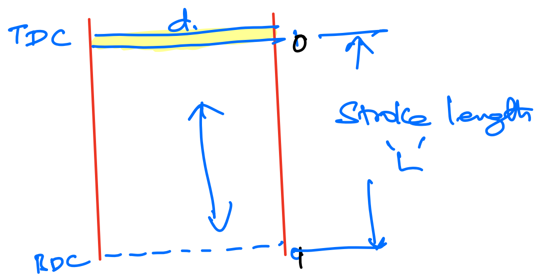
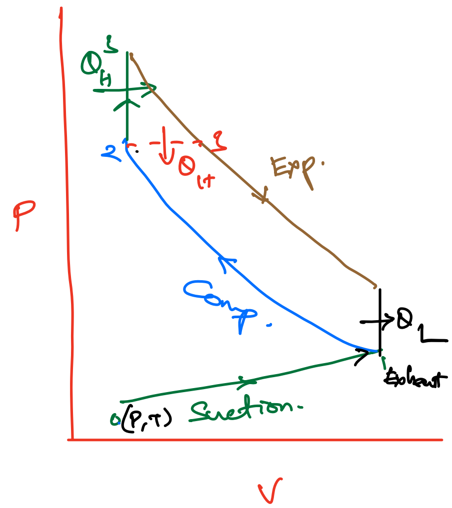
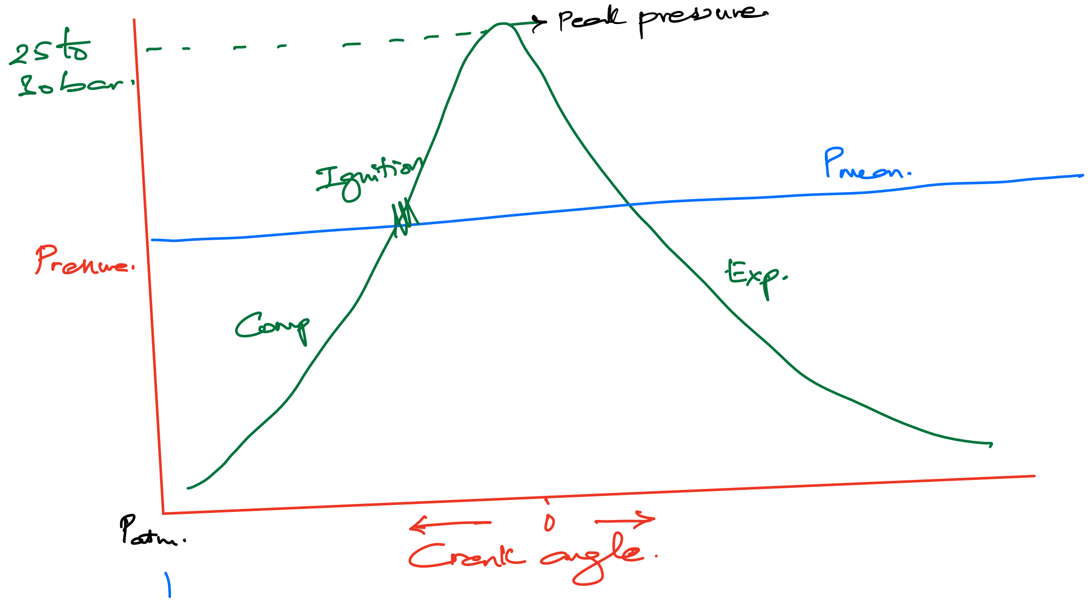
I.C. Engines: 4-stroke I.C. engines, Combustion of SI engine and CI engine, Knocking and Detonation, Performance analysis of I.C Engines, heat balance, Morse test, Willian's line method. **06 hours**

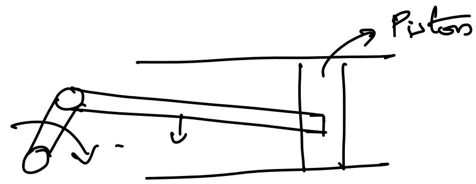
Four stroke I.C. Engine.





In a conventional S.I Engine → Fuel & air mixture. (Intake system).





Performance parameters of I.C Engine.

1) Mechanical Efficiency:

$$\eta_{mech} = \frac{\text{Brake power / Power available @ Shaft}}{\text{Indicated power / Energy supplied.}}$$

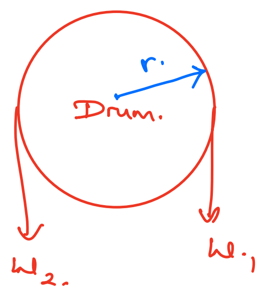
Brake power = Torque x Angular velocity.

$= T \times \omega$ $\qquad \omega = \frac{2\pi N}{60}$.

$$B.P = \frac{2\pi N T}{60} \text{ kW.}$$

T = Torque → N-m.

1) Rope brake drum dynamometer.



$T = W_{net} * \text{radius}$

$W_{net} = W_1 - W_2$.

2) Inductive dynamometer. → V*I.

$$\text{Indicated Power} = \frac{P_m L A n}{60} \times i$$

P_m = Mean effective pressure N/m^2.

L = Stroke length 'm'

A = C/s area of the piston 'm^2'

n = Rotational speed of the engine.

($n = \frac{N}{2}$ for 4 stroke engine)

i = Number of cylinders.

[$Q_H \longrightarrow IP = \dot{m}_f * C_V$.
$\dot{m}_f$ = Mass flow rate of fuel.
C_V = Calorific value of fuel.] (X)

2) Specific power output.

It is defined as the ratio of brake power per unit of piston displacement.

$$\text{Specific output} = \frac{B.P}{LA}$$

$$= P_{m_{bp}} * N. * \text{Constant} \rightarrow (X)$$

3) Volumetric Efficiency:

$$\eta_{vol} = \frac{\text{Mass of the charge actually sucked in. by the engine. [Swept Volume].}}{\text{Mass of the charge corresponding to the cylinder intake. (P \& T) conditions.}}$$

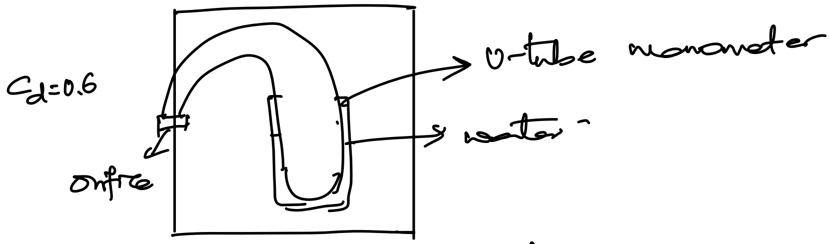
4) Thermal Efficiency: (Brake power)

$$\eta_{th} = \frac{\text{Brake Power / Power available @ shaft}}{\text{Heat supplied } Q_H}$$

$$\eta_{th} = \frac{B.P}{m_f * C_V}$$

$\dot{m}_f$ = Mass of fuel supplied in kg/s.
C_V = Calorific value of the fuel.

5) Measurement of Air Consumption



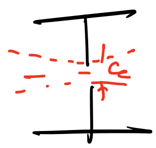
h_w = Head of water.

$$H_a \cdot \rho_a = h_w \cdot \rho_w \rightarrow H_a = \frac{h_w \cdot \rho_w}{\rho_a} \rightarrow \text{m of Air.}$$

Velocity of the air $\vec{V} = \sqrt{2gH_a}$

Volume of air flowing through the orifice.

$$V_a = A_o \cdot \vec{V} \cdot C_d \sqrt{2gH_a} \quad m^3/s \quad (Q_a)$$

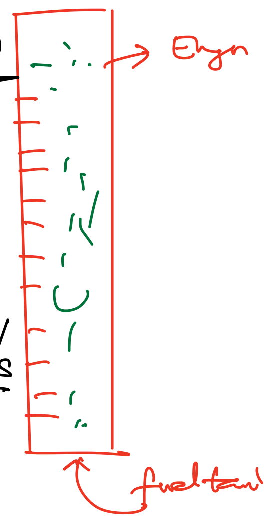


6) Measurement of fuel consumption.

Burette → 200cc (or) 300cc.

Connected b/n the fuel tank and the engine.

Using stop watch → $\frac{\text{Amount of fuel consumed}}{\text{given time.}}$



$$[\dot{m}_f] \text{ Fuel consumption} = \frac{X_{cc} * \text{Specific gravity}}{1000 \times t.} \quad kg/s$$

Specific fuel consumption (BSFC):

$$BSFC = \frac{\dot{m}_f}{B.P} = kg/kW\,h.$$

($\dot{m}_f$ → kg/hr, B.P → kW.)

Heat Balance Sheet

A heat balance sheet is an account of heat supplied and heat utilized by the I.C Engine. Heat blance in done on hour basis (OR) Second basis. (or) minute.

i) Heat supplied to the engine.

$$Q_s = \dot{m}_f * C_V.$$

$\dot{m}_f = kg/s$

C_V = Calorific value in kJ/kg. [Lower calorific value]

ii) Heat equivalent/converted to B.P.

$$B.P = \frac{2\pi N T}{60} \text{ KW. (or) } kJ/min.$$

iii) Heat taken away by the exhaust gases.

$$Q_g = m_g \cdot C_{pg} \left(T_{g\,exit} - T_{\infty} \right) \text{ KW (or) } kJ/min$$

$m_g = (m_a + m_f) \rightarrow$ m_a = mass of air.
m_f = mass of fuel.

C_{pg} = Specific heat of the exhaust.

$T_{g\,exit}$ = Exhaust gas temperature in °C

T_{∞} = Ambient/atmospheric temperature in °C

iv) Heat carried away by cooling water.

$$Q_w = m_w \times C_{pw} (T_{w_{exit}} - T_{w_{inlet}}) \quad KJ/s \text{ (OR) } KJ/min.$$

m_w = Mass of cooling water.

C_{pw} = Specific heat of water

$T_{w_{exit}}$ = Exit water temperature.

$T_{w_{inlet}}$ = Inlet water temperature.

Heat Balance Sheet in minute basis.

Heat input/min.	KJ/min	%	Heat utilization/min	KJ/min	%
Heat supplied by burning of fuel.	Q_s. (100)	100	Heat into BP	B.P. (45)	45
			Heat carried away by exhaust gas	Q_g (22)	22.
			Heat carried by cooling water.	Q_w (20)	20
			Unaccounted heat. $= Q_s - (BP + Q_g + Q_w)$	Q_{un}. (15)	15.
Total.	(100)	100%.	Total.	(100)	100%.

IP = Indicated Power

BP = Brake Power

FP = Frictional Power.

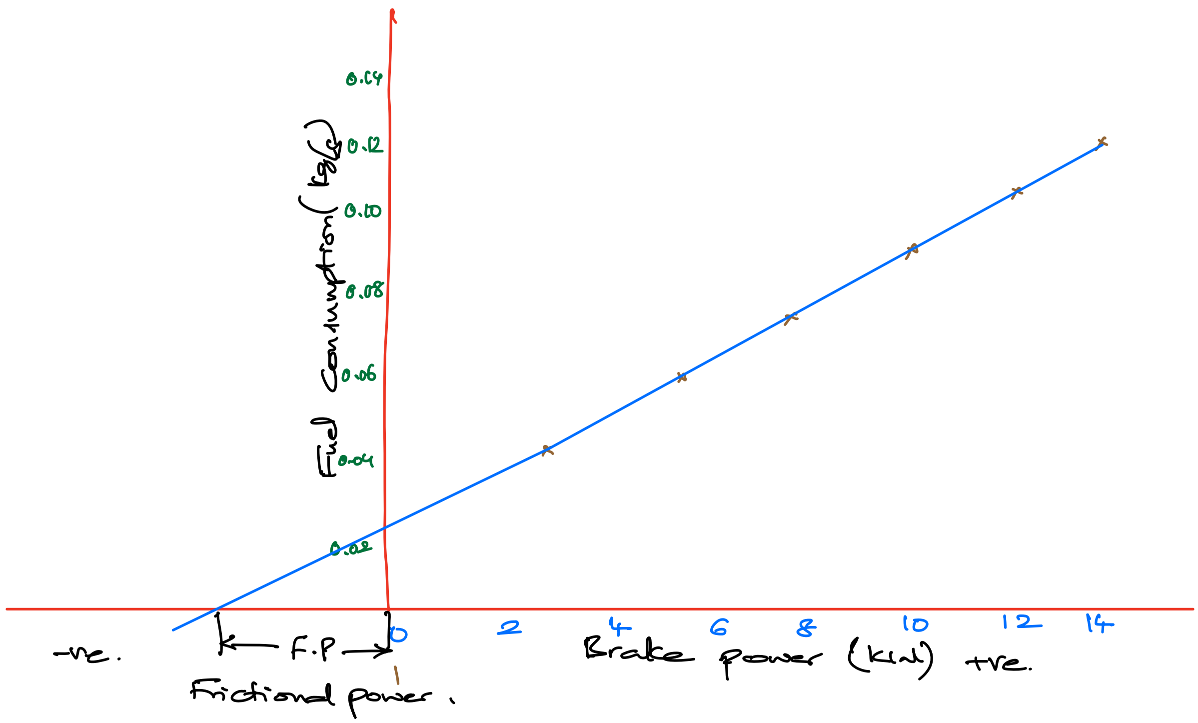
Measurement of Frictional power:

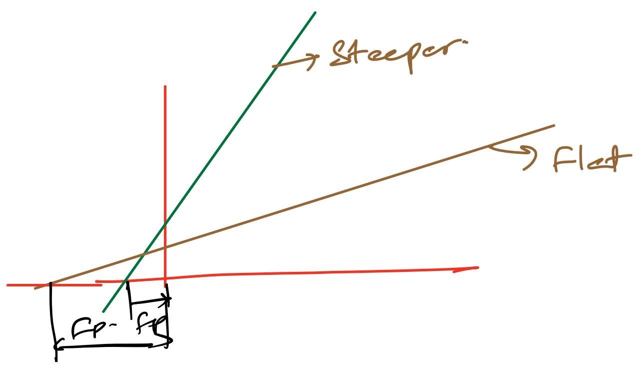
1) Willan's Line method ✓
2) Morse Test. ✓
3) I.P & B.P → measurement.
4) Motoring Test.
5) Retardation test.

1) Willan's Line method:

a) Fuel consumption of the engine → kg/s (or) g/s.

b) Brake power of the engine is measured using the dynamometer in kW (or) W.





2) Morse Test → Multicylinder engines

Let us consider a three cylinder engine.

$$= ip_1 + ip_2 + ip_3 = \sum_{i=1}^{k=3} ip \rightarrow (1)$$

$$\sum_{i=1}^{k=3} ip_k = B_t + F_t \longrightarrow B_t = \sum_{i=1}^{3} ip_k - F_t \rightarrow (2)$$

If the first cylinder is cut-off, then it will not produce any power. Frictional losses will remain same.

$$\sum_{i=2}^{k=3} ip_k = B_1 + F_t \longrightarrow B_1 = \sum_{i=2}^{k=3} ip_k - F_t \rightarrow (3)$$

∴ Indicated power 'ip' of the first engine would be.

$$ip_1 = \sum_{i=1}^{k=3} ip_k - \sum_{i=2}^{k=3} ip_k = B_t + F_t - B_1 - F_t.$$

$$ip_1 = B_t - B_1 \rightarrow (4)$$

$$ip_2 = B_t - B_2 \rightarrow (5)$$ [∵ If cylinder '2' is cut-off].

If the first & second cylinder is cut-off, there is no power from the first & second cylinder.

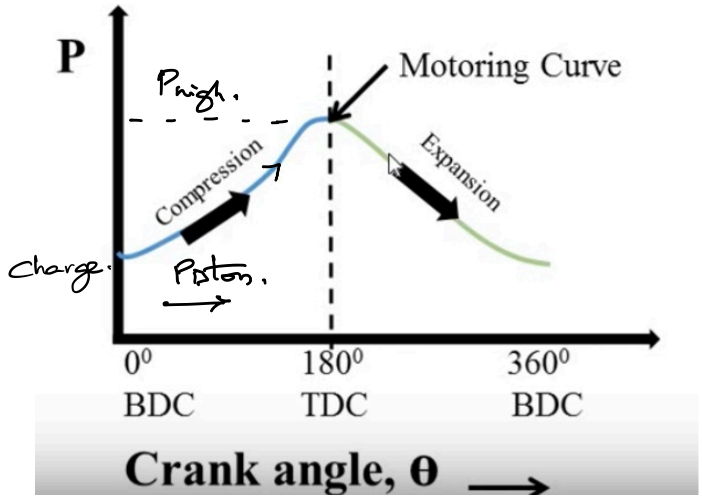
$$\sum_{i=3}^{k=3} = B_3 + F_t \rightarrow (6)$$

$$ip_3 = B_t - B_3 \rightarrow (7)$$

Frictional power is given by.

$$F_t = (ip_1 + ip_2 + ip_3) - B_t \rightarrow (8)$$

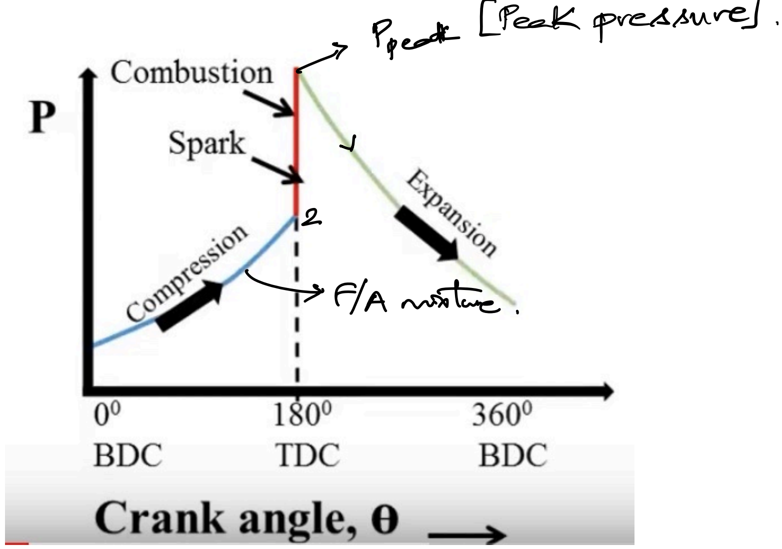
Stages of combustion in S.I Engines.



1) Both inlet and Exhaust Valves are closed and piston moves from BDC to TDC, compression takes place.

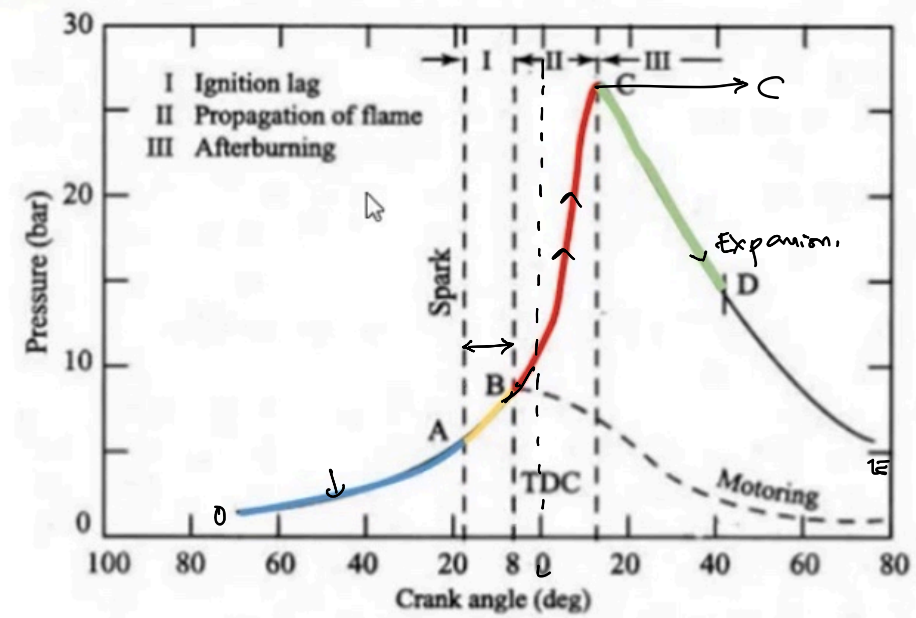
2) If the piston moves from TDC to BDC, expansion take place.

3) If there is no Combustion, the P V/s θ diagram is called as Motoring curve.



1) Theoritical P V/s θ diagram where the spark occur at TDC, so the pressure rise due to combustion of fuel and the expansion of the combustion takes place.

Actual stages of Combustion in S.I Engine.



Stages of Combustion in an SI Engine

1) O to A — Compression process [Fuel Air mixture] enters the engine.
A is the spark point (ignition point).

Stage I → A to B → Ignition delay ($\frac{1}{10}$th of second)

2) It is the duration between the spark(A) and the start of the combustion. (B).

Stage II → B to C → Flame propagation

3) It is the duration between the point 'B' and point 'C'. Max heat is generated during this phase.

4) Point 'A' is approximately 30° to 35° before TDC.

5) Point 'C' is about 5° to 10° after TDC.

Stage III → C to D → After burning.

6) Theoritically combustion should stop at point 'C', but in actual combustion process it will continue even after point 'C'.

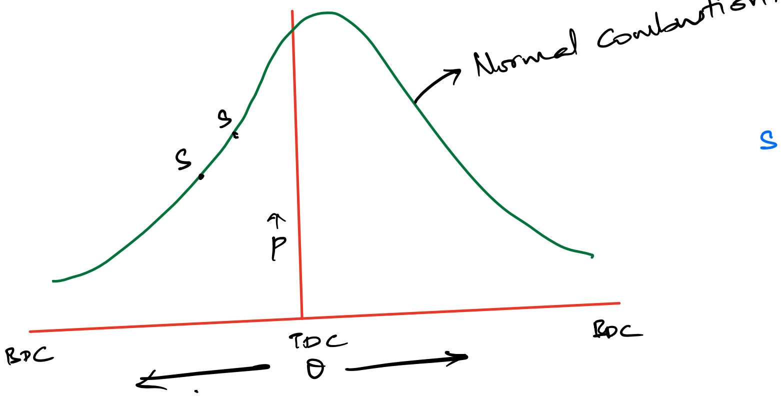
7) It may be due to rich mixture of Air & fuel.

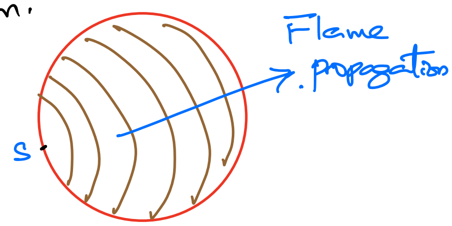
8) Approximately around 10% of heat is liberated.

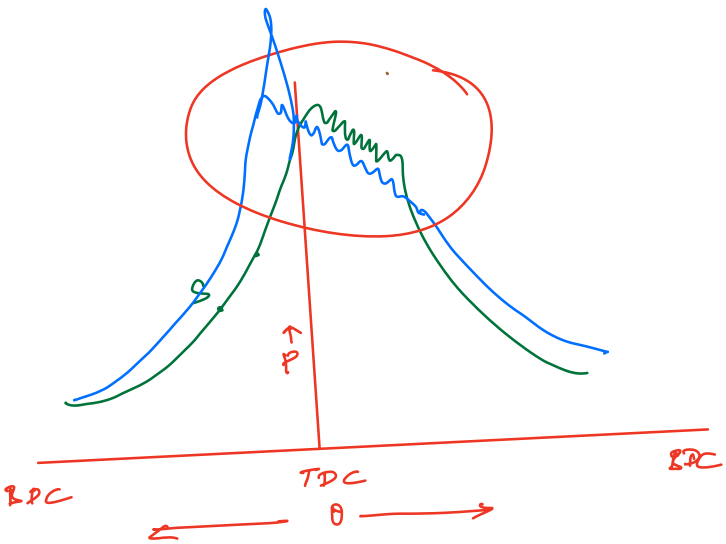
7) To achieve max. advantage of high pressure due to the combustion, the peak pressure should be just after the TDC.

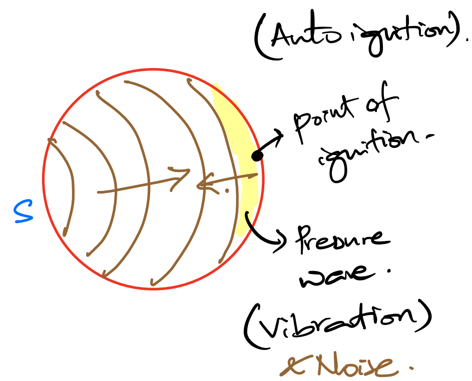
Phenomenon of knocking:

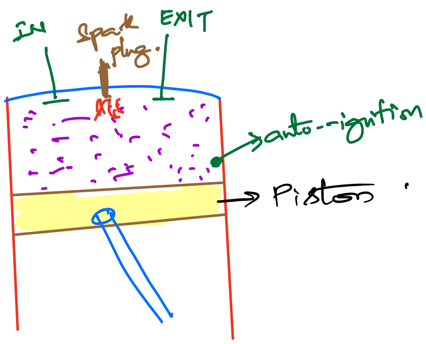
1) If compression ratio is increased, the engine has to be robust in design.



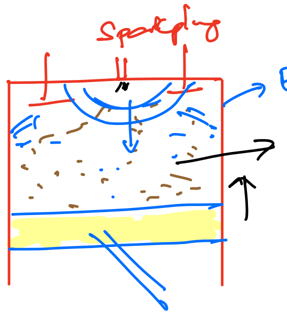








Detonation (To explode/Detonate)

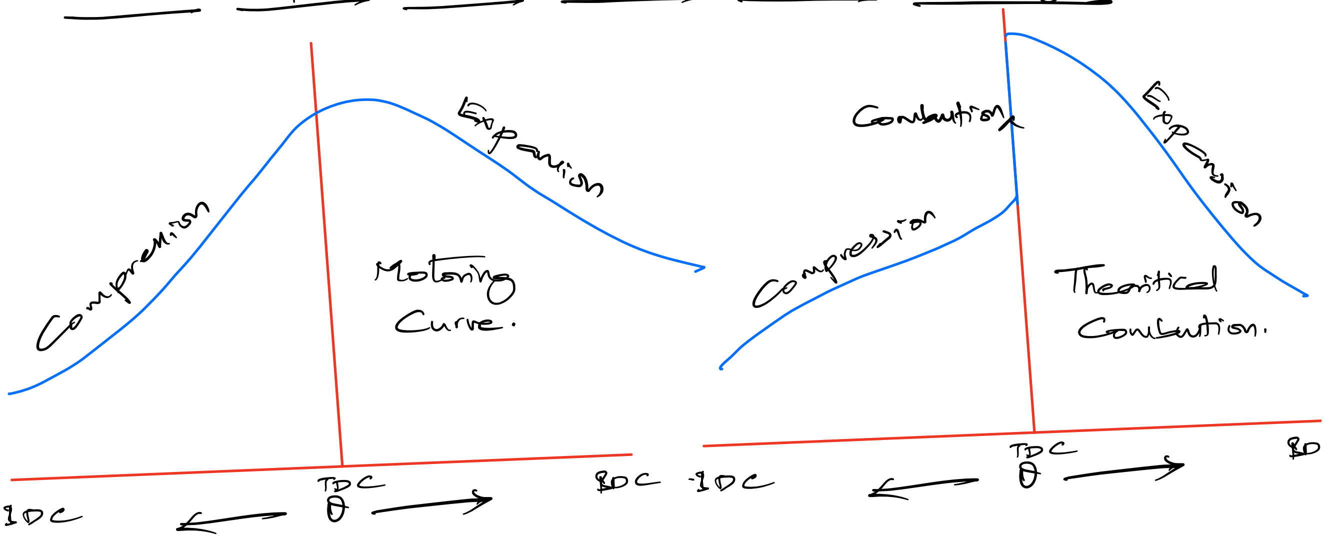


1) Detonation is the spontaneous combustion of the end-gas (remaining air fuel mixture) in the cylinder/chamber.
2) It occurs after the normal combustion, which is initiated by the spark plug.
3) If the combustion process moves too fast and the pressure peak occurs too early.
4) This result in excessive pressure & temperature, unstable pressure pulses lead to explosion.

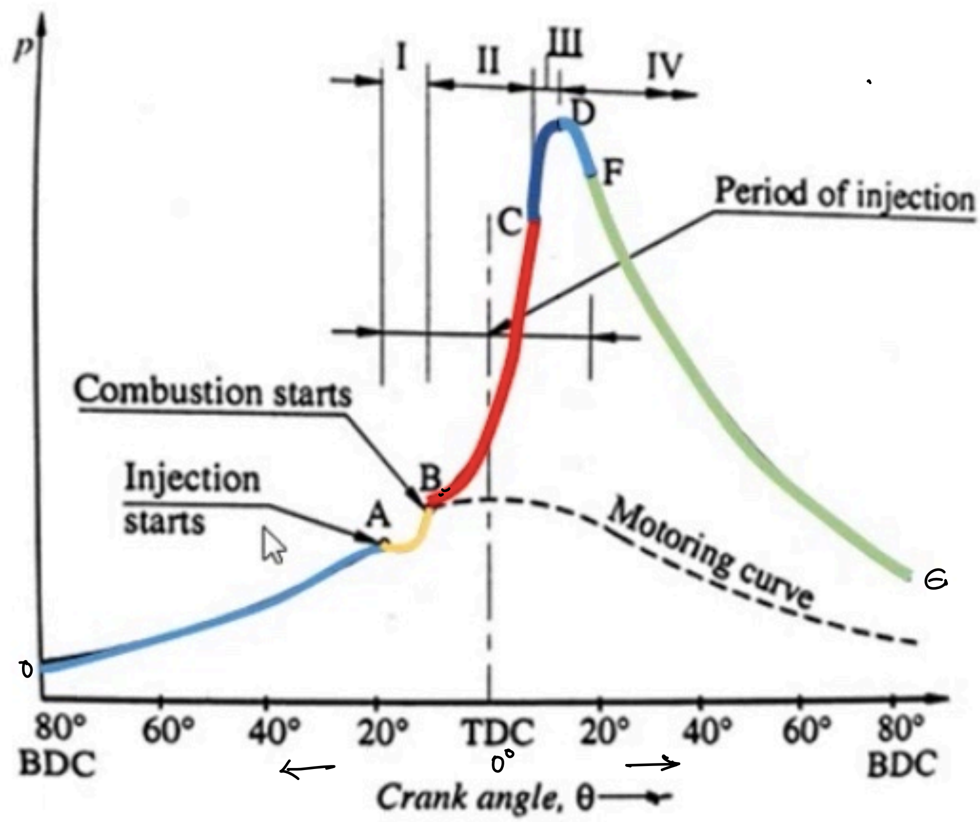
Detonation v/s knocking:

Detonation is the cause and knocking is the after effect.

Combustion process in a Compression Iquition Engine:



Stages of Combustion in C.I Engine.



i) 0 to A → Compression of Air.

Stage I → A to B. Ignition delay / Pre flame combustion.

2) a) Physical delay:

Fuel is injected at 'A' in the form of fine spray. the fuel start absorbing heat from the surrounding temperature of air and vapourization of fuel start.

b) Chemical delay:

The chemical reaction between the air and the fuel begin. It ends when the air fuel mixture ignites and flame appears at point 'B'.

Stage II → Uncontrolled combustion:

3) The time and place of ignition is not fixed.

4) Fuel is continuously sprayed for approximately 30 to 40° of the crank angle.

5) Fuel is still mixing with air, while the combustion process has already started at point 'B'. Flame propagation is uncontrolled.

Stage III → C to D: Controlled Combustion.

6) At 'C' all the mixture accumulated is properly burnt.

7) As the pressure and temperature inside the cylinder become very high.

8) Whatever the fuel injected will readily get ignited due to swirl without any delay period due to high temperature and pressure.

9) About 70 to 80% of the total heat evolved during this stage of combustion.

Stage IV → D-F : After burning.

10) The small quantity of fuel particle may burn after point 'D'.

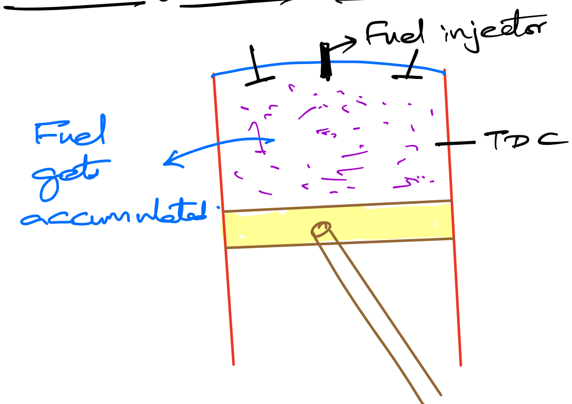
11) The reasons for after burning:

a) Heterogeneous mixture.

b) Poor distribution of fuel particles.

c) Heavier molecules of fuel.

Knocking in C.I. Engine: (Diesel Knock).



1) If the delay period in C.I engine is long, large amount of fuel will be injected and gets accumulated

2) The auto-ignition of this large amount of fuel will lead to high pressure and temperature.

1. The following observations have been made from the test of a four cylinder, four-stroke petrol engine. Diameter of the cylinder = 100 mm; stroke = 150 mm; speed = 1600 rpm; Area of indicator diagram = $5.5X10^{-4}m^2$; Length of the indicator diagram = 55 mm; spring constant = 3.5 bar/m; Determine the indicated power of the engine.

Sol: Data: $d = 0.1m$; $L = 0.15m$; $k = 4$; $N = 1600$ rpm; $n = N/2 = 800$ rpm.

$A = 5.5 \times 10^{-4}\ m^2$; $L_d = 0.055\ m$; $K_s = 35$ bar/mm.

$$P_m = \frac{A \times K_s}{L_d}$$

$$P_m = \frac{5.5 \times 10^{-4} \times 3.5}{55 \times 10^{-3}}$$

$$P_m = 3.5 \times 10^5\ N/m^2$$

$$P_m = 3.5\ bar.$$

Indicated Power:

$$ip = \frac{P_m L A n}{60} \times K.$$

$$= \frac{3.5 \times 10^5 \times 0.15 \times \frac{\pi}{4} \times 0.1^2 \times 800}{60} \times 4$$

$$ip \simeq 22\ kW.$$

2. A gasoline engine (petrol engine) working on Otto cycle consumes 8 litres of petrol per hour and develops 25 kW. The specific gravity of petrol is 0.75 and its calorific value is 44,000 kJ/kg. Determine the indicated thermal efficiency of the engine.

Sol: $m = 8 \times 10^3$; $ip = 25$ kW; $S = 0.75$; $C_V = 44000$ kJ/kg. $\eta_{ith} = ?$

Mass of fuel consumed in kg/s.

$$\dot{m}_f = \frac{m_f S}{1000 t} = \frac{8 \times 10^3 \times 0.75}{1000 \times 3600} = 1.67 \times 10^{-3}\ kg/s.$$

Indicated thermal efficiency η_{ith}:

$$\eta_{ith} = \frac{ip}{Q_H} = \frac{ip}{\dot{m}_f \times CV.}$$

$$= \frac{25 \times 10^3}{1.67 \times 10^{-3} \times 44000 \times 10^3}$$

$$\eta_{ith} = 34\%.$$

3. The bore and stroke of a water cooled, vertical, single-cylinder, four stroke diesel engine are 80 mm and 110 mm respectively.The torque is 23.5 N-m. Calculate the brake mean effective pressure. What would be the mean effective pressure and torque if the engine rating is 4 kW at 1500 rpm?

Sol: Data: $d = 0.08$ m; $L = 0.11$ m; $T = 23.5$ N-m.

i) To find P_{mbp}. ii) $B.P = 4$ kW, $N = 1500$ rpm. P_{mbp}, T

Case 1: Brake Power $BP = \frac{2\pi N T}{60 \times 10^3} \times k$ $k = 1$

$$= \frac{2\pi \, 1500 \times 23.5}{60 \times 10^3}$$

$$B.P = \frac{P_m L A n}{60 \times 10^3} K.$$

$B.P = 3.69$ kW.

$A = \frac{\pi d^2}{4}$

$A = \frac{\pi \times 0.08^2}{4}$

$A = 5.02 \times 10^{-3}$

Brake mean pressure $P_{mbp} = \frac{BP \times 60 \times 10^3}{L A n}$

$$= \frac{3.69 \times 60 \times 10^3}{0.11 \times 5.02 \times 10^{-3} \times \frac{1500}{2}}$$

$$P_{mbp} = 5.35 \text{ bar}.$$

Case 2: Torque $T = \frac{B.P \times 60 \times 10^3}{2\pi N}$

$$= \frac{4 \times 60 \times 10^3}{2 \times \pi \times 1500}$$

$$T = 25.47 \text{ N-m}.$$

$$P_{mbp} = \frac{BP \times 60 \times 10^3}{LAN}$$

$$= \frac{4 \times 60 \times 10^3}{0.11 \times 5.02 \times 10^{-3} \times \frac{1500}{2}}$$

$$P_{mbp} = 5.79 \text{ bar}.$$

4. Find the air fuel ratio of a four stroke, single cylinder, air cooled engine with fuel consumption time for 10 cc in 20.4s and air consumption time for $0.1m^3$ in 16.3s. If the load is 7 N at the speed of 3000 rpm. Find also the brake specific fuel consumption in kg/kWh and brake thermal efficiency. Assume the density of air as $1.175 kg/m^3$ and specific gravity of the fuel to be 0.7. The lower heating value of the fuel is 43 MJ/kg and the dynamometer constant is 5000.

Sol: Data: $V_f = 10cc$, $t_f = 20.4s$ $V_a = 0.1m^3$; $t_a = 16.3s$. $W = 7N$; $N = 3000rpm$

$\rho_a = 1.175 kg/m^3$; $S = 0.7$; $C_v = 43 MJ/kg$. $A = 5000$.

To find. i) $\frac{m_a}{m_f}$ ii) bsfc iii) η_{bth}.

i) Mass of air: $\dot{m}_a = \frac{V_a \times \rho_a}{t_a} = \frac{0.1 \times 1.175}{16.3} = 7.2 \times 10^{-3} kg/s$.

Mass of fuel: $\dot{m}_f = \frac{V_f \times S}{1000 \times t_f} = \frac{10 \times 0.7}{1000 \times 20.4} = 0.343 \times 10^{-3} kg/s$.

$A/F = \frac{\dot{m}_a}{\dot{m}_f} = \frac{7.2 \times 10^{-3}}{0.34 \times 10^{-3}} = 21.17$.

ii) Brake Specific fuel consumption.

$bsfc = \frac{\dot{m}_f}{B.P}$

$= \frac{0.34 \times 10^{-3} \times 3600}{4.2}$

$bsfc = 0.294 kg/kWh$.

$B.P = \frac{WN}{A}$

$= \frac{7 \times 3000}{5000}$

$B.P = 4.2 kW$.

iii) Brake thermal efficiency.

$\eta_{bth} = \frac{B.P}{Q_H} = \frac{B.P}{\dot{m}_f CV}$

$= \frac{4.2 \times 10^3}{0.343 \times 10^{-3} \times 43 \times 10^6}$

$\eta_{bth} = 28.48\%$

6. An eight cylinder, four stroke engine of 90 mm bore, 80 mm stroke and with a compression ratio of 7 is tested at 4500 rpm on a dynamometer which has 540 mm arm. During a 10 minute test, the dynamometer scale beam reading was 42 kg and the engine consumed 4.4 kg of gasoline having a calorific value of 44,000 kJ/kg. Air at 27°C and 1 bar was supplied to the carburetor at a rate of 6 kg/min. Find (i) the brake power, (ii) the brake mean effective pressure, (iii) the brake specific fuel consumption, (iv) the brake specific air consumption, (v) volumetric efficiency , (vi) the brake thermal efficiency and (vii) the air fuel ratio.

Sol: Data: $k=8$; $n=N/2$; $d=0.09\,m$; $L=0.08\,m$; $r_c=7$; $N=4500\,rpm$;

$r_{arm}=0.54\,m$; $t=10\,min$; $W=42\times9.81=412.02\,N$; $m_f=4.4\,kg$.

$C_V=44000\,kJ/kg$; $T_a=27+273=300\,K$; $p_a=1\,bar$; $\dot{m}_a=6\,kg/min$.

To find: i) bp ii) $P_{m_{bp}}$ iii) bsfc iv) bsac v) η_{vol} vi) η_{bth} vii) $\frac{A}{F}$

i) Brake Power

$$bp=\frac{2\pi NT}{60\times10^3}$$

$T=W\,r_{arm}$

$=42\times9.81\times0.54$

$T=222.49\,N\text{-}m.$

$$=\frac{2\times\pi\times4500\times222.49}{60\times10^3}$$

$bp=104.8\,kW \rightarrow$ (8 Engines)

ii) Brake mean effective pressure, $P_{m_{bp}}$.

$$P_{m_{bp}}=\frac{bp\times60\times10^3}{LAn.k}$$

$n=\frac{N}{2}$.

$$=\frac{104.8\times60\times10^3}{0.08\times\frac{\pi}{4}(0.09)^2\times\frac{4500}{2}\times8}$$

$P_{m_{bp}}=6.86\,bar.$

iii) Brake Specific fuel Consumption;

$$bsfc=\frac{\dot{m}_f}{bp}$$

$\dot{m}_f=\frac{m_f}{t}=\frac{4.4}{10}=0.44\,kg/min.$

$\dot{m}_f=0.44\times60=26.4\,kg/hr.$

$$=\frac{26.4}{104.8}$$

$=0.252\,kg/kWh.$

iv) Brake Specific Air consumption:

$$bsac=\frac{\dot{m}_a}{bp}=\frac{6\times60}{104.8}$$

$=3.43\,kg/kWh.$

v) Volumetric efficiency η_v

$$\eta_v = \frac{V_a}{V_{stroke}} = \frac{5.17}{9.16} = 56\%$$

From the characteristic gas equation $PV = mRT$

$$V_a = \frac{m_a R T_a}{P_a} = \frac{6 \times 287 \times 300}{1 \times 10^5} = 5.17 \ m^3/min.$$

$$V_{stroke} = LAnK. = 0.08 \times \frac{\pi}{4}(0.09)^2 \times \frac{4500}{2} \times 8 = 9.16 \ m^3/min.$$

vi) Brake thermal efficiency:

$$\eta_{bth} = \frac{B.P}{Q_H} = \frac{B.P}{\dot{m}_f \times C_V.}$$

$$= \frac{104.8 \times 10^3}{\frac{4.4}{10 \times 60} \times 44000 \times 10^3}$$

$$\eta_{b_{th}} = 32.4\%$$

vii) Air fuel ratio.

$$A/F = \frac{\dot{m}_a}{\dot{m}_f} = \frac{6 \ kg/min.}{\frac{4.4}{10} \ kg/min}$$

$$A/F = 13.63$$

7. A gasoline engine working on four- stroke develops a brake power of 20.9 kW. A Morse test was conducted on this engine and the brake power (kW) obtained when each cylinder was made inoperative by short circuiting the spark plug are 14.9, 14.3, 14.8 and 14.5 respectively. The test was conducted at constant speed. Find the indicated power, mechanical efficiency and brake mean effective pressure when all the cylinders are firing. The bore of the engine is 75mm and the stroke is 90 mm. The engine is running at 3000 rpm.

Sol: $bp_t = 20.9$ kW; $b_1 = 14.9$ kW; $b_2 = 14.3$ kW; $b_3 = 14.8$ kW; $b_4 = 14.$

$d = 0.075$ m; $L = 0.09$ m; $N = 3000$ rpm; $k = 4$

To find i) ip_t ii) η_{mech} iii) P_{mbp}.

i) Indicated power $ip_t = ip_1 + ip_2 + ip_3 + ip_4$.

$$= (bp_t - b_1) + (bp_t - b_2) + (bp_t - b_3) + (bp_t - b_4)$$

$$= (20.9 - 14.9) + (20.9 - 14.3) + (20.9 - 14.8) + (20.9 - 14.5)$$

OR

$$= 4\,bp_t - (b_1 + b_2 + b_3 + b_4) \rightarrow ip_t = k.bp_t - (b_1 + b_2 + .. b_k)$$

$ip_t = 25.1$ kW.

ii) Mechanical efficiency: $\eta_{mech} = \dfrac{bp_t}{ip_t}$

$$= \frac{20.9}{25.1}$$

$$\eta_{mech} = 83.2\%$$

iii) Brake mean effective pressure.

$$P_{mbp} = \frac{B.P \times 60 \times 10^3}{L A n k}$$

$n = \dfrac{N}{2}$

$$= \frac{20.9 \times 60 \times 10^3}{0.09 \times \frac{\pi}{4}(0.075)^2 \times \frac{3000}{2} \times 4}$$

$P_{mbp} = 5.25$ bar.

8. The following observations were recorded during a trail of a four – stroke, single cylinder oil engine. Duration of trial = 30 min ; oil consumed = 4 litres ; calorific value of oil = 43 MJ/kg ; specific gravity of fuel = 0.8 ; average area of the indicator diagram = $8.5cm^2$; length of the indicator diagram = 8.5 cm; Indicator spring constant = 5.5 bar/cm; brake load = 150 kg; spring balance reading = 20 kg; effective brake wheel diameter = 1.5 m ; speed = 200 rpm ; cylinder diameter = 30 cm ; stroke = 45 cm ; jacket cooling water = 10 kg/min ; temperature rise of cooling water = $36°C$. Calculate (i) indicated power, (ii) brake power, (iii) mechanical efficiency, (iv) brake specific fuel consumption, (v) indicated thermal efficiency, and (vi) heat carried away by cooling water.

Sol: $t = 30$ min; $m_f = 4000$ cc; $C_V = 43$ MJ/kg; $S = 0.8$; $A_i = 8.5\ cm^2$; $L_i = 8.5$ cm

$K_s = 5.5$ bar/cm; $W = 150 \times 9.81$ N; $r_{drum} = 1.5/2 = 0.75$ m; $N = 200$ rpm;

$d = 0.3$ m; $L = 0.45$ m; $\dot{m}_w = 10$ kg/min; $\Delta T_w = 36°C$; $S_{spring} = 20 \times 9.81$ N.

i) Indicated Power:

$$ip = \frac{P_{m_{ip}} L A n K}{60 \times 10^3}$$

$$P_{m_{ip}} = \frac{A_i}{L_i} \times K_s = \frac{8.5}{8.5} \times 5.5 = 5.5 \text{ bar}$$

$$n = N/2.$$

$$ip = \frac{5.5 \times 10^5 \times 0.45 \times \frac{\pi}{4} \times 0.3^2 \times \frac{200}{2} \times 1}{60 \times 10^3}.$$

$$ip = 29.16 \text{ kW}.$$

ii) Brake Power:

$$bp = \frac{2\pi N T}{60 \times 10^3}.$$

$$T = (W - S) \times r_{drum}.$$

$$T = (150 - 20) \times 9.81 \times 0.75$$

$$T = 956.48 \text{ N-m}.$$

$$bp = \frac{2 \times \pi \times 200 \times 956.48}{60 \times 10^3}.$$

$$bp = 20.05 \text{ kW}.$$

iii) Mechanical Efficiency:

$$\eta_{mech} = \frac{bp}{ip} = \frac{20.03}{29.16}$$

$$\eta_{mech} = 68.7\%.$$

iv) Brake specific fuel consumption:

$$bsfc = \frac{\dot{m}_f}{bp} = \frac{6.4}{20.05}.$$

$$bsfc = 0.32 \text{ kg/kWh}.$$

$$\dot{m}_f = \frac{m_f \times S}{1000 \times t} \times 60 = \frac{4000 \times 0.8 \times 60}{1000 \times 30} = 6.4 \text{ kg/hr}.$$

v) Indicated thermal efficiency:

$$\eta_{ith} = \frac{ip}{Q_H}$$

$$Q_H = \dot{m}_f \times C_v = \frac{6.4}{3600} \times 43 \times 10^6 = 76.44 \text{ kW}.$$

$$\therefore \eta_{ith} = \frac{29.16}{76.44} = 38.15\%$$

(X) Brake thermal eff.

$$\eta_{bth} = \frac{bp}{Q_H} = \frac{20.03}{76.44}$$

$$\eta_{bth} = 26.20\%.$$

vi) Heat carried away by the cooling water.

$$\dot{Q}_w = \dot{m}_w C_{pw} \Delta T_w.$$

$$= \frac{10}{60} \times 4.187 \times 10^3 \times 36$$

$$\dot{Q}_w = 25.12 \text{ kW}.$$

9. A four stroke gas engine has a cylinder diameter of 25 cm and stroke 45 cm. The effective diameter of the brake is 1.6 m.The observations made in a test of the engine were as follows. Duration of test = 40 min; Total number of revolutions = 8080 ; Total number of explosions = 3230; Net load on the brake = 80 kg ; mean effective pressure = 5.8 bar; Volume of gas used = 7.5m^3; Pressure of gas indicated in meter = 136 mm of3water (gauge);Atmospherictemperature=17°C; Calorific value of gas=19MJ/m^3 atNTP; Temperature rise of cooling water = 45°C; Cooling water supplied = 180 kg. Draw up a heat balance sheet and find the indicated thermal efficiency and brake thermal efficiency. Assume atmospheric pressure to be 760 mm of mercury.

Sol: Data: $d = 0.25$ m; $L = 0.45$ m; $r_{drum} = \frac{1.6}{2} = 0.8$ m; $t = 40$ min.

$N_{total} = 8080$; $N = \frac{8080}{40} = 202$ rpm; $n_{total} = 3230$; $n = \frac{3230}{40} = 80.75$

$W = 80 \times 9.81$ N; $P_{im} = 5.8$ bar; $m_f = 7.5$ m^3; $\dot{V}_f = \frac{7.5}{40} = 0.1875$ m^3/min.

$P_{guge} = 136$ mm of H_2O; $T_{atm} = 17 + 273 = 290$ K; $C_v = 19$ MJ/m^3;

$\Delta T_w = 45°C$; $\dot{m}_w = \frac{180}{40} = 4.5$ kg/min; $P_{atm} = 760$ mm of Hg.

To find i) η_{ith} ii) η_{bth} iii) Heat Balance sheet.

Indicated power $ip = \frac{P_m L A n K}{60 \times 10^3}$ $(\because K = 1)$

$$= \frac{5.8 \times 10^5 \times 0.45 \times \frac{\pi}{4}(0.25)^2 \times 80.75}{60 \times 10^3} \times 1$$

$$ip = 17.24 \text{ kW}.$$

Absolute pressure of the gas;

$$P_{gas} = P_{gauge} + P_{atm.} = \frac{H_w}{S_{Hg}} + P_{atm.}$$

$$= \frac{136}{13.6} + 760$$

$$P_{gas} = 770 \text{ mm of Hg.}$$

$PV = mRT$; $P_{NTP} V_{NTP} = mRT_{NTP}$;

$$V_{NTP} = \frac{V}{T} * \frac{T_{NTP}}{P_{NTP}} * P.$$

$$= \frac{0.1875}{290} * \frac{298}{760} \times 770$$

$$V_{NTP} = 0.195 \text{ m}^3/\text{min.}$$

Heat supplied $Q_H = V_{NTP} * CV_{NTP}$.

$$= 0.195 * 19 \times 10^6.$$

$$Q_H = 3705 \text{ KJ/min.}$$

Brake power $bp = \frac{2\pi NT}{60 \times 10^3}$.

$T = W r.$

$= 80 \times 9.81 \times 0.8.$

$T = 627.84$ N-m.

$$= \frac{2 \times \pi \times 202 \times 627.84}{60 \times 10^3}$$

$bp = 13.28$ KJ/s (or) KW.

Heat equivalent of bp in KJ/min.

$$Q_{bp} = 13.28 \times 60 = 796.8 \text{ KJ/min.}$$

Heat taken away by cooling water.

$$Q_w = m_w C_{pw} \Delta T_w.$$

$$= 4.5 \times 4.187 \times 45$$

$$Q_w = 847.86 \text{ KJ/min.}$$

Frictional power $FP = ip - bp$.

$= 17.24 - 13.28$.

$FP = 3.96$ KW.

Heat equivalent of $Q_{FP} = 3.96 \times 60 = 237.6$ KJ/min.

Unaccounted heat → $U_H = Q_H - (Q_{bp} + Q_w + Q_{fp})$

$= 3705 - (796.8 + 847.86 + 237.6)$

$U_H = 1822.74$ KJ/min.

Heat balance sheet on minute basis.

Item No.	Particulars.	Heat Energy Input KJ/min	Heat Energy Input %	Heat Energy Spent KJ/min	Heat Energy Spent %
1	Heat supplied by gas	3705	100		
2	Heat equivalent of bp.			796.8	21.5
3.	Heat lost to cooling water.			847.86	22.8
4.	Heat equivalent of F.P.			237.6	6.3
5.	Unaccounted heat. (By difference)			1822.74.	49.4
	Total.	3705	100	≃3705	100.

10. A test on a two-stroke engine gave the following results at full load.
Speed = 350 rpm; Net brake load = 65 kg ; mean effective pressure = 3 bar ; Fuel consumption = 4 kg/h ; Jacket cooling water flow rate = 500 kg/h ; jacket water temperature at inlet = $20°C$; jacket water temperature at outlet = $40°C$; Test room temperature = $20°C$; Temperature of exhaust gases = $400°C$; Air used per kg of fuel = 32 kg ; cylinder diameter = 22 cm ;stroke = 28 cm; effective brake diameter = 1 m ; Calorific value of fuel = 43 MJ/kg ; Mean specific heat of exhaust gases = 1 kJ/kg-K. Find indicated power, brake power and draw up a heat balance for the test in kW and in percentage.

Sol: Data: $n = N = 350$ rpm; $W = 65 \times 9.81$ N; $P_{im} = 3$ bar; $\dot{m}_f = 4$ kg/hr.

$\dot{m}_w = 500$ kg/h; $T_{wi} = 20°C$; $T_{we} = 40°C$; $T_{atm} = 20°C$; $T_{exh} = 400°C$

$\left(\frac{A}{F}\right) \frac{\dot{m}_a}{\dot{m}_f} = 32$; $d = 0.22$ m; $L = 0.28$ m; $r_{drum} = \frac{1}{2} = 0.5$ m; $C_v = 43$ MJ/kg.

$C_{p_{gas}} = 1$ kJ/kg-K. To find i) ip ii) bp iii) Heat balance in kW

Indicated power $ip = \frac{P_m L A n}{60 \times 10^3}$ [n = N]

$$= \frac{3 \times 10^5 \times 0.28 \times \frac{\pi}{4}(0.22)^2 \times 350}{60 \times 10^3}$$

$ip = 18.62$ kW.

Brake power $bp = \frac{2\pi NT}{60 \times 10^3} = \frac{2 \times \pi \times 350 \times 65 \times 9.81 \times 0.5}{60 \times 10^3} = 11.68$ kW.

Heat supplied $Q_H = \dot{m}_f \times C_v$.

$$= \frac{4}{3600} \times 43 \times 10^6$$

$Q_H = 47.8$ kW.

Heat taken away cooling water.

$$Q_w = \dot{m}_w C_{pw}(T_{we} - T_{wi})$$

$$= \frac{500}{3600} \times 4.187(40 - 20)$$

$Q_w = 11.63$ kW.

Heat carried away by exhaust gases.

$$Q_{exh} = \dot{m}_g C_{pg}(T_{g_{exh}} - T_{atm})$$

$m_g = \dot{m}_a + \dot{m}_f = 32\dot{m}_f + \dot{m}_f = 32 \times 4 + 4 = 132 \text{ kg/hr.}$

$$Q_{exh} = \frac{132}{3600} \times 1 \left(400 - 20\right)$$

$$Q_{exh} = 13.93 \text{ kW.}$$

Unaccounted heat $= Q_H - (bp + Q_{exh} + Q_w)$

$= 47.8 - (11.68 + 13.93 + 11.63)$

$= 10.56 \text{ kW.}$

Heat balance sheet:

Item No.	Particulars.	Heat Energy Input		Heat Energy Spent	
		kW	%	kW.	%
1	Heat supplied by the fuel	47.8	100.		
2	Heat equivalent to bp.			11.68.	24.43
3.	Heat lost to cooling H_2O			11.63.	24.41
4.	Heat lost to Exhaust gas			13.93.	29.1
5.	Unaccounted heat (by difference)			10.56.	22.06.
	Total.	47.8	100	47.8	100

11. In a trial of a single-cylinder oil engine working on dual cycle, the following observations were made: Compression ratio=15; Oil consumption: 10.2 kg/h; Calorific value: 43890 kJ/kg; Air consumption: 3.8 kg/min; Speed= 1900 rpm; Torque on the brake drum: 186 N-m; Quantity of the cooling water used=15.5 kg/min; Temperature rise=36°C; Exhaust gas temperature=410°C; Room temperature=20°C, C_p of the exhaust gases=1.17 kJ/kg-K. Calculate (i) Brake power. (ii) Brake specific fuel consumption. (iii). Brake thermal efficiency. Draw heat balance sheet on minute basis.

Sol: Data: $K=1$; $r_c=15$; $\dot{m}_f=10.2$ kg/h; $C_V=43890$ KJ/kg; $\dot{m}_a=3.8$ kg/min; $T=186$ N-m; $N=1900$ rpm; $\dot{m}_w=15.5$ kg/min; $\Delta T_w=36°C$; $T_g=410°C$; $T_{atm}=20°C$; $C_{pg}=1.17$ KJ/kg-K. To find: i) bp ii) bsfc iii) η_{bth}. iv) Heat balance sheet in min basis.

i) Brake power: $bp=\frac{2\pi NT}{60\times10^3}=\frac{2\times\pi\times1900\times186}{60\times10^3}=37$ KW.

ii) $bsfc=\frac{\dot{m}_f}{bp}=\frac{10.2}{37}=0.276$ kg/Kwh.

iii) Brake thermal efficiency $\eta_{bth}=\frac{bp}{Q_H}=\frac{bp}{\dot{m}_f\times C_V}$.

$$=\frac{37\times10^3}{\frac{10.2}{3600}\times43890\times10^3}$$

$$\eta_{bth}=29.75\%$$

Heat Balance sheet calculation: (min basis)

a) Heat supplied $Q_H=\dot{m}_f\times C_V$.

$$=\frac{10.2}{60}\times43890\times10^3$$

$$Q_H=7461 \text{ KJ/min}$$

b) Heat equivalent of bp:

$$Q_{bp}=bp\times60=37\times60=2220 \text{ KJ/min}$$

c) Heat carried by the cooling water:

$$Q_w=m_w C_{pw}\Delta T_w$$

$$=15.5\times4.187\times36$$

$$Q_w=2326 \text{ KJ/min}$$

d) Heat carried by exhaust gases.

$$Q_g = m_g C_{pg} (T_g - T_{atm})$$

$$= 3.97 \times 1.17 (410 - 20)$$

$$Q_g = 1811.5 \text{ KJ/min.}$$

$$m_g = \dot{m}_a + \dot{m}_f$$

$$= 3.8 + \frac{10.2}{60}$$

$$m_g = 3.97 \text{ kg/min.}$$

e) Unaccounted heat (difference).

$$Q_{un} = Q_H - (Q_{bp} + Q_w + Q_g)$$

$$= 7461 - (2220 + 2336 + 1811.5)$$

$$Q_{un} = 1093.5 \text{ KJ/min.}$$

Heat balance sheet.

Item No.	Particulars.	Heat Energy Input		Heat Energy Spent	
		KJ/min	%	KJ/min	%
1	Heat supplied by the fuel.	7461	100.		
2	Heat equivalent to bp.			2220	29.8.
3.	Heat taken by cooling water			2336	31.3.
4	Heat taken by exhaust gases.			1811.5	24.3.
5.	Unaccounted heat (by difference).			1093.5	14.6
	Total.	7461	100.	7461	100.