KEMENTERIAN PENGAJIAN TINGGI

POLITEKNIK MALAYSIA PORT DICKSON

Internal Combustion Engine

VOLUME 1

Mohd Firdaus Bin Abu Bakar
Mohd Izad Affendy Bin Mohd Yusof

POLITEKNIK
MALAYSIA
PORT DICKSON

INTERNAL COMBUSTION ENGINE (VOLUME 1)

Perpustakaan Negara Malaysia Cataloguing-in-Publication Data

Mohd. Firdaus Abu Bakar, 1987-
INTERNAL COMBUSTION ENGINE. (Volume 1) / Mohd Firdaus Bin Abu Bakar, Mohd Izad Affendy Bin Mohd Yusof.
Mode of Access: Internet
eISBN 978-967-2897-61-3
1. Combustion engineering.
2. Engines.
3. Government publications--Malaysia.
4. Electronic books.
I. Mohd. Izad Affendy Mohd. Yusof, 1987-.
II. Title.
621.4023

PUBLISHED BY:
Politeknik Port Dickson
KM14, Jalan Pantai, 71050 Si Rusa
Port Dickson, Negeri Sembilan

OCTOBER 2022

Acknowledgement

PATRON
Dr. Ishak Bin Mohamad
Director, Politeknik Port Dickson

ADVISORS
Abd Rahim Bin Ibrahim
Deputy Director (Academy), Politeknik Port Dickson
Khairun Syatirin Bin Md Salleh
Head of Mechanical Engineering Department, Politeknik Port Dickson

EDITOR
Mohd Nahar Bin Ahmad
Mechanical Engineering Department, Politeknik Port Dickson

FASILITATOR
Nin Hayati Bin Mohd Yusof
Ragunathan A/L Jayaraman
Che Azlina Bin Che Norohoseni

WRITERS
Mohd Firdaus BIn Abu Bakar
Mohd Izad Affendy Bin Mohd Yusof

We would like to convey our utmost gratitude to the Department of Polytechnic and Community College Education praticulary the E-learning and Instructional Division (BIPD) for funding our e-book project and this is our original module. If there is any, credit are mentioned accordingly in this the ebook.

Preface

The internal combustion engine e-book covers a topic such as types of engines, engine process analysis, combustion process, engine criterions and comparison, as well as various engine parts and their function. This course is compulsory for all student who takes an automotive engineering course in all Polytechnics.

The content in this e-book are relevant to the syllabus which has been made by Curriculum Division, Department of Polytechnic and Community College Education (DPCCE) and all of information in this e-book is suitable for all automotive engineering student as their reference in their studies.

Hopefully by the publication of this e-book make students more understand especially in internal combustion engine concept.

Table of Content

Table of Content

List of Figure

List of Figure

List of Figure

List of Table

List of Table

CHAPTER 1

TYPE OF ENGINES

TYPES OF ENGINE

Engine Classification

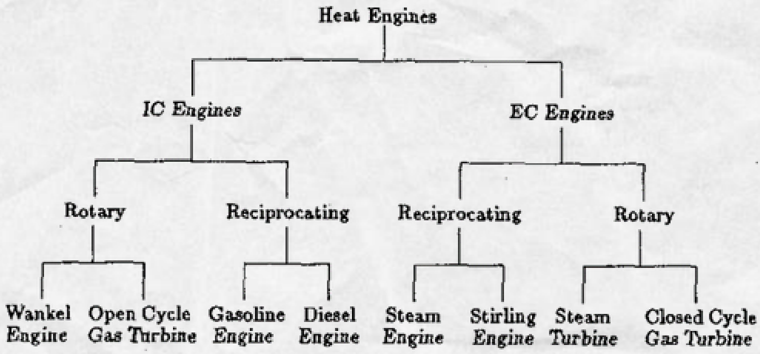


Figure 1.1 : Classification of engine

Definition of engine

A change of form of energy to the other form is called an engine

Internal Combustion Engine

Air fuel (A/F) mixture which induce during intake process was combust inside the combustion chamber. Example: Gasoline Engine, Diesel Engine, Wankel Engine and Gas Turbine Engine

External Combustion Engine

Combustion take place outside the combustion chamber. Example: Stirling Engine, Steam Engine

TYPES OF ENGINE

Types of Ignition

a) Spark Ignition or SI – Gasoline or Petrol Engine

b) Compression Ignition or CI – Diesel Engine

Spark Ignition or SI Engine

a) The combustion is started by a spark created by a spark plug .

b) The A/F was ignite by a spark which is produce from the spark plug electrode (high voltage)

Compression Ignition or CI Engine

The combustion is happen due to high temperature and high pressure inside the combustion chamber (CC) and make the A/F mixture self-ignites

Engine Operation Principle

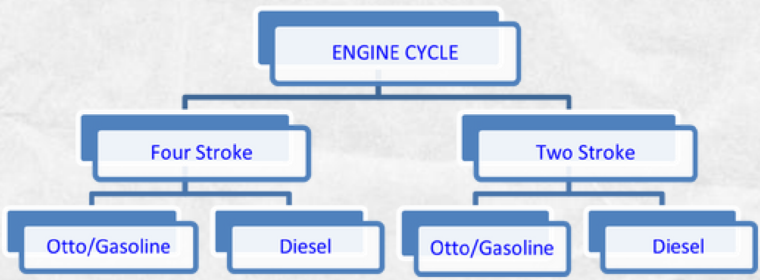


Figure 1.2 : Engine Operation

TYPES OF ENGINE

Two Stroke Engine

The two stroke engine was only moved from bottom dead center (BDC) to top dead center (TDC) to complete the stroke of the piston (one revolution of crankshaft)

Basically, this kind of engine consist:

a)Intake
b)Compression
c)Power
d)Exhaust

The intake and compression stroke is done in one process and the power and exhaust stroke is done one process. That is why it is called 2-stroke engine.

Two stroke engine can be categorized into:

a. Spark Ignition (SI)
b. Compression Ignition (CI)

TYPES OF ENGINE

Two Stroke Engine (SI engine)

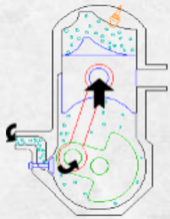
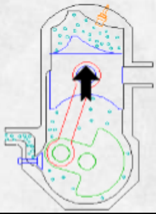
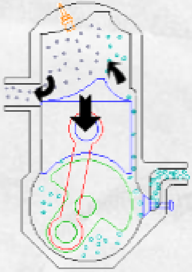
Table 1.1 : Two-Stroke (SI) Engine Process

PROCESS	DISCRIPTION
Intake/ Induction	a. The A/F mixture is coming into the crankcase cause by the vacuum created b. Piston move from BDC to TDC
Compression	a. The piston move from BDC to TDC and make the A/F compress
Power	a. Then, a spark form spark plug will ignites the A/F mixture. b. The piston will move down form TDC to BDC
Transfer / Exhaust	a. The exhaust gas will going out from the cylinder by an exhaust port which is open due to piston move form TDC to BDC

TYPES OF ENGINE

Two Stroke Engine (SI engine)

Table 1.2 : Diagram of two-Stroke (SI) Engine Process

STROKE	DIAGRAM	CRANK ROTATION
Intake/ Induction		One Revolution
Compression		
Power		
Transfer / Exhaust		

TYPES OF ENGINE

Two Stroke Engine (CI engine)

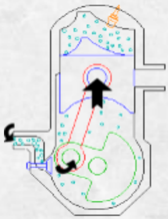
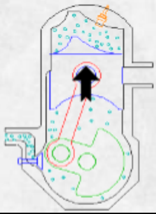
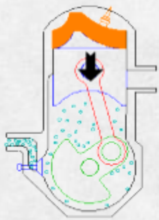
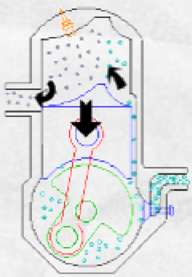
Table 1.3 : Two-Stroke (CI) Engine Process

PROCESS	DISCRIPTION
Intake/ Induction	a. 100% of air is coming into the crankcase cause by the vacuum created b. Piston move from BDC to TDC
Compression	a. The piston move from BDC to TDC and make the 100% of air compressed b. Piston move form BDC to TDC
Power	a. Because of a high pressure and high temperature, the fuel mixture is self-ignites b. Piston move from TDC to BDC
Transfer / Exhaust	a. The exhaust gas will going out from the cylinder by an exhaust port which is open due to piston move form TDC to BDC

TYPES OF ENGINE

Two Stroke Engine (CI engine)

Table 1.4 : Diagram of two-Stroke (CI) Engine Process

STROKE	DIAGRAM	CRANK ROTATION
Intake/ Induction		One Revolution
Compression		
Power		
Transfer / Exhaust		

TYPES OF ENGINE

Advantage and Disadvantages of Two Stroke Engine

Advantages:
a)Produce more power compare to four stroke engine
b)Lighter
c)Simple construction

Disadvantages:
a)Terrible polluters
b)Inefficient fuel consumption

TYPES OF ENGINE

Four Stroke Engine

There is two types of four-stroke engine:
a) Spark Ignition
b) Compression Ignition

Same as two stroke engine, this four stroke consist of:
a)Intake
b)Compression
c)Power
d)Exhaust

Two revolution of crankshaft will complete all stroke as stated above.

TYPES OF ENGINE

Four Stroke Engine (SI engine)

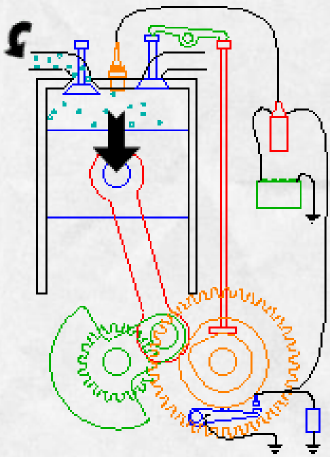
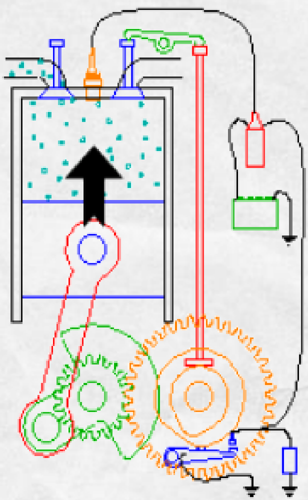
Table 1.5 : Four-Stroke (SI) Engine Process

PROCESS	DISCRIPTION
Intake	a. Air fuel (A/F) mixture induce inside the combustion chamber (CC) b. Intake valve opened while exhaust valve closed. c. The piston moved from TDC to BDC
Compression	a. The piston moved from BDC to TDC b. Due to piston movement, the A/F mixture was compressed c. All valve closed
Power	a. Then, a spark form spark plug will ignites the A/F mixture. b. The piston moved form TDC to BDC c. All valves closed
Exhaust	a. The exhaust gas will going out from the cylinder b. Exhaust valve opened while intake valve closed. c. The piston moved from BDC to TDC

TYPES OF ENGINE

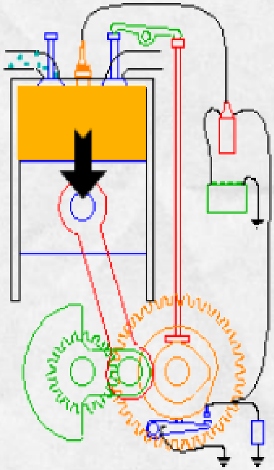
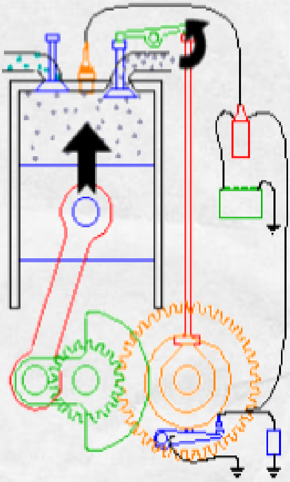
Four Stroke Engine (SI engine)

Table 1.6 : Diagram of four-stroke (SI) Engine Process

STROKE	DIAGRAM	CRANK ROTATION
Intake		One Revolution
Compression		

TYPES OF ENGINE

Four Stroke Engine (SI engine)

STROKE	DIAGRAM	CRANK ROTATION
Power		Two Revolution
Exhaust		

TYPES OF ENGINE

Four Stroke Engine (CI engine)

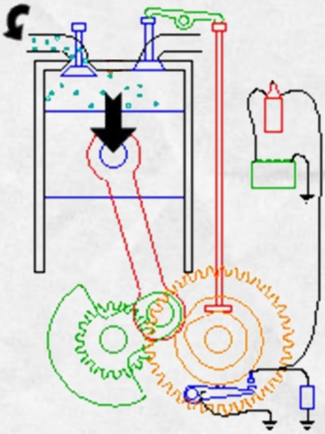
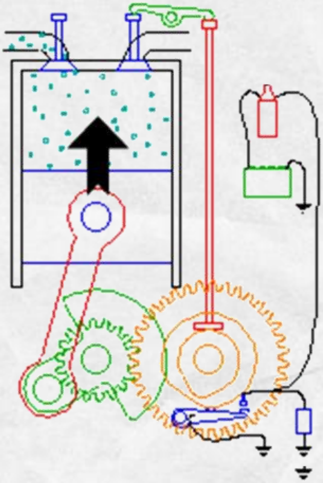
Table 1.7 : Four-Stroke (CI) Engine Process

PROCESS	DISCRIPTION
Intake	a. Only 100% air is coming inside the combustion chamber (CC) b. Intake valve opened while exhaust valve closed. c. The piston moved from TDC to BDC
Compression	a. The piston moved from BDC to TDC b. Due to piston movement, 100% of air was compressed c. At the end of compression, the fuel injector will inject diesel into the CC d. All valve closed
Power	a. Because of a high pressure and high temperature, the fuel mixture is self-ignites b. Piston move from TDC to BDC c. All valve closed
Exhaust	a. The exhaust gas will going out from the cylinder b. Exhaust valve opened while intake valve closed. c. The piston moved from BDC to TDC

TYPES OF ENGINE

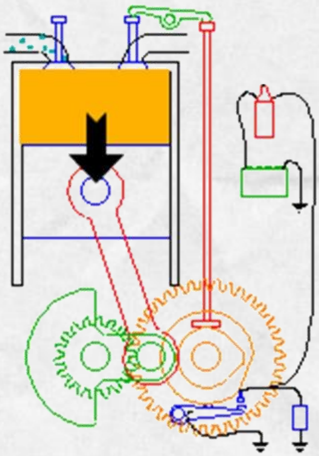
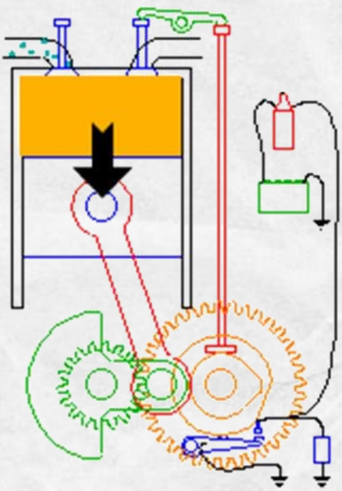
Four Stroke Engine (CI engine)

Table 1.8 : Diagram of four-stroke (CI) Engine Process

STROKE	DIAGRAM	CRANK ROTATION
Intake		One Revolution
Compression		

TYPES OF ENGINE

Four Stroke Engine (CI engine)

STROKE	DIAGRAM	CRANK ROTATION
Power		Two Revolution
Exhaust		

TYPES OF ENGINE

Four Stroke Engine (CI engine)

Characteristics of CI Engine

a. No carburetor, no electrical ignition system only fuel injection component such as fuel injector pump
b. 100% of air is coming into the cylinder
c. Temperature is increased during compression
d. Fuel in the form of mist is injected into the compressed air at a high temperature, and the fuel is burnt.
e. Due to high pressure needs, the fuel must use pump to inject the fuel into the combustion chamber.
f. 21:1 is the compression ratio, while 5000 kPa pressure was produce (end of compressoion)

TYPES OF ENGINE

Comparison between two stroke engine and four stroke engine

Table 1.9 : Comparison between 2-stroke engine and 4-stroke engine

Two Stroke Engine	Four Stroke Engine
One revolution of the crankshaft will complete all stroke	Two revolution of the crankshaft will complete all stroke
A lighter flywheel can be used.	A heavier flywheel is needed.
Engine is lighter and more compact.	Engine is heavier and bulkier.
Greater cooling and lubrication requirements due to higher rate of wear and tear.	Lesser cooling and lubrication requirements due to Lower rate of wear and tear.

TYPES OF ENGINE

Comparison between two stroke engine and four stroke engine

Two Stroke Engine	Four Stroke Engine
Only has a ports (no valves)	Contains intake and exhaust valves
The initial cost of the engine is less.	The initial cost of the engine is more.
Low volumetric efficiency	Higher volumetric efficiency
Lower thermal efficiency	Higher thermal efficiency

TYPES OF ENGINE

Wankel engine

1. Engine used triangular rotor which have three equal working spaces.
2. There is no component of petrol or diesel engine such as camshaft, piston, rocker arms and valves
3. One revolution of triangular rotor will complete all four-stroke

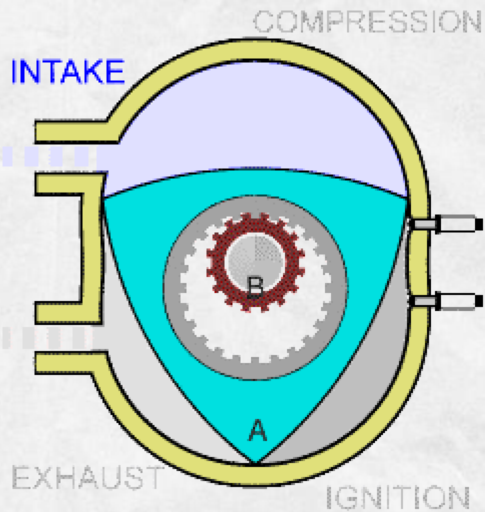


Figure 1.3: Rotary engine (Wankel)

Wankel engine process

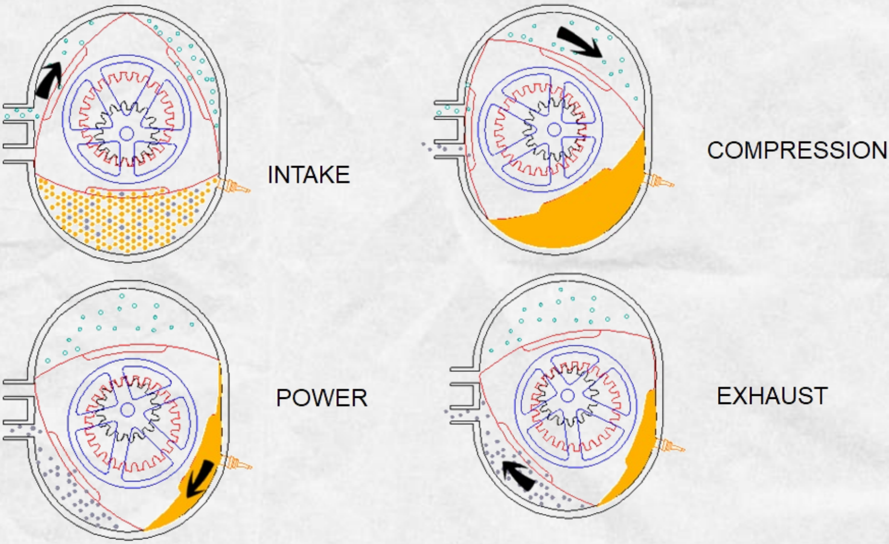


Figure 1.4: Wankel engine process

TYPES OF ENGINE

Advantages and Disadvantages of Wankel engine

Advantages

a. Lighter in weight and compact
b. Smaller in size
c. Lower vibration due to continuous rotation of rotor
d. Produces higher power compared to piston engine
e. Higher reliability

Disadvantages

a. More fuel consumption
b. Higher carbon monoxide (CO) emissions
c. Higher manufacturing costs
d. Harder to meet US emissions
e. Low compression ratio

TYPES OF ENGINE

Stirling Engine

Main Components

a. Piston
b. Displacer
c. Flywheel
d. Burner

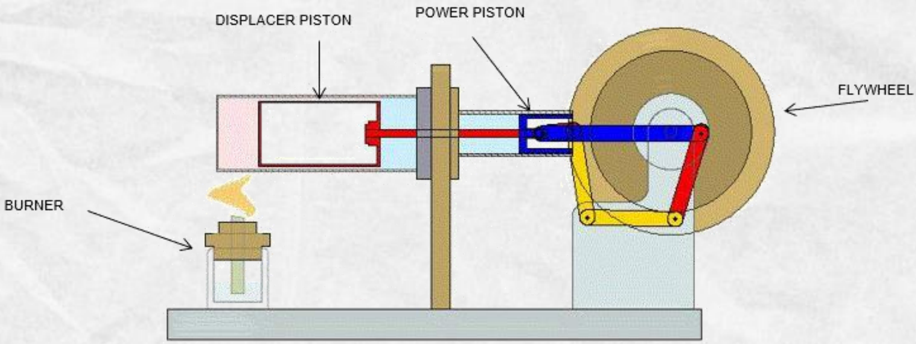


Figure 1.5 : Stirling engine components

Operating of Stirling Engine

a. A burner was use at the top of piston to make it hot (red colour) while the blue colour was the side which is cooled.
b. Then, the piston will move to the cool side after the gas heated
c. After that, the air move back to the hot area and this will continuous as long as the burner was still have a flame.

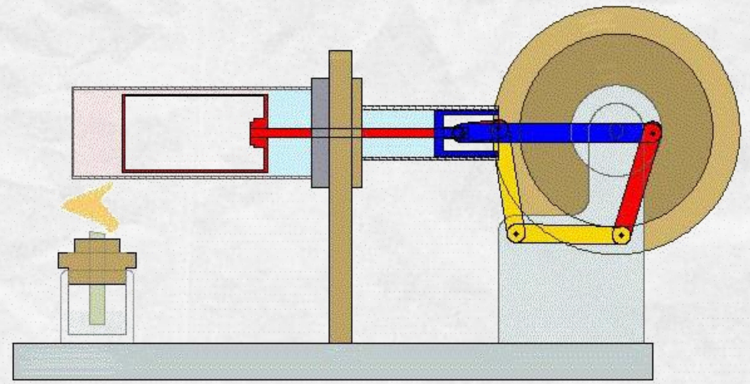


Figure 1.6 : Stirling engine configuration

TYPES OF ENGINE

Natural Aspirated Engine (N/A)

Normal engine, no turbocharged or supercharged

Air fuel (A/F) was coming inside the combustion chamber (CC) because of a vacuum created inside the CC.

Turbocharged and a supercharged engine is a force engine which forced more air coming inside the CC

Figure 1.7 : N/A engine

TYPES OF ENGINE

Advantages and Disadvantages of N/A engine

Table 1.10 : Advantages and disadvantages of N/A engine

Advantages	Disadvantages
a. Easier maintenance	a. Lower efficiency
b. Lower production and development costs	b. Lower power to weight ratio
c. Higher reliability	c. Small potential for tuning
d. Direct throttle response	

TYPES OF ENGINE

Tutorial

1. A. List Four (4) characteristic of CI engine.
   B. Describe the difference between spark ignition and compression ignition.
   C. By using the aid of a diagram, explain the operation of four stroke SI engine

2. A. Describe the meaning of Compression Ignition (CI) engine
   B. Compare the difference between 4-stroke and 2-stroke engine

.

CHAPTER 2

ENGINE PROCESS ANALYSIS

ENGINE PROCESS ANALYSIS

AIR STANDARD CYCLE

a. The air standard cycle is a cycle followed by a heat engine which uses air as the working medium. Since the air standard analysis is the simplest and most idealistic, such cycles are also called ideal cycles and the engine running on such cycles are called ideal engine.

b. The actual gas power cycles are rather complex. To reduce the analysis to a manageable level, an air standard cycle is based on the following assumptions:

    i. The working fluid is air, which continuously circulates in a closed loop and always behave as an ideal gas

    ii. All processes, of which the cycles are made up, are internally reversible processes.

    iii. The combustion process is replaced by a heat-addition process from an external source.

    iv. The exhaust process is replaced by a heat-rejection process that restores the working fluid to its initial state.

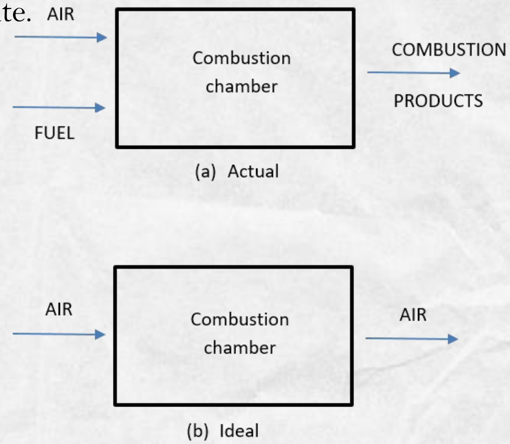


Figure 2.1: The combustion process in ideal cycles

ENGINE PROCESS ANALYSIS

RECIPROCATING ENGINE

The reciprocating engine is common use for a vehicle because it very versatile and have wide range of application. Common to most reciprocating engines is a linkage known as a crank-slider mechanism. This mechanism is one of several capable of producing the straight-line, backward-and-forward motion

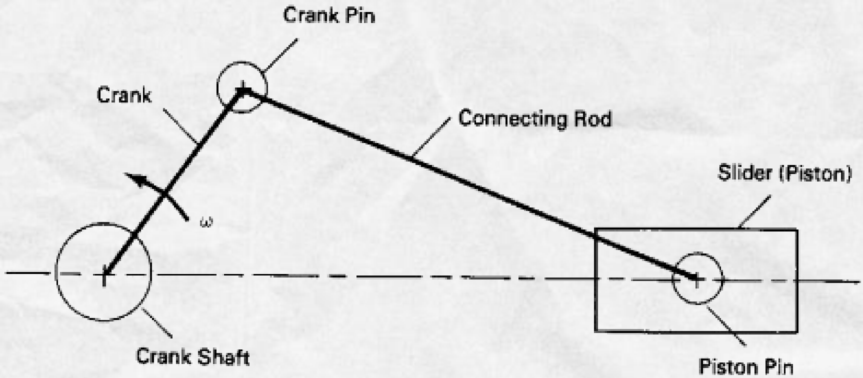


Figure 2.2: Reciprocating concept

The piston reciprocates in the cylinder between two fixed position called the top dead center (TDC) and the bottom dead center (BDC). Stroke of the engine is a movement of the piston between TDC and BDC. The diameter of the piston is called bore. The air or air-fuel mixture is drawn into the cylinder through the intake valve, and the combustion products are expelled from the cylinder through the exhaust valve (fig 2.3).

ENGINE PROCESS ANALYSIS

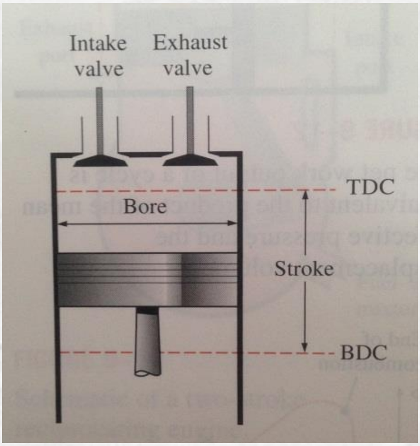


Figure 2.3: Nomenclature of reciprocating engine

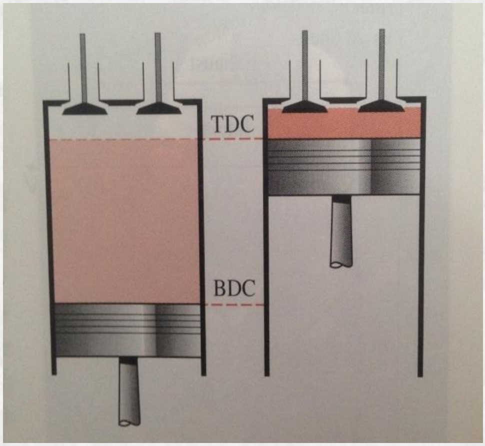


Figure 2.4: Displacement and clearance volume

The minimum volume formed in the cylinder when the piston is at TDC is called the clearance volume while the displacement volume is a volume displace by a piston as it moves between TDC and BDC (fig 2.4). The ratio between maximum volumes to the minimum volume is called compression ratio, r.

$$r = \frac{V_{max}}{V_{min}} = \frac{V_{BDC}}{V_{TDC}}$$

Mean effective pressure (MEP) is a fictitious pressure. If it acted on the piston during the entire power stroke, would produce the same amount of net work as that produced during the actual cycle (fig 2.5).

ENGINE PROCESS ANALYSIS

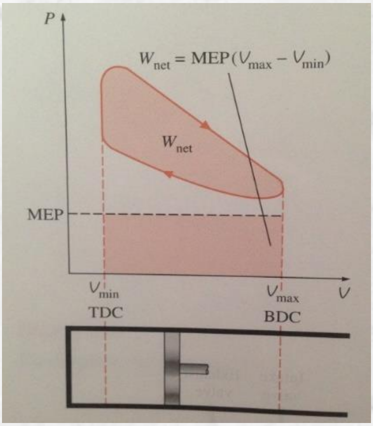


Figure 2.5: The Wnet is same with the Mean Effective Pressure (MEP)

Wnet=MEP x piston area x stroke=MEP x displacement volume

or

$$MEP = \frac{W_{net}}{V_{max} - V_{min}} = \frac{w_{net}}{v_{max} - v_{min}}$$

ENGINE PROCESS ANALYSIS

OTTO CYCLE FOR SI ENGINE

The Otto cycle is the ideal cycle for spark ignition engines. In most spark ignition engines, the pistons execute four complete strokes within the cylinder, and the crankshaft completes two revolutions for each thermodynamics cycle. This engine are called four-stroke internal combustion engine.

The Otto cycle is the ideal air standard cycle for the petrol engine, the gas engine, and the high-speed oil engine. Figure 2.6 below shown that the work available from the cycle equal enclosed area of p-v diagram.

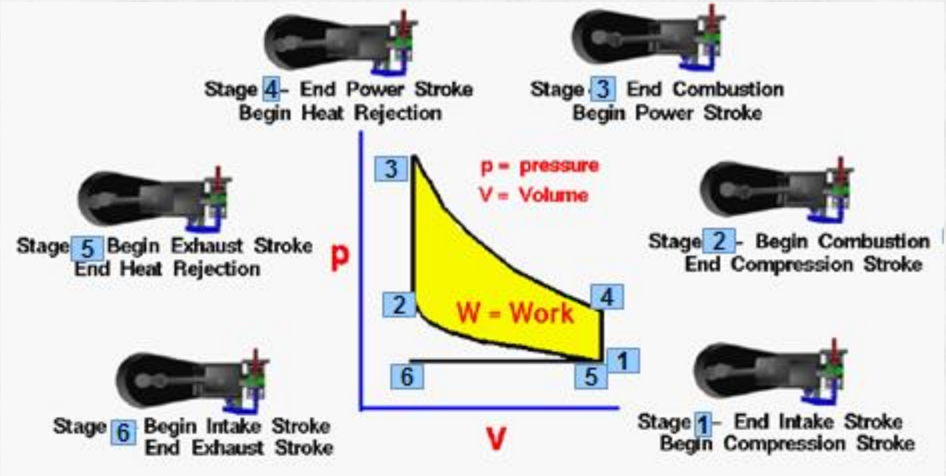
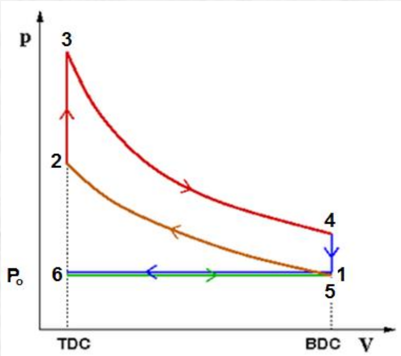


Figure 2.6: The p-v diagram of Otto Cycle

ENGINE PROCESS ANALYSIS

Analysis for Otto Cycle



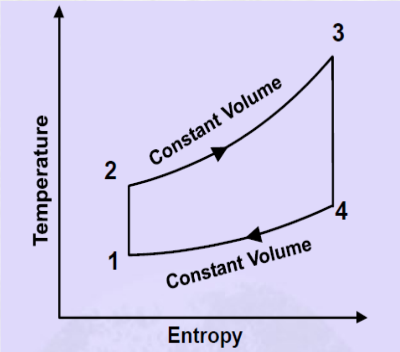


Figure 2.7: Comparison between P-V diagram and T-S diagram of Otto Cycle

Process 6 -1 – Constant pressure intake of air at Po. Intake valve open and Exhaust valve closed

$$P_1 = P_6 = P_0$$
$$W_{6-1} = P_0(V_1 - V_6)$$

Process 1 -2 – Isentropic compression Stroke All valve closed

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

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

ENGINE PROCESS ANALYSIS

Process 2 -3 – Constant Volume heat input (Combustion)-All valve closed

$$V_3 = V_2 = V_{TDC}$$

$$Q_{2-3} = Q_{in} = m_m c_v (T_3 - T_2)$$

Process 3-4 – Isentropic power or expansion stroke- All valve close

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

$$\frac{P_4}{P_3} = \left(\frac{V_3}{V_4}\right)^{\gamma} = \left(\frac{1}{r_v}\right)^{\gamma}$$

Process 4 -5 – Constant Volume heat rejection. Exhaust valve open and intake valve closed

$$V_4 = V_5 = V_1 = V_{BDC}$$

$$Q_{4-5} = Q_{out} = m_m c_v (T_5 - T_4) = m_m c_v (T_1 - T_4)$$

Process 5-6 – Constant Pressure exhaust stroke at Po- Exhaust valve open intake valve closed

$$P_5 = P_6 = P_o$$

$$W_{5-6} = P_o (V_6 - V_5) = P_o (V_6 - V_1)$$

ENGINE PROCESS ANALYSIS

Thermal Efficiency of Otto cycle

$$\eta_{otto} = \left(\frac{Q_{in} - Q_{out}}{Q_{in}}\right) = \left(\frac{W_{nett}}{Q_{in}}\right) = 1 - \left(\frac{Q_{out}}{Q_{in}}\right)$$

$$= 1 - \left(\frac{m_m C_v (T_4 - T_1)}{m_m C_v (T_3 - T_2)}\right)$$

$$= 1 - \left(\frac{(T_4 - T_1)}{(T_3 - T_2)}\right)$$

$$= 1 - \left(\frac{(T_4 - T_1)}{(T_4 - T_1) r_v^{\gamma - 1}}\right) = 1 - \left(\frac{1}{r_v^{\gamma - 1}}\right)$$

C_v= 0.718 kJ/kgK ; γ= 1.4.

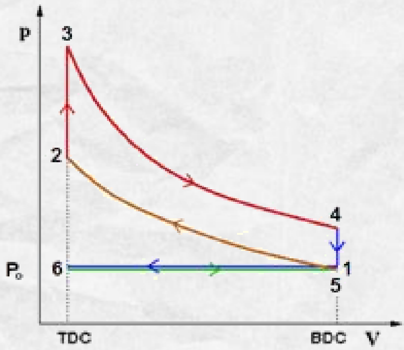
ENGINE PROCESS ANALYSIS

EXAMPLE 1:

1. A 4-stroke petrol engine operate on standard air otto cycle with compression ratio 9:1. At early of compression stroke, the temperature is 83°C and pressure 105 kN/m2. Highest temperature of the cycle is 1520°C. Sketch P-V diagram of the cycle, determined the temperature and pressure at each of important point of the process and thermal efficiency of the engine.

   Given that :

   $PV^{1.4}$= constant



Information from question:

$R_c = 9$

$T_1 = 83^0C = 356\ K$

$P_1 = 105\ kN/m^2$

$T_3 = 1520^0C = 1793\ K$

$T_2 = T_1\ (r_c)^{k-1} = 356\ (9)^{0.4} = \mathbf{857.33\ K}$

$P_2 = P_1\ (r_c)^{k} = 105(9)^{1.4} = \mathbf{2275.8\ kPa}$

PV=MRT

$(\frac{PV}{MRT})_2 = (\frac{PV}{MRT})_3$

$P_3 = P_2\ (T_3/T_2)$

$= 2275.8\ (1793\ /\ 857.33)$

$= \mathbf{4759.6\ kPa}$

$Q_{in} = mC_v\ (T_3 - T_2) = 0.718(1973 - 857.33)$

$= \mathbf{67.18\ kJ/kg}$

$T_4 = T_3\ (1/r_c)^{k-1} = 1793\ (1/9)^{0.4}$

$= \mathbf{744.53\ K}$

$P_4 = P_3\ (1/r_c)^{k} = 4759.6\ (1/9)^{1.4}$

$= \mathbf{219.6\ kPa}$

$Q_{out} = mC_v\ (T_4 - T_1) = 0.718(744.53 - 356)$

$= \mathbf{278.96\ kJ/kg}$

$\eta_{otto} = 1 - \left(\frac{Q_{out}}{Q_{in}}\right) = 1 - (278.96\ /\ 671.8)$

$= \mathbf{0.58\ @\ 58\ \%}$

ENGINE PROCESS ANALYSIS

DIESEL CYCLE FOR CI ENGINE

The diesel cycle is the ideal cycle for CI reciprocating engines. In SI engine, the air-fuel mixture is compressed to a temperature that is below the auto ignition temperature of the fuel, and the combustion process is occurring by firing the spark plug. In CI engines, the air is compresses to a temperature that is above the auto-ignition temperature of the fuel, and combustion starts on contact as the fuel is injected into this hot air. Figure 2.8 shown that the spark plug are replaced by a fuel injector in diesel engine. .

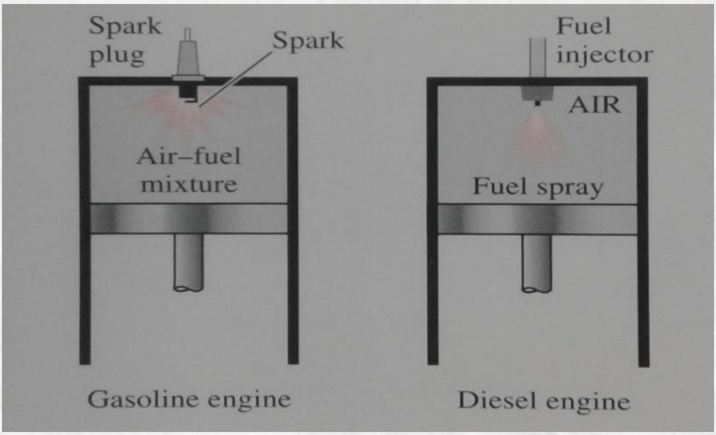
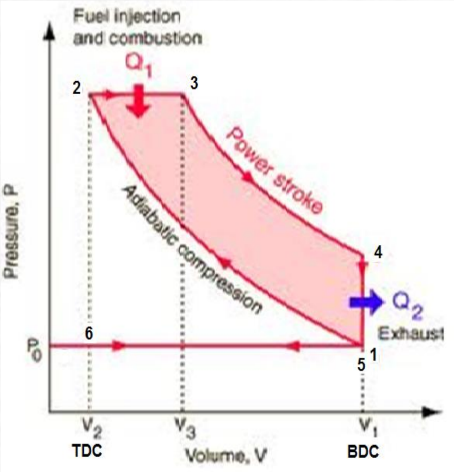


Figure 2.8: The replacement of spark plug with the fuel injector during the compression process

ENGINE PROCESS ANALYSIS

Analysis for Diesel Cycle



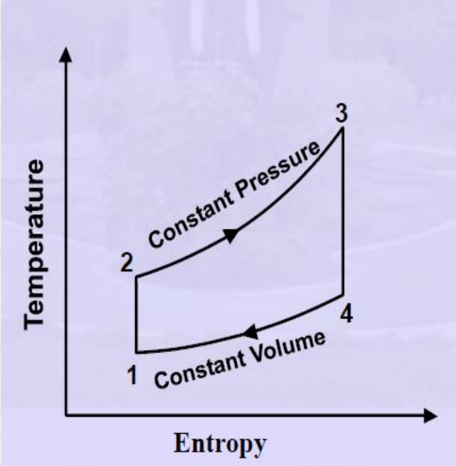


Figure 2.9: Comparison between P-V diagram and T-S diagram of Diesel Cycle

Process 6 -1 – Constant pressure intake of air at Po-Intake valve open and Exhaust valve closed

$$P_1 = P_6 = P_0$$
$$W_{6-1} = P_0(V_1 - V_6)$$

Process 1-2 – Isentropic compression Stroke-All valve closed

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

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

ENGINE PROCESS ANALYSIS

Process 2-3 – Constant Pressure heat input (Combustion)-All valve closed

$$Q_{2-3} = Q_{in} = m_m c_p (T_3 - T_2)$$

$$T_3 = T_{\max}$$

Cutoff Ratio: Defined as the change in volume that occurs during combustion given as a ratio:

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

Process 3-4 – Isentropic power or expansion stroke- All valve close

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} = \left(\frac{V_3}{V_2} \times \frac{V_2}{V_4}\right)^{\gamma-1} = \left(\beta \times \frac{1}{r_v}\right)^{\gamma-1} = \left(\frac{\beta}{r_v}\right)^{\gamma-1}$$

$$\frac{P_4}{P_3} = \left(\frac{V_3}{V_4}\right)^{\gamma} = \left(\frac{V_3}{V_2} \times \frac{V_2}{V_4}\right)^{\gamma} = \left(\beta \times \frac{1}{r_v}\right)^{\gamma} = \left(\frac{\beta}{r_v}\right)^{\gamma}$$

Process 4-5 – Constant Volume heat rejection-Exhaust valve open and intake

$$V_4 = V_5 = V_1 = V_{BDC}$$

$$Q_{4-5} = Q_{out} = m_m c_v (T_5 - T_4) = m_m c_v (T_1 - T_4)$$

ENGINE PROCESS ANALYSIS

Process 5-6 – Constant Pressure exhaust stroke at Po- Exhaust valve open intake valve closed

$$P_5 = P_6 = P_o$$

$$W_{5-6} = P_o(V_6 - V_5) = P_o(V_6 - V_1)$$

Thermal Efficiency of Diesel cycle

$$\eta_{diesel} = \left(\frac{Q_{in} - Q_{out}}{Q_{in}}\right) = \left(\frac{W_{nett}}{Q_{in}}\right) = 1 - \left(\frac{Q_{out}}{Q_{in}}\right)$$

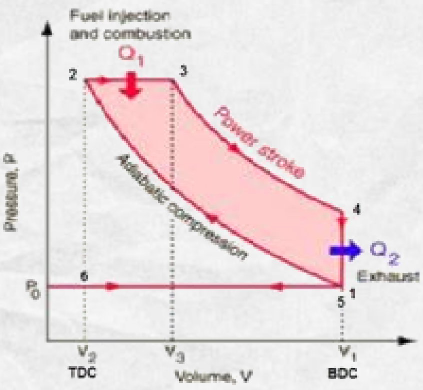
$$= 1 - \left(\frac{m_m C_v (T_4 - T_1)}{m_m C_p (T_3 - T_2)}\right)$$

$$= 1 - \left(\frac{1}{\gamma}\frac{(T_4 - T_1)}{(T_3 - T_2)}\right) \quad = 1 - \frac{1}{r_v^{\gamma-1}}\left[\frac{\beta^{\gamma} - 1}{\gamma(\beta - 1)}\right]$$

ENGINE PROCESS ANALYSIS

EXAMPLE 2:

1. Diesel engine has a temperature and a pressure at 15°C and 1 bar respectively at start of isentropic compression stroke. The compression ratio is 12/ 1 and the maximum cycle temperature is 1100°C. Calculate the air standard thermal efficiency based on the diesel cycle. [$\gamma = 1.4, C_p = 1.005, C_v = 0.71$]



Information from question:

$R_c = 12$

$T_1 = 15°C = 288$ K

$P_1 = 1 bar = 100$ kPa

$T_3 = 1100°C = 1373$ K

$T_2 = T_1 (r_c)^{k-1} = 288 (12)^{0.4} = \mathbf{778.15\ K}$

$P_2 = P_1 (r_c)^k = 100(12)^{1.4} = \mathbf{3242.3\ kPa}$

$Q_{in} = mC_{ph} (T_3 - T_2) = 1.005(1373 - 778.15)$

$= \mathbf{597.8\ kJ/kg}$

$\beta = \frac{V_3}{V_2} = \frac{T_3}{T_2} = 1373 / 778.15 = \mathbf{1.76}$

$T_4 = T_3 (\beta / r_c)^{k-1} = 1373 (1.76/12)^{0.4}$

$= \mathbf{637.74\ K}$

$P_4 = P_3 (\beta / r_c)^k = 3242.3 (1.76/12)^{1.4}$

$= \mathbf{220\ kPa}$

$Q_{out} = mC_v (T_4 - T_1) = 0.718(637.1 - 288)$

$= \mathbf{250.65\ kJ/kg}$

$\eta_{otto} = 1 - \left(\frac{Q_{out}}{Q_{in}} \right) = 1 - (250.65 / 597.8)$

$= \mathbf{0.58\ @\ 58\ \%}$

ENGINE PROCESS ANALYSIS

DUAL CYCLE

a. Dual Combustion Cycle (also known as the limited pressure or mixed cycle is a thermal cycle that is a combination of the Otto cycle and the Diesel cycle
b. Heat is added partly at constant volume and partly at constant pressure
c. The advantage of which is that more time is available for the fuel to completely combust

Analysis for Dual Cycle

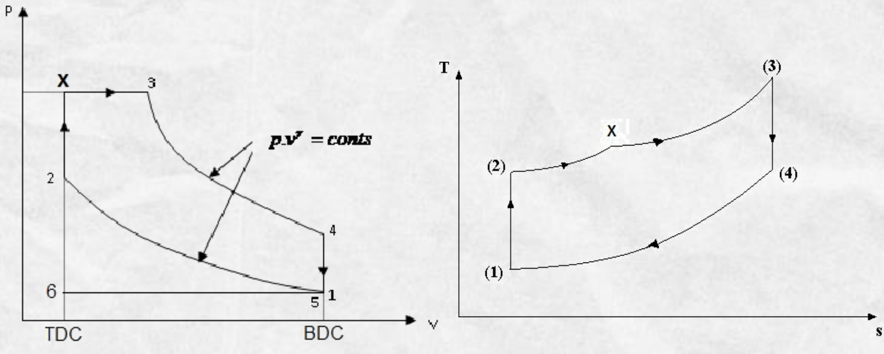


Figure 2.10: Comparison between P-V diagram and T-S diagram of Dual Cycle

Process 6 -1 – Constant pressure intake of air at Po-Intake valve open and Exhaust valve closed

$$P_1 = P_6 = P_0$$
$$W_{6-1} = P_0(V_1 - V_6)$$

ENGINE PROCESS ANALYSIS

Process 1-2 – Isentropic compression Stroke-All valve closed

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

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

Process 2-x – Constant volume heat input (first part of combustion).All valves closed.

$$V_x = V_2 = V_{TDC}$$

$$Q_{2-x} = m_m c_v (T_x - T_2)$$

$$P_x = P_{\max} = P_2 \left(\frac{T_x}{T_2}\right)$$

Pressure ratio is defined as the rise in pressure during combustion given as ratio

$$\alpha = \frac{P_x}{P_2} = \frac{P_3}{P_2} = \frac{T_x}{T_2} = \left(\frac{1}{r_v}\right)^{\gamma} \left(\frac{P_3}{P_1}\right)$$

Process x-3 – Constant pressure heat input (second part of combustion).All valves closed.

ENGINE PROCESS ANALYSIS

Process x-3 – Constant pressure heat input (second part of combustion).All valves closed.

$$P_3 = P_x = P_{max}$$

$$Q_{x-3} = m_m c_p (T_3 - T_x).....(kJ)$$

$$T_3 = T_{max}$$

Cutoff Ratio, $\beta = \frac{V_3}{V_x} = \frac{V_3}{V_2} = \frac{T_3}{T_x}$

Heat In, $Q_{in} = Q_{2-x} + Q_{x-3}$

Process 3-4 – Isentropic power or expansion stroke- All valve close

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1} = \left(\frac{V_3}{V_2} \times \frac{V_2}{V_4}\right)^{\gamma-1} = \left(\beta \times \frac{1}{r_v}\right)^{\gamma-1} = \left(\frac{\beta}{r_v}\right)^{\gamma-1}$$

$$\frac{P_4}{P_3} = \left(\frac{V_3}{V_4}\right)^{\gamma} = \left(\frac{V_3}{V_2} \times \frac{V_2}{V_4}\right)^{\gamma} = \left(\beta \times \frac{1}{r_v}\right)^{\gamma} = \left(\frac{\beta}{r_v}\right)^{\gamma}$$

Process 4-5 – Constant Volume heat rejection-Exhaust valve open and intake

$$V_4 = V_5 = V_1 = V_{BDC}$$

$$Q_{4-5} = Q_{out} = m_m c_v (T_5 - T_4) = m_m c_v (T_1 - T_4)$$

ENGINE PROCESS ANALYSIS

Process 5-6 – Constant Pressure exhaust stroke at Po- Exhaust valve open intake valve closed

$$P_5 = P_6 = P_o$$

$$W_{5-6} = P_o(V_6 - V_5) = P_o(V_6 - V_1)$$

Thermal Efficiency of Dual cycle,

$$\eta_{dual} = \left(\frac{Q_{in} - Q_{out}}{Q_{in}}\right) = 1 - \left(\frac{Q_{out}}{Q_{in}}\right)$$

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

$$= 1 - \left(\frac{(T_4 - T_1)}{(T_x - T_2) + \gamma(T_3 - T_x)}\right)$$

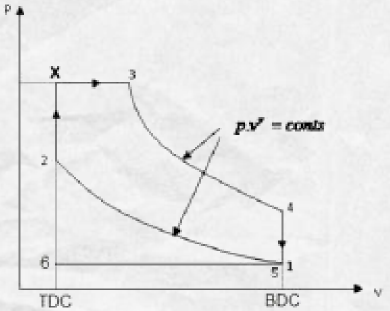
$$= 1 - \left(\frac{1}{r_v}\right)^{\gamma - 1}\left[\frac{\alpha\beta^{\gamma} - 1}{\gamma\alpha(\beta - 1) + (\alpha - 1)}\right]$$

ENGINE PROCESS ANALYSIS

EXAMPLE 3:

An oil engine takes in air at 1.01 bar, 20^0C and the maximum cycle pressure is 69 bar. The compression ratio is 18/1. Draw the *p-v* diagram and calculate the air standard thermal efficiency based on the dual combustion cycle. Assume that the heat added at constant volume is equal to the heat added at constant pressure.

[C_v=0.718 kJ/kg.K , C_p=1.005kJ/kg.K, γ=1.4]



Information from question:

$R_v = 18$

$T_1 = 20^0C = 293$ K

$P_1 = 1.01\text{bar} = 101$ kPa

$P_3 = P_x = 69$ bar $= 6900$ kPa

$Q_{in\ 2\text{-}x} = Q_{in\ x\text{-}3}$

$T_2 = T_1 (r_v)^{k-1} = 293\ (18)^{0.4} = \mathbf{931.1\ K}$

$P_2 = P_1 (r_v)^{k} = 101(18)^{1.4} = \mathbf{5777\ kPa}$

$$\alpha = \frac{P_x}{P_2} = \frac{P_3}{P_2} = \frac{T_x}{T_2} = 6900/5777 = \mathbf{1.19}$$

$$T_x = \frac{P_3}{P_2}(T_2) = \frac{6900}{5777}(931.1)$$

$= \mathbf{1112.1\ K}$

$Q_{in\ 2\text{-}x} = mC_v\ (T_2 - T_x) = 0.718(1112.1 - 931.1)$

$= \mathbf{129.96\ kJ/kg}$

$Q_{in\ 2\text{-}x} = Q_{in\ x\text{-}3} = mC_p\ (T_3 - T_x)$

$129.96 = 1.005\ (T_3 - 1112.1)$

$T_3 = \mathbf{1241.4\ K}$

$$\beta = \frac{V_3}{V_x} = \frac{T_3}{T_x} = 1241.4 / 1112.1 = \mathbf{1.12}$$

$T_4 = T_3\ (\beta / r_v)^{k-1} = 1241.4\ (1.12/18)^{0.4}$

$= \mathbf{408.2\ K}$

$P_4 = P_3\ (\beta / r_v)^{k} = 6900\ (1.12/18)^{1.4}$

$= \mathbf{141.38\ kPa}$

$Q_{out} = mC_v\ (T_4 - T_1) = 0.718(408.2 - 293)$

$= \mathbf{82.7\ kJ/kg}$

$$\eta_{otto} = 1 - \left(\frac{Q_{out}}{Q_{in}}\right) = 1 - (82.7 / 2\text{x}129.96)$$

$= \mathbf{0.68\ @68\ \%}$

CHAPTER 3

COMBUSTION AND FUEL CHARACTERISTIC

COMBUSTION AND FUEL CHARACTERISTIC

Introduction

a. In Internal Combustion (IC) Engine, combustion occurs when fuel were burn by spark plug (SI engine) and compression (CI engine)

b. Fuel is a Hydrocarbon (HC) that consist combination of hydrogen and carbon. Both of the element easy to combine with oxygen (O_2)

c. Fuel (hydrocarbon) will burn together with oxygen and produce carbon monoxide (CO) and carbon dioxide (CO_2).

COMBUSTION AND FUEL CHARACTERISTIC

Table 3.1 : Terms in combustion

TERM	DEFINITION
Combustion	Combustion is A/F was burned at a correct ratio 14.7:1
Normal Combustion	Combustion process done at the right time (Combustion stroke)
Abnormal Combustion	A combustion starts without the need of spark plug either before or after power stroke
Ignition	A/F which have been mixed will burned and ignite

COMBUSTION AND FUEL CHARACTERISTIC

TERM	DEFINITION
Pre-Ignition	This Is one process that fuel are ignite by hot spot that come from exhaust valve or carbon deposition.
Detonation	The last part of fuel charges explode or burns almost instantly to produce spark knock
Self-Ignition	Combustion occurs before the piston achieve higher crank angle.
Ignition Delay	The time of starting injection and ignition of fuel.
Timing advance	Spark plug will produce spark early before the right time.
Retarded timing	Fuel was late ignite compare to original specified time.

Combustion and Fuel Characteristic

Combustion in Spark Ignition Engine (SI)

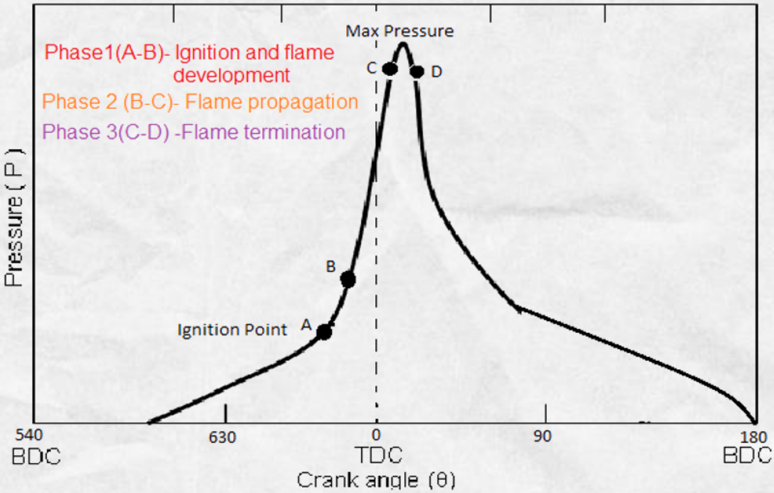


Figure 3.1 : Pressure vs crank angle (Spark Ignition)

Combustion and Fuel Characteristic

Combustion in Spark Ignition Engine (SI)

Table 3.2 : Explanation of combustion in SI engine

PHASE	DESCRIPTION
1st Ignition and flame development)	a. Combustion is happen due to spark from a spark plug. b. Occurs at 10˚ to 30˚ before TDC c. Combustion starts slowly
2nd (Flame propagation)	a. Start from point B at the figure. b. At this time pressure extremely increase and showing that combustion occurred at high rate.
3rd (Flame termination)	a. Point where by the combustion stop (Point D) b. Occurs at 15˚ to 20˚ after TDC.

COMBUSTION AND FUEL CHARACTERISTIC

Knocking

a. Knocking is a high pressure pulse that can cause damage to the engine.
b. Knocking is happen when two flame fronts (spark plug and early ignition) hit each other

Cause of knocking

a. Without the spark plug, the A/F will self ignite
b. Self ignition temperature is lower than temperature of air fuel mixture
c. Wrong spark plug used
d. Excessive carbon deposition on exhaust valve

Effect of knocking

a. Loss of engine power
b. Pollution
c. Higher FC
d. Engine damage

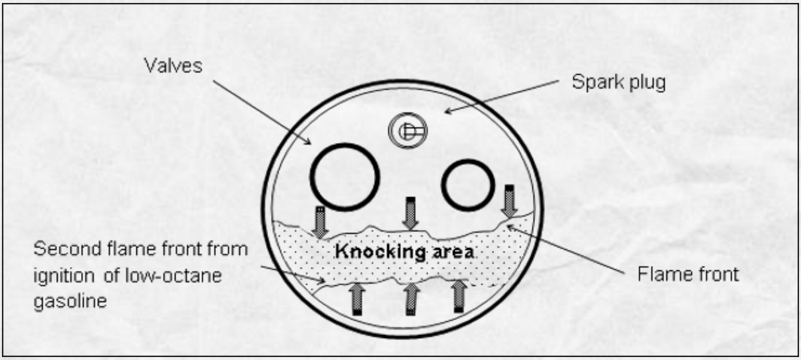


Figure 3.2 : Knocking inside the combustion chamber (top views)

COMBUSTION AND FUEL CHARACTERISTIC

Reduce engine knocking

a. Increase the flame of combustion
b. Reduce heat of final combustion
c. Use high quality of fuel (RON 97 and above)
d. Use correct spark plug

Figure 3.3 : Spark plug

Figure 3.4 : High quality of fuel (RON 97)

Combustion and Fuel Characteristic

Knocking Phenomenon

This knocking phenomenon can be affect by this item:

1. Charge temperature – When excessive compression happen, the pressure/ temperature will be increase and knocking will occur
2. Injection timing – Too much advance timing will increase peak cylinder pressure
3. Atomization – Wrong mixture contribute to the excessive heating / lowering effective octane
4. Engine speed (RPM) – Increase the pressure
5. The quality of fuel – Not enough octane rating contribute to the fuel more likely to explode

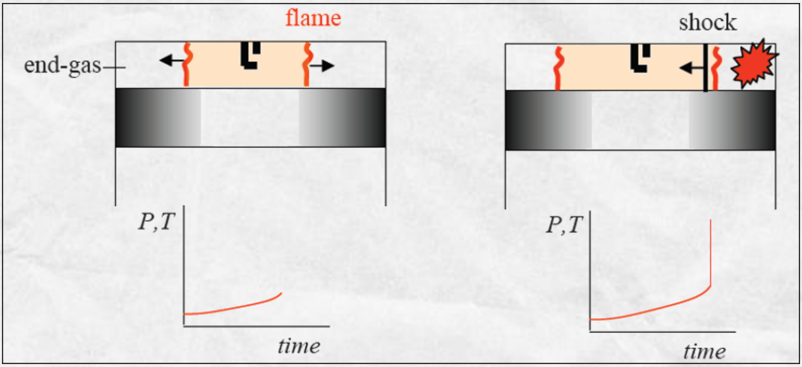


Figure 3.5 : Knocking phenomenon

COMBUSTION AND FUEL CHARACTERISTIC

Richardo Diagram

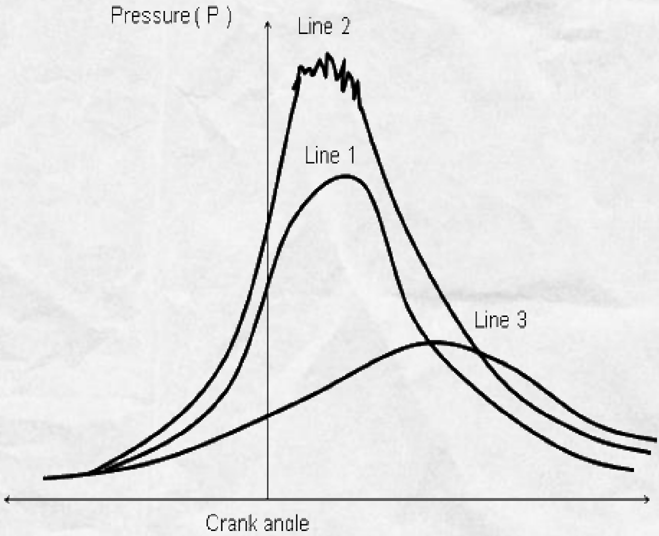


Figure 3.6 : Graph of pressure vs crank angle

Explanation of Richardo Diagram

a) Line 1
Good Combustion

b) Line 2
Bigger crank angle
Early Combustion
Knocking will occur

c) Line 3
Smaller crank angle
Late combustion
Lower max pressure and power

Combustion and Fuel Characteristic

Differences between graph of knocking

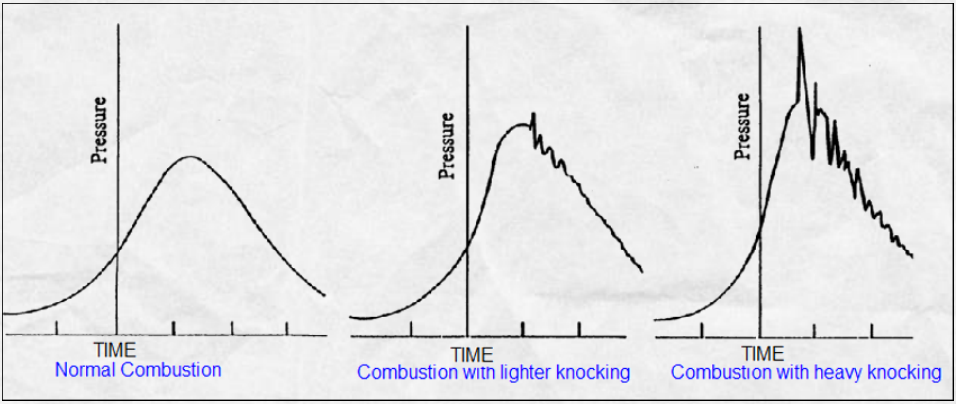


Figure 3.7 : Graph of pressure vs time

COMBUSTION AND FUEL CHARACTERISTIC

Combustion in CI Engine

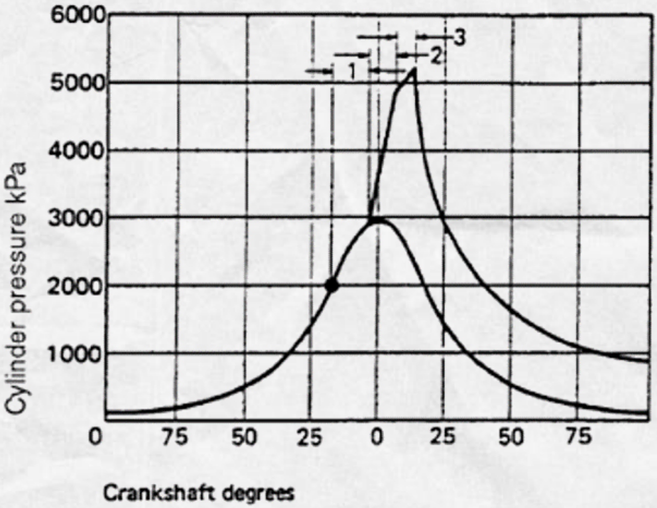


Figure 3.8 : Pressure VS crank angle (Compression Ignition)

COMBUSTION AND FUEL CHARACTERISTIC

Combustion in Compression Ignition Engine (CI)

Table 3.3: Explanation of combustion in CI engine

PHASE	DESCRIPTION
1st (Delay period)	a. The period between the early of combustion and the start of fuel injection. b. Delay period phase depend on the condition and type of fuel.
2nd (Flame propagation)	a. Air-fuel mixture combust with high rate. b. Flame propagation depend on delay period. The longer delay period, more time for air and fuel to mix.
3rd (Control combustion)	a. Fuel still injected in to the cylinder. b. The rate of combustion depend on air-fuel mixture.

Combustion and Fuel Characteristic

Octane Number (Petrol engine)

a. Octane number is also used to measure the antilock quality of a gasoline

b. Two standard reference fuels used are isooctane (ON=100) and n-heptane (ON=0)

c. Higher octane number, less likely it will self-ignite

d. Research Octane Number (RON)

Cetane Number (Diesel engine)

a. Cetane number is one relative measure about how easy the fuel to self ignite.

b. Use for compression ignition engine (CI)

c. Larger cetane number means the quicker the fuel to self ignite. Smaller cetane number means longer ignition delay (delay period) and slower the fuel to self ignite.

d. Two standard reference fuels used are n-cetane and alpha metil-naftalena

COMBUSTION AND FUEL CHARACTERISTIC

Stoichiometric Number

1. Stoichiometric ratio between air fuel mixture is an enough oxygen in a mixture to complete a combustion
2. A/F mixture that contain more air or oxygen is called LEAN mixture
3. A/F mixture that contain less air or oxygen is called RICH mixture
4. Balanced stoichiometric combustion between isooctane(gasoline) and oxygen:

$$C_8H_{18} + 12.5O_2 \longrightarrow 8CO_2 + 9H_2O$$

COMBUSTION AND FUEL CHARACTERISTIC

Tutorial

A. Describe the term below:
   i. Stoichiometric ratio
   ii. Pre-ignition
   iii. Ignition delay

B. Briefly differentiate between uncontrolled combustion and abnormal combustion

C. Sketch three (3) graph of pressure vs. crank angle degree diagrams and explain the combustion process below:
   i. Normal combustion with no knocking
   ii. Light knocking of combustion
   iii. Heavy knocking of combustion

REFERENCES

John Heywood (2018), *Internal Combustion Engine Fundamental 2E*.Mc Graw Hill Profesional.ISBN 1260116115.

Rakash Kumar Maurya (2018). *Characteristics And Cantral Of Low Temperature Combustion EnginesEmploying Gasoline Ethanol and Methanol.Springer*. ISBN 0941-5122

Richard Van Basshuysan,Fred Schafer (2016), *Internal Combustion Engine Handbook*. SAE International,ISBN 9780768080247.

V.Ganeson (2015) *I.C Engines,Fourth Edition*, Mc Graw Hill. ISBN (13) 978-1-25-900619-7

Tim Dum, Kevin Jesser, Brad Kerr, Robert Mann, (2014). *Automotive Light Vehicle Level 1.* Curier Companies. ISBN 13. 978-1-4496-9781-5

e ISBN 978-967-2897-61-3

9 7 8 9 6 7 2 8 9 7 6 1 3