INTERNAL COMBUSTION ENGINES

What is a heat engine?

- A heat engine is a device which works on a cycle, receives heat energy liberated by burning of fuel (chemical energy) and produces the work.

How heat engines are classified?

- Heat engines are classified in many ways.
- But according to the place where fuel is burnt, heat engines are classified as
  (i) External combustion engine (EC engine).
  (ii) Internal combustion engine (IC engine).

Difference between EC and IC engine

External Combustion Engine	Internal Combustion Engine
• In this type of heat engine, fuel is burnt outside the engine i.e. in a furnace.	• In this type of heat engine, fuel is burnt inside the engine i.e. in an engine cylinder.
• Large in size.	• Compact in size.
• High initial cost.	• Low initial cost.
• Cheaper fuels may be used like, coal, wood etc.	• Fuels are costly like petrol, diesel etc.
• Less suitable for mobile application.	• Suitable for mobile application.

Classification of I.C. Engine

According to the Cycle of Operation	Two Stroke Cycle Engine	• An engine in which during two strokes of piston (two times movement of piston from one dead centre to another dead centre), there is only one power stroke, is called two stroke cycle engine.
	Four Stroke Cycle Engine	• An engine in which during four strokes of piston (four times movement of piston from one dead center to another dead center), there is only one power stroke, is called four stroke cycle engine.

According to Thermodynamic Cycle of Combustion	Otto Cycle Engine	• An engine which works on Otto cycle is called Otto cycle engine. • All petrol engine works on Otto cycle.
	Diesel Cycle Engine	• An engine which works on diesel cycle is called Diesel cycle engine. • All diesel engine works on Diesel cycle.
	Duel Cycle Engine	• An engine which works on duel cycle is called Duel cycle engine.

According to Number of Cylinders	Single Cylinder Engine	• An engine in which there is only one cylinder is called single cylinder engine.
	Multi Cylinder Engine	• An engine, in which there is more than one cylinder is called multi cylinder engine.

According to Speed of the Engine	• Low Speed Engine
	• Medium Speed Engine
	• High Speed Engine

According to Action of Product of Combustion upon the Piston	Single Acting Engine	• An engine in which product of combustion acts on only one side of piston is known as single acting engine.
	Double Acting Engine	• An engine in which product of combustion acts on both the sides of piston, is known as double acting engine.

According to Arrangement of Cylinder/Piston	Horizontal Engine	• An engine in which cylinder is located horizontally is known as horizontal engine.
	Vertical Engine	• An engine in which cylinder is located vertically is known as vertical engine.
	V- Type Engine	• An engine in which, two cylinders are located in v-shape is called v-type engine.

	Y- Type Engine	• An engine in which cylinders are located in y-shape is called y-shape engine.
	Radial Engine	• An engine in which cylinders are located radically is known as radial engine
	Opposed Cylinder engine	• An engine in which two cylinders are located opposite to each other is known as opposed cylinder engine.
	Opposed Piston engine	• An engine in which two pistons are located opposite to each other is known as opposed piston engine.
	In- Line engine	• An engine in which cylinders are arranged in one line is called in line engine.

According to Method of Governing the Engine	• It is essential to run the IC Engine at constant speed. • Using different governing method as written below, IC engine can be run at constant speed.
	Quantity Governing Engine
	Quality Governing Engine
	Hit and Miss Governing

According to Method of Igniting Fuel	Spark Ignition System	• An engine in which fuel is burnt due to spark is known as spark ignition engine. • It is also known as **SI Engine**. • All petrol engines are SI engines. • It requires spark plug.
	Compression Ignition System	• An engine in which fuel is burnt due to high compression of air is known as compression ignition engine. • It is also known as **CI Engine**. • All diesel engines are CI engines. • It requires fuel pump and fuel Injector.
	Electronics Ignition System	• In this type of system fuel is burnt using electronics system.

According to Method of Cooling the Cylinder	Air cooled engine	• An engine in which air is used for cooling the engine cylinder known as air cooled engine. • Extended surfaces (Fins) are provided outside the cylinder for air cooling system.
	Water cooled engine	• An engine in which water/liquid is used for cooling the engine cylinder is known as water cooled engine. • Radiator, upper and lower hose connections and water cooling channel in engine cylinder are required for water cooling system.

According to Method of Fuel Supply to the Engine Cylinder	Carburetor Engine	• An engine in which mixture of fuel (petrol) and air is supplied to IC engine from carburetor is known as carburetor engine. • All petrol engines are carburetor type engines.
	Air injection Engine	• An engine in which only air is supplied to IC engine in known as air injection engine. • All diesel engines are air injection type engines.

According to Suction Pressure	Naturally Aspirated Engine	• An engine in which air and petrol (for petrol engine) or air (for diesel engine) is supplied to engine cylinder at atmospheric pressure is known as naturally aspirated engine.
	Super Charged Engine	• An engine in which air and petrol (for petrol engine) or air (for diesel engine) is supplied to engine cylinder after increasing its pressure using compressor is known as super charged engine. • It is used for engines at high altitudes.

According to Uses/Application	• Stationary Engine
	• Portable Engine
	• Automobile Engine
	• Tractor Engine
	• Aero Engine
	• Marine Engine

Different Parts of an I.C. Engine

Cylinder
- It is the fixed part of an engine in which piston reciprocates.
- Fuel burns inside the cylinder.
- In water cooled engine, cylinder wall contains the passage to circulate the cooling water to cool the cylinder.

Cylinder Head
- Top portion of the cylinder is covered with cylinder head.
- Valve and valve mechanisms of 4-stroke IC engine are located in cylinder head.
- Spark plug of petrol engine and fuel injector of diesel engine is located on the cylinder head.

Piston
- The reciprocating part of an IC engine is known as piston
- It reciprocates in the cylinder.
- In four stroke engine, flat shape of piston and in two stroke engine, crown shape of the piston is provided.

Piston Rings
- The metallic rings placed on the periphery of a piston are known as piston rings.
- They are used to create gas-tight joint between cylinder and piston.

Connecting Road
- It connects the piston to the crank.

Crank
- Crank connects the connecting road to crank shaft.

Crank Shaft
- It is a shaft which rotates as the piston of IC engine reciprocates.

Gudgeon Pin (piston pin)
- The pin connecting one end of connecting rod with piston is known as piston pin.

Crank Pin
- Pin connecting other end of connecting road with crank is known as crank pin.

Fly Wheel

- A wheel connected to the crank shaft is known as flywheel.
- It is used to control the speed of IC engine.
- It stores the excess energy during power stroke and gives back during other strokes.

Crankcase

- It is the enclosed part of an IC engine in which crank is enclosed.

Different Parts of an I.C. Engine (Only for Petrol Engine)

Carburetor

- It is used only in petrol engine.
- It is used to filter and mix air with petrol in proper proportion.

Spark Plug

- It is also used only in petrol engine.
- It is used to produce an arc to ignite (burn) the mixture of air and petrol (charge).

Different Parts of an I.C. Engine (Only for Diesel Engine)

Diesel Fuel Pump (Fuel pump)

- It is used only in diesel engine.
- It is used to increase the pressure of diesel more than pressure of air.

Fuel Injector (Fuel Atomizer)

- It is also used only in diesel engine.
- It is used to spray the high pressure diesel into the cylinder.

Working of Four Stroke Cycle Petrol Engine

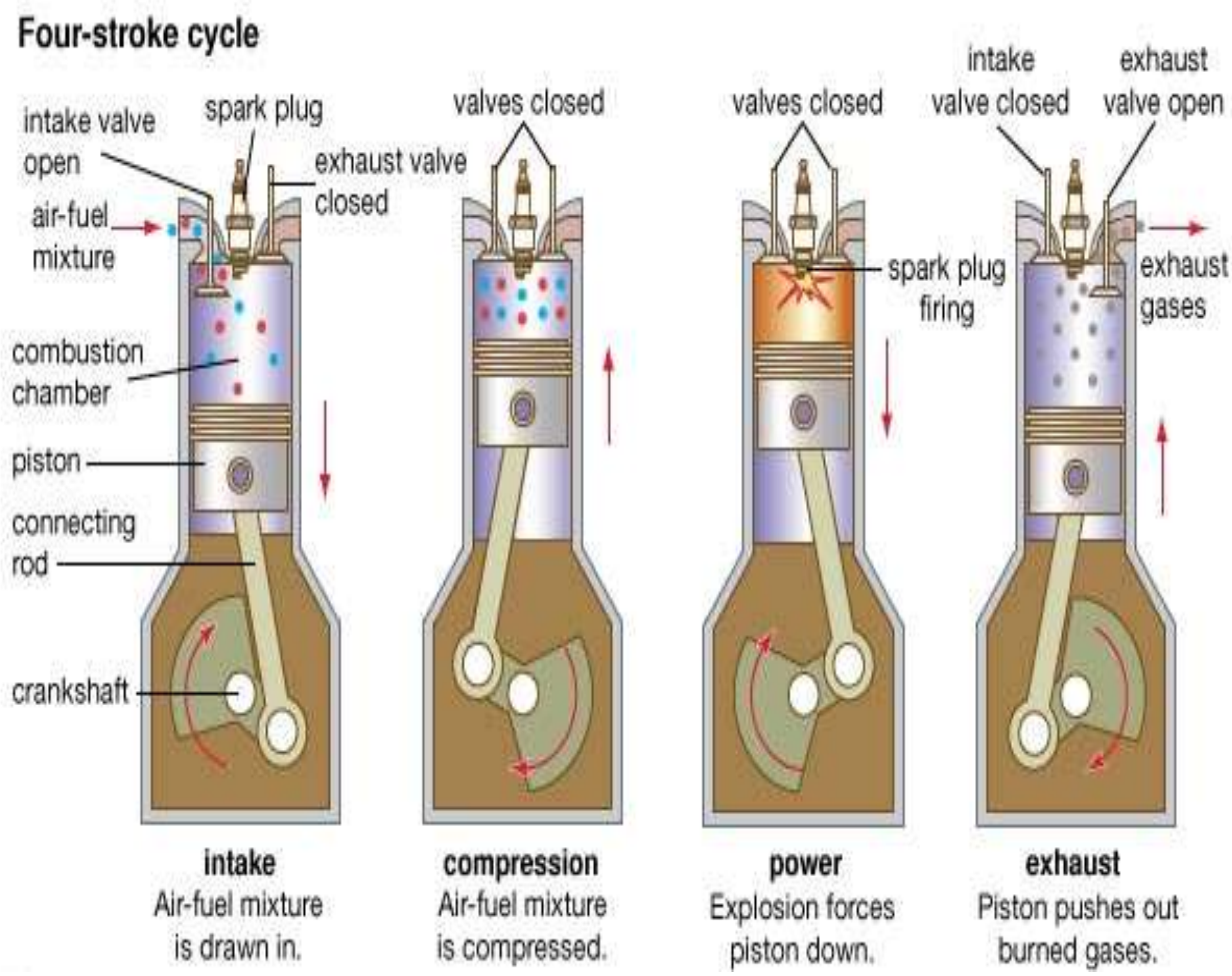
- The working of four stroke petrol engine is divided into four strokes viz., (1) Suction Stroke, (2) Compression Stroke, (3) Expansion Stroke and (4) Exhaust Stroke.

First Stroke (Suction Stroke)	• Piston moves from TDC to BDC for vertical engine. • Crank rotates from 0° to 180°. • During this stroke, ○ Inlet valve is open and Exhaust valve is close. ○ Mixture of air and petrol (charge) from carburetor enters into the cylinder.
Second Stroke (Compression Stroke)	• Piston moves from BDC to TDC for vertical engine. • Crank rotates from 180° to 360° (0°). • During this stroke, ○ Both the valves are close. ○ Mixture of air and petrol (charge) is compressed to high pressure and high temperature.

AT THE END OF COMPRESSION STROKE
• Spark is generated inside the cylinder using spark plug. • Due to spark, burning of petrol takes place. • High pressure and high temperature ~~hot~~ gases are generated which exerts pressure on the piston.

Third Stroke (Power Stroke, Expansion Stroke)	• Piston moves from TDC to BDC for vertical engine. • Crank rotates from 0° to 180°. • During this stroke, ○ Both the valves are close. ○ Under the action of high pressure and high temperature hot gases piston moves from TDC to BDC. ○ Work is delivered by the engine during the stroke.
Fourth Stroke (Exhaust stroke, Scavenging)	• Piston moves from BDC to TDC for vertical engine. • Crank rotates from 180° to 360° (0°). • During this stroke, ○ Inlet valve is close and Exhaust valve is open. ○ Product of combustion (exhaust gases, burnt gases) is thrown out to the atmosphere from exhaust valve.
• In this type of IC engine carburetor and spark plug are used. • Out of four strokes of piston, there is only one power stroke. • Out of two complete rotation of crank, there is only one power stroke.	

Working of Four Stroke Cycle Petrol Engine



Working of Four Stroke Cycle Diesel Engine

- The working of four stroke diesel engines is also divided into four strokes viz., (1) Suction, (2) Compression, (3) Expansion and (4) Exhaust Stroke.

First Stroke (Suction Stroke)	• Piston moves from TDC to BDC for vertical engine. • Crank rotates from 0^{O} to 180^{O}. • During this stroke, o Inlet valve is open and Exhaust valve is close. o Only air from air filter enters into the cylinder.
Second Stroke (Compression Stroke)	• Piston moves from BDC to TDC for vertical engine. • Crank rotates from 180^{O} to 360^{O} (0^{O}). • During this stroke, o Both the valves are close. o Air is compressed to high pressure and high temperature. o At the end of compression stroke, temperature of air is more than the ignition temperature of diesel.

AT THE END OF COMPRESSION STROKE
• Diesel is compressed using diesel fuel pump (fuel pump) and sprayed into cylinder using fuel injector (fuel atomizer). • As the temperature of compressed air inside the cylinder is more than the ignition temperature of diesel, diesel automatically starts burning (igniting). • High pressure and high temperature hot gases are generated which exerts pressure on the piston.

Third Stroke (Power Stroke, Expansion Stroke)	• Piston moves from TDC to BDC for vertical engine. • Crank rotates from 0^{O} to 180^{O}. • During this stroke, o Both the valves are close. o Under the action of high pressure and high temperature hot gases piston moves from TDC to BDC. o Work is delivered by the engine during the stroke.
Fourth Stroke (Exhaust stroke, Scavenging)	• Piston moves from BDC to TDC for vertical engine. • Crank rotates from 180^{O} to 360^{O} (0^{O}). • During this stroke, o Inlet valve is close and Exhaust valve is open. o Product of combustion (exhaust gases, burnt gases) is thrown out to the atmosphere from exhaust valve.
• In this type of IC engine, diesel fuel pump & fuel Injector are used. • Out of four strokes of piston, there is only one power stroke. • Out of two complete rotation of crank, there is only one power stroke.	

Working of Two Stroke Petrol Engine

- This type of engine contains ports instead of valves.
- It contains inlet, exhaust and transfer port which opens and close due to movement of piston.

First Stroke	• Piston is at TDC. • Inlet port located below piston is open at that time. • Thus, mixture of petrol and air from carburetor enters into cylinder below the piston (crankcase). • Exhaust and transfer ports are close. • Piston is moving from TDC to BDC. • So, there is a power stroke (expansion stroke) above piston and suction stroke below the piston. • When piston moves down from TDC to BDC, Inlet port is closed and suction stroke below the piston ends. • When piston moves further down, exhaust port open. • Exhaust gases are thrown out to the atmosphere. • When piston moves down further, transfer port opens, due to which fresh air and petrol mixture transfers from below the piston to above the piston. • Thus, two processes happen simultaneously viz., an exhaust stroke above piston and transfer of mixture from below piston to above piston. • When piston reaches at BDC, first stroke is over.
Second Stroke	• Piston moves from BDC to TDC. • Initially it closes the transfer port and then exhaust port. • As both the ports are close, mixture of air and petrol is compressed above the piston. So, compression stroke starts above the piston. • When piston moves up further, inlet port below the piston opens. • So, fresh mixture of air and petrol from carburetor enters in the engine below the piston. • Thus, above piston compression stroke and below the piston suction stroke. • Piston reaches at the TDC and compression is over.

AT THE END OF COMPRESSION STROKE
• Spark is generated by spark plug. • Petrol ignites and high pressure and high temperature gases are generated which exerts pressure on the piston and again first stroke starts. (cycle repeats)
• In this type of I.C. engine, out of two strokes of piston, there is only one power stroke. • Out of one complete rotation of crank, there is only one power stroke.

Working of Two Stroke Diesel Engine

- Working of two stroke diesel engine is same as working of two stroke petrol engine except
  - Only air enters through inlet port.
  - Only air is compressed during compression stoke and
  - Diesel is compressed using fuel pump and injected using fuel injector at the end of compression stroke.

Diff. Between 4 Stroke & 2 Stroke Engine

Criteria	4 - Stroke	2 - Stroke
Moving Parts	More	Less
Power Stroke	One in 2 Rev.	One in 1 Rev.
Overall Size	Large	Small
Engine Wt.	Heavy	Light
Fuel Cons.	Less	More
Ther. Effi.	More	Less
Scavenging	Effective	Not Effective
Power Gener.	Half	Double
Application	Heavy	Very Light

Diff. Between 4 Stroke & 2 Stroke Engine

Criteria	4 - Stroke	2 - Stroke
Valves	Yes	No, Ports
Mechanism-Valve Operation	Yes	No
Piston	Flat	Curved

Diff. Between 4 Stroke & 2 Stroke Engine

Criteria	4 - Stroke	2 - Stroke
Power Stroke	One in 4-S	One in 2-S
Energy Fluctuation	More	Less
Flywheel Size	Heavier	Lighter
Temp. of Engine	Cooler	Hotter
Volu. Effi.	More	Less

Some Important Equations to Solve the Problems

Piston Speed

$$V_P = \frac{2 \times L \times N}{60} \ \ in\ \boldsymbol{m/sec}$$

Where,
L = Length of stroke (stroke length) in **m**.
N = Engine speed in revolution per minute, **rpm**.

Indicated Power

$$IP = \frac{P_m L A n}{60} \times Number\ of\ Cylinder \ \ in\ \ \boldsymbol{Watt}$$

Where,

$$P_m = Indicated\ mean\ effective\ pressure\ in\ {}^{\boldsymbol{N}}/_{\boldsymbol{m^2}} = mep = imep$$

$$= \ Spring\ Scale\ \left(\frac{{}^{\boldsymbol{N}}/_{\boldsymbol{m^2}}}{\boldsymbol{cm}}\right) \times \frac{Area\ of\ indicator\ Diagram\ (\boldsymbol{cm^2})}{Length\ of\ indicator\ Diagram\ (\boldsymbol{cm})}$$

$$A = Area\ of\ cylinder(piston) = \frac{\pi}{4} D^2 \ \ in\ \boldsymbol{m^2}$$

$$D = Inside\ diameter\ of\ cylinder = outside\ diameter\ of\ piston$$

$$= cylinder\ bore\ in\ \boldsymbol{m}$$

$$n = \frac{Number\ of\ power\ stroke}{minute} = \frac{N}{2}\ for\ 4 - stroke\ \ \& = N\ for\ 2 - stroke\ engine$$

Brake Power

$$BP\ in\ \boldsymbol{Watt} = \frac{2\pi NT}{60} = \frac{P_{mb}LAn}{60} \times Number\ of\ Cylinder$$

Where,

$T = Brake\ Torque\ in\ \boldsymbol{N-m}$

$T = Effective\ load\ on\ brake\ drum\ in\ \boldsymbol{N}\ \times Effective\ radius\ of\ brake\ drum\ in\ \boldsymbol{m}$

$T = (W - S)\ in\ \boldsymbol{N}\ \times \left(\frac{D_{brakedrum} + d_{rope}}{2}\right)\ in\ \boldsymbol{m}$

$W = Load\ on\ brake\ drum\ in\ \boldsymbol{kg}\ \times 9.81\ in\ \boldsymbol{N}$

$S = Spring\ Balance\ reading\ in\ \boldsymbol{kg}\ \times 9.81\ in\ \boldsymbol{N}$

$D_{brakedrum} = Diameter\ of\ brake\ drum\ in\ \boldsymbol{m}$

$d_{rope} = Diameter\ or\ rope\ in\ \boldsymbol{m}$

$P_{mb} = Brake\ mean\ effective\ pressure\ in\ \boldsymbol{N}/\boldsymbol{m^2} = bmep$

$A = Area\ of\ cylinder(piston) = \frac{\pi}{4}D^2\ \ in\ \boldsymbol{m^2}$

$D = Inside\ diameter\ of\ cylinder = outside\ diameter\ of\ piston$
$\qquad = cylinder\ bore\ in\ \boldsymbol{m}$

$$n = \frac{Number\ of\ power\ stroke}{minute} = \frac{\boldsymbol{N}}{\boldsymbol{2}}\ for\ 4-stroke\ \ \& = \boldsymbol{N}\ for\ 2-stroke\ engine$$

Friction Power

$$Friction\ Power, FP = IP - BP$$

Mechanical Efficiency

$$Mechanical\ Efficiency, \eta_{mechanical} = \frac{BP\ in\ \boldsymbol{kW}}{IP\ in\ \boldsymbol{kW}} X100$$

Thermal efficiency

$$Brake\ Thermal\ Efficiency, \eta_{Brake\ Thermal} = \frac{BP\ in\ \boldsymbol{kW}}{m_{fuel}\ in\ \frac{\boldsymbol{kg}}{\boldsymbol{sec}} \times CV\ in\ \frac{\boldsymbol{kJ}}{\boldsymbol{kg}}} \times 100$$

$$Indicated\ Thermal\ Efficiency, \eta_{Indicated\ Thermal} = \frac{IP in\ \boldsymbol{kW}}{m_{fuel} in\ \frac{\boldsymbol{kg}}{\boldsymbol{sec}} \times CV in\ \frac{\boldsymbol{kJ}}{\boldsymbol{kg}}} \times 100$$

Where,

$$m_{fuel} = mass\ of\ fuel\ used\ in\ \frac{\boldsymbol{kg}}{\boldsymbol{sec}} = \frac{mass\ of\ fuel\ used\ in\ \frac{\boldsymbol{kg}}{\boldsymbol{hr}}}{3600}$$

$$m_{fuel}\ in\ \frac{\boldsymbol{kg}}{\boldsymbol{sec}} = Volume\ of\ fuel\ used\ in\ \frac{\boldsymbol{m^3}}{\boldsymbol{sec}} \times Specific\ gravity\ of\ fuel\ \times 1000$$

$$1\ \boldsymbol{litre} = 10^{-3}\boldsymbol{m^3}\ \ or\ \ 1\ \boldsymbol{m^3} = 1000\ \boldsymbol{litre}$$

$$CV = Calorific\ Value\ of\ fuel\ in\ \boldsymbol{KJ/kg}$$

Relative efficiency

$$\eta_{relative} = \frac{\eta_{Indicated\ Thermal}}{\eta_{air\ standard}} \times 100$$

$$\eta_{relative} = \frac{\eta_{Brake\ Thermal}}{\eta_{air\ standard}} \times 100$$

Where,

$$\eta_{air\ standard} = 1 - \frac{1}{\gamma} \times \frac{(T_4 - T_1)}{(T_3 - T_2)}$$

$$= 1 - \frac{1}{(r)^{\gamma-1}} \times \frac{(\rho^{\gamma} - 1)}{\gamma \times (\rho - 1)}\ \ in\ case\ of\ \boldsymbol{diesel\ engine}$$

$$\eta_{air\ standard} = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)} = 1 - \frac{1}{(r)^{\gamma-1}} = 1 - \frac{T_1}{T_2}\ in\ case\ of\ \boldsymbol{petrol\ engine}(\boldsymbol{otto\ cycle})$$

Volumetric Efficiency

$$\eta_{volumetric} = \frac{Actual\ volume\ of\ (air + petrol) or\ air\ suckedin\ cylinder\ at\ atm.condition}{Swept\ volume, V_s} \times 100$$

Specific Fuel Consumption

$$Brake\ specific\ fuel\ consumption, bsfc\ in\ \frac{\boldsymbol{kg}}{\boldsymbol{kWh}} = \frac{m_{fuel}\ in\ {}^{\boldsymbol{kg}}/_{\boldsymbol{hr}}}{BP\ in\ \boldsymbol{kW}}$$

$$Indicated\ specific\ fuel\ consumption, isfc\ in\ \frac{\boldsymbol{kg}}{\boldsymbol{kWh}} = \frac{m_{fuel}\ in\ {}^{\boldsymbol{kg}}/_{\boldsymbol{hr}}}{IP\ in\ \boldsymbol{kW}}$$

Specific Output

$$Specific\ Output\ in\ \frac{\boldsymbol{kW}}{\boldsymbol{m^2}} = \frac{BP\ in\ \boldsymbol{kW}}{A\ in\ \boldsymbol{m^2}}$$

Solved Numerical

1	Following readings were taken during test of single cylinder four stroke oil engines. Cylinder diameter = 250 mm. Stroke length = 400 mm. Mean effective pressure = 6.5 bar. Engine speed = 250 rpm. Net load on brake = 1080 N. Effective diameter of brake = 1.5 m. Fuel used per hr = 10 kg. Calorific value of fuel = 44300 kJ/kg. Calculate (1) Indicated power, (2) Brake power, (3) Mechanical efficiency & (4) Indicated thermal efficiency.
	Dia. Of Cylinder, D = 0.25 m Area of Cylinder, A = (3.14/4) * 0.25 * 0.25 = 0.0490625 m^2 Stroke Length, L = 0.4 m **Torque** Torque, T =(W-S) *$R_{effective}$ =1080* 0.75 = 810 Nm. **Mean Effective Pressure** imep = P_m =650000 N/m^2 **Fuel used** m_f = 10 kg/hr =10/3600 kg/sec = 0.0027777 kg/sec. **Indicated Power** $IP = \frac{P_m * L * A * N}{60 * 1000 * 2} * \text{Number of Cylinder}$ $IP = \frac{650000 * 0.4 * 0.0490625 * 250}{60 * 1000 * 2} * 1 = 26.5755 \text{ kW}$ **Brake Power** $BP = \frac{2 * \pi * N * T}{60 * 1000} = \frac{2 * 3.14 * 250 * 810}{60 * 1000} = 21.195 \text{ kW}$ **Mechanical efficiency** $\eta_{Mech} = \frac{BP}{IP} = \frac{21.195}{26.5755} = 0.79754 = 79.754\,\%$ **Indicated Thermal efficiency** $\eta_{indicated\ Thermal} = \frac{IP}{m_f * CV} = \frac{26.5755}{0.0027777 * 44300} = 0.215969 = 21.5969\,\%$

2	A six Cylinder 4-stroke I.C engine is to develop 89.5 kW indicated power at 800 rpm. The stroke to bore ratio is 1.25:1. Assuming mechanical efficiency of 80% and brake mean effective pressure of 5 bar. Determine the diameter and stroke of engine.
	Six cylinder four stroke IC Engine IP = 89.5 kW L/D = 1.25 η_{Mech} = 0.8 P_{mb} = 5 bar = 500000 N/m^2 **Brake Power** BP = IP * (Mechanical Efficiency)= 89.5*0.8 =71.6 kW $\text{Brake Power, BP} = \frac{P_{mb}*L*A*N}{60*1000*2} * \text{Number of Cylinder}$ (This equation is based used only when brake mean effective pressure is given or we have to calculate the brake mean effective pressure.) $71.6 = \frac{500000 * L * A * 800}{60 * 1000 * 2} * 6$ L * A = 0.00358 $L * \frac{\pi}{4} D^2 = 0.00358$ $\frac{L}{D} * \frac{\pi}{4} D^3 = 0.00358$ $1.25 * \frac{\pi}{4} D^3 = 0.00358$ $D^3 = 0.0036484076$ **D = 0.154 m and L = 0.1925 m**

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