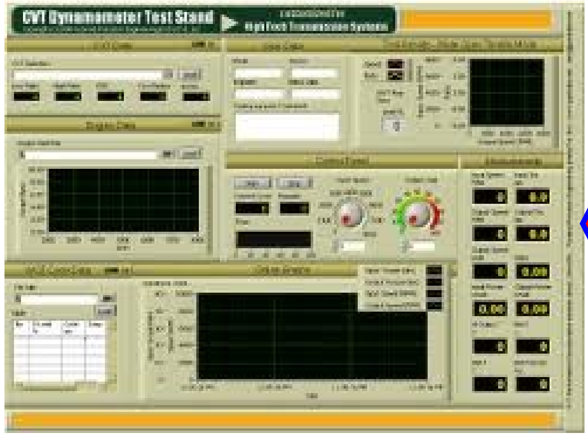
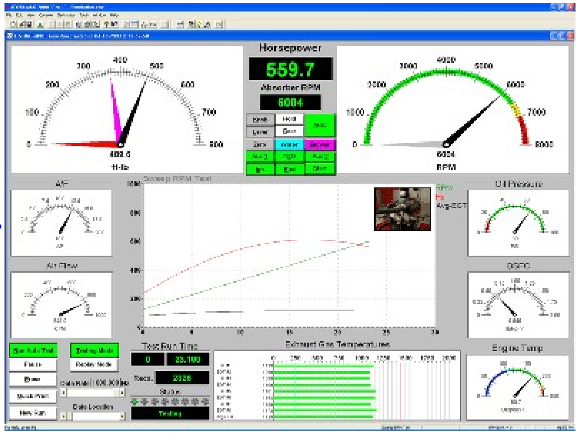
ENGINE PERFORMANCE AND TESTING

Basics of Engine Performance Parameters





- ❖ The term performance usually means how well an engine is doing its job in relation to the input energy or how effectively it provides useful energy in relation to some other comparable engines.
- ❖ The practical engine performance parameters of interest are;
  - ➢ Power,
  - ➢ Efficiencies
  - ➢ Fuel Consumption
- ❖ Every engine has a practical limit of maximum power and efficiency.
- ❖ IC engine generally operates within a useful range of speed. At each speed the power output varies and it has maximum usable value.
- ❖ The ratio of power developed to the maximum usable power at the same speed is called the load.
- ❖ The specific fuel consumption varies with load and speed.

Mean Effective Pressure

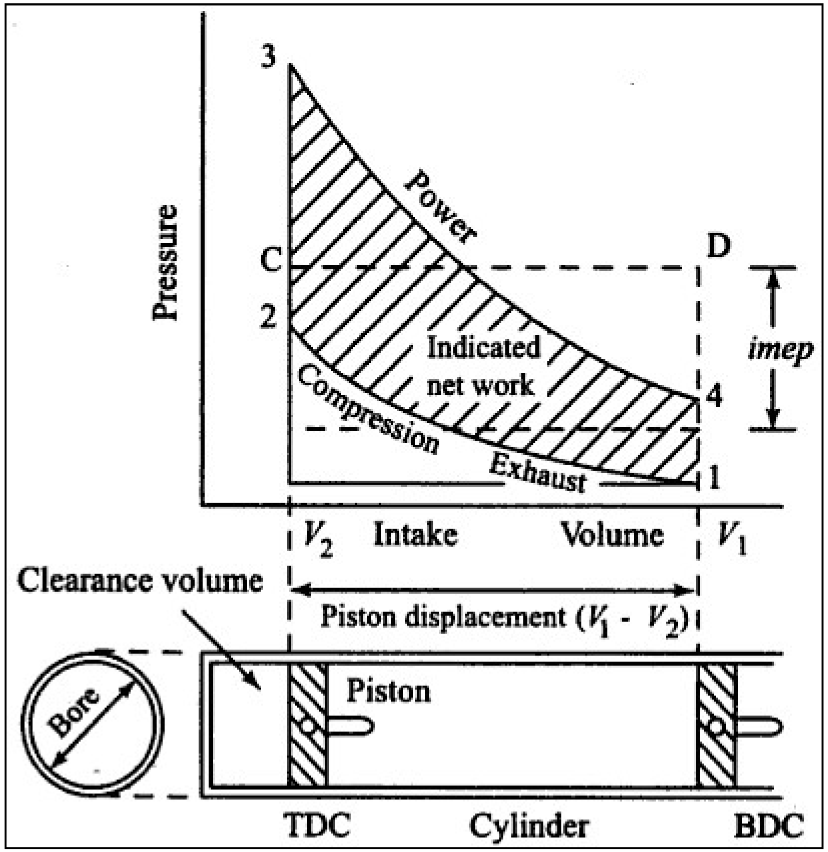
- The indicated net work of the cycle is represented by the area 1234 enclosed by the process lines.
- If the area of the rectangle ABCD is same as 1234 then the vertical distance between horizontal lines AB and CD represent the indicated mean effective pressure (*imep or p_{im}*).
- The indicated mean effective pressure calculated as:

$$p_{im} = \frac{Net\ work\ in\ cycle}{V_1 - V_2}$$

- For actual cycle the indicated mean effective pressure is calculated as:

$$p_{im} = \frac{Area\ of\ the\ indicator\ diagram}{Length\ of\ the\ indicator\ diagram} \times K$$

Where *K = Indicator sprint constant*



p-V diagram of an ideal 4-stroke engine

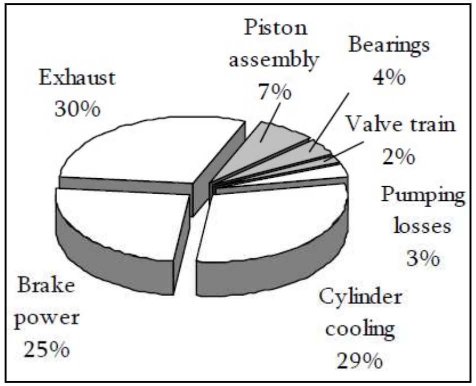
Definition of Indicated Mean Effective Pressure: The average pressure within an engine cylinder during a working cycle, calculated from an indicator diagram.

Engine Performance Terminology

Thermal Power or Fuel Energy

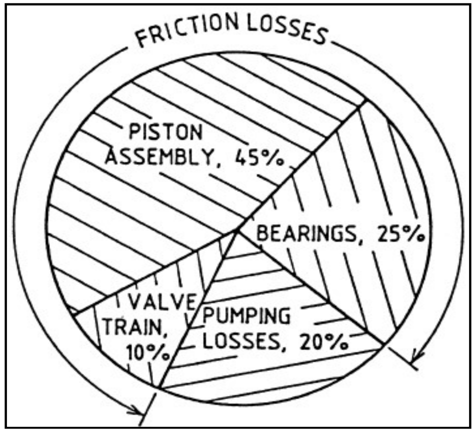
- The fuel energy is the amount of heat that is released during the combustion of specified amount of it.
- It's measured in units of energy per unit of fuel, usually mass, such as: kj/kg, kj/kmole.
- The heat of combustion for fuels is expressed as HHV or LHV.
- The formula for calculating the fuel power is the amount of fuel multiplied by heating value of fuel.

Fuel Power (kj/s) or kw = mass flow rate of fuel (kg/s) * LHV (kj/kg)



Indicated Power

- Indicated power is the theoretical maximum output power of the engine.
- The indicated power is the total power available from the expanding of the gases in the cylinders negating any friction, heat loss or entropy within the system.



Brake Power

- Brake power is the power output of the drive shaft of an engine without the power loss caused by gears, transmission, friction, etc.
- It's called also pure power, useful power, true power or wheel power as well as other terms.

Mechanical efficiency

- Mechanical efficiency is how much of the power developed by the expanding of the gases in cylinders is actually delivered as useful power.
- This formula is written as: **η= BP/IP**

Power Calculations

❖ Indicated Power(IP)

➢ The indicated power is calculated as:

$$\boxed{IP = \frac{P_{im} A L \left(N \; or \; \frac{N}{2}\right) n}{60} \; kW}$$

P_{im} = Mean effective pressure (kPa)

A = Cross sectional area of the cylinder (m^2)

L = Stroke of piston

N = Revolution per minute (RPM)

N → 2 stroke engine

N/2 →4 stroke engine

n = Number of cylinder

❖ Brake Power(BP)

➢ The power available at the crank shaft is called the brake power(BP) or shaft power (SP).

➢ The power available at the crank shaft is always less than the IP due to friction.

➢ The brake power is calculated as below:

$$\boxed{BP = \frac{2\pi T N}{60} \; kW}$$

T= Torque transmitted to the crankshaft (kNm)

N = Revolution per minute (RPM)

N → 2 stroke engine

N/2 →4 stroke engine

❖ Friction Power(FP)

➢ As the internal parts of an engine move, they rub against each other and lose energy due to friction which causes power loss.

➢ The friction power is calculated as below:

FP= IP - BP

Indicator Diagram and Related Calculations

❖ The area of the indicator diagram represents the magnitude of the net work done .

❖ The area under the path 1-2 represents work done by the system and the area under 2-1 work done upon the system.

❖ The mean effective pressure is defined as:

$$\boxed{p_{im} = \frac{a_d}{l_d} \times K}$$

K = Indicator spring constant.

❖ Work done in one engine cycle;

p_{im} A L

A= π/4 D2 and L= Stroke of piston.

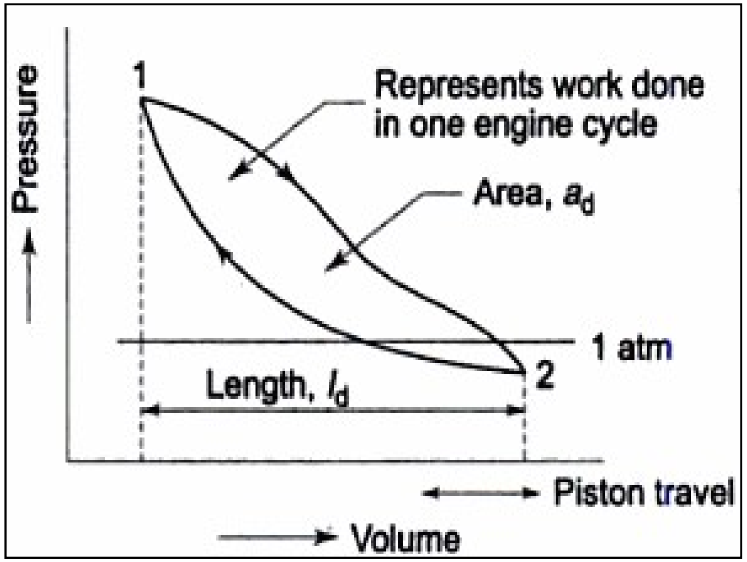
❖ For a 2-stroke engine work done in a minute,

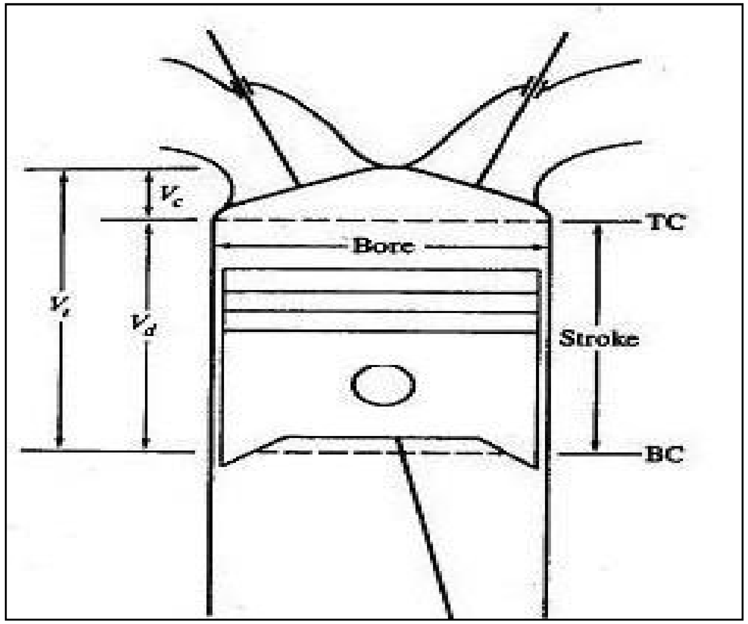
IP= p_{im} A LN

❖ For a 4-stroke engine work done in a minute;

IP= p_{im} A LN/2

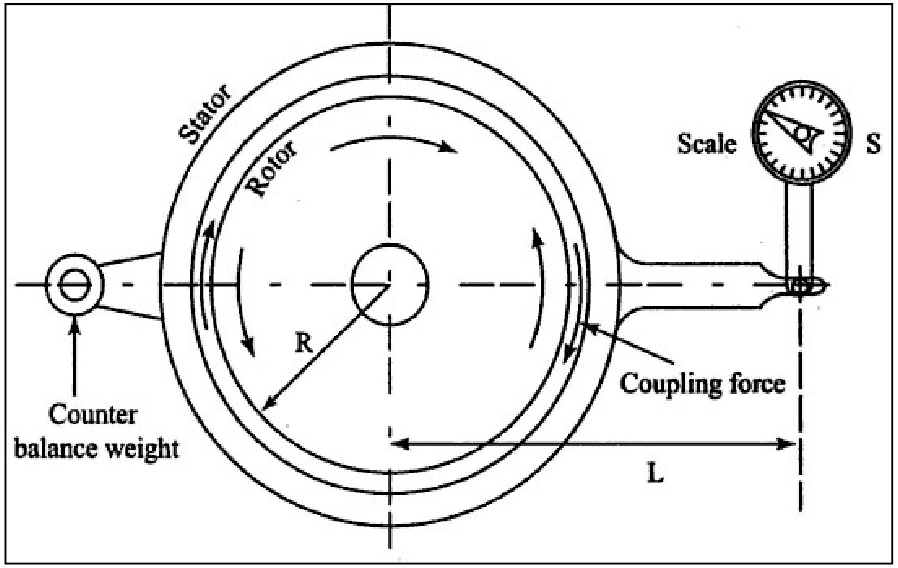
N speed in RPM.





Measurement of Brake Power

- ❖ Measurement of brake power involves determination of torque and angular speed of engine output shaft (crank shaft). To measure brake power *Dynamometer* is used.
- ❖ The term dynamometer and brake mean the same except the dynamometer contains a measuring device to indicate the amount of force required to stop the engine.



Dynamometer

- ❖ Dynamometer broadly classified in Absorption dynamometer and Transmission Dynamometer.

Absorption dynamometer

- ❖ These dynamometers measure and absorb the power output of the engine to which they are coupled
- ❖ The power absorbed is usually dissipated as heat.
- ❖ Examples of such dynamometers are Prony brake, rope brake, hydraulic and eddy current dynamometer etc.

Transmission Dynamometer

- ❖ In transmission dynamometer the power is transmitted to the load coupled to the engine after it is indicated on some type of scale. These are also called torque-meter.

Basic Principle of Dynamometer

- A rotor driven by the engine under test, is mechanically, hydraulically or electromagnetically coupled to a stator.
- For every revolution of the shaft, the rotor periphery moves through a distance $2\pi R$ against the coupling force F. Hence work done per revolution can be given as;

$$W = 2\pi RF$$

- The external moment or torque is S x L, where S is the scale reading and L is the arm length.
- This moment balances the turning moment R x F. Hence it can be written as;

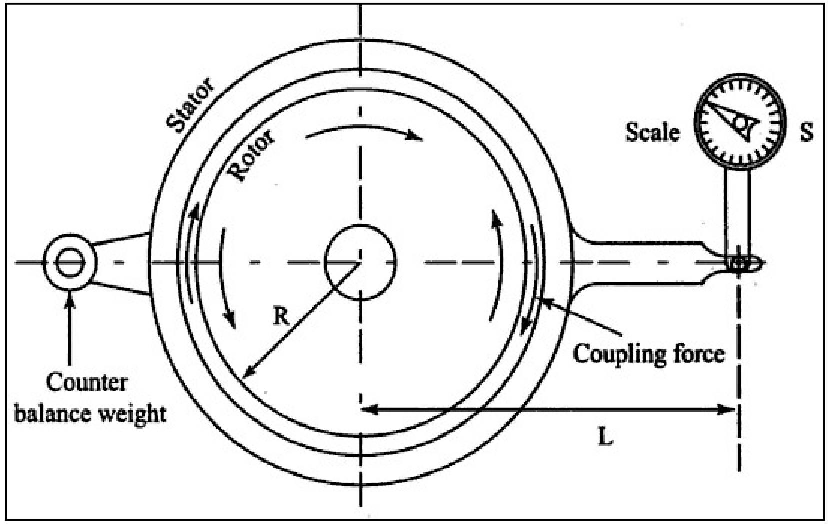
$$S \times L = R \times F$$

- Work done per revolution will be;

$$W = 2\pi SL$$

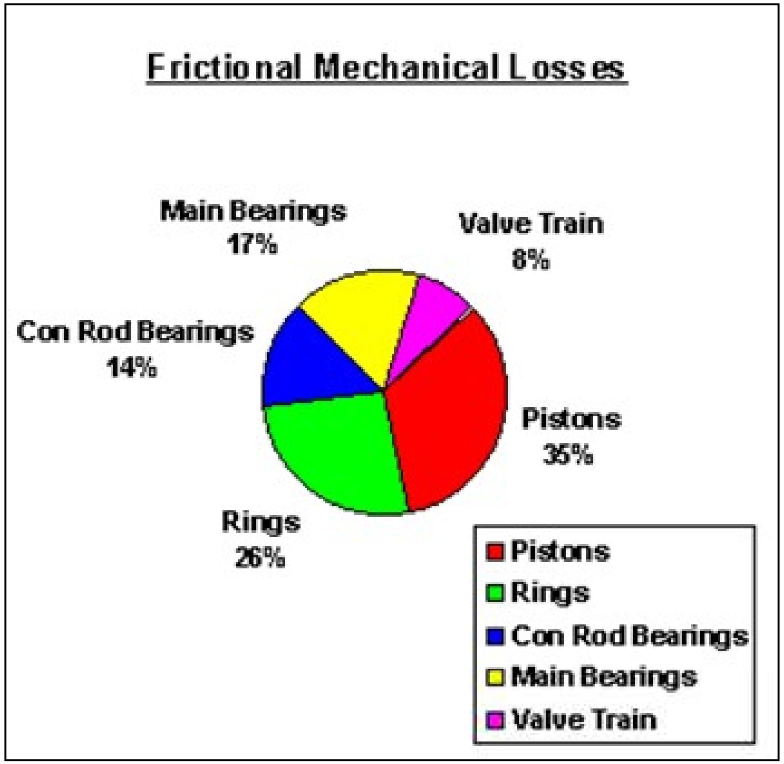
- Work done per second will be = $2\pi SLN/60$
- Now torque is $T = S \times L$,
- The brake power is given by

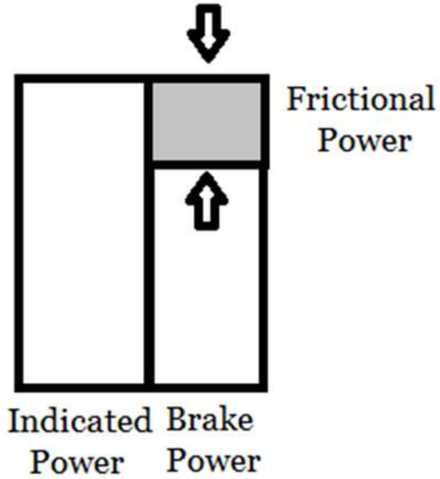
$$\boxed{BP = \frac{2\pi SLN}{60} = \frac{2\pi NT}{60}}$$



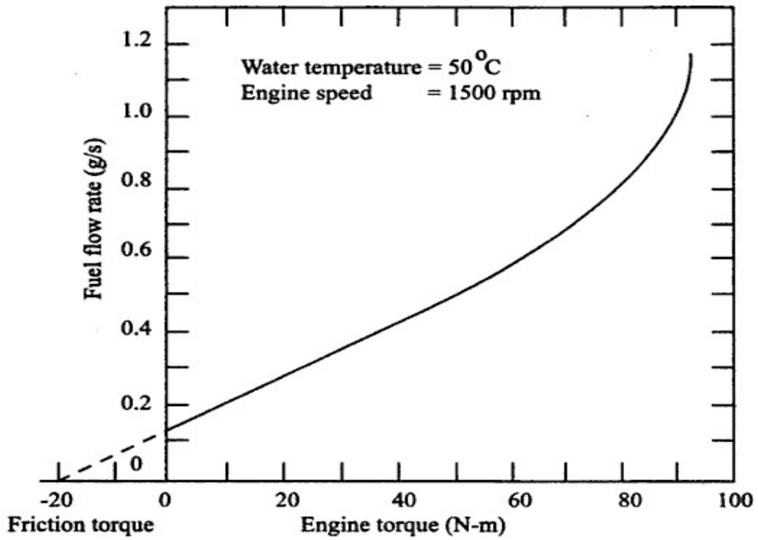
Measurement of Friction Power

- The friction loss is made up of;
  - Friction between the piston and the cylinder walls,
  - Friction between Piston rings and cylinder walls,
  - Friction between Crankshaft and cam shaft and their bearings,
  - Loss incurred by driving the accessories such as water pump, ignition unit etc.,
  - Friction in valve trains,
- It should be the aim of the designer to have minimum loss of power in friction.
- Following methods are used to find the friction power:
  - Willian's line method
  - Morse test
  - Motoring test
  - Retardation test
  - Measuring IP and BP , then FP = IP - BP





Willian's Line Method



- ❖ A graph connecting fuel consumption (y-axis) and brake power (x-axis) at constant speed is drawn and it is extrapolated on the negative axis of brake power.
- ❖ The intercept of the negative axis is taken as the friction power of the engine at that speed.
- ❖ Since in most of the power range the fuel consumption and brake power is linear which permit extrapolation.
- ❖ The main drawback of this method is the long distance to be extrapolated from data measured between 5 and 40% load towards the zero line of fuel in put.
- ❖ The changing slope along the curve indicates part efficiencies of increments of fuel. The pronounced change in the slope of this line near full load reflects the limiting influence of t he air-fuel ratio and of the quality of combustion.

Morse Test

- This test is only applicable to multi cylinder engines.
- In this test the engine is first run at the required speed by adjusting the throttle in SI engine or the pump rack in CI engine and the output is measured.
- Then one cylinder is cutout by short circuiting the spark plug in SI engine or by disconnecting the injector in CI engine.
- Under this condition all the other cylinder will motor the cutout cylinder and the engine speed is brought to its original value by reducing the load.
- This will ensure that the frictional power is the same while the brake power of the engine will be with one cylinder less.
- When k cylinder is active: $ip_1 + ip_2 + ip_3 + \cdots + ip_k = \sum_1^k bp_k + fp_k$
- When one cylinder cut down: $ip_2 + ip_3 + \cdots + ip_k = \sum_2^k bp_k + fp_k$
- Subtracting above two $ip_1 = \sum_1^k bp_k - \sum_2^k bp_k$
- Similarly we can calculate indicative power for other cylinders and total $ip = \sum_1^k ip_k$
- Now brake power for k cylinder is already measured, hence $fp_k = ip_k - bp_k$

Performance Parameters: Fuel Consumption and Fuel-Air Ratio

- Specific fuel consumption is the ratio that compares the fuel used by the engine to the amount of power the engine produces.
- There are different types of specific fuel consumption of internal combustion engines: indicated specific fuel consumption (ISFC) and brake specific fuel consumption (BSFC).
- The formula for calculating the specific fuel consumption is written as:

$$isfc = \frac{Fuel\ consumption\ per\ unit\ time}{Indicated\ power}$$

$$bsfc = \frac{Fuel\ consumption\ per\ unit\ time}{brake\ power}$$

Fuel–Air Ratio

- A mixture that contains just enough air for complete combustion of all the fuel in the mixture is called a chemically correct or stoichiometric fuel-air ratio.
- A mixture having more fuel than that in a chemically correct mixture is termed as rich mixture and a mixture that contains less fuel is called lean mixture.

Fuel-Air Equivalence Ratio

- It is the ratio of actual air fuel ratio to the stoichiometric fuel-air ratio and denoted by φ.

$$\varphi = \frac{Actual\ fuel\ air\ ratio}{Stoichiometric\ fuel\ air\ ratio}$$

- If φ=1 then stoichiometric (chemically correct) mixture, φ>1 then rich mixture and φ<1 then lean mixture.

Engine Efficiencies

Volumetric Efficiency

- Volumetric efficiency of an engine is an indication of the measure of the degree to which the engine fills its swept volume.
- It is defined as the ratio of the mass of air inducted into the engine cylinder during the suction stroke to the mass of the air corresponding to the swept volume of the engine at atmospheric pressure and temperature.
- For supercharged engine, volumetric efficiency has no meaning as it comes out to be more than unity.

$$\text{Volumetric efficiency, } \eta_v = \frac{\text{Mass of charge actually sucked in}}{\text{Mass of charge corresponding to the cylinder intake } P \text{ and } T \text{ conditions}}$$

Thermal Efficiency

- Thermal efficiency of an engine is defined as the ratio of the output to that of the chemical energy input in the form of fuel supply.
- It may be based on brake or indicated output. It is the true indication of the efficiency with which the chemical energy of fuel (input) is converted into mechanical work.

$$\text{Brake thermal efficiency} = \frac{bp}{m_f \times C_v}$$

C_v = Calorific value of fuel, kJ/kg, and

m_f = Mass of fuel supplied, kg/sec.

Engine Efficiencies

Indicated Thermal Efficiency (η_{ith})

- It is the ratio of energy in the indicated power (IP), to the input fuel energy in appropriate units.

$$\eta_{ith} = \frac{IP}{E} = \frac{IP}{mass\ of\ fuel\ per\ sec \times calorific\ value\ of\ fuel}$$

Brake Thermal Efficiency (η_{bth})

- It is the ratio of energy in the brake power (BP) to the input fuel energy in appropriate units.

$$\eta_{bth} = \frac{BP}{E} = \frac{BP}{mass\ of\ fuel\ per\ sec \times calorific\ value\ of\ fuel}$$

Air standard Efficiency

- Air standard efficiencies are the efficiencies of air standard cycles.
- It is a function of compression ratio and other parameters.
- It gives the upper limit of the efficiency obtainable from an engine.

Relative Efficiency

- It is actual efficiency obtained from an engine to the theoretical efficiency of the engine cycle.

$$Relative\ efficiency = \frac{Actual\ brake\ thermal\ efficiency}{Air - standard\ efficiency}$$

Parameters Affecting Performance Characteristics

Combustion Rate and Spark Timing

- ❖ The spark should be timed and the combustion rate controlled such that the maximum pressure occurs as close to the beginning of the power stroke as possible.
- ❖ As a general rule the spark timing and combustion rate are regulated in such a way that approximately one half of the total pressure rise due to combustion has occurred as the piston reaches TDC on the compression stroke.

Air-fuel Ratio

- ❖ The air-fuel ratio must be correct to get optimum engine performance.
- ❖ It is usually set as close as possible to the best economy proportion during normal cruising speed, and as close as possible to the best power proportions when maximum performance is required.

Compression Ratio

- ❖ An increase in compression ratio increase the thermal efficiency and is generally advantageous.
- ❖ The compression ratio in most SI engines are limited by knock, and the use of economically feasible antiknock quality fuels.
- ➢ Increasing compression ratio increase the friction of the engine, particularly between piston rings and cylinder walls.
- ➢ There is a point at which further increase in compression ration would not be profitable.

Parameters Affecting Performance Characteristics

Engine Speed

- At low speed , a greater length of time is available for heat transfer to the cylinder walls and therefore a great proportion of heat loss occurs.
- Up to a certain point higher speed produce greater air consumption and therefore greater IP.
- Higher speed however accompanied by rapidly increasing FP and by greater inertia in moving parts
- Consequently the engine speed must be a compromise.

Mass of Induced Charge

- The greater the mass of the charge inducted , the higher the power produced.
- For a fixed geometry it is desirable to induct a charge to a maximum possible density giving the highest volumetric efficiency.