is supplied with gas at 5 bar and 1000 K and expands it adiabatically to 1 bar. The mean specific heat at constant pressure and constant volume are 1.0425 kJ/kg K and 0.7662 kJ/kg K respectively. (i) Draw the temperature-entropy diagram to represent the processes of the simple gas turbine system and (ii) Calculate the power developed in kW per kg of gas per second and the exhaust gas.**

Given: P1 = 1 bar; P2 = 5 bar; T3 = 1000 K; Cp = 1.0425 kJ/kg K; Cv = 0.7662 kJ/kg K

$$\gamma = \frac{c_p}{c_v} = \frac{1.0425}{0.7662} = 1.36$$

(*i*) **Temperature-entropy (T-s) diagram :**

Temperature-entropy diagram representing the processes of the simple gas turbine system is shown in Fig. 13.53.



(*ii*) **Power required :**

$$\frac{T_4}{T_3} = \left(\frac{p_1}{p_2}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{1}{5}\right)^{\frac{1.36-1}{1.36}} = 0.653$$

$\therefore$ $T_4 = 1000 \times 0.653 = 653$ K

Power developed per kg of gas per second

$= c_p (T_3 - T_4)$

$= 1.0425 (1000 - 653) =$ **361.7 kW.**

Air Standard Cycle, Air- Fuel Cycle and Actual Cycles:

1. **Air Standard Cycles**
   - A. Carnot Cycle
   - B. Stirling Cycle
   - C. Ericsson Cycle
   - D. Otto Cycle
   - E. Diesel Cycle
   - F. Dual cycle
2. **Air-Fuel Cycles**
3. **Actual Cycles**

Difference between an air standard cycle and a fuel air cycle:

1. Air standard cycles are theoretical cycles, where as fuel air cycles are real.
2. Air standards cycles are closed cycles means we are assumed that same air is continuously circulating, but in air fuel cycles (open cycles) fresh air intake takes place in every suction process.
3. Air standard cycles are consists of reversible processes but fuel air cycles are consists of irreversible processes.
4. Ideal gas equation i.e PV = mRT are valid in each point of air standard cycles, but not valid in actual cycles.
5. The value of Cp, Cv are constant with respect to temperature in air standard cycles, but Cp, Cv values varies with temp in actual fuel air cycles.
6. In air standard cycles it is assumed that heat is added from outside source, but in actual cycles the hidden chemical energy of fuel converts into heat energy.

Actual cycle:

The Actual cycle in the Thermodynamics is a cycle of operations experienced by the actual internal combustion engine where the efficiency of this actual internal combustion engine is much lower than the Ideal cycle or Air-Standard cycle due to various losses in the processes.

Major losses in the Actual Cycles:

Following are the different major losses occurred during the actual cycle.

- Incomplete combustion of fuel.
- Progressive combustion.
- Variation in the specific heat of the fuel for the different temperatures.
- Heat transfer into the walls of the combustion chamber.
- Due to the Exhaust-blowdown at the end of the exhaust process.
- Dissociation of the combustion products.
- Gas Exchange process.

Comparison of the Actual Cycles and the Air-standard Cycles:

The actual cycles for the IC engines differ from the Air-standard cycles in many respects. The main differences are listed below.

- The working substance of the actual cycle is the mixture of the air and fuel vapour along with the combustion products left from the previous cycle.
- Instead of the instantaneous combustion of the air-fuel mixture progressive combustion.
- Variation of the specific heats with the temperatures.
- The change in the composition, temperature and actual amount of the fresh charge because of the residual gases.
- Change in the chemical composition of the working substance.

- The major influence in the thermal efficiency and the power output of the engine is exercised by the following three factors.

  - Time Loss factor
  - Heat Loss factor
  - Exhaust blowdown Factor

1. Time Loss factor

The loss due to the time required for the mixing of fuel and air and also for the combustion.

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.

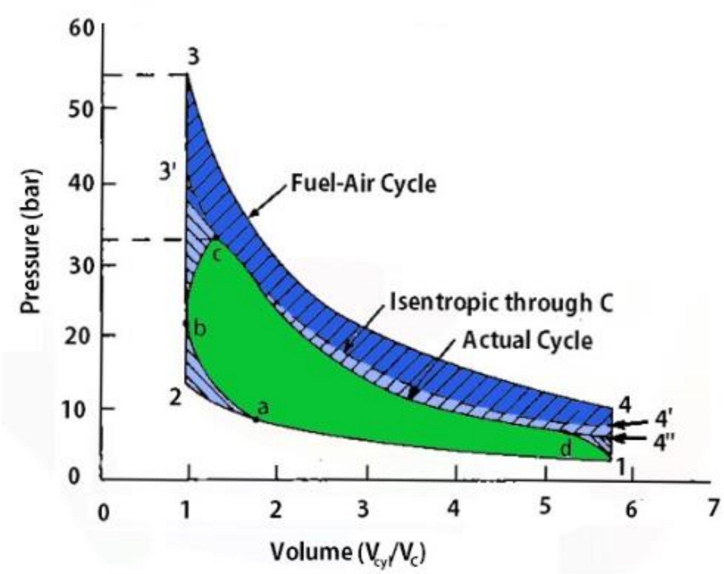


Fig: Time losses representation with P-V diagram

Due to the time taken for the complete combustion, the peak pressure generated by the combustion at the minimum cylinder volume (At **2**) will not occur, which means at the piston at the TDC. It will occur sometime after the TDC. The pressure will rise from **b** to **c** as shown on the graph.

Path 2 → 3 represents if the combustion is instantaneous at constant volume. Which mean instantaneous at where the piston is at TDC.

But the path b → c represents the actual cycle where the piston starts moving from the TDC around 30° to 40° of crankshaft rotation.

The path 2 → 3 represents the expansion stroke in the air-standard cycle. Whereas the path c → d represents the expansion stroke in the actual engine.

The area which is hatched and painted them in blue represents the amount of work would have been done. This loss of useful work results in reduced in the efficiency of the cycle. This is called the time loss due to progressive combustion.

Factors cause the Time loss in actual cycles:

- The flame velocity which in turn depend upon the type of fuel and the fuel-air ratio.

- The shape and size of the combustion chamber.
- The distance from the point of ignition to the opposite side of the combustion space.

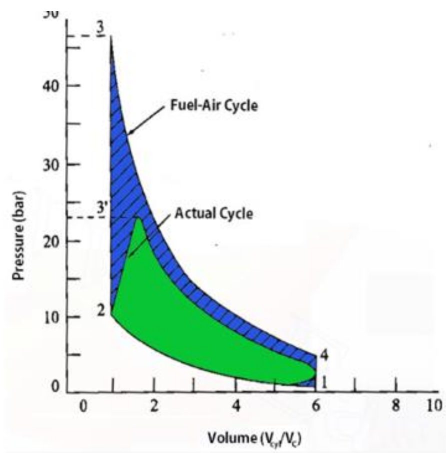
What we can do to reduce the time loss factor or maintain the peak pressure in the cylinder?

We can simply vary the spark time in advance in actual timing.

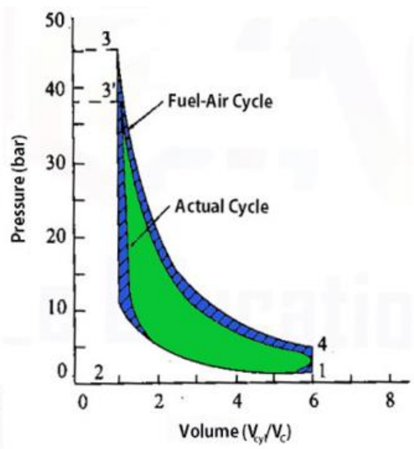
Following are the different variations of spark time by the crank angle.

Cycle	Ignition Advance	Max. cycle pressure (bar)	Mean effective pressure (bar)	Efficiency (%)	Actual cycle η / Fuel cycle η
Fuel Air cycle	**0°**	**44**	**10.20**	**32.2**	**1.00**
Actual cycle	**0°**	**23**	**7.50**	**24.1**	**0.75**
Actual cycle	**17°**	**34**	**8.35**	**26.3**	**0.81**
Actual cycle	**35°**	**41**	**7.60**	**23.9**	**0.74**

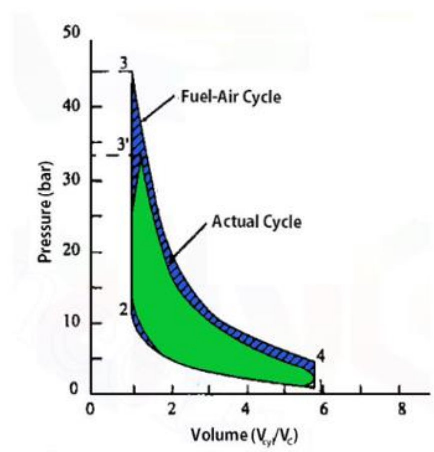
We have the following graph representation of the P-V diagram for actual and the fuel-air cycle for the Spark advance by 0°



Spark advance by 0° (Spark at Top dead Center)



Spark advance by 35°



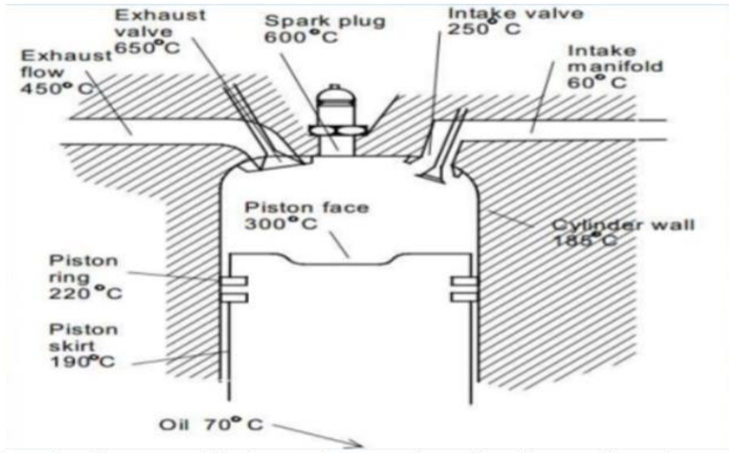
Optimum advancement of spark (15°-30°)

2. Heat Loss factor

Loss of heat from the gases to the cylinder walls.

This is due to the transfer of the heat through water jackets and cooling fins. Also, some heat is being transferred during the compression and expansion processes.

- Heat transfer from the burned gases have significant effect on the P-V line.
- Due to heat transfer during combustion, the pressure at the end of combustion in the real cycle will be lower.
- During expansion, heat transfer will cause the gas pressure in the real cycle to fall below an isentropic expansion line as the volume increases.
- A decrease in efficiency results from this heat loss.



Engine heat profile in various regions leading to heat losses.

IC engines have four operations, suction, compression, combustion and expansion/exhaust. Among those, the Heat loss will occur during the Combustion and the expansion strokes.

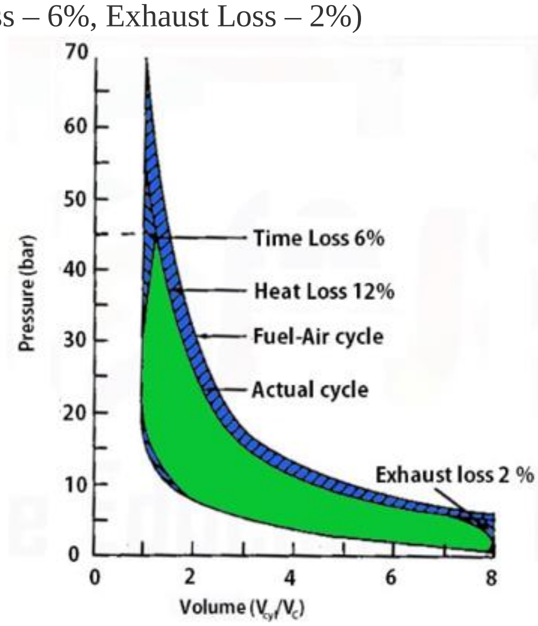
Heat loss during the combustion process definitely has a high influence on cycle efficiency. Whereas the heat loss during the end of expansion stroke will have effectively less influence on the cycle efficiency.

Ways of Heat loss in actual cycles:

During the combustion process in the IC engines, the heat flows from the cylinder gases through cylinder walls and cylinder head into the cooling fins or water jacket.

The heat also loses from the piston head into the piston rings carried away by the lubricating oil or flow through the cylinder walls into the water jacket.

Following is the P-V diagram for the three different losses (Time Loss, Heat Loss, and Exhaust Loss). Among these three losses, Heat loss has a 12% loss of energy which is a high amount compared to the other two losses (Time loss – 6%, Exhaust Loss – 2%)



Time Loss, Heat Loss, Exhaust Loss in Petrol Engine

The main effect of the Heat loss in combustion and expansion of the engine will reduce the maximum temperature which will result in lower specific heats.

The above diagram shows all the three different losses, Time loss – 6%, Heat Loss – 12%, and the Exhaust loss 2% are determined on a Cooperative fuel research Engine (CFR Engine).

One important thing is that In Air-standard cycle also it is assumed that, not all amount of heat can be converted into work. Only a certain amount of heat input will be considered as converted into useful work. The rest is rejected under the expansion stroke.

3. Exhaust blowdown Factor

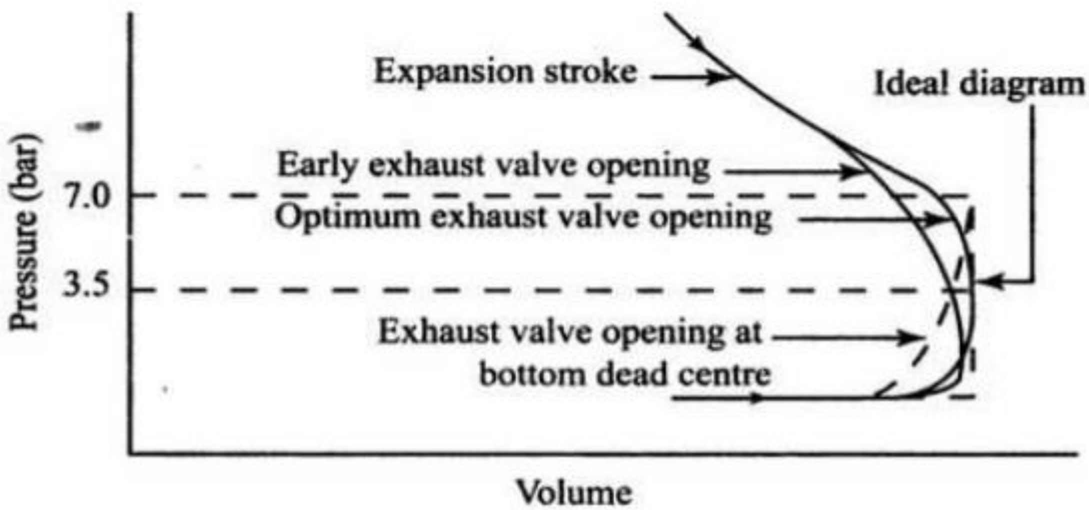
The loss of work due to the early opening of the exhaust valve in the expansion stroke of the engine.

Blowdown loss is due to the early opening of exhaust valves. This results in drop in pressure, and a loss of work output during expansion stroke. Too early opening results in loss of expansion work.

- In the real engine operating cycle, the exhaust valve is opened some 60° before BC to reduce the pressure during the first part of the exhaust stroke in four-stroke engines and to allow time for scavenging in two stroke engines.
- The gas pressure at the end of the expansion stroke is therefore reduced below the isentropic line.
- A decrease in expansion-stroke work transfer results.

Blowdown is nothing but the escape of the combustion particles from the cylinder when the exhaust valve opens. The timing of the opening of the exhaust valve will also have an influence on the efficiency of the engine since there is this Exhaust blown loss during the cycle. This loss depends on the timing of the Exhaust valve opening.

As we can see the following P-V diagram of a petrol engine with all three losses (Time Loss, Heat Loss and Exhaust Loss) with the occupied percentages of loss during the cycle. It is noted that the loss of this exhaust blown is 2%. Which is comparatively less than the other two losses (Time loss-6% and Heat Loss-12%) which means it will have less effect on the efficiency of the engine.

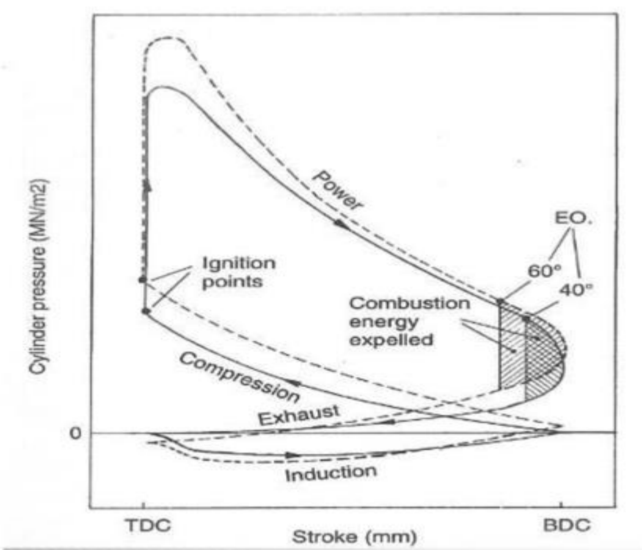


Effect of Exhaust valve opening time on Exhaust Blowdown

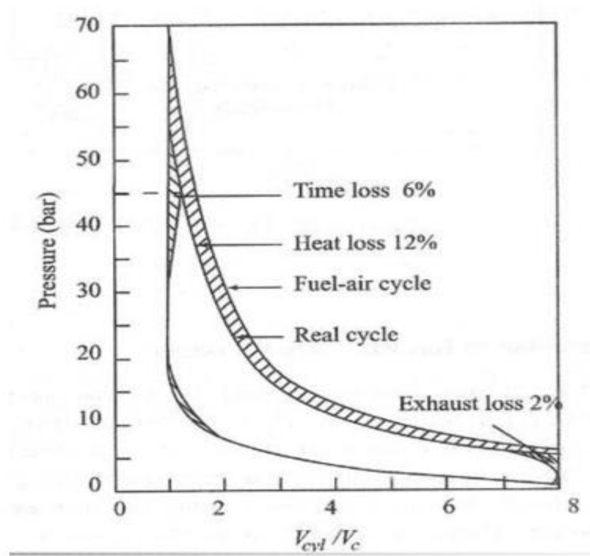
But This Exhaust Loss also has to be considered to improve the overall efficiency of the engine. Generally, the cylinder pressure at the end of the expansion stroke is about 7 bar depending on the compression ratio employed.

- If the exhaust valve is opened at the Bottom dead center then the piston has to do the work against the cylinder pressure due to the early part of the exhaust stroke. See the dashed line representation in the above P-V diagram.
- If the Exhaust valve is opened too early, then some portion of the expansion stroke is lost.
- The optimum duration to open the exhaust valve is 40° to 70° before BDC thereby reducing the cylinder pressure to halfway (let's say 3.5 bar) before the exhaust stroke begins.

Effect of exhaust valve opening



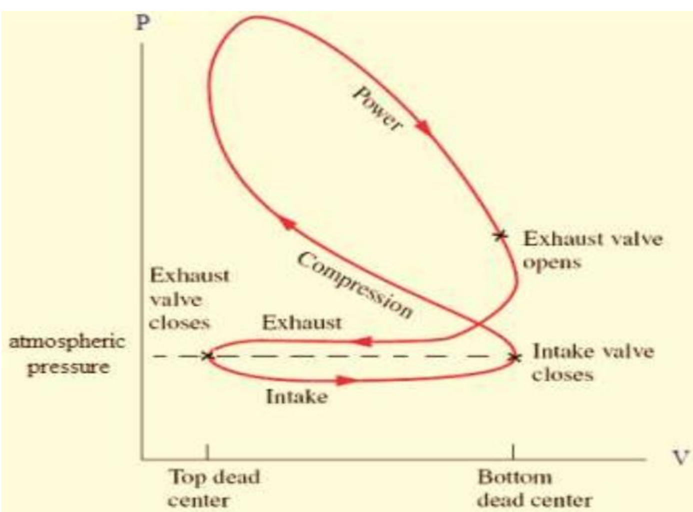
The effects of exhaust valve early opening

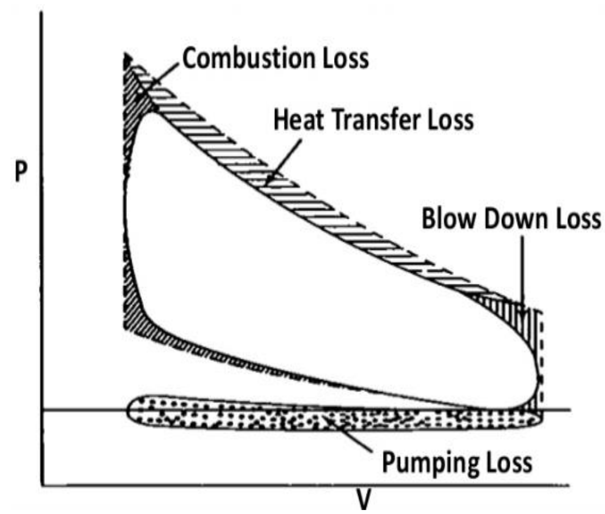


The Time loss, heat loss & exhaust loss

Loss due to gas exchange processes / Pumping losses

- Pumping work is the difference between the work done in expelling the gases (during exhaust stroke) and the work done in inducing the fresh charge (during suction stroke). The loss is due to the pumping gases from low inlet pressure to high exhaust pressure.





Rubbing friction losses

- Rubbing friction loss is due to friction between the piston and chamber walls, friction in various bearings and also includes the energy spent in operating various auxiliary equipment such as cooling fans, water pumps etc.

- The piston ring friction increases rapidly with engine speed. It also increases to a small extent with increase in mean effective pressure. The bearing friction and the auxiliary friction also increase with engine speed.

- **What is thermodynamic cycle?**

It is defined as the series of process performed on the system, so that the system attains the original state.

- **What are the assumptions made for air standard cycle analysis?**

The work medium is a perfect gas throughout.
The working medium does not undergo chemical change through the cycle. Kinetic and potential energies of the working fluid are neglected.
The operation of the engine is frictionless.
Heat is supplied and rejected in the reversible manner.

- **Mention various processes in dual cycle.**

Isentropic compression process, Constant volume heat addition Constant pressure heat addition, isentropic expansion and Constant volume heat rejection.

- **Define air standard cycle efficiency.**

It is defined as the ratio of work done by the cycle to the heat supplied to the cycle.

- **Name the factors that affect air standard efficiency of diesel cycle.**

Compression ratio and Cut off ratio

- **For the same compression ratio and heat supplied, state the order of decreasing of Otto, diesel and dual cycle.**

$\eta_{Otto} > \eta_{dual} > \eta_{diesel}$

- **What is the effect of cut off ratio on the efficiency of diesel cycle when the compression ratio is kept constant?**

When cut off ratio of diesel increases, the efficiency of the cycle is decreased when compression ratio is kept constant and vice versa.

- **Which cycle is more efficient with respected to the some compression ratio?**

For same compression ratio, Otto cycle is more efficient than diesel cycle.

- **Define mean effective pressure as applied to gas power cycles.**

The **mean effective pressure** can be regarded as an **average pressure** in the cylinder for a complete engine cycle. By definition, mean effective pressure is the ratio between the work and engine displacement (stroke (or) swept volume). (i.e) m.e.p, $p_{me} = W / v_s$

- **Define the term compression ratio.**

The compression ratio is the ratio of the total (maximum) volume to the clearance (minimum) volume.
(i.e) Compression ratio, $r = v_1 / v_2$

- **Define the term cut off ratio.**

The cutoff ratio is the ratio of the volume after combustion to the volume before combustion.
For example: Diesel engine, cutoff ratio, $\rho = v_3 / v_2$

UNIT – 2: INTERNAL COMBUSTION ENGINES
Introduction of IC Engines: Classification of IC engines - Components and their function - Valve timing diagram and port timing diagram - Comparison of two stroke and four stroke engines, S.I and C.I engines. Fuel Systems: S.I. Engine: Carburetor - Mechanical and electrical fuel pump - C.I. Engine: Fuel injection pump - Fuel injector - Types of fuel injector nozzles. Cooling Systems: Cooling requirements - Air cooling and water cooling (thermosyphon and forced circulation system). Lubrication Systems: Petroil, splash, pressurized and mist lubrication. Ignition Systems: Function of an ignition system - Battery coil, magneto coil and electronic ignition system using contact breaker and contact triggers.

On successful completion of this unit, students will be able to:

Course Outcomes		POs related to COs
CO2	Know the basic knowledge of an engine, identify the types, components of IC engines and explain the functions of each.	PO1

WEB SOURCE REFERENCES:

1	https://nptel.ac.in/courses/112106133/2
2	http://en.wikipedia.org/wiki/mechanical
3	http://en.wikipedia.org/wiki/Applied_Thermal_Engineering
4	https://www.brighthubengineering.com/thermodynamics/4125-air-standard-cycle-part-one/
5	www.sciencedirect.com
6	www.journals.elseier.com

ADDITIONALRESOURCES:

1. **Anna university tutorials (Internal Server)**
2. **Thermal engineering Books (PDF Formats)**
3. **Online Objective Questions**
4. **Videos Materials if any (You tube)**

UNIT – 2: INTERNAL COMBUSTION ENGINES

1. What is the function of camshaft and crank shaft?

CAMSHAFT: It converts the rotary motion of the camshaft in to a straight line motion. Thus the cams are to open and close the intake and exhaust valves.
CRANK SHAFT: It converts the reciprocating motion of the piston into rotary motion.

2. What are the functions of piston rings?

Usually there of two sets of rings mounted on piston. The upper piston rings are called compression rings and their function is to provide gas tight seal and to prevent leakage of high pressure gas.
The lower piston is called oil control rings whose function is to provide effective seal and to prevent leakage of oil in engine cylinder.

3. What is the function of push rod and rocker.

The overhead value mechanism requires a push rod and the rocker arm to push the valve against the spring pressure. Here the cam operates the valve tappet which actuates the push rod provide vertically in the side of the crank case. Push rod further operates the rocker arm which actuates the value against the spring tension, there by opening the valve.

4. What is the function of choke valve?

Choke valve is fixed at the top of the air horn. It is closed at the time of starting. Thus it closes the air supply. The whole suction is applied on the nozzle which delivers sufficient fuel making the mixture rich.

5.What are the requirements of good carburetor?

- Capacity of supplying correct fuel mixture at different engine loads and speeds.
- Ease in starting of engine in cold (or) hot conditions.
- Economical fuel supply.
- Maintaining a suitable reserve of fuel in float chamber.

6.What is the function of idling jet in carburetor?

- To achieve richer mixtures, special idling arrangement comprising idling fuel passage and idling port incorporated in carburetors.
- When the throttle is closed for slow speeds (or) idling, the suction below the throttle raises the fuel in the idle tube and the fuel is directly send to the intake pipe.

7.List the essential requirements of a good fuel?

High calorific value, Low ignition temperature, Not produce any harmful gases.

8.What are the basic requirements of a fuel injection system of a diesel engine?

- The beginning as well as the end of injection should takes place sharply.
- The injection of fuel should occur at the correct movement, correct rate and correct quantity as required by the varying engine load.

9.Define cetane number of a fuel?

The cetane number is defined as the percentage volume of normal cetane in a mixture of normal cetane and alpha methyl, naphthalene, cetane number determines the quality of diesel fuel. If a diesel fuel is low in cetane number, it will ignite relatively high temperature. If the fuel is of high cetane number, it will ignite relatively low temperature.

10. How do you rate the S.I engine fuels?

S.I. engine fuels are rated by octane number. It is defined as percentage of Iso- Octane in the mixture of Iso-Octane and normal heptanes.

Classify the internal combustion engine.

IC engines are classified are based on:

Number of strokes per cycle

- Four stroke engine
- Two stroke engine

Cycle operations

- Otto cycle engine
- Diesel cycle engine
- Dual combustion cycle engine

Types of fuel used

- Petrol engine
- Diesel engine
- Gas engine

Methods of charging

- Naturally aspirated engine
- Supercharged engine

Types of ignition

- Spark –ignition engine
- Compression ignition engine

Types of cooling

- Air cooling
- Water cooling

Speed

- Low speed engine
- Medium speed engine
- High speed engine

Number of cylinders

- Single
- Two
- Four
- Six
- Eight
- Twelve

Arrangement of cylinders

- Straight or in line engine
- Horizontal engine
- Radial engine
- V – engine
- Opposed cylinder engine

Method of governing

- Quality governing
- Quantity governing

Valve arrangement

- L-head
- I-head
- F-head
- T-head

Compare four stroke and two stroke cycle engines.

Four stroke engine:

- Power is developed for every two revolutions of the crankshaft
- Consists of valves, camshafts and tappets.
- For the same size, power is less for same number of revolutions.
- There is one working stroke for every two revolutions of the crankshaft.
- There are many moving parts and hence there is more friction and less mechanical efficiency.
- The exhaust gases are fully burnt and leave as the exhaust. Therefore has more output.
- Engine is water cooled.
- Used in cars and commercial vehicles.
- The engine uses less lubricating oil.

Two stroke engine:

- Power is developed for every one revolutions of the crankshaft.
- Consists only of ports with no valves, camshaft and tappets.
- For the same size, power is more for the same of revolutions.
- There is no working stroke for every revolution of crankshaft.
- There are few moving parts and hence there is less friction and more mechanical efficiency.
- Some amount of fresh charge mixes with the exhaust and leaves the exhaust.

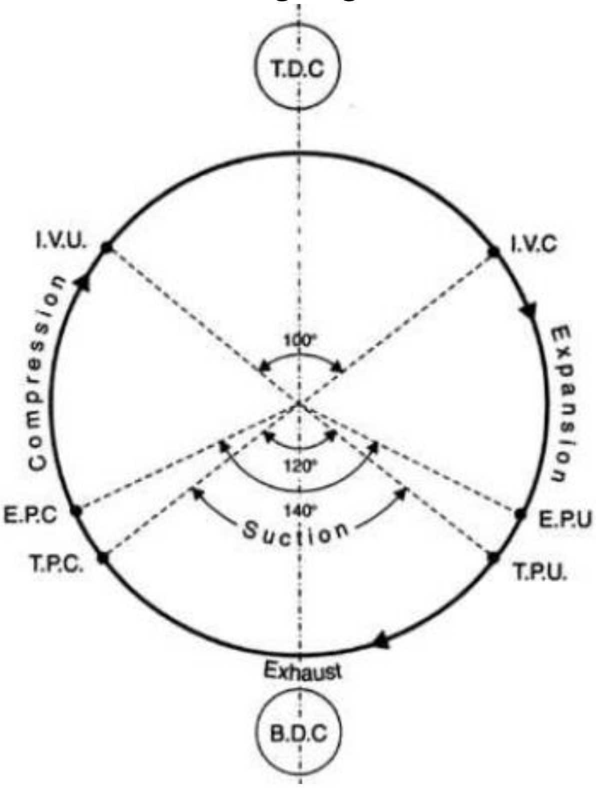
Therefore the engine has less output.

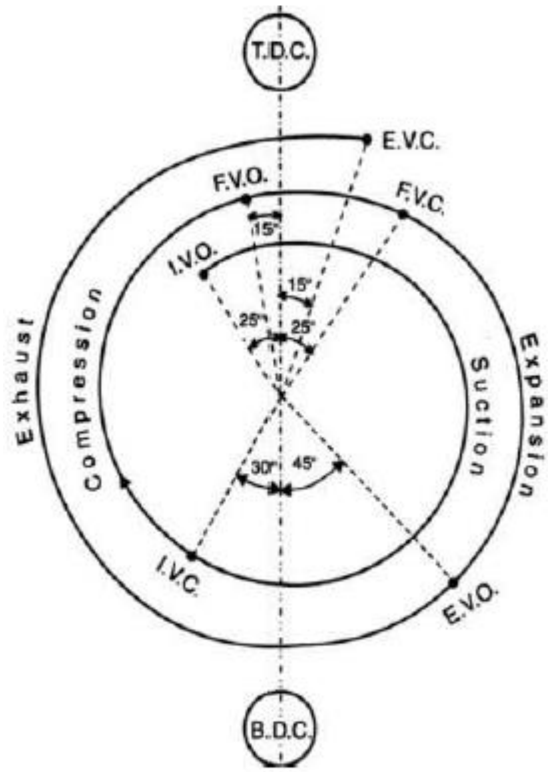
- Engine is air cooled.
- Used in motor cycles, scooters and small boats.

Explain the main difference between a 2-stroke and 4- stroke cycle engine.

S:NO	PETROL ENGINE	DIESEL ENGINE
1	During the suction stroke , air fuel mixture is drawn from carburettor.	During the suction stroke , air is only drawn from the atmosphere.
2	Carburettor is used to mix the air and fuel in required proportion.	Fuel injector is required to inject the fuel into cylinder in atomized form.
3	Spark plug is required to ignite the fuel air mixture.	Fuel is ignited automatically by high pressure and temperature air.
4	It is operated by Otto cycle or Constant volume cycle.	It is operated by Diesel cycle or constant pressure cycle.
5	Compression ratio varies from 6to8.	Compression ratio varies from 12to18.
6	The starting is easy due to low compression ratio.	The starting is little difficult due to higher compression.
7	Running cost is high because of high cost of fuel.	Running cost is less because of lower cost of fuel.
8	For the same power, less space is required.	For the same power, more space is required.

Draw the Port Timing diagram of two stroke cycle diesel engine.





Draw the Valve Timing diagram of four stroke cycle diesel engine.

Diesel engines. Fig. shows the actual valve timing diagram of a *four stroke "Diesel cycle" engine* (theoretical valve timing diagram, is however the same as Fig. . Inlet valve opens 10° to 25° in advance of T.D.C. position and closes 25° to 50° after the B.D.C. position. Exhaust valve opens 30° to 50° in advance of B.D.C. position and closes 10° to 15° after the T.D.C. position. The fuel injection takes place 5° to 10° before T.D.C. position and continues up to 15° to 25° near T.D.C. position.

Explain the construction and working of a fuel injector with a neat sketch.

An **Injection Pump** is the device that pumps fuel into the cylinders of a diesel engine. Traditionally, the injection pump is driven indirectly from the crankshaft by gears, chains or a toothed belt (often the timing belt) that also drives the camshaft. It rotates at half crankshaft speed in a conventional four-stroke engine. Its timing is such that the fuel is injected only very slightly before top dead centre of that cylinder's compression stroke. It is also common for the pump belt on gasoline engines to be driven directly from the camshaft. In some systems injection pressures can be as high as 200 MPa (30,000 PSI).

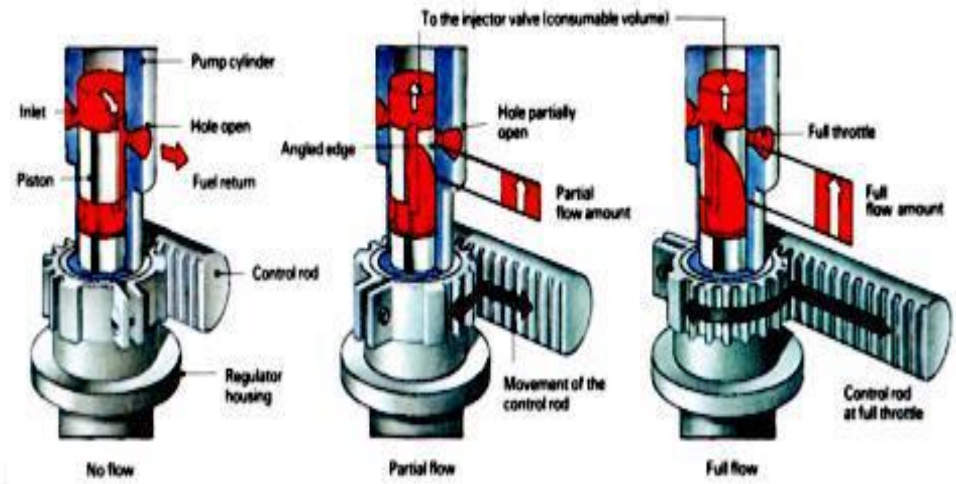
Earlier diesel pumps used an in-line layout with a series of cam-operated injection cylinders in a line, rather like a miniature inline engine. The pistons have a constant stroke volume, and injection volume (i.e., throttling) is controlled by rotating the cylinders against a cut-off port that aligns with a helical slot in the cylinder. When all the cylinders are rotated at once, they simultaneously vary their injection volume to produce more or less power from the engine. Inline pumps still find favour on large multi-cylinder engines such as those on trucks, construction plant, static engines and agricultural vehicles.

Distributor diesel injection pump

For use on cars and light trucks, the rotary pump or distributor pump was developed. It uses a single injection cylinder driven from an axial cam plate, which injects into the individual fuel lines via a rotary distribution valve. Later incarnations such as the Bosch VE pump vary the injection timing with crank speed to allow greater power at high crank speeds, and smoother, more economical running at slower revs. Some VE variants have a pressure-based system that allows the injection volume to increase over normal to allow a turbocharger or supercharger equipped engine to develop more power under boost conditions.

Inline diesel metering pump

All injection pumps incorporate a governor to cut fuel supply if the crank speed endangers the engine - the heavy moving parts of diesel engines do not tolerate overspeeding well, and catastrophic damage can occur if they are over-revved.



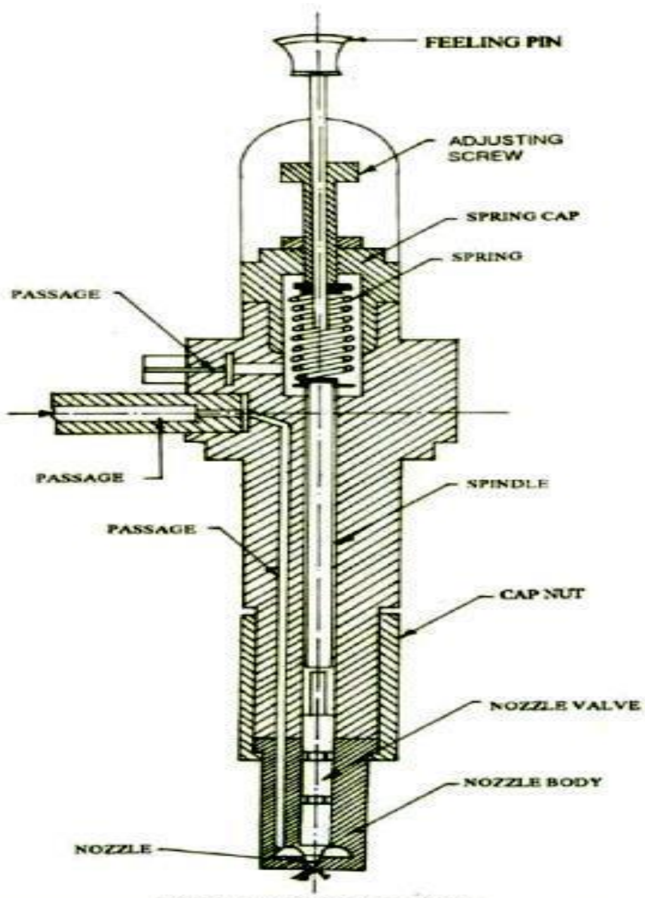


Fig. Fuel injector

Explain the working principle of Simple carburetor with a neat sketch.

Functions of carburetor

- It maintains a small reserve of petrol in the float chamber at a constant head.
- It atomizes and vaporizes the fuel.
- It prepares a mixture of petrol and air in correct proportions.
- It supplies a fine spray of petrol.

Simple carburetor

The main components of simple carburetor are: float chamber, float, nozzle, venture, throttle valve, inlet valve, and metering jet. In the float chamber, a constant level of the petrol is maintained by the float and a needle valve.

The float chamber is ventilated to atmosphere. This is used to maintain atmospheric pressure inside the chamber. The float which is normally a metallic hollow cylinder rises and closes the inlet valve as the fuel level in the float chamber increases to certain level.

The mixing chamber contains venture, nozzle, and throttle valve the venture tube is fitted with the inlet manifold. This tube has a narrow opening called venture. The nozzle keeps the same level of petrol as that of the level in the float chamber. The mixing chamber has two butterfly valves. One is to allow air into the mixing chamber known as choke valve. The other is to allow air –fuel mixture to the engine known as throttle valve.

Working

During the suction stroke, vacuum is created inside the cylinder. This causes pressure difference between the cylinders and d outside the carburetor. Due to this, the atmospheric air enters into the carburetor. The air flows through the venturi. The venturi increases the velocity of air enters into the carburetor. The flows through venturi. The venturi increases the velocity of air and reduces the pressure. This provides the partial vacuum at the tip of the nozzle. Because of this vacuum, the fuel comes out from the nozzle in the form of fine spray. These fine fuel particles mix with the incoming air to form air –fuel mixture. Thus, it gives homogeneous mixture of air- fuel to the engine.

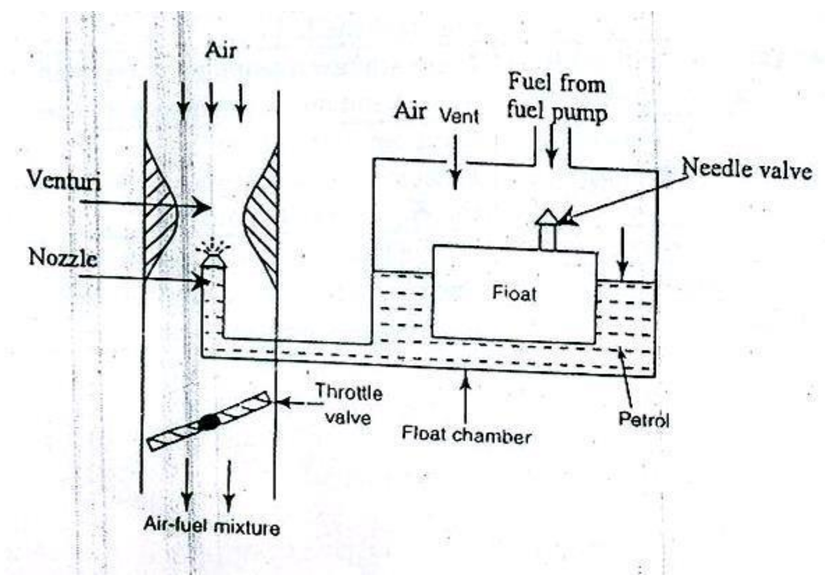


Fig: Simple Carburettor

COOLING SYSTEM

There are mainly two types of cooling systems:

(a) Air cooled system, and

(b) b) Water cooled 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:

(b.a) Amount of air flowing through the fins.

(b.b) Fin surface area.

(b.c) Thermal conductivity of metal used for fins.

Cylinder with Fins

Advantages of Air Cooled System

Following are the advantages of air cooled system:

a.a.1. Radiator/pump is absent hence the system is light.

a.a.2. In case of water cooling system there are leakages, but in this case there are no leakages.

a.a.3. Coolant and antifreeze solutions are not required.

a.a.4. 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.

Explain why cooling is necessary in an I.C engine? With neat sketches describe the working of water cooling system used for multi-cylinder. Why should a pump and thermostat be provided in the cooling system of an engine?

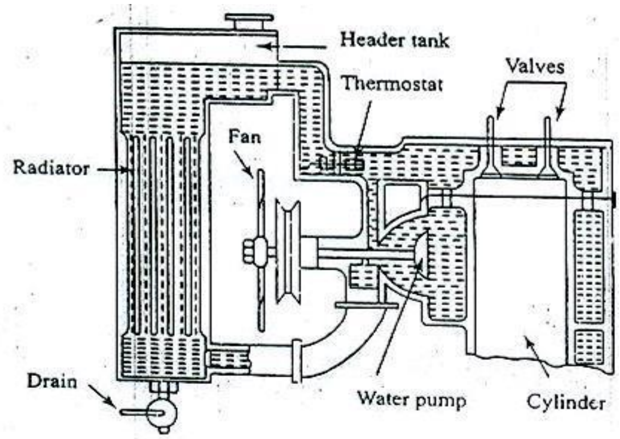
As a result of the combustion of fuel in the cylinders of the engine a considerable amount of heat is produced. All heat is not utilized as power at the crankshaft, with only about 20% of the heat being used as power at the crankshaft 35% of the heat is transferred to the cylinder walls which constitutes the power loss.

The heat should be prevented from being transferred to the cylinder walls as it causes the pre-ignition of charge. Further, the lubricant might also burn because of the excessive heat. The burning of the lubricant in turn might lead to seizure of the piston.

While the engine is running, heat should be continuously removed from the engine. For this purpose, various methods of cooling the engine are utilized.

Water cooling system

In a water cooling system, water jackets are provided in the cylinder block and the cylinder head. Water fills up these jackets and the heart from the cylinder is transferred to the water in the jackets thus cooling in the cylinder.



Cooling of an automobile

When the water passes through the radiator, it is cooled by the cold air drawn by a fan. The cold water again reaches the cylinder block by means of thermo siphon system. However this method of circulation of water is not effective as the heat dissipated by the engine is so large that it is not possible to cool the engine quickly by the thermo siphon system. To enable faster cooling a pump is introduced in the system between the radiator and the engine block at the lower side. This pump is rotated by the crankshaft by means of a belt. When the pump, water is circulated with some force, in the positive direction. Therefore the heat of engine block is removed quickly without any difficulty.

Water pump

A pump is used in the water cooling system for increasing the velocity of the circulating water .Water pump is rotated by the crankshaft through a v-belt.

Thermostat

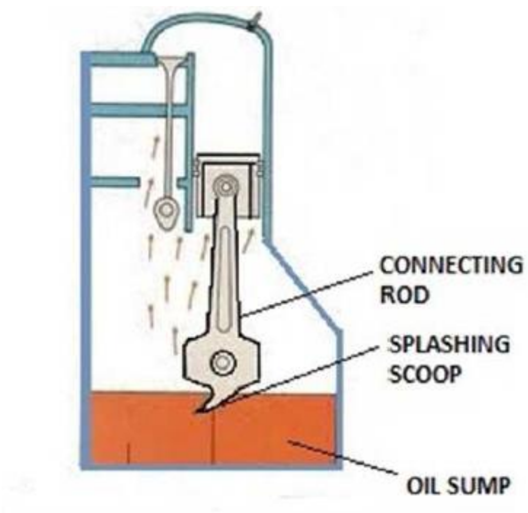
It consists of a metallic part, which either expands or contracts when it comes in contact with hot or cold water. When the valve comes in contact with cold water, it closes. When the water is hot, the valve rises above its seat and hot water passes through the valve to the radiator. The principle of braking up and mixing the fuel with the air is called carburetion.

Lubrication System:

Splash type lubrication

This type of lubrication is generally used in some small four-stroke engines. In its construction a cap is present on the big end of the connecting rod which consists of a scoop. When the connecting rod is at the lowest position, the scoop gets dipped into the oil, thus it directs the oil into the holes present in the bearing. Due to the splash of the scoop oil reaches the lower position of the cylinder walls, crankshaft and other parts which requires lubrication. Oil level inside the pump is maintained a pump which takes oil from the sump through a filter.

It is suitable for low and medium speed engines, which is generally having moderate bearing load pressure. This system does not serve properly for high speed engines, which normally operates at high bearing pressure.



SPLASH SYSTEM LUBRICATION

Explain the pressure feed lubrication system with neat diagram?
The supply of lubricating oil between the moving parts of motor vehicles is called lubrication.

Significance of lubricants

- To reduce friction
- To reduce wear
- To provide cooling effect
- To provide cleaning action
- To provide cushioning effect
- To provide sealing

There are five system of lubrication

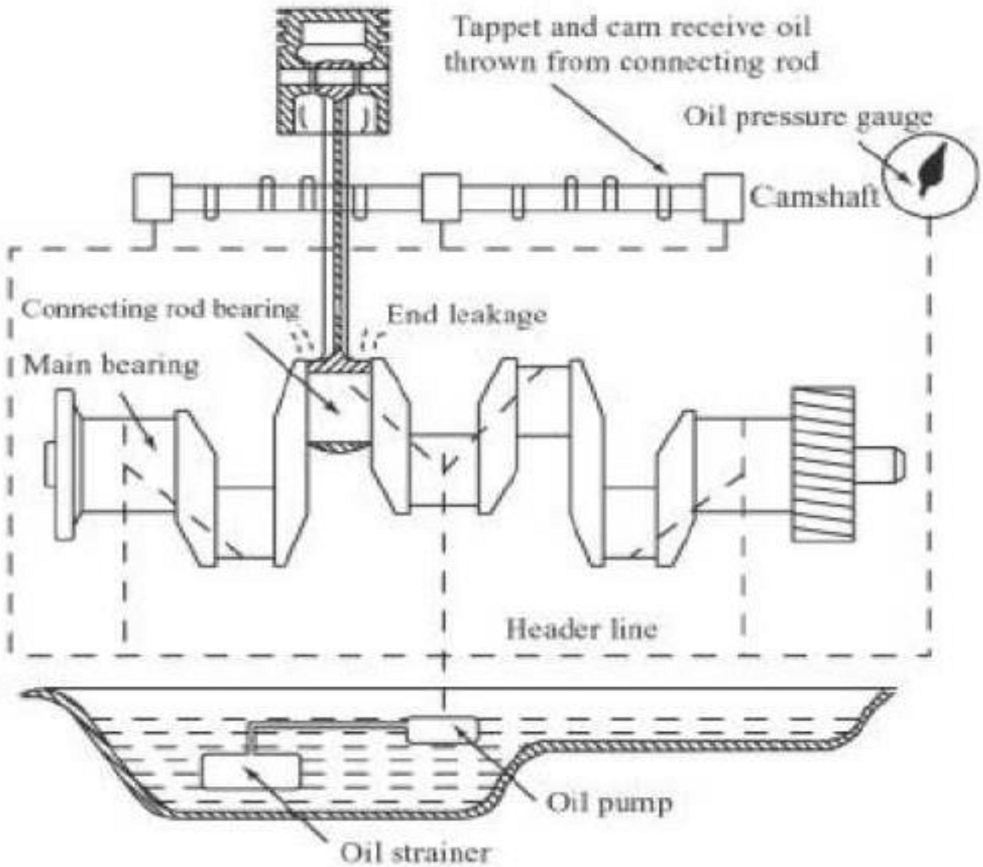
- Petroil system
- Splash system
- Pressure- feed system
- Combined splash and pressure feed system
- Dry sump system

Pressure feed/ full pressure system:

FULL PRESSURE SYSTEM

In this system oil is pumped from oil sump and it is distributed to various parts requiring lubrication. The oil is drawn from the oil sump through a filter and it is pumped by means of gear pump. Here oil is delivered at a pressure of 1.5 bar to 4 bar.

In the pressure feed system, oil is forced is forced with sufficient pressure to enable it to reach even the smallest clearances.
The clearance between the surfaces of the rotating parts of the engine is generally less than 0.001mm.The value of clearance is same for the engine parts moving to and fro. The splashed oil does not have enough force to reach inside such small spaces. Therefore oil is forced with sufficient pressure so that it reaches small clearance.
An oil pump is used in the pressure feed –system. The oil pump is operated by the crankshaft and is placed in the oil pump. Oil is pumped from the oil sump with sufficient pressure through the oil lines.
The leaves through the outlet of the pump and first reaches the oil distributor. Pipes from the distributor convey the lubricating oil to the various parts of the engine.



One of the pipes leading from the distributor, supplies oil to main bearings of the crankshaft. Through the holes drilled through the crankshaft and crankpin bearings, oil passes through the main bearings into the crank-arms. The oil finally reaches the crankpin bearings. A hole is drilled in the central portion of the connecting rod. Once the lubricating oil reaches the crankpin bearings, it is passed through the holes in the connecting rod. Finally it reaches the gudgeon bearings, from where it splashed under the pressure from the hole of the connecting rod and gudgeon pin bearings. The oil lubricates the cylinder walls from where the oil drips into the sump.

Another pipe supplies oil from the oil distributor under pressure to the timing gears and chain. Once the timing gears are well lubricated, oil returns to the oil sump.

Figure shows the pressure-feed lubricating system in a complete form for a four cylinder in-line engine an oil pump takes the lubricating oil from the wet sump through the strainer. This oil then passes through the filter and reaches the main oil line at a pressure of 200 to 400kpa and lubricates various parts of the engine.

Ignition system:

The development of high speed, high compression internal combustion engine requires a reliable high-speed ignition system. This is met by a high-tension ignition system that uses a spark plug as the source of ignition. The electrical energy to the spark plug is supplied by one of the following systems and is termed accordingly.

1. Battery ignition system
2. Magneto ignition system

Main Parts of battery ignition system:

Battery

A battery is used to provide energy for ignition. It is work as storage of energy and charged by dynamo, which is driven by engine. It converts chemical energy to electric energy. Two types of battery used in spark ignition system, lead acid battery and alkaline battery. The first one is used in light duty commercial vehicle and the other one is used in heavy duty commercial vehicle. It is housed in primary side of ignition coil.

Ignition switch:

It is used to turn on and off the ignition system. Battery is connected to the primary winding of ignition coil by ignition switch and ballast resistor.

Ballast resistor:

It is connected in series with primary winding to regulate current in primary winding. It is used to prevent injury due to overheating of ignition coil. It controls the current passes through primary winding. It is made by iron. Iron has property of increase electrical resistance rapidly by increase in temperature at certain limit. This additional resistance resists flowing current which control the temperature of ignition coil.

Ignition coil:

Ignition coil is the main body of battery ignition system. The purpose of ignition coil is to step up the battery voltage (6 or 12) to a high voltage, which is sufficient to produce spark at spark plug. It consist a magnetic core or soft wire or sheet, and two electrical winding called primary winding and secondary winding. The primary winding has generally 200-300 turn and the end are connected to exterior terminal. The secondary has almost 21000 turns of copper wire which is insulated to withstand with high voltage. It is located inside the primary winding and its one end connected to secondary winding and other end is grounded either to primary winding or to the metal case. This entire unit is enclosed in a metal container which makes it a compact unit.

Contact breaker:

This is a mechanical device making and braking the primary circuit to ignition coil. When the points are closed current flow in ignition coil and when it open, flow of current stopped.

Capacitor:

It is simple electrical capacitors in which two metal plate are separated by an insulating material with a distance. Commonly air is used as insulating material but for particular technical requirement some high quality insulating material is used.

Distributor:

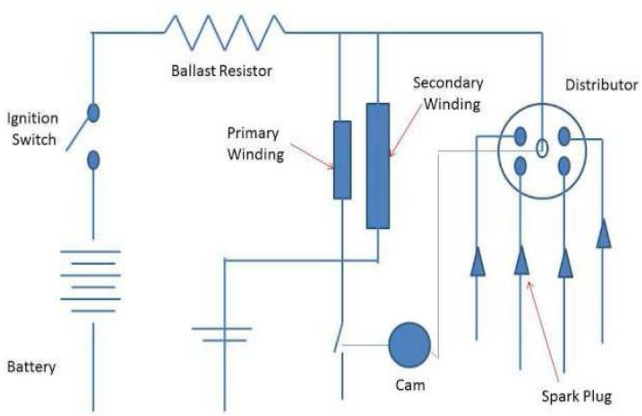
Distributor is used in multi cylinder engine to regulate spark in each spark plug at correct sequence. It distribute ignition surge in individual spark plug in correct sequence. There are two types of distributor. One is known as carbon brush type and the other one is gap type. In carbon brush type carbon brush carried by the rotor arm sliding over the metallic segment embedded into the distributor cap or molded insulating material. This makes electric connection or secondary winding with spark plug. In gap type distributor electrode of rotor arm pass close to but does not make contact with the distributor cap. So there is no wear of electrode.

Spark plug:

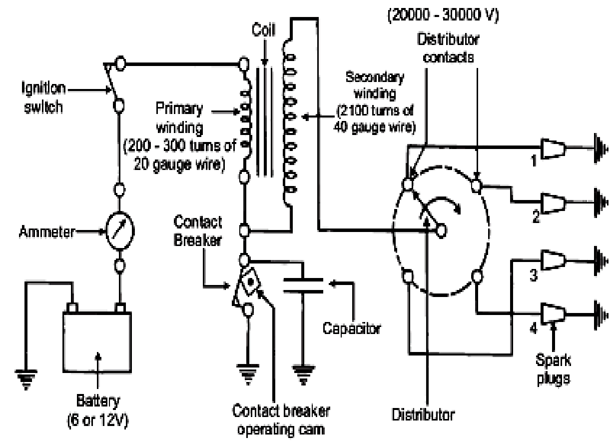
A spark plug generally has two electrodes which are separated with each other. A high potential discharge flows through it which generate spark and ignite the combustion mixture in cylinder. It mainly consist two electrodes a steel shell and an insulator. The central electrode connected with the supply of ignition coil. It is well insulated with the outer steel shell which is grounded. There is a small air gap between steel shell and central electrode, between which spark is generated. The electrode usually made by high nickel alloy so it can withstand with high temperature and corrosion resistance.

Working of Battery Ignition System:

In the battery ignition system ignition coil stores the energy in form of magnetic field and deliver it at the instant of ignition, in form of high voltage current with high tension wire to correct spark plug. The diagram of four cylinder battery ignition system is as follow.



(or)



First low voltage current flow form battery to the primary coil through ignition switch and ballast resistor.

Ballast resistor regulates the temperature of ignition coil by regulating current passing form it.

The ignition capacitor connected in parallel with contact breaker. One end of secondary winding is also grounded through contact breaker.

When the ignition switch is closed, the primary winding of the coil is connected to the positive terminal, and current flow through it known as primary current.

The current flows form primary coil produces a magnetic field which induces an EMF in secondary coil.

The cam regulates the contact breaker. Wherever the breaker open, current flows into condenser, which charged the condenser.

As the condenser become charger the primary current falls and the magnetic field collapses. This will induces a much higher voltage in condenser.

Now the condenser discharge into the battery which reverses the direction of both primary current and magnetic field. This will induce a very high EMF in secondary winding.

Now this high voltage EMF produce spark at correct spark plug through distributor.

Advantages and Disadvantages:

Advantages:

1. At the time of starting or at low speed good spark is available.
2. The battery which is used to generate spark can be used to light other auxiliary like headlight, tell light etc.
3. Initial expenditure is less and it has low maintenance cost.
4. Ignition system is not affected by adjusting spark timing in battery ignition system.

Disadvantages:

1. Time available of built up the current and stored energy is decrease as speed of engine increases.
2. Contact breaker subjected to both electrical and mechanical wear which results short maintenance interval.
3. The primary voltage decreases as the engine speed increase. So it is not fully reliable of high speed engine.

Magneto Ignition System:

Parts of Magneto Ignition System:

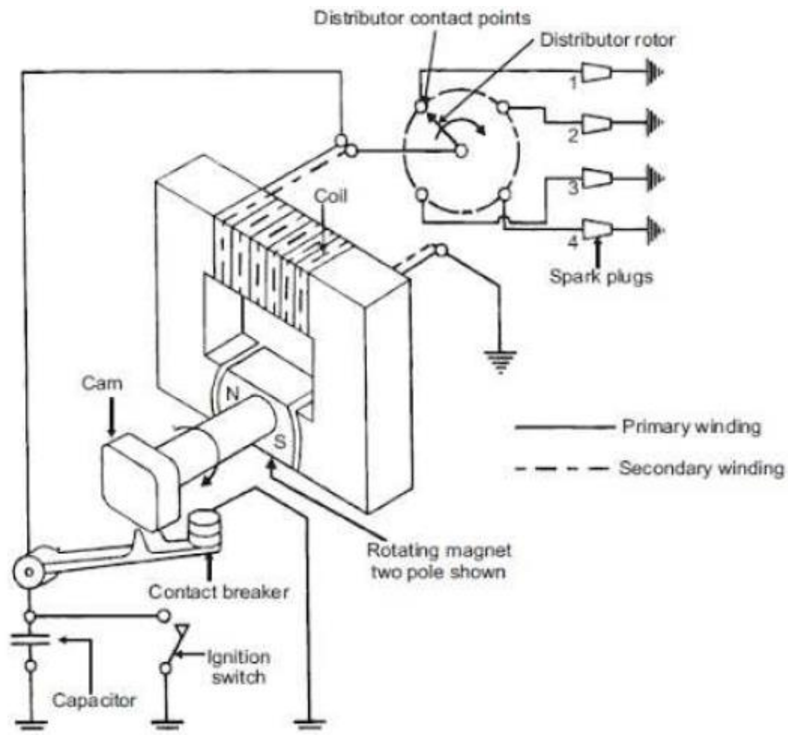
Magneto: It is the major part of this type of ignition system because it is source of energy. A magneto is a small electric generator which is rotate by the engine and is capable of produce a very high voltage and does not need battery as a source of external energy. The magneto contains both primary and secondary winding thus it does not require a separate coil to boost up the voltage required to operate the spark plug. There are two types of magneto. First one is known as armature rotating type and other one is known as magnet rotating type. In the first type, the armature rotates between the stationary magnets. On the other hand in second type armature is stationary and the magnates are rotating around armature.

Distributor: Distributor is used in multi cylinder engine to regulate spark in each spark plug at correct sequence. It distribute ignition surge in individual spark plug in correct sequence. There are two types of distributor. One is known as carbon brush type and the other one is gap type. In carbon brush type carbon brush carried by the rotor arm sliding over the metallic segment embedded into the distributor cap or molded insulating material. This makes electric connection or secondary winding with spark plug. In gap type distributor electrode of rotor arm pass close to but does not make contact with the distributor cap. So there is no wear of electrode.

Spark Plug: A spark plug generally has two electrodes which are separated with each other. A high potential discharge flow through it which generate spark and ignite the combustion mixture in cylinder. It mainly consist two electrodes a steel shell and an insulator. The central electrode connected with the supply of ignition coil. It is well insulated with the outer steel shell which is grounded. There is a small air gap between steel shell and central electrode, between which spark is generated. The electrode usually made by high nickel alloy so it can withstand with high temperature and corrosion resistance.

Capacitor: It is simple electrical capacitors in which two metal plate are separated by an insulating material with a distance. Commonly air is used as insulating material but for particular technical requirement some high quality insulating material is used.

Working of Magneto Ignition System: The working principle of magneto ignition system is same as battery ignition system except in the magneto ignition system Magneto is used to produce energy except battery. The diagram of four cylinder magneto ignition system is as follows.



First when the engine starts or during cranking magneto rotate which generates a very high voltage.

The ignition capacitor connected in parallel with contact breaker. One end of magneto winding is also grounded through contact breaker.

The cam regulates the contact breaker. Wherever the breaker open, current flows into condenser, which charged the condenser.

As the condenser become charger the primary current falls and the magnetic field collapses. This will induces a much higher voltage in condenser.

Now this high voltage EMF produce spark at correct spark plug through distributor.

As the engine speed is low at starting, the current generated by the magneto is quite small. As the engine speed increases the flow of current also increases. Thus with magneto ignition system there is always starting problem and sometimes a separate battery needed for stating. This ignition system is best suited at high speed so it is used in racing cars, aircraft engines etc.

Advantages and Disadvantages:

Advantages:

1. This system is more reliable at medium and high speed.

2. It is more reliable because no battery is used.

3. It requires less frequently maintenance.

Disadvantages:

1. It has starting problem due to low cranking speed at starting.

2. It is more expensive compare to battery ignition system.

3. There is possibility of misfire due to leakage because wiring carry very high voltage.

UNIT – 3: COMBUSTION IN IC ENGINES

S.I. Engine: Normal and abnormal combustion - Importance of flame speed and effect of engine variables - Type of abnormal combustion, pre ignition and knocking (concept only) - Fuel requirements and fuel rating, antiknock additives - Combustion chambers. C.I. Engine: Stages of combustion - Delay period and its importance - Effect of engine variables - Diesel knock - Combustion chambers - Fuel requirements and fuel rating

On successful completion of this unit, students will be able to:

Course Outcomes		POs related to COs
CO3	Demonstrate the basic knowledge and analyze the types and stages of combustion in SI and CI engines.	PO1

WEB SOURCE REFERENCES:

1	https://nptel.ac.in/courses/112106133/2
2	http://en.wikipedia.org/wiki/mechanical
3	http://en.wikipedia.org/wiki/Applied_Thermal_Engineering
4	https://www.brighthubengineering.com/thermodynamics/4125-air-standard-cycle-part-one/
5	www.sciencedirect.com
6	www.journals.elseier.com

ADDITIONALRESOURCES:

1. **Anna university tutorials (Internal Server)**
2. **Thermal engineering Books (PDF Formats)**
3. **Online Objective Questions**
4. **Videos Materials if any (You tube)**

COMBUSTION:

Combustion may be defined as a relatively rapid chemical combination of hydrogen and carbon in fuel with oxygen in air resulting in liberation of energy in the form of heat.

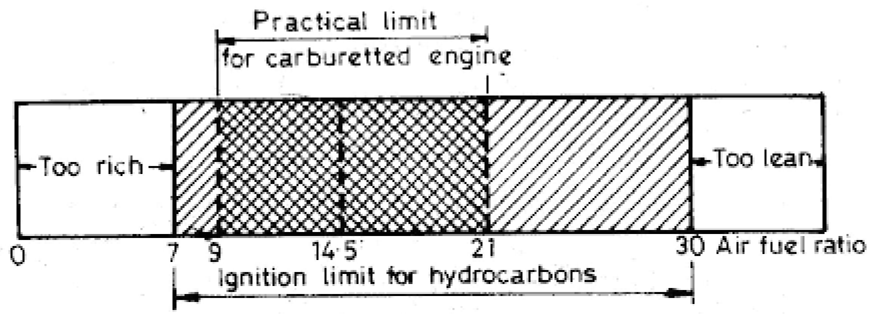
Following conditions are necessary for combustion to take place

1. **The presence of combustible mixture**
2. **Some means to initiate mixture**
3. **Stabilization and propagation of flame in Combustion Chamber**

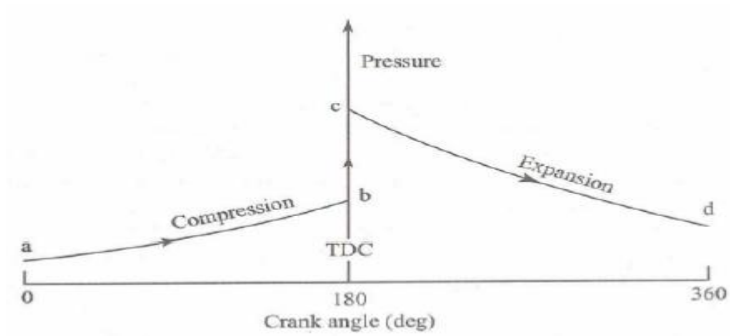
In S I Engines, carburetor supplies a combustible mixture of petrol and air and spark plug initiates combustion

IGNITION LIMITS

Ignition of charge is only possible within certain limits of fuel-air ratio. Ignition limits correspond approximately to those mixture ratios, at lean and rich ends of scale, where heat released by spark is no longer sufficient to initiate combustion in neighbouring unburnt mixture. For hydrocarbons fuel the stoichiometric fuel air ratio is 1:15 and hence the fuel air ratio must be about 1:30 and 1:7|



THEORIES OF COMBUSTION IN SI ENGINE

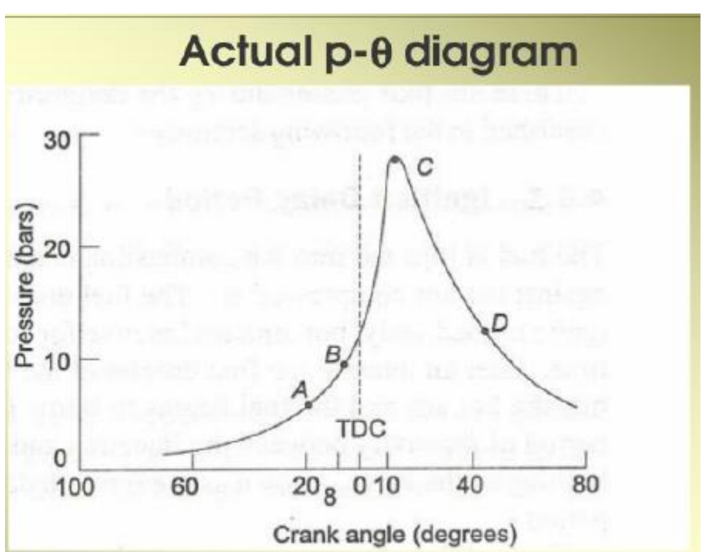


Combustion in SI engine may roughly divided into two general types: Normal and Abnormal (knock free or Knocking). Theoretical diagram of pressure crank angle diagram is shown. (a→b) is compression process, (b→c) is combustion process and (c→d) is an expansion process. In an ideal cycle it can be seen from the diagram, the entire pressure rise during combustion takes place at constant volume i.e., at TDC. However, in actual cycle this does not happen.

RICHARD'S THEORY OF COMBUSTION.

Sir Ricardo, known as father of engine research describes the combustion process can be imagined as if it is developing in two stages:

1. **Growth and development of a self propagating nucleus flame. (Ignition lag)**
2. **Spread of flame through the combustion chamber**



Three stages of combustion:

According to Ricardo, There are three stages of combustion in SI Engine as shown

1. Ignition lag stage
2. Flame propagation stage
3. After burning stage

1. Ignition lag stage: There is a certain time interval between instant of spark and instant where there is a noticeable rise in pressure due to combustion. This time lag is called IGNITION LAG.

   Ignition lag is the time interval in the process of chemical reaction during which molecules get heated up to self ignition temperature , get ignited and produce a self propagating nucleus of flame. The ignition lag is generally expressed in terms of crank angle (θ1). The period of ignition lag is shown by path ab. Ignition lag is very small and lies between 0.00015 to 0.0002 seconds. An ignition lag of 0.002 seconds corresponds to 35 deg crank rotation when the engine is running at 3000rpm. Angle of advance increases with the speed. This is a chemical process depending upon the nature of fuel, temperature and pressure proportions of exhaust gas and rate of oxidation or burning.

2. Flame propagation stage:

Once the flame is formed at "b", it should be self sustained and must be able to propagate through the mixture. This is possible when the rate of heat generation by burning is greater than heat lost by flame to surrounding.

After the point "b", the flame propagation is abnormally low at the beginning as heat lost is more than heat generated. Therefore pressure rise is also slow as mass of mixture burned is small. Therefore it is necessary to provide angle of advance 30 to 35 deg, if the peak pressure to be attained 5-10 deg after TDC. The time required for crank to rotate through an angle θ2 is known as combustion period during which propagation of flame takes place.

3.After burning:

Combustion will not stop at point "c" but continue after attaining peak pressure and this combustion is known as after burning. This generally happens when the rich mixture is supplied to engine.

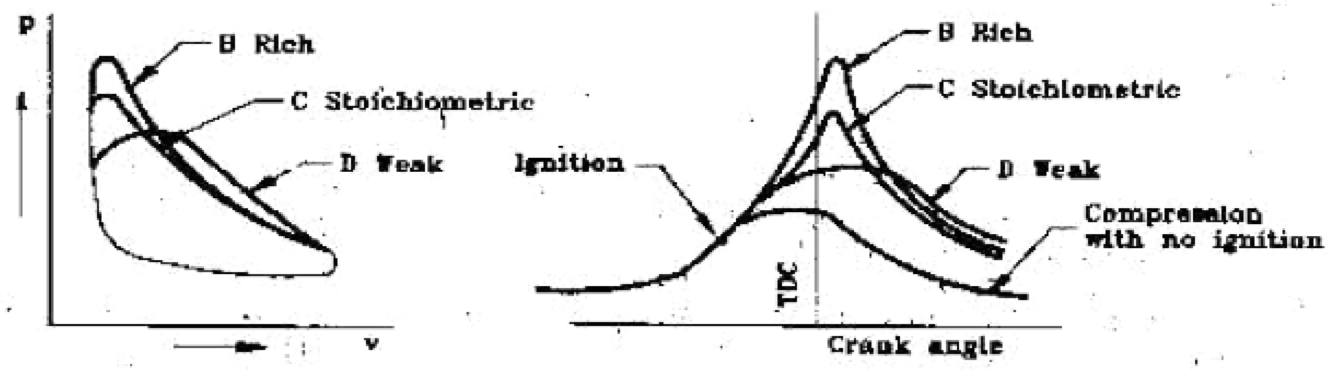
Factors affecting the flame propagation:

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

1. Air fuel ratio
2. Compression ratio
3. Load on engine
4. Turbulence and engine speed
5. Other factors

1. A : F 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 (C CO instead of C0 and also results in production of less heat and flame speed remains low. The effects of A: F ratio on p-v diagram and p-0 diagram are shown below :



2. **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. Figure above shows the effect of compression ratio on pressure (indirectly on the speed of combustion) with respect to crank angle for same A: F ratio and same angle of advance. Higher compression ratio increases the surface to volume ratio and thereby increases the part of the mixture which after-burns in the third phase.

3. **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 throttle, the initial and final pressure of the mixture after compression decreases 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. This difficulty can be partly overcome by providing rich mixture at part loads but this definitely increases the chances of after-burning. 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 S,I. engines which causes wastage of fuel and discharge of large amount of CO with exhaust gases.

4. Turbulence : Turbulence plays very important role in combustion of fuel as the flame speed is directly proportional to the turbulence of the mixture. This is because, the turbulence increases the mixing and heat transfer coefficient or heat transfer rate between the burned and unburned mixture. The turbulence of the mixture can be increased at the end of compression by suitable design of the combustion chamber (geometry of cylinder head and piston crown).

Insufficient turbulence provides low flame velocity and incomplete combustion and reduces the power output. But excessive turbulence is also not desirable as it increases the combustion rapidly and leads to detonation. Excessive turbulence causes to cool the flame generated and flame propagation is reduced.

Moderate turbulence is always desirable as it accelerates the chemical reaction, reduces ignition lag, increases flame propagation and even allows weak mixture to burn efficiently.

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. 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 characteristics of all petrol engines.

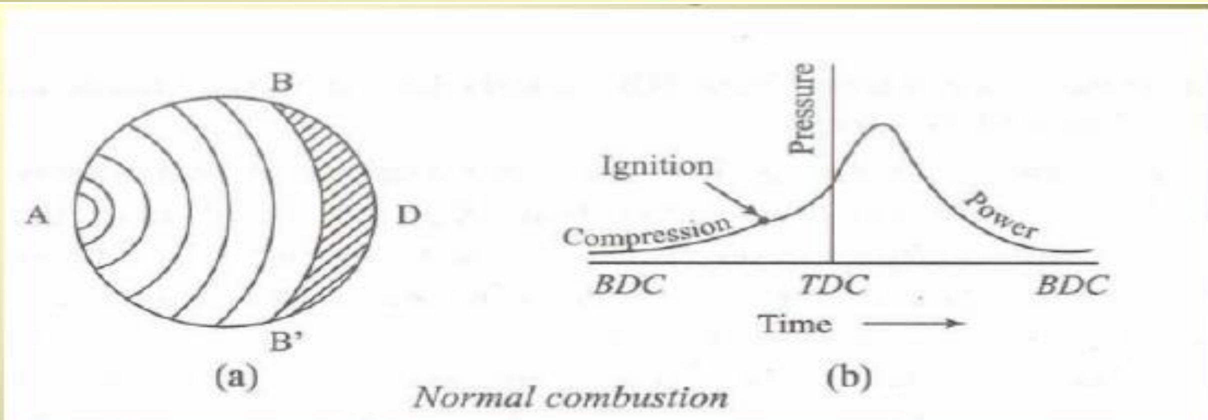
Engine Size

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.

5. Other Factors. Among the other factors, the factors which increase the flame speed are supercharging of the engine, spark timing and residual gases left in the engine at the end of exhaust stroke. The air humidity also affects the flame velocity but its exact effect is not known. Anyhow, its effect is not large compared with A :F ratio and turbulence.

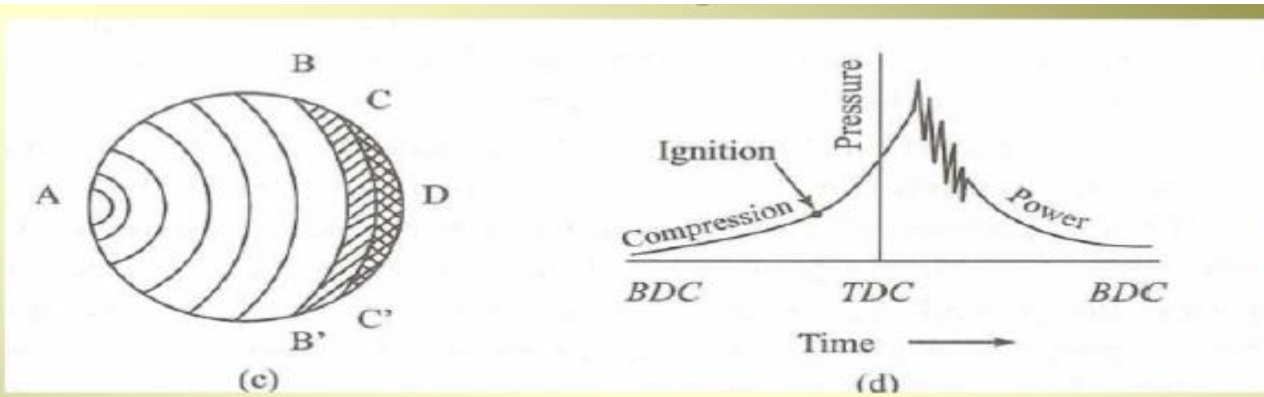
Knocking

- **Normal Combustion:** When the flame travels evenly or uniformly across the combustion chamber.
- **Abnormal Combustion:** When the combustion gets deviated from the normal behavior resulting in loss of performance or damage to the engine.



Normal combustion

Flame travels from A→D and compresses the end charge BB´D and raises its temperature. Temperature also increases due to heat transfer from the flame front. Now, if the final temperature is less than the auto-ignition temperature, Normal Combustion occurs and charge BB´D is consumed by the flame itself.



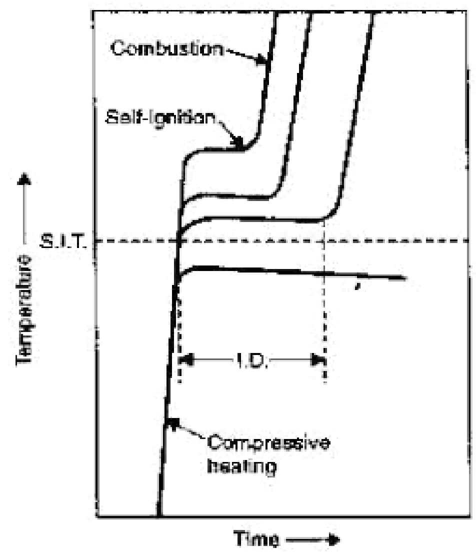
Now, if the final temperature is greater than and equal to the auto-ignition temperature, the charge BB´D auto-ignites (knocking). A second flame front develops and moves in opposite direction, where the collision occurs between the flames. This causes severe pressure pulsation, and leads to engine damage/failure.

AUTO IGNITION:

A mixture of fuel and air can react spontaneously and produce heat by chemical reaction in the absence of flame to initiate the combustion or self-ignition. This type of self-ignition in the absence of flame is known as Auto-Ignition. The temperature at which the self-ignition takes place is known as self-igniting temperature. The pressure and temperature abruptly increase due to auto-ignition because of sudden release of chemical energy.

This auto-ignition leads to abnormal combustion known as detonation which is undesirable because its bad effect on the engine performance and life as it abruptly increases sudden large amount of heat energy. In addition to this knocking puts a limit on the compression ratio at which an engine can be operated which directly affects the engine efficiency and output.

Auto-ignition of the mixture does not occur instantaneously as soon as its temperature rises above the self-ignition temperature. Auto-ignition occurs only when the mixture stays at a temperature equal to or higher than the self-ignition temperature for a "finite time". This time is known as delay period or reaction time for auto-ignition. This delay time as a function of compression ratio is shown in adjacent figure.



S.I.T. → Self-ignition temperature
I.D. → Ignition delay
Fig. Self-ignition charactristics of fuels.

As the compression ratio increases, the delay period decreases and this is because of increase in initial (before combustion) pressure and temperature of the charge. The self-ignition temperature is a characteristic of fuel air mixture and it varies from fuel to fuel and mixture strength to mixture - strength of the same fuel.

PRE-IGNITION:

Pre-ignition is the ignition of the homogeneous mixture of charge as it comes in contact with hot surfaces, in the absence of spark .

Auto ignition may overheat the spark plug and exhaust valve and it remains so hot that its temperature is sufficient to ignite the charge in next cycle during the compression stroke before spark occurs and this causes the pre-ignition of the charge.

Pre-ignition is initiated by some overheated projecting part such as the sparking plug electrodes, exhaust valve head, metal corners in the combustion chamber, carbon deposits or protruding cylinder head gasket rim etc.

pre-ignition is also caused by persistent detonating pressure shockwaves scoring away the stagnant gases which normally protect the combustion chamber walls. The resulting increased heat flow through the walls, raises the surface temperature of any protruding poorly cooled part of the chamber, and this there fore provides a focal point for pre-ignition.

Effects of Pre-ignition

- It increase the tendency of denotation in the engine
- It increases heat transfer to cylinder walls because high temperature gas remains in contact with for a longer time
- Pre-ignition in a single cylinder will reduce the speed and power output
- Pre-ignition may cause seizer in the multi-cylinder engines, only if only cylinders have pre-ignition

Combustion Chamber – SI Engine

- The design of combustion chamber has an important influence upon the engine performance and its knock properties. The design of combustion chamber involves the shape of the combustion chamber, the location of the sparking plug and the disposition of inlet and exhaust valves. Because of the importance of combustion chamber design, it has been a subject of considerable amount of research and development in the last fifty years. It has resulted in raising the compression ratio from 4: 1 before the First World War period to 8: 1 to 11:1 in present times with special combustion Chamber designs and suitable anti-knock fuels.

BASIC REQUIREMENTS OF A GOOD COMBUSTION CHAMBER

- High power output
- High thermal efficiency and low specific fuel consumption
- Smooth engine operation
- Reduced exhaust pollutants.

DIFFERENT TYPES OF COMBUSTION CHAMBERS

1. T-head combustion chamber.
2. L-head combustion chamber.
3. I-head (or overhead valve) combustion chamber.
4. F-head combustion chamber.

T Head Type Combustion chambers

- This was first introduced by Ford Motor Corporation in 1908. This design has following disadvantages.
- Requires two cam shafts (for actuating the in-let valve and exhaust valve separately) by two cams mounted on the two cam shafts.
- Very prone to detonation. There was violent detonation even at a compression ratio of 4. This is because the average octane number in 1908 was about 40 -50.

L Head Type Combustion chambers

- It is a modification of the T-head type of combustion chamber. It provides the two values on the same side of the cylinder, and the valves are operated through tappet by a single camshaft. This was first introduced by Ford motor in 1910-30 and was quite popular for some time. This design has an advantage both from manufacturing and maintenance point of view.

Advantages:

- Valve mechanism is simple and easy to lubricate.
- Detachable head easy to remove for cleaning and decarburizing without disturbing either the valve gear or main pipe work.
- Valves of larger sizes can be provided.

Disadvantages:

- Lack of turbulence as the air had to take two right angle turns to enter the cylinder and in doing so much initial velocity is lost.
- Extremely prone to detonation due to large flame length and slow combustion due to lack of turbulence.
- More surface-to-volume ratio and therefore more heat loss. Extremely sensitive to ignition timing due to slow combustion process Valve size restricted.
- Thermal failure in cylinder block also.
- In I-head engine the thermal failure is confined to cylinder head only

Over head valve or I head combustion chamber

- The disappearance of the side valve or L-head design was inevitable at high compression ratio of 8 : 1 because of the lack of space in the combustion chamber to accommodate the valves. Diesel engines, with high compression ratios, invariably used overhead valve design. Since 1950 or so mostly overhead valve combustion chambers are used. This type of combustion chamber has both the inlet valve and the exhaust valve located in the cylinder head. An overhead engine is superior to side valve engine at high compression ratios.

The overhead valve engine is superior to side valve or L-head engine at high compression ratios, for the following reasons:

•Lower pumping losses and higher volumetric efficiency from better breathing of the engine from larger valves or valve lifts and more direct passageways.

•Less distance for the flame to travel and therefore greater freedom from knock, or in other words, lower octane requirements.

•Less force on the head bolts and therefore less possibility of leakage (of compression gases or jacket water). The projected area of a side valve combustion chamber is inevitably greater than that of an overhead valve chamber.

•Removal of the hot exhaust valve from the block to the head, thus confining heat failures to the head. Absence of exhaust valve from block also results in more uniform cooling of cylinder and piston.

•Lower surface-volume ratio and, therefore, less heat loss and less air pollution.

•Easier to cast and hence lower casting cost.

F- Head combustion chamber

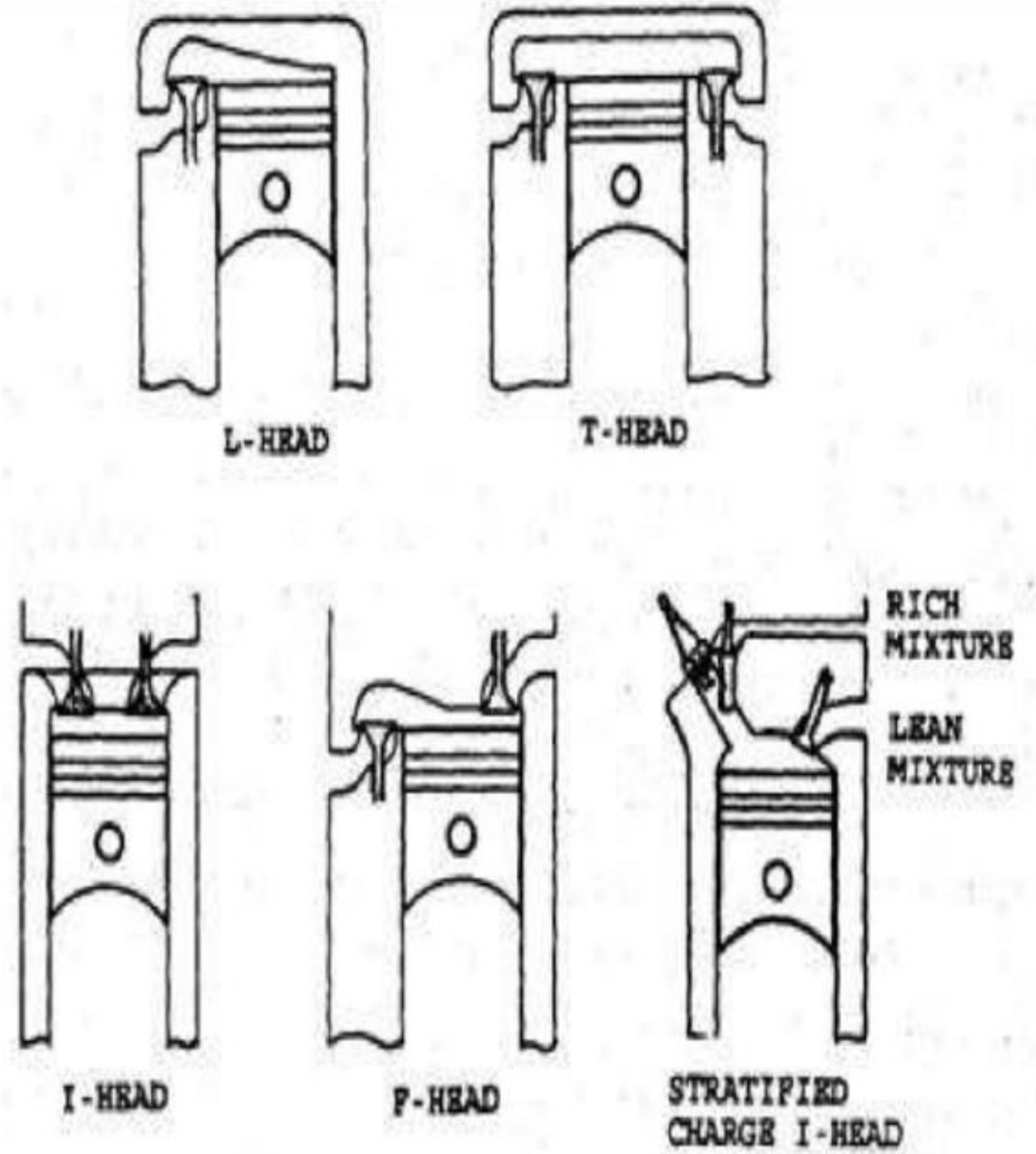
- In such a combustion chamber one valve is in head and other in the block. This design
- is a compromise between L-head and I-head combustion chambers.

Advantages :

- High volumetric efficiency
- Maximum compression ratio for fuel of given octane rating High thermal efficiency
- It can operate on leaner air-fuel ratios without misfiring.

Drawback:

- This design is the complex mechanism for operation of valves and expensive special shaped piston.


L-HEAD
T-HEAD
I-HEAD
F-HEAD
RICH
MIXTURE
LEAN
MIXTURE
STRATIFIED
CHARGE I-HEAD

COMBUSTION CHAMBER IN CI ENGINE

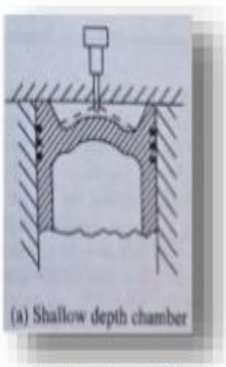
TYPES OF COMBUSTION CHAMBERS

- Direct Injection (DI) Type – These also called open combustion chambers. The entire combustion space lies in the
  main cylinder and the fuel is injected into this volume.

- Indirect Injection (IDI) Type – In this type of combustion chambers, combustion space is divided into two parts, one in the cylinder head and other in the main cylinder. Fuel is generally injected in the part which lies in cylinder head.

DIRECT INJECTION COMBUSTION CHAMBERS

- Shallow Depth Chamber



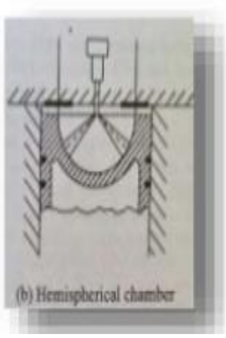
(a) Shallow depth chamber

In shallow depth chamber, depth of the cavity provided in the piston in small.

Due to this, the squish is negligible.

It is usually adopted for large engines running at low speeds.

- Hemispherical Chamber



(b) Hemispherical chamber

This design also gives small squish.

However, its depth to diameter radius can be varied to obtain desired type of squish for better performance.

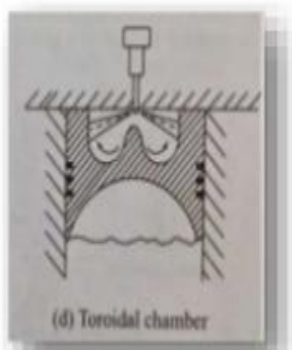
- Cylindrical Chamber

This design is a modification of cylindrical chamber in the form of truncated cone.

Swirl is produced by masking the valve up to 180 deg. of circumference.

Squish produced is better than the previous two designs.

- Toroidal Chamber



This design produces a powerful squish along with air movement.

The masking needed on the valves is small, and thus, it makes better utilisation of oxygen.

INDIRECT INJECTION COMBUSTION CHAMBERS

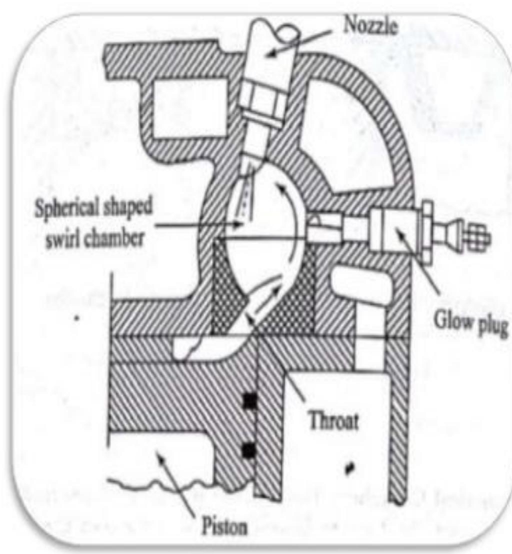
- Swirl Chamber

Swirl Chamber is provided in the cylinder head. A throat which is tangent to this chamber connects it with the main cylinder.

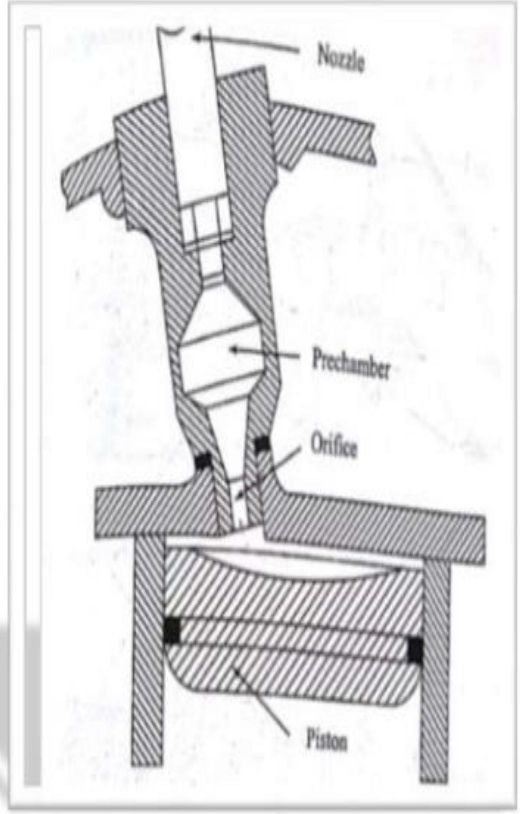
During compression, air flows into the swirl chamber through the throat. Tangential direction of air motion generates rotary motion inside the swirl chamber.

Fuel in injected into the chamber, and the combustion products travel back to the main cylinder at much higher velocity.

This type of chamber is used where fuel quality cannot be controlled, where reliability is more important than fuel economy



▪ Pre-ignition Chamber

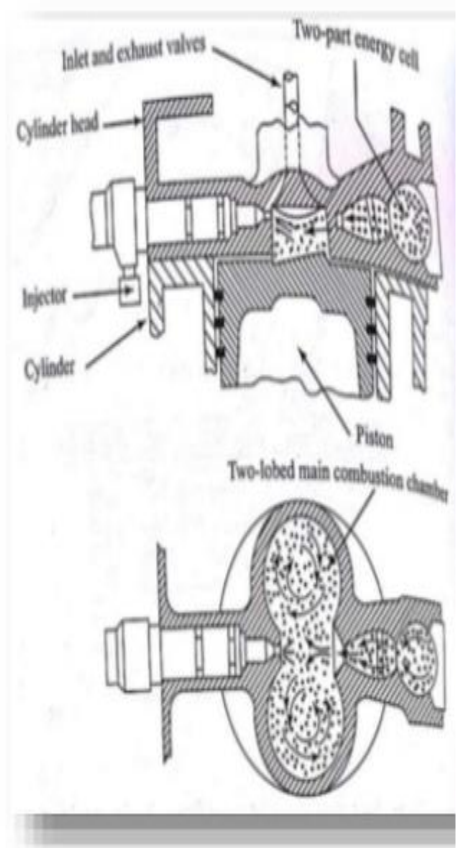


It consists of a pre-ignition chamber (40% of total combustion space) connected with the main cylinder through small no. of holes.

During compression, piston forces the air into pre-ignition chamber. Fuel is then injected into the chamber due to which combustion takes place.

The resulting pressure rise forces the combustion products at higher velocities through small holes into the main cylinder, where bulk of combustion takes place.

▪ Air-Cell Chamber



The clearance volume is divided into two parts – one in the main cylinder and rest in energy cell.

Energy cell is divided into two parts – major and minor, which are separated from each other and from the cylinder by narrow orifices.

Pressure in the energy cell is low, therefore, air is forced at high velocity into the energy cell on compression. After the injection of fuel, combustion takes place inside energy cell and hot burning gases blow out through small holes into the main chamber.

These hot gases provides swirling movement in main chamber, which results in complete combustion.

DIRECT INJECTION VS INDIRECT INJECTION

Injection Type	Advantages	Drawbacks
Direct Injection	Minimum heat loss during compression	Requires high fuel injection pressure.
	Fine atomization because of multi-hole nozzle	Necessity of accurate metering of fuel
Indirect Injection	Injection pressure required is low	Poor Cold starting performance
	Direction of spraying of fuel is not important.	Specific fuel consumption is high

UNIT – 4: TESTING AND PERFORMANCE OF IC ENGINES

Performance parameters - 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.

On successful completion of this unit, students will be able to:

Course Outcomes		POs related to COs
CO4	Investigation on IC engines for performance improvement and emission reduction to environment.	PO1, PO2, PO3, PO4, PO7

WEB SOURCE REFERENCES:

1	https://nptel.ac.in/courses/112106133/2
2	http://en.wikipedia.org/wiki/mechanical
3	http://en.wikipedia.org/wiki/Applied_Thermal_Engineering
4	https://www.brighthubengineering.com/thermodynamics/4125-air-standard-cycle-part-one/
5	www.sciencedirect.com
6	www.journals.elseier.com

ADDITIONALRESOURCES:

1. **Anna university tutorials (Internal Server)**
2. **Thermal engineering Books (PDF Formats)**
3. **Online Objective Questions**
4. **Videos Materials if any (You tube)**

1. **A single cylinder IC engine working on 4-stroke cycle runs at 400RPM.The engine cylinder is 10cm in diameter and 15cm in stroke. If the mean effective pressure is 6.5 Bar. Calculate Indicated Power developed by the engine?**
   Given, 4-Stroke single cylinder, N=400 RPM, K=1, Diameter=10cm = 0.1m, Area=$7.85X10^{-3}$,
   Length=15cm=0.15m, P_{mi}=6.5 Bar=$6.5X10^5$ N/m^2

   I.P =?

   I.P=P_{mi}.L.A.N.K /60 = $(6.5X10^5)X(0.15)X(7.85X10^{-3})X(400/2)X(1)$ /60 =2551.25 W =2.551 KW

2. **A 2-Cylinder I.C Engine working on 2-Stroke cycle is to develop an Indicated Power of 30 KW at 1000 RPM. If the mean effective pressure is 6 bar. Find the necessary bore and stroke of the piston. Assume stroke is 1.5 times the bore?**
   Given, N=1000 RPM, K=2, I.P=30 KW, P_{mi} =$6X10^5$ N/m^2, L= 1.5D
   We know that, I.P=P_{mi}.L.A.N.K /60
   30 =$(6X10^5)X(L)X(\pi/4(D)^2)X(1000)X(2)$ /60X1000
   D =0.108384 m =108.384 mm
   L=1.5(D) =1.5(0.108384) =0.162576 m =162.576 mm

3. **An Otto cycle gas engine as a cylinder 25cm in diameter and stroke of the piston is 45cm .It works under the following conditions. Speed = 180rpm, Mis-fires per minute = 8, Mean effective pressure = 6.5bar, Mechanical efficiency = 80%, Find IP, BP &FP**
   Given, D=25cm, L=45cm, N=180rpm, Mis-fire=8, P_{mi}=$6.5X10^5$
   Mechanical Efficiency=80%=0.8
   I.P=P_{mi}.L.A.N.K /60 =$6.5X10^5X0.45X\pi/4(0.25)X172X1$ /60 = 41159.7725 W = 41.59 KW
   Mechanical Efficiency=BP/IP
   0.8X41.59=BP BP=33.032KW
   IP=BP+FP FP=IP-BP =41.59-33.032 =8.558KW

4. **A diesel engine has a compression ratio of 14 to 1 and the fuel supply is cut off at 0.08 of the stroke. If the relative efficiency is 0.52.Estimate the mass of fuel of CV = 43700kJ/kg which would be required per kW-hr**
   Given:
   Compression ratio=14:1, r=14=V_1/V_2 , Cut off =0.52, Calorific Value=43700 kJ/kg, K=1
   Cut off $V_3-V_2=(0.08)V_s$ $=(0.08)(V_1-V_2)$
   Mass of fuel, m_f =?
   Cut off $(V_3-V_2)=0.08(V_1-V_2)$ $=0.08(14V_2-V_2)$
   (V_3-V_2) $=0.08(13V_2)$
   $V_3=1.04V_2+V_2$ $=2.04V_2$
   $V_3/V_2=2.04 = \rho$
   Air standard Diesel cycle Efficiency:

$$\eta_{th} = 1 - \frac{1}{r^{\gamma-1}}\left(\frac{\alpha^{\gamma}-1}{\gamma(\alpha-1)}\right)$$

   = $1-(1/14^{1.4-1})[(2.04^{1.4}-1/1.4(2.04-1)]$ =0.59X100 =59%
   Now,
   Relative Efficiency=Indicated Thermal Efficiency / Diesel Efficiency
   Indicated Thermal Efficiency=Relative Efficiency X Diesel Efficiency=0.307X100=30.7%
   Mass of fuel:-
   Indicated Thermal Efficiency = I.P X 3600 / m_f.C.V (kJ/Kg-kW-hr)
   0.307=1X3600 / m_f (C.V/I.P)
   =1X3600 / m_f (43700/1)
   m_f =0.268 Kg

5. A four stroke single cylinder oil engine the following observations will be recorded bore = 300mm, Stroke = 400mm, Speed = 200r.p.m, Cycle = 4-Stroke, Duration of trail = 60min, Fuel consumption = 7.05Kg, calorific value of fuel = 44000KJ/kg, Area of indicated Diagram = 322mm^2, Length of Indicated diagram = 62mm, Spring index = 1.1bar/mm, Net load on brakes = 1324.35N, Brake drum Diameter = 1600mm, Total mass of Jacket cooling water = 495Kg, Temperature rise of Jacket cooling water = 38^{0}C, Temperature of exhaust gas = 300^{0}C, Air consumption = 311Kg. Assume specific heat of exhaust gas = 1.004kJ/Kg-Kelvin , specific heat of water = 4.186kJ/Kg-Kelvin, Room Temperature = 20^{0}C. Determine 1. Power available at brakes, 2 .Indicated power developed, 3. Efficiency of mechanical, 4. Thermal efficiencies and 5. Draw up for a heat balance sheet of trail.

Given,

Bore diameter [D] =300 mm=0.3 m,
Stroke length (l) =400 mm=0.4 m
Speed (N)=200 mm
N=100
CYCLE=4-stroke
Duration of Trail =60 min
M_f=7.05 kg
C_V=44000 KJ/kg
K=1
A_l=322 mm^2
L_i=62 mm

S=1.1 bar/mm
W_b =1324.35 N
D_b=1600 mm
M_W=495 kg
T_W=38^{0}C
T_g=300^0
M_a=311 Kg
C_{pg}=1.004 KJ/kg-K
C_w= 4.186 KJ/Kg-K
Room temperature (T_a) =20^{0}C

To find

Brake Power=?
Efficiency of mechanical=?
Indicated thermal efficiency=?
Efficiency of brake thermal efficiency=?
Heat balance sheet =?

Soln: P_{mi}=A.S/l =0.322X1.1/62 =5.71

Brake power =2πNT/60

Where, T=WxR =1324.35x0.8 =1059.480

BP =2πx200x1059.480/60
=22.189KW

Indicated power =P_{mi}x Lx Ax nx K/60
=0.885x0.4xπ/4(0.322)^{2}x100x1/60x1000 =26.9KW

Frictional power =IP-BP =26.9-22.18 =4.7 kw

Mechanical efficiency =(BP/IP)X100 =(22.18/26.9)X100 =82.49%

Indicated thermal efficiency =IPx3600/m_fxCV
=26.9x3600/7.05x44000 =0.3121x100 =31.21%

Brake thermal efficiency =BPx3600/m_fxCV
=22.189x3600/7.05x44000 =0.257x100 =25.7%

Heat balance sheet:

Heat supplied			**Heat Utilized/Spent**		
	KJ/hr	%	Heat	KJ/hr	100%
Q_S =m_f x C_V	310200.00	100.00	BP Q_g Q_W Q_{uacc}	79880.40 89410.21 78738.66 62170.73	25.75 28.82 25.38 20.05
Q_s	**310200.00**	**100.00**	**Q**	**310200.00**	**100.00**

6. In a test with a 4-cylinder 4-stroke petrol engine the following results were obtained for a particular setting and speed.

   Brake power with all cylinders working with24 KW
   Brake power 1-cylinder cut off =16.2 KW
   Brake power 2-cylinder cut off =16.7 KW
   Brake power 3-cylinder cut off =16.8 KW
   Brake power 4-cylinder cut off =17.3 KW
   Estimate the I.P of engines and its Mechanical Efficiency?

Given

Brake power : 24 KW, Brake power$_1$:16.2 KW, Brake power$_2$:16.7 KW,
Brake power$_3$:16.8 KW, Brake power$_4$:17.3 KW
Indicated power (IP_1) $=BP-BP_1$ =24-16.2 =7.8 KW
Indicated power (IP_2) $=BP-BP_2$ =24-16.7 =7.3 KW
Indicated power (IP_3) $=BP-BP_3$ =24-16.8 =7.2 KW
Indicated power (IP_4) $=BP-BP_4$ =24-17.3 =6.7 KW
Indicated power $=IP_1+IP_2+IP_3+IP_4$ =7.8+7.3+7.2+6.7 =29 KW
Mechanical Efficiency=Brake power/Indicated power =(24/29) =0.8275 =82.75%

UNIT – 5: AIR COMPRESSOR

Classification of air compressor - Reciprocating compressor - Workdone by single stage reciprocating air compressor with and without clearance volume - Efficiencies of reciprocating compressor - Multistage air compressor and inter cooling - Types of rotary air compressors (basics only) - Comparison between reciprocating and rotary air compressors.

On successful completion of this unit, students will be able to:

Course Outcomes		POs related to COs
CO5	Demonstrate the basic knowledge of an air compressor in developing the analytical models.	PO1, PO2, PO3, PO4

WEB SOURCE REFERENCES:

1	https://nptel.ac.in/courses/112106133/2
2	http://en.wikipedia.org/wiki/mechanical
3	http://en.wikipedia.org/wiki/Applied_Thermal_Engineering
4	https://www.brighthubengineering.com/thermodynamics/4125-air-standard-cycle-part-one/
5	www.sciencedirect.com
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UNIT – 5: AIR COMPRESSOR

1. **What is meant by free air delivered?**

The free air delivered is the actual volume delivered at this state pressure reduced to intake pressure and temperature and expressed in terms of m^3/min.

2. **What are the advantages of multi stage compressor with Inter cooling over single stage compressor for the same pressure ratio?**

- It improves the efficiency for the given pressure ratio.
- It reduces the leakage loss considerably.
- It gives the more uniform torque and hence, a smaller size of fly wheel is required.
- It reduces the constant of the compressor.

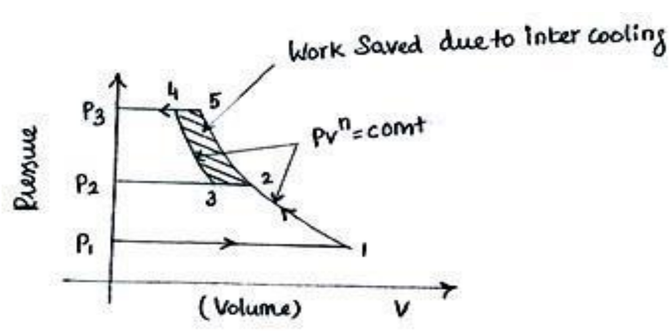
3. **Classify the various types of air compressor.**

1. According to the design and principle of operation.
   a. Reciprocating compressor b. Rotary compressor
2. According to the action.
   a. Single acting compressor b. Double acting compressor
3. According to the number of stages.
   a. Single stage compressor b. Multi stage compressor
4. According to pressure limit.
   a. Low pressure compressor b. Medium pressure compressor c. High pressure compressor
5. According to the capacity.
   a. Low capacity compressor b. Medium capacity compressor c. High capacity compressor

4. **What is meant by inter cooling?**

An inter cooler is a simple heat exchanger. It exchanges the heat of compressor air from the low pressure compressor to the circulating water before the air enters to the high pressure compressor. Purpose of inter cooling is to minimize work compression.

5. **Draw the p-v diagram of a two stage reciprocating air compressor.**



6. **Define the mechanical and isothermal efficiency of a reciprocating air compressor.**

Mechanical efficiency:

It is defined as the ratio between brake powers to the indicated power.

Efficiency = brake power / indicated power.

Isothermal efficiency:

It is defined as the ratio between isothermal works to the actual work of the compressor.

Efficiency = isothermal work / actual work

7. **How is the inter cooler used to reduce the power consumption of compressor?**

An inter cooler is a simple heat exchanger. It exchanges the heat of compressed air from the low-pressure compressor to the circulating water before the air enters to the high-pressure compressor. The purpose of inter of cooling is to minimize the work of compression.

8. **What are a slip factor and a pressure co-efficient?**

Slip factor is the ratio of whirl velocity of static pressure to tip velocity. Pressure co-efficient is the ratio of isentropic work of the compressor to the euler work (u.vw).

9. **Give the expression for work done for a two stage with perfect cooling.**

$$W = (2n / n-1)(P_1V_1)\,[(P_3/P_1)^{n-1/2n} - 1]$$

10. **Why clearance is necessary and what is its effect on the performance of reciprocating compressor?**

When piston reaches the top dead centre in the cylinder, there is a dead space between piston top and cylinder head. This space is known as clearance space and the volume occupied by this space is known as clearance volume.

11. **Discuss the effect of clearance upon the performance of an air compressor.**

The volumetric efficiency of air compressor increases with decrease in clearance of the compressor.

12. **Give two merits of rotary compressor over reciprocating compressor.**

- Rotary compressor gives uniform delivery of air
- Rotary compressors are smaller in size for the same discharge.

13. **What is the difference between complete or perfect inter cooling and incomplete or imperfect inter cooling.**

Perfect inter cooling:

When the temperature of air leaving the inter cooler is equal to the original atmospheric air temperature then the inter cooling known as perfect inter cooling.

Imperfect inter cooling:

When the temperature of air leaving the inter cooling or inter cooler is more than original atmospheric air temperature, then inter cooling is known as imperfect inter cooling

14. **Define mean effective pressure. How is it related to indicate of an IC engine?**

It is defined as the hypothetical pressure which is considered to be acting on the piston through the stroke. I.P = p_m L A N k / 60

Where, p_m = mean effective pressure L = Stroke length (mm) A = Area (mm^2)

N = Speed (rpm) k = no of cylinders

15. A single acting two stage reciprocating air compressor with complete inter cooling delivers 0.175 kg/sec of air at 16 bar. The compression and expansion follows the law pV^n= Constant. Calculate the power required to drive the compressor. Take R=0.287 kJ/kg K.

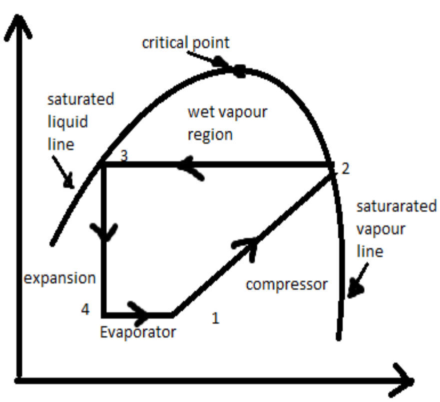
Given data

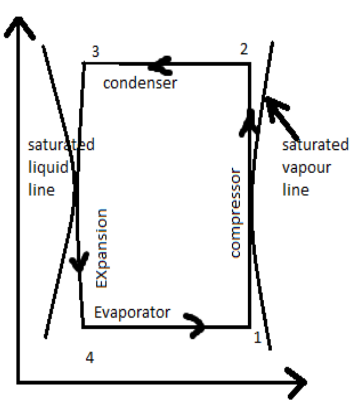
P_1=1.013 bar=1.013x10^5 N/m^2
P_3=16 bar =16x10^5 N/m^2
T_1=273 K
$W = x .(n/n-1)\ p_1v_1\ [(p_3\ /p_1)^{n-1/nx} -1]$ here
$x=2\ p_1v_1=mRT_1$
$W=2x(1.3/1.3-1)x0.175x0.287x273x((16x10^5/1.013x10^5)^{(1.3-1/1.3)x1/2}-1)$

=44.62kJ/sec ,

P=44.62kW

16. Sketch the T-s and p-h diagrams for the vapour compression cycle when the vapour after compression is dry saturated.





1. **A single stage single acting compressor delivers 15 m^3 of free air per minute from 1 bar to 8 bar. The speed of compressor is 300rpm assuming that compression and expansion follow the law $PV^{1.3}=C$ and clearance is $(1/16)^{th}$ of swept volume ,find the diameter and stroke of the compressor. Take L/D=1.5.The temperature and pressure of air at the suction are same as atmospheric air.**

   Given data:

   $V_0=15m^3/min$ $P_1=1bar=100kP_a$ $P_2=8bar=800kP_a$ N=300rpm $PV^{1.3}=C$
   N=1.3 $V_C/V_S=1/6$ L/D=1.5

Solution:

$$\eta_{vol} = 1-(v_c/ v_s)[(p_2/p_1)^{1/n}-1]$$

$$= 1-1/16[(8/1)^{1/1.3}-1]$$

$$=0.753 = 75.3 \%$$

w.k.t, $V_a = V_s \times \eta_{vol} \times 300$

$15 = V_s \times 0.753 \times 300$

$V_s = 0.0664\ m^3$

$v_s = (\pi/4)D^2 \times L = 0.0664$

$(\pi/4)D^2 \times 1.5D=0.0664$

$D=0.3834\ m$

L/D=1.5

L=1.5 ×D

=1.5 ×0.3834

= 0.5751 m

2. A 2kg/s of air enters the LP cylinder of two stage compressor. The overall pressure ratio is 9:1. The air at inlet to the compressor is 100kpa and 35°C. The index of compression in each cylinder is 1.3. Find the inter cooler pressure for perfect inter cooling. Also find the minimum power required and % power saved over single stage compression.

Given data: $m = 2kg/s$ $p_3 / p_1 = 9$

$p_1 = 100kpa$

$p_3 = 900kpa$

$T_1 = 35^0C + 273 = 308k$

$n = 1.3$

Solution:

w.k.t, Inter cooler pressure $p_2 = \sqrt{p_3\ p_1} = \sqrt{(100 \times 900)} = 300kpa$

Work done for x no. of stage

$W = xn/n\text{-}1\ p_1v_1\ [(p_x + 1/p_1)^{n-1/nx} - 1]$ here x=2

$= 2(1.3)/1.3\text{-}1 \times 2 \times 0.287 \times 308\ [(9)^{1.3-1/2\times1.3} - 1]$

Power, $P_1 = 442.13$ kW

Work done for single stage

$W = n / n\text{-}1\ p_1v_1\ [(p_2 / p_1)^{n-1/n} - 1]$ $W = n / n\text{-}1\ mRT_1\ [(p_2 / p_1)^{n-1/n} - 1]$

$= 1.3 / 1.3 - 1 \times 2 \times 0.287 \times 308\ [(9)^{1.3-1/1.3} - 1]$

$= 505.9$ kJ/s

Power, $P_2 = 505.9$ kW

Saving in power = 505.9 – 442.13 = 3.77kW

% of saving in power = $p_2\text{-}p_1/p_2$ = 63.77/505.9 = 12.6%

3. A three stage air compressor delivers 5.2m³ of free air /minute. The suction pressure and temperature are 1bar and 30⁰C. The pressure and temperature are 1.03bar and 20⁰C at free air condition. The air is cooled at 30⁰C after each stage of compression. The delivery pressure of the compressor is 150bar.The R.P.M of the compressor is 300.The clearances of L.P, I.P, and H.P cylinders are 5% of the respective strokes. The index of compression and re-expansion in all stages is 1.35.Neglecting pressure losses, find the B.P of the motor required to run the compressor if the mechanical efficiency is 80%.

Given data:

$V_0=V_a=5.2\ m^{3}/min$ $P_1=1\ bar=100\ kpa$ $P_0=1.03\ bar=103\ kpa$ $T_0=20^0C=20+273=293\ K$

$T_1=T_2=T_3=T_4=30^0C=303\ K$ $P_4=150\ bar=15000\ kpa$ $N=300\ rpm$ $C = 5\% = 0.08,$

$\eta_{mech} = 80\% = 0.08$

Solution: Inter cooler pressure, $p_2/p_1 = (p_4/p_1)^{1/3} = (150/1)^{1/3}$

$p_2/p_1 = 5.31$

$p_2/p_1 = p_3/p_2 = p_4/p_3 = 5.31$

w.k.t, $v_a = 5.2\ m^3/min = 5.2/60 = 0.0867\ m^3/sec$

Then, $p_0v_0 / T_0 = p_1v_{a1} / T_1$

$103 \times 0.0867 / 293 = 100 \times v_{a1} / 303$

$v_{a1} = 0.0923\ m^3/sec$

Similarly,

$p_0v_0 / T_0 = p_2v_{a2} / T_2$

$103 \times 0.0867 / 293 = 531 \times v_{a2} / 303$

$v_{a2} = 0.0174\ m^3/sec$

$p_0v_0 / T_0 = p_3v_{a3} / T_3$

Similarly,

$103 \times 0.0867 / 293 = 2819.61 \times v_{a3} / 303$

$v_{a3} = 0.00328\ m^3/sec$

Work done on the compressor,

$W = n / n\text{-}1\ p_1va_1 [(p_2 / p_1)^{n-1/n} – 1] + n / n\text{-}1\ p_2va_2 [(p_3 / p_2)^{n-1/n} – 1] + n / n\text{-}1\ p_3va_3 [(p_4 / p_3)^{n-1/n} – 1]$

$W = 1.35/1.35\text{-}1 \times 103 \times 0.0923 [(5.31)^{1.35-1/1.35} – 1] + 1.35/1.35\text{-}1 \times 531 \times 0.0174 [(5.31)^{1.35-1/1.35} – 1] + 1.35/1.35\text{-}1 \times 2819.61 \times 0.00328 [(5.31)^{1.35-1/1.35} – 1]$

IP = 57.91 kW

$\eta_{mech} = BP/IP$

$BP = \eta_{mech} \times IP = 0.8 \times 57.91$

Brake power of motor, BP = 46.33 Kw

4. A single cylinder, single stage air compressor has cylinder diameter 160mm and stroke length 300mm. It draws the air into its cylinder at a pressure of 100kpa at 27°C. The air then compressed to a pressure of 650kpa. If the compressor runs at a speed of 2rev/s, determine a) Mass of air compressed per cycle, b) Work required per cycle and c) Power required to derive the compressor in kW Assume the compression process follows pv = constant.

Given data:

$D = 160mm = 0.16m$

$L = 300mm = 0.3m$ $p_1 = 100kpa$

$T_1 = 27 + 273 = 300 K$

$P_2 = 650kpa$

$N = 2 rev/s$

$pv^Y = c; Y=1.4$

Solution:

Work done during isothermal compression

$W = mRT_1 \ln (p_2 / p_1)$

$W = p_1v_1 \ln (p_2 / p_1)$

w.k.t,

$v_1 = \pi/4 D^2L$

$= \pi/4 (0.16)^2(0.3)$

$= 6.03 \times 10^{-3}m^3$

Substituting v_1 in work done equation

$W = p_1v_1 \ln (p_2 / p_1)$

$= 100 \times 6.03 \times 10^{-3} \times \ln (650 / 100)$

$= 1.13$ kJ

Power, $P = W \times N / 60$

$= (1.13 \times 120) / 60$

$= 2.26$ kW

w.k.t,

$p_1v_1 = mRT_1$

$m = (100 \times 6.03\times10^{-3}) / (0.287 \times 300)$

$= 0.007$kg

5. A single cylinder, single acting reciprocating air compressor with a bar of 12cm, and stroke of 16cm runs at 410rpm. At the beginning of compression, the pressure and temperature in the cylinder are 0.98bar and 40°C. The delivery pressure is 6bar. The index of compression is 1.32. The clearance is 6% of stroke volume. Determine the volume of air delivered referred to 1bar and 20°C. What is the compressor power required?

Given data:

$D = 12cm = 0.12m$ $L = 16cm = 0.16m$ $N = 410rpm$ $p_1 = 0.98bar = 98kpa$

$T_1 = 40 + 273 = 313K$ $p_2 = 6bar = 600kpa$ $n = 1.32$

$v_c = 6\%v_s = 0.06v_s$ $p_0 = 1bar = 100kpa$ $T_0 = 20 + 273 = 293K$

Solution:

w.k.t,

$v_s = \pi/4\ D^2L = \pi/4\ (0.12)^2(0.16) = 0.0018\ m^3$

w.k.t,

$v_1 = v_c + v_s = 0.06\ v_s + v_s = 1.06\ v_s = 1.06 \times 0.0018 = 1.908 \times 10^{-3}\ m^3$

Work done on the single stage compressor with clearance volume.

$W = n / n\text{-}1\ p_1\ v_a\ [(p_2 / p_1)^{n-1/n} - 1]$

w.k.t,

$p_3\ v_3^n = p_4\ v_4^n$

$(v_4/v_3)^n = p_3/v_3 = p_2/v_1$

$(v_4/v_3)^n = p_2/v_1$

$v_4/v_c = (p_2/p_2)^{1/n}$

$v_4 = v_c \times (p_2/p_2)^{1/n}$

$= 0.06 \times 0.0018\ (600/98)^{1/1.32} = 4.26 \times 10^{-4} m^3$

w.k.t, $v_a = v_1 - v_4$

$= 1.908 \times 10^{-3} - 4.26 \times 10^{-4} = 0.00148\ m^3$

Substituting v_a value in work done equation.

$W = 1.32 / 1.32\text{-}1 \times 98 \times 0.00148\ [(600 / 98)^{1.32-1/1.32} - 1]$

$= 0.329$ kJ Power, $P = W \times V / 60 = (0.329 \times 410)/60$

$= 2.25$ kW

w.k.t,

$p_0v_0/T_0 = p_2v_d/T_2$

$v_0 = T_0/p_0 \times p_2v_d/T_2$………….. (1)

w.k.t,

$T_2/T_1 = [p_2 / p_1]^{n-1/n}$

$T_2 = [p_2 / p_1]^{n-1/n} \times T_1 = 313 \times (600/98)^{1.32-1/1.32} = 485.6\ K$

$p_1\ v_1^n = p_2\ v^n$

$v_2 = v_1 \times (p_1/p_2)^{1/n}$

$= 1.908 \times 10^{-3} \times (98/600)^{1/1.32}$

$= 0.00048\ m^3$

w.k.t, $v_d = v_2 - v_3$

$= 0.00048 - 0.06 \times 0.0018 \Longrightarrow 0.000372\ m^3$

Substituting T_0, p_0, p_2, T_2, and v_d in (1)

$v_0 = (293/100) \times (600/485.6) \times 0.00037 = 0.0013\ m^3$

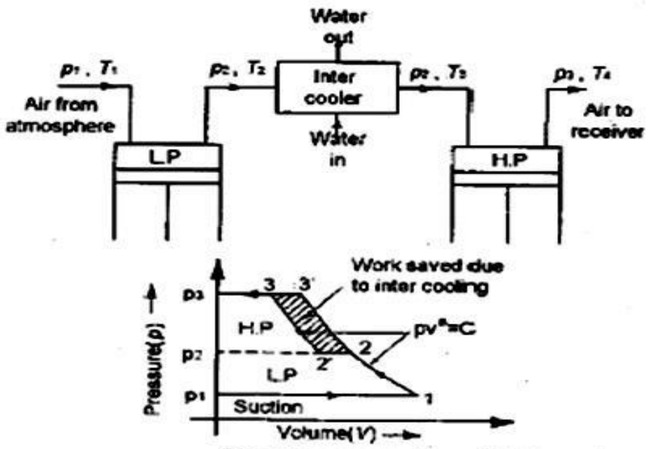
6. **Explain the construction and working principle of Multi stage compressor and discuss the perfect and in-perfect inter-cooling with neat sketch.**

Assumptions Made In Multistage Compression

1. Suction and delivery pressures remain constant during each stage.
2. The index of compression is same in each stage
3. The inter cooling in each stage is at constant temperature.
4. The mass of air handled by the low pressure and high-pressure cylinders are same.

Advantages of Multistage Air Compressor

1. Work done per kg of air is reduced in multistage compression with intercooler compared to single stage compression for same delivery pressure.
2. Better mechanical balance can be achieved with multistage compressors.
3. It reduces the leakage loss considerably.
4. Volumetric efficiency is improved by increasing number of stag
5. It gives more uniform torque, and hence a smaller size flywheel required.
6. Lower operating temperature permits the use of cheaper in for construction.
7. Better lubrication due to the lesser working temperature.



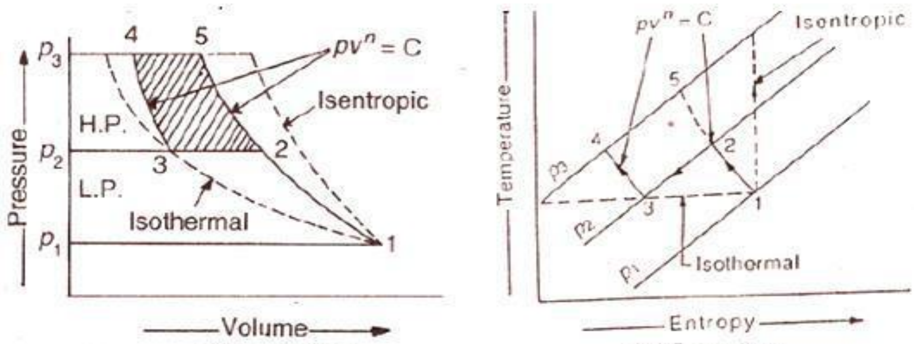
Two stage compression with inter cooler

<u>Intercooling of air in a two-stage reciprocating air compressor:</u>

Efficiency of the intercooler plays an important role in the working of a two-stage reciprocating air compress. Following two types of intercooling are important from the subject point of view:

1. Complete or perfect intercooling:

When the temperature of the air leaving the intercooler (i.e. T_3) is equal to the original atmospheric air temperature (i.e. T_1) then the intercooling is known as complete or perfect intercooling. In this case, the point 3 lies on the isothermal curve as shown in

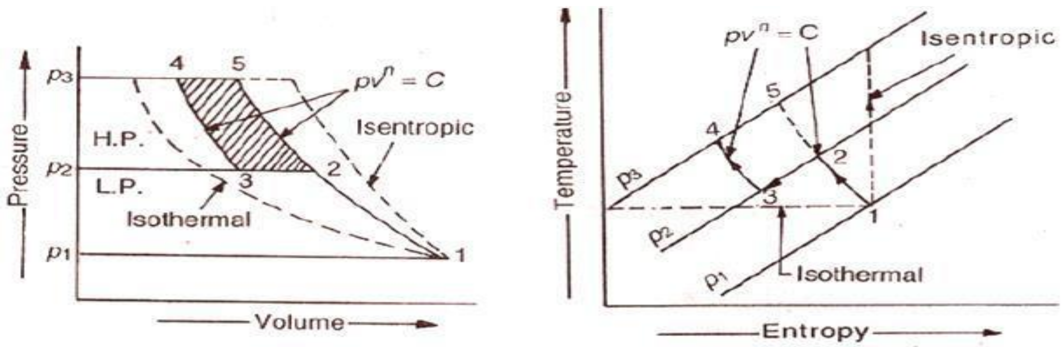


(a) p-v diagram. (b) T-s diagram.

:

2. Incomplete or imperfect intercooling:

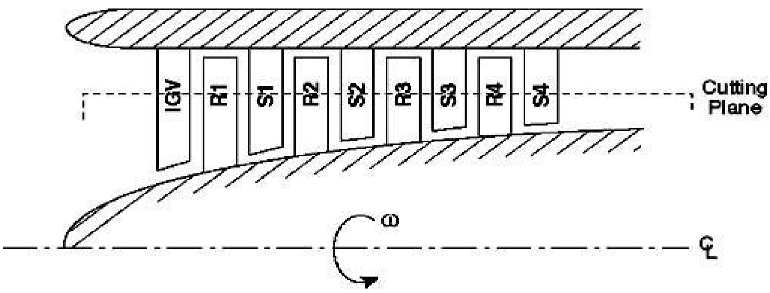
When the temperature of the air leaves the intercooler (i.e. T_3) is more than the original atmospheric air temperature (i.e. T_1), then the intercooling is known as incomplete or imperfect intercooling. In this case, the point 3 lies on the right side of the isothermal curve as shown in below figure:



(a) p-v diagram (b) T-s diagram

7. Explain the working principle of axial flow compressor.

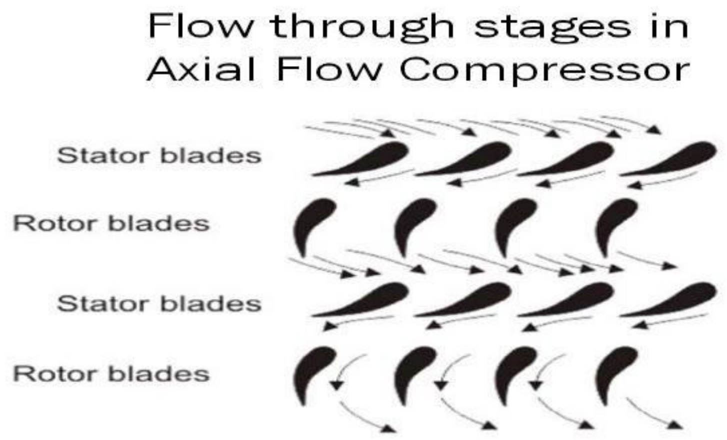
Axial compressors are rotating, aerofoil based compressors in which the working fluid principally flows parallel to the axis of rotation. This is in contrast with centrifugal, axi-Centrifugal and mixed –flow compressors where the air may enter axially but will have a significant radial component on exit.



Axial Flow Compressors– Basic Operation

- Axial flow compressor is capable of higher pressure ratio on a single shaft.
- The energy transfer in a single stage is very limited.
- But ease of combining axial flow stages leads to pressure ratios of upto 6/1 or higher
- Thus axial flow compressor is considered as consisting of many stages

- Single stage is considered as a fan
- For most aircraft & industrial gas turbine, axial flow compressor is used



FACULTY INCHARGE
Mr.R.SATHEESH
Asso.Prof.,
Dept. of Mechanical Engg.