I C Engine

LECTURE 2

Applications

Table 1.3 Application of Engines

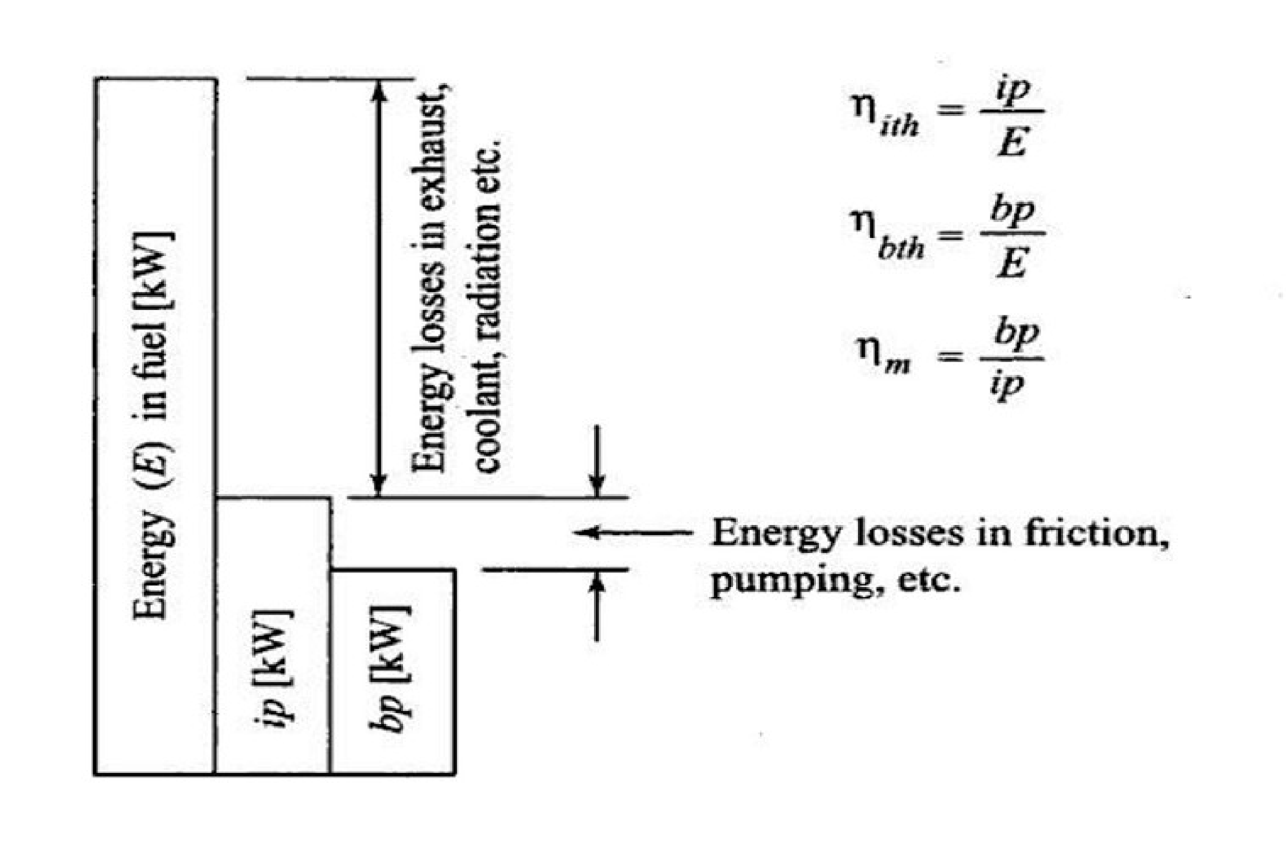
IC Engine		EC Engine	
Type	Application	Type	Application
Gasoline engines	Automotive, Marine, Aircraft	Steam Engines	Locomotives, Marine
Gas engines	Industrial power	Stirling Engines	Experimental Space Vehicles
Diesel engines	Automotive, Locomotive, Power, Marine	Steam Turbines	Power, Large Marine
Gas turbines	Power, Aircraft, Industrial, Marine	Close Cycle Gas Turbine	Power, Marine

Engine Performance Parameters

The engine performance is indicated by the term *efficiency*, η. Five important engine efficiencies and other related engine performance parameters are given below:

(i)	Indicated thermal efficiency	(η_{ith})
(ii)	Brake thermal efficiency	(η_{bth})
(iii)	Mechanical efficiency	(η_m)
(iv)	Volumetric efficiency	(η_v)
(v)	Relative efficiency or Efficiency ratio	(η_{rel})
(vi)	Mean effective pressure	(p_m)
(vii)	Mean piston speed	$(\bar{s}_p)$
(viii)	Specific power output	(P_s)
(ix)	Specific fuel consumption	(sfc)
(x)	Inlet-valve Mach Index	(Z)
(x)	Fuel-air or air-fuel ratio	$(F/A$ or $A/F)$
(xi)	Calorific value of the fuel	(CV)

Energy Flow in IC Engine



Indicated Thermal Efficiency

Indicated thermal efficiency is the ratio of energy in the indicated power, *ip*, to the input fuel energy in appropriate units.

$$[ht]\eta_{ith} = \frac{ip\ [\mathrm{kJ/s}]}{\text{energy in fuel per second [kJ/s]}}$$

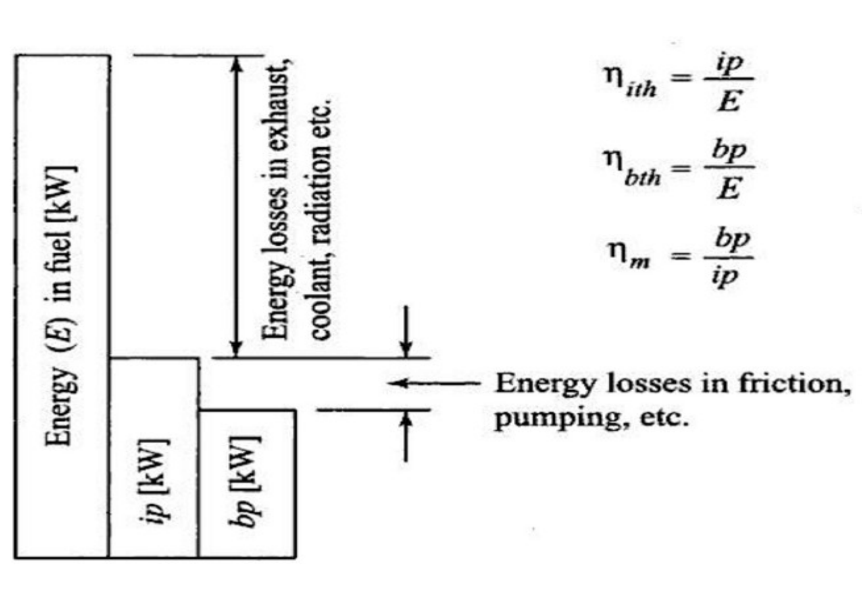
$$= \frac{ip}{\text{mass of fuel/s} \times \text{calorific value of fuel}}$$

Brake Thermal Efficiency and Mechanical Efficiency

$$\eta_{bth} = \frac{bp}{\text{Mass of fuel/s} \times \text{ calorific value of fuel}}$$

$$\eta_m = \frac{bp}{ip} = \frac{bp}{bp + fp}$$

$$fp = ip - bp$$



Volumetric Efficiency

Volumetric efficiency is defined as the volume flow rate of **air** into the intake system divided by the rate at which the volume is displaced by the system.

$$\eta_v = \frac{\dot{m}_a}{\rho_a V_{disp} N/2}$$

Relative efficiency or Efficiency ratio

$$\eta_{rel} = \frac{\text{Actual thermal efficiency}}{\text{Air-standard efficiency}}$$

Mean Effective Pressure

$$ip = \frac{p_{im} L A n K}{60 \times 1000}$$

$$p_{im} = \frac{60000 \times ip}{L A n K}$$

Mean Piston Speed

An important parameter in engine applications is the mean piston speed, $\overline{s}_p$. It is defined as

$$\overline{s}_p = 2LN$$

Specific Power output

Specific power output of an engine is defined as the power output per unit piston area and is a measure of the engine designer's success in using the available piston area regardless of cylinder size. The specific power can be shown to be proportional to the product of the mean effective pressure and mean piston speed.

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

Specific Fuel Consumption

The fuel consumption characteristics of an engine are generally expressed in terms of specific fuel consumption in kilograms of fuel per kilowatt-hour. It is an important parameter that reflects how good the engine performance is. It is inversely proportional to the thermal efficiency of the engine.

$$\text{sfc} = \frac{\text{Fuel consumption per unit time}}{\text{Power}}$$

Equivalence 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 (or excess air) is called a lean mixture. The ratio of actual fuel-air ratio to stoichiometric fuel-air ratio is called equivalence ratio and is denoted by ϕ.

$$\phi = \frac{\text{Actual fuel-air ratio}}{\text{Stoichiometric fuel-air ratio}} \tag{1.19}$$

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

Typical Design Parameters

Table 1.4 Typical Design and Performance Data for Modern Internal Combustion Engines

	Operating cycle (Stroke)	Compression ratio	Bore (m)	Stroke/bore ratio	Rated Maximum Speed (rev/min)	Rated Maximum *bmep* (atm)	Weight/Power ratio (kg/kW)	Approx. best *bsfc* (g/kW h)
Spark-ignition engines								
Small (e.g. motorcycles)	2/4	6–10	0.05–0.085	1.2–0.9	4500–7500	4–10	5.5–2.5	350
Passenger cars	4	8–10	0.07–0.1	1.1–0.9	4500–6500	7–10	4–2	270
Trucks	4	7–9	0.09–0.13	1.2–0.7	3600–5000	6.5–7	6.5–2.5	300
Large gas engines	2/4	8–12	0.22–0.45	1.1–1.4	300–900	6.8–12	23–35	200
Wankel engines	4	≈ 9	0.57 dm^3 per chamber		6000–8000	9.5–10.5	1.6–0.9	300
Compression-ignition engines								
Passenger cars	4	16–20	0.075–0.1	1.2–0.9	4000–5000	5–7.5	5–2.5	250
Trucks	4	16–20	0.1–0.15	1.3–0.8	2100–4000	6–9	7–4	210
Locomotive	4/2	16–18	0.15–0.4	1.1–1.3	425–1800	7–23	6–18	190
Large engines	2	10–12	0.4–1	1.2–3.0	110–400	9–17	12–50	180

Problems

The mechanical efficiency of a single-cylinder four-stroke engine is 80%. The frictional power is estimated to be 25 kW. Calculate the indicated power (*ip*) and brake power (*bp*) developed by the engine.

Solution - $\eta_m = 80\%$ $fp = 25\,kW$

$$\eta_m = \frac{bp}{ip} = \frac{bp}{bp + fp} \Rightarrow 0.8 = \frac{bp}{bp+25}$$

$$\Rightarrow bp = 100\,kW$$

$$ip = bp + fp = 100 + 25 = 125\,kW$$

Problems

Find out the speed at which a four-cylinder engine using natural gas can develop a brake power of 50 kW working under following conditions. Air-gas ratio 9:1, calorific value of the fuel = 34 MJ/m^3, Compression ratio 9:1, volumetric efficiency = 70%, indicated thermal efficiency = 35% and the mechanical efficiency = 80% and the total volume of the engine is 2 litres.

Solution :- Total Volume/cylinder = $\frac{2000}{4}$ = 500 cc

swept Vol/cy = 450 cc

Vol of air/inducted charge/cyl = $\eta_v \times 450 = 0.7 \times 450 = 315$ cc

Vol of gas/cylinder = $\frac{315}{9}$ = 35 cc

Energy Supplied/cyl = 35 cc × 34 $\frac{MJ}{m^3}$ = 1.19 kJ

$\eta_m = \frac{bp}{ip}$

$ip = \frac{bp}{\eta_m} = \frac{50}{0.8}$ → 62.5 kW

$\eta_{ith} = \frac{IP}{\text{Energy Supplied}}$

$0.35 = \frac{62.5 \text{ kW}}{\text{Energy Supplied}}$

Energy = $\frac{62.5 \text{ kW}}{0.35}$ = 178.6 kW

178.6

Energy supplied $(E_1) = 178.6$ kW

E_1 / cylin is $= \dfrac{178.6 \text{ kW}}{4 \times (N/120)} = 1.19$ kJ $\left(\dfrac{N}{2 \times 60}\right)$

$N = 4500$ RPM

Problems

A four-stroke, four-cylinder diesel engine running at 2000 rpm develops 60 kW. Brake thermal efficiency is 30% and calorific value of fuel (CV) is 42 MJ/kg. Engine has a bore of 120 mm and stroke of 100 mm. Take $\rho_a = 1.15$ kg/m^3, air-fuel ratio = 15:1 and $\eta_m = 0.8$. Calculate (i) fuel consumption (kg/s); (ii) air consumption (m^3/s); (iii) indicated thermal efficiency; (iv) volumetric efficiency; (v) brake mean effective pressure and (vi) mean piston speed

Sol (i) Fuel consumption.

$$\eta_{bth} = \frac{bp}{\dot{m}_f \times CV}$$

$$\dot{m}_f = \frac{bp}{\eta_{bth} \times CV} = \frac{60\,kW}{0.3 \times 42\,MJ/kg} = 4.76 \times 10^{-3}\ \frac{kg}{s}$$

(ii) Air Consumption

$$\frac{A}{F} = \frac{15}{1}$$

$$m_a = 15 \times m_f$$
$$= 71.43\ kg/s$$
$$= \frac{71.43 \times 10^{-3}}{\rho_a}$$
$$= \frac{71.43\ kg/s}{1.15\ kg/m^3} = 62.11 \times 10^{-3}\ \frac{m^3}{s} =$$

(iii)

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

$$= \frac{(bp/\eta_m)}{4.76 \times 10^{-3} \times 42\,\frac{MJ}{kg}} = \frac{0.375}{}$$

$$\text{Vol eff} = \frac{V_{actual}}{\frac{\pi}{4} D^2 \times L \times \frac{N}{2 \times 60} \times 4}$$

$$= \frac{62.11 \times 10^{-3}}{\frac{\pi}{4} \times (0.12)^2 \times 0.1 \times \frac{2000}{2 \times 60} \times 4}$$

$$= 0.82 \%$$

Firing Order

$$bmep = \frac{bp}{LAnK} = \frac{60\ kW}{0.1 \times \frac{\pi}{4} \times 0.12^2 \times \frac{2000}{2 \times 60} \times 4} = \cancel{93.9\ bar}$$

7.96 bar