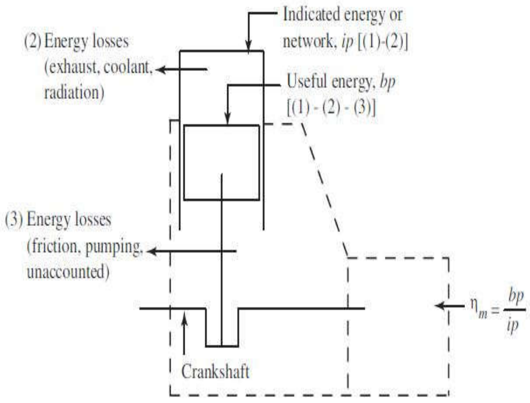
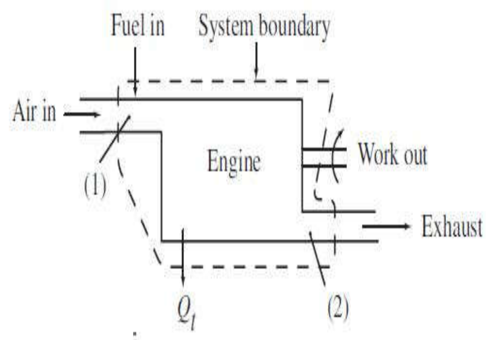
***THE FIRST LAW ANALYSIS OF ENGINE CYCLE:***




Energy flow through reciprocating engine




Reciprocating engine as an open system

Engine performance parameter:

1. ***Indicated power***
2. ***Brake power***
3. ***Frictional power***
4. ***Fuel consumption***
5. ***Air consumption***
6. ***Brake thermal efficiency***
7. ***Indicated thermal efficiency***
8. ***Mechanical Efficiency***
9. ***Volumetric efficiency***
10. ***Air–fuel ratio***

# 1. Indicated power (IP)

It is defined as the rate of work done on the piston by burning of charge inside the cylinder. It is evaluated from an indicated diagram obtained from the engine. It is the gross power produced by the engine.
It is calculated as
IP = Indicated mean effective pressure x Swept volume rate

$$= \frac{p_{mi}\, L\, A\, n\, k}{60}\ (\text{kW})$$

Where k = Number of cylinders

$p_{mi}$ = Indicated mean effective pressure, (kPa or kN/m$^2$)
L = Stroke length, (m)
A = (π /4) d$^2$, cross-sectional area of cylinder of bore, d, (m)
n = Number of working strokes per minute, when engine has a speed of N rotations per minute
= N for 2-stroke engines
=N/2 for 4-stroke

Another way of specifying the indicated mean effective pressure $p_{im}$ is from the knowledge of engine indicator diagram ($p$-$V$ diagram). In this case, $p_{im}$, may be defined as

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

where the length of the indicator diagram is given by the difference between the total volume and the clearance volume.

## 2. Brake power (BP)

It is the net power available at the engine shaft for external use. It is measured by the brake dynamometer which can be loaded to measure the brake power of the engine.
It is calculated as

Brake power = brake load ($F$) × velocity of brake drum ($2\pi R N/60$)

or $$BP = \frac{2\pi N(FR)}{60{,}000} = \frac{2\pi NT}{60{,}000}\ (\text{kW})$$

where, $F$ = Braking force, (N)

$R$ = Effective radius of the brake drum (m)

= 1/2 (Dia. of brake drum + Dia. of the rope)

$T$ = $FR$, the torque is the product of force $F$ and effective radius $R$ of the brake drum

$N$ = Speed of the engine in rpm

Brake power can also be obtained in terms of brake mean effective pressure ($p_{mb}$) as

$BP$ = Brake mean effective pressure × Swept volume rate

$$= \frac{p_{mb}\ L\ A\ n\ k}{60}\ (\text{kW})$$

where, $k$ = Number of cylinders

$p_{mb}$ = Brake mean effective pressure, (kPa or $kN/m^2$)

$L$ = Stroke length, (m)

$A$ = $(\pi/4)\,d^2$, cross-sectional area of cylinder of bore, $d$, (m)

$n$ = Number of working strokes per minute, when engine has a speed of $N$ rotation per minute

$= N$ for two-stroke engine

$= \frac{N}{2}$ for a four-stroke engine

## 3. Frictional power (FP)

It is the part of the indicated power which is used to overcome the frictional effects within the engine. The friction power also includes power required to operate the fuel pump, lubrication pump, valves, etc. Therefore, it is given as the difference between the indicated power and brake power.

$$FP = IP - BP$$

## 4. Fuel consumption:

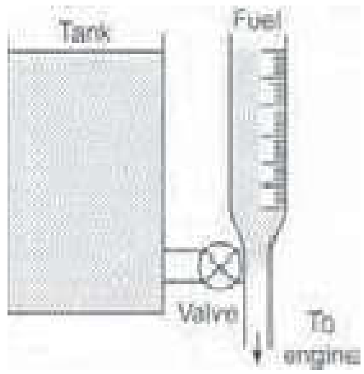
A calibrated burette can be used for fuel consumption measurement

$$\dot{m}_f = \frac{V_{fuel} \times \rho_{fuel} \times 3600}{\Delta t} \text{ (kg/h)}$$

where, $V_{fuel}$ = Volume of fuel in $m^3$ used in tim $\Delta t$,

$\rho_{fuel}$ = Density of fuel, and

$\Delta t$ = Time in seconds.




## 5. Specific Fuel Consumption (sfc)

It is defined as the ratio of the mass of fuel consumed per hour per unit power output (BP).

It is also designated as *Bsfc* (*brake specific fuel consumption*). It is a parameter which decides the economical power production from an engine.

$$Bsfc \text{ or } sfc = \frac{\dot{m}_f \text{ (kg/h)}}{BP \text{ (kW)}} \text{ (kg/kWh)}$$

The specific fuel consumption in kg/kWh based on the indicated power (*IP*) is called the *Isfc* (*indicated specific fuel consumption*) and is expressed as

$$Isfc = \frac{\dot{m}_f \text{ (kg/h)}}{IP \text{ (kW)}} \text{ (kg/kWh)}$$

## *Air-consumption rate:*

Air-consumption rate of an engine can be effectively calculated by means of an orifice meter.

The volume flow rate of air passing through the orifice, in $m^3/s$, can be calculated by using the relation

$$\dot{V}_a = A_{orifice} \times \text{velocity of air}$$

which can be expressed as

$$\dot{V}_a = \frac{\pi}{4} d_o^2 \, C_d \sqrt{2 \, g \, h_a}$$

where, $\dot{V}_a$ = Volume flow rate of air, $m^3/s$

$d_o$ = Diameter of orifice, m

$C_d$ = Coefficient of discharge of orifice

$g$ = 9.81 $m/s^2$, acceleration due to gravity

$h_a$ = Head of air = $\frac{\rho_w h_w}{\rho_{air}}$ (m),

$h_w$ = Water column in m and

$\rho_w$ = density of water,

$\rho_{air}$ = density of air.

The mass-flow rate of air through the orifice can be calculated as

$$\dot{m}_a = \rho_{air} \times \dot{V}_a$$

## *Air-Fuel Ratio(A/F):*

It is the ratio between the mass of the air and mass of the fuel supplied to the engine. It is expressed as

$$\text{A/F} = \frac{\dot{m}_a \text{ (mass flow rate of air)}}{\dot{m}_f \text{ (mass flow rate of fuel)}}.$$

Theoretically, the correct (stoichiometric) air–fuel ratio is 15. But the combustion of air–fuel mixture can take place in A/F ratio ranges from 12 to 19 for petrol engines and 20 to 60 in Diesel engines.

The ratio of actual fuel-air ratio to stoichiometric fuel-air ratio is called equivalence ratio and is denoted by $\phi$.

$$\phi = \frac{\text{Actual fuel-air ratio}}{\text{Stoichiometric fuel-air ratio}}$$

Accordingly, $\phi = 1$ means stoichiometric (chemically correct) mixture, $\phi < 1$ means lean mixture and $\phi > 1$ means rich mixture.

## Mean Piston Speed (sp) =2LN

Where L is the stroke and N is the rotational speed of the crankshaft in rpm

### *Specific Power Output (Ps):*

Specific power output of an engine is defined as the power output per unit piston area

$$\text{Specific power output, } P_s = bp/A$$
$$= \text{constant} \times p_{bm} \times \overline{s}_p$$

## *Indicated thermal efficiency:*

The indicated thermal efficiency is defined as the ratio of the indicated power to the heat supply rate, i.e.

$$\eta_{ith} = \frac{IP}{\dot{m}_f \times CV}$$

## *Brake thermal efficiency:*

The power output of an engine is obtained from the combustion of charge. Thus the *overall efficiency* of an engine is given by brake thermal efficiency, i.e.,

$$\eta_{bth} = \frac{\text{Brake power}}{\text{Energy supply rate}} = \frac{BP}{\dot{m}_f \times CV}$$

where, $\dot{m}_f$ = mass flow rate of the fuel (kg/s)

$CV$ = Calorific value of fuel, (kJ/kg)

**Mechanical Efficiency ($\eta_{mech}$)**

It is the ratio of the brake power and indicated power.

$$\eta_{mech} = \frac{BP}{IP}$$

It can also be expressed as

$$\eta_{mech} = \frac{\text{Brake thermal efficiency}}{\text{Indicated thermal efficiency}} = \frac{\eta_{bth}}{\eta_{ith}}$$

and $$\eta_{mech} = \frac{\text{Brake mean effective pressure}}{\text{Indicated mean effective pressure}} = \frac{p_{mb}}{p_{mi}}$$

## ***Relative efficiency or Efficiency ratio:***

### Relative Efficiency

It is the ratio of actual thermal efficiency to air standard efficiency of the engine. It is sometimes referred as *efficiency ratio*. It is expressed as

$$\eta_{Relative} = \frac{\text{Brake thermal efficiency}}{\text{Air standard efficiency}}$$

Relative efficiency for most of the engines varies from 75 to 95% with air standard efficiency.

### Volumetric Efficiency ($\eta_{vol}$)

It is defined as the ratio of the mass of the actual charge inducted into the cylinder to the mass of the charge corresponding to the swept volume, or

$$\eta_{vol} = \frac{\text{Actual mass flow rate of the charge}}{\text{Density} \times \text{Swept volume per second}}$$

$$= \frac{\dot{m}_a \text{ (kg/s)}}{\rho_a \left(\frac{\pi}{4} d^2 L\right) \frac{n}{60}}$$

where, $\rho_a$ = Density of inlet charge,

$d$ = bore, $L$ = stroke

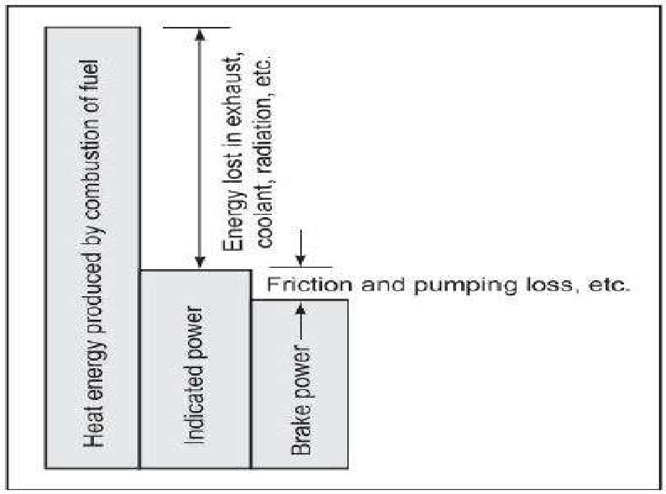
$n$ = Number of effective suction strokes per cycle per minute

$n$ = $N$ for a two-stroke engine

$= \frac{N}{2}$ for a four-stroke engine

The volumetric efficiency can also be defined as the ratio of the volume of the charge inducted in the cylinder, measured at NTP to the swept volume of the cylinder.

$$\eta_{vol} = \frac{V_{act}}{V_s}$$




*Heat energy distribustion in an IC engine*

***Calorific value*** of a fuel is the thermal energy released per unit quantity of the fuel when the fuel is burned completely and the products of combustion are cooled back to the initial temperature of the combustible mixture. Other terms used for the calorific value are heating value and heat of combustion.

When the products of combustion are cooled to 25 ◦C practically all the water vapour resulting from the combustion process is condensed. The heating value so obtained is called the higher calorific value or gross calorific value of the fuel.

The lower or net calorific value is the heat released when water vapour in the products of combustion is not condensed and remains in the vapour form.