IC Engines

Short notes for B.Tech Mechanical · GATE ME

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1. Introduction and Classification

- **Heat engine** turns chemical energy of fuel into mechanical work. **IC engine**: combustion happens inside the cylinder (petrol, diesel engines). **EC engine**: combustion outside (steam engine).

➤ Classification

Basis	Types
Ignition	Spark ignition (SI, petrol / CNG), compression ignition (CI, diesel)
Strokes per cycle	Four-stroke, two-stroke
Cycle	Otto (constant volume), Diesel (constant pressure), dual
Cooling	Air cooled, water cooled
Cylinder layout	Inline, V, opposed, radial
Fuel supply	Carburettor, port injection (MPFI), direct injection, CRDI

➤ Engine terms

- **Bore** D = cylinder diameter. **Stroke** L = distance between TDC and BDC (L = 2 x crank radius).
- **Swept volume** Vs = (π/4) D^2 L. **Clearance volume** Vc = volume at TDC.

FORMULA Compression ratio r = (Vs + Vc) / Vc. Petrol engines: about 8–12. Diesel engines: about 14–22.

Four-stroke vs two-stroke

Point	Four-stroke	Two-stroke
Power strokes	One every 2 revolutions	One every revolution
Valves	Inlet and exhaust valves	Ports (simple), no valves in small engines
Fuel economy	Better	Poorer (fresh charge lost in scavenging)
Weight per power	Heavier	Lighter
Use	Cars, trucks, bikes	Small mopeds, outboards, large marine diesels

- **Valve timing** (4-stroke): inlet opens before TDC, closes after BDC; exhaust opens before BDC, closes after TDC. Valve overlap = both valves open near TDC.

2. Air Standard Cycles

- Assumptions: air as ideal gas, constant specific heats, reversible processes, heat addition replaces combustion.

FORMULA Otto efficiency $\eta = 1 - 1 / r^{(\gamma-1)}$. It depends only on r (and γ).

FORMULA Diesel efficiency $\eta = 1 - (1 / r^{(\gamma-1)}) \times (\rho^{\gamma} - 1) / (\gamma(\rho - 1))$, ρ = cut-off ratio V3/V2.

- Dual (limited pressure) cycle: heat added partly at constant volume, partly at constant pressure.

Comparison

Condition	Efficiency order
Same compression ratio and heat input	Otto > Dual > Diesel
Same max pressure and temperature	Diesel > Dual > Otto

- **Mean effective pressure** (mep) = net work / swept volume. Higher mep means more power from a given size.

EXAMPLE Otto cycle, $r = 8$, $\gamma = 1.4$. $8^{0.4} = 2.297$. $\eta = 1 - 1/2.297 = 1 - 0.435 =$ 56.5%.

EXAMPLE Diesel cycle, $r = 16$, $\rho = 2$, $\gamma = 1.4$. Find η.

- 16^0.4 = 3.031. 2^1.4 = 2.639.
- (2.639 − 1) / (1.4 × 1) = 1.171.
- η = 1 − 1.171 / 3.031 = 1 − 0.386 = **61.4%**.

➤ Fuel–air and actual cycles

- Real efficiency is lower due to: variable specific heats, dissociation at high temperature, heat loss to walls, finite combustion time, exhaust blowdown, pumping (gas exchange) loss and friction.
- Fuel–air cycle efficiency is roughly 75–80% of air standard; actual cycle is lower still.

3. Engine Performance

FORMULA Indicated power IP = pm L A n k / 60 (n = N/2 for 4-stroke, N for 2-stroke; k = number of cylinders).

FORMULA Brake power BP = 2π N T / 60. Friction power FP = IP − BP. Mechanical efficiency ηm = BP / IP.

Quantity	Formula
Brake thermal efficiency	BP / (mf × CV)
Indicated thermal efficiency	IP / (mf × CV)
Volumetric efficiency	Actual air volume taken in / swept volume
Brake specific fuel consumption (bsfc)	mf / BP (kg/kWh)
Air-fuel ratio	ma / mf

EXAMPLE 4-stroke, single cylinder, D = 100 mm, L = 120 mm, N = 1500 rpm, imep = 7 bar, BP = 6.6 kW, fuel 2 kg/h, CV = 42000 kJ/kg.

- A = (π/4) × 0.1^2 = 0.007854 m^2. n = 1500/2 = 750 per min.
- IP = 7 × 10^5 × 0.12 × 0.007854 × 750 / 60 = 8247 W = **8.25 kW**.
- ηm = 6.6 / 8.25 = **80%**.
- Fuel power = 2 × 42000 / 3600 = 23.33 kW. Brake thermal η = 6.6 / 23.33 = **28.3%**.
- bsfc = 2 / 6.6 = **0.303 kg/kWh**.

➤ Measuring friction power

- **Willan's line** (diesel only): plot fuel rate vs BP, extend to zero fuel; the negative BP intercept = FP.
- **Morse test** (multi-cylinder): cut off one cylinder at a time, bring speed back with load. IP of that cylinder = BP (all) − BP (with it cut off).
- Motoring test, retardation test.

➤ Heat balance sheet

- Fuel energy goes to: brake power (about 25–35%), cooling water, exhaust gases, and unaccounted losses (radiation, friction heat).

4. Combustion in SI Engines

- Stages (Ricardo): 1) **ignition lag** (preparation, chemical), 2) **flame propagation** (main pressure rise), 3) **after-burning**.
- **Normal combustion**: flame starts at the spark plug and travels smoothly across the chamber.
- **Knock (detonation)**: the unburnt **end gas** self-ignites before the flame reaches it. It gives a sharp pressure rise and metallic pinging, and can damage pistons.
- **Pre-ignition**: mixture ignites before the spark, from hot spots (glowing plug, carbon deposits).
- Fuel rating: **octane number** = % iso-octane in an iso-octane + n-heptane blend that knocks like the fuel. Iso-octane = 100, n-heptane = 0.
- Anti-knock: higher octane fuel, retard spark, lower compression ratio, more turbulence, cooler charge, smaller bore.

5. Combustion in CI Engines

- Stages: 1) **ignition delay** (physical + chemical), 2) **rapid (uncontrolled) combustion**, 3) **controlled combustion**, 4) **after-burning**.
- **Diesel knock**: long delay lets a lot of fuel collect; it burns at once and pressure rises too fast.
- Fuel rating: **cetane number** = % n-cetane (hexadecane) in a blend with alpha-methylnaphthalene. Higher cetane = shorter delay.

➤ Factors that reduce knock (opposite in SI and CI)

Factor	SI engine (to reduce knock)	CI engine (to reduce knock)
Compression ratio	Low	High
Inlet temperature	Low	High
Inlet pressure	Low	High
Fuel self-ignition	Hard (high octane)	Easy (high cetane)
Delay	Long (end gas burns before self-ignition)	Short

REMEMBER Things that cause knock in SI engines prevent it in CI engines. SI wants a fuel that resists self-ignition; CI wants one that self-ignites quickly.

- SI combustion chambers: compact, spark plug central, short flame travel, squish for turbulence.
- CI chambers: open (direct injection) or divided (pre-chamber, swirl chamber).

6. Fuel Supply and Ignition

- **Carburettor**: venturi creates low pressure that draws fuel from the float chamber. Simple carburettors give a richer mixture at higher air flow, so compensating jets are added.
- **MPFI**: injector at each inlet port, ECU-controlled; better economy and emissions. **GDI**: petrol injected directly into the cylinder.
- **Diesel injection**: high-pressure pump + injector. **CRDI** (common rail): a common high-pressure rail; ECU controls timing and multiple injections; quieter, cleaner.
- SI load control = **quantity governing** (throttle valve). CI load control = **quality governing** (fuel quantity only, no throttle).
- Mixture for petrol: stoichiometric A/F ≈ 14.7 : 1. Rich for cold start, idling and full power; lean for cruising.
- Ignition systems: battery (coil), magneto (no battery, small engines), electronic / CDI.

7. Cooling, Lubrication and Supercharging

- Cooling: air (fins, bikes) or water (radiator, pump, thermostat). Too much cooling lowers efficiency; too little causes seizure and knock.
- Lubrication systems: mist (2-stroke, oil mixed with petrol), wet sump, dry sump. Oil property: viscosity index (less change with temperature is better).
- **Supercharging**: pushing more air into the cylinder (by a blower driven from the crankshaft) to get more power from the same size.
- **Turbocharging**: compressor driven by an exhaust gas turbine; uses exhaust energy; common in diesel engines. **Intercooler** cools the compressed air for higher density.
- Supercharging an SI engine increases knock tendency; in CI engines it reduces knock.

8. Emissions and Control

Pollutant	Main cause	Control
CO	Rich mixture, poor oxygen	Lean mixture, catalytic converter
HC	Unburnt fuel (wall quenching, crevices, misfire)	Catalytic converter, better combustion
NOx	High combustion temperature	EGR, SCR (urea), retard timing
Particulate matter (soot)	Diesel, rich zones	DPF (diesel particulate filter)

- **Three-way catalytic converter** (platinum, palladium, rhodium): oxidises CO and HC, reduces NOx. Works well only near the stoichiometric ratio, so it uses a lambda (oxygen) sensor.
- **EGR**: part of the exhaust sent back to the intake lowers flame temperature and NOx.
- India moved from BS-IV to BS-VI in April 2020, with tighter limits on NOx and PM.

- Alternative fuels: CNG, LPG, ethanol blends (E20), biodiesel, hydrogen. Electric and hybrid drives are growing fast.

9. Most Asked Questions (practice)

1. Compare SI and CI engines. Compare 2-stroke and 4-stroke engines.
2. Draw the valve timing diagram of a 4-stroke SI engine.
3. Derive the efficiency of Otto and Diesel cycles and compare them.
4. Why is the actual cycle efficiency less than the air standard efficiency?
5. Define IP, BP, FP, mep, volumetric and thermal efficiency. Solve a performance problem.
6. Explain the Morse test and Willan's line method.
7. Explain stages of combustion and knock in SI engines. What is octane number?
8. Explain ignition delay and diesel knock. Compare knock factors in SI and CI.
9. Explain MPFI and CRDI systems.
10. Explain the main pollutants and the working of a three-way catalytic converter.

TIP In GATE ME, IC engine numericals are mostly Otto / Diesel / dual cycle efficiency, mep, IP/BP, volumetric efficiency and bsfc. Keep 4-stroke $n = N/2$ in mind; it is the most common mistake.