INTERNAL COMBUSTION ENGINES

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Lecture # 9 (Air and Fuel Induction)

8. DUAL-FUEL ENGINES

For various technical and financial reasons, some engines are designed to operate using a combination of two fuels. For instance, in some third-world countries dual-fuel engines are used because of the high cost of diesel fuel. Large CI engines are run on a combination of natural gas and diesel oil. Natural gas is the main fuel because it is more cheaply available. However, natural gas is not a good CI fuel by itself because it does not readily self-ignite (due to its high octane number). A small amount of diesel oil is injected at the proper cycle time. This ignites in a normal manner and initiates combustion in the natural gas–air mixture filling the cylinder. Combinations of fuel input systems are needed on these types of engines.

9. INTAKE FOR TWO-STROKE CYCLE ENGINES

- Inlet air in two-stroke cycle engines must be input at a pressure greater than atmospheric.
- Following blowdown, at the start of the intake process, the cylinder is still filled with exhaust gas at atmospheric pressure.
- There is no exhaust stroke or intake stroke.
- Air under pressure enters the cylinder and pushes most of the remaining exhaust residual out the still-open exhaust port.
- This is called **scavenging.**
- When most of the exhaust gas is out, the exhaust port closes, and the cylinder is left filled with mostly air and fuel.

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9. INTAKE FOR TWO-STROKE CYCLE ENGINES

Cross Scavenged Intake slots and exhaust slots are located on opposite sides of the cylinder wall. Proper design is required to assure that the intake air deflects up without *short-circuiting* and leaving a stagnant pocket of exhaust gas at the head end of the cylinder.

Loop Scavenged Intake and exhaust ports are on the same side of the cylinder wall, and incoming air flows in a loop.

Uniflow Scavenged or Through-Flow Scavenged Intake ports are in the cylinder walls and exhaust valves in the head (or intake valves are in the head and exhaust ports are in the wall, which is less common). This is the most efficient system of scavenging but requires the added cost of valves.

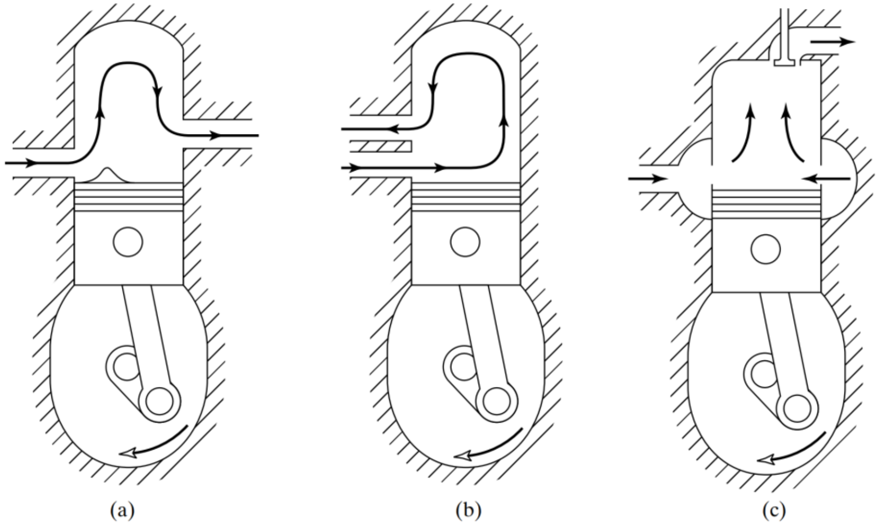


FIGURE 22

Common scavenging geometries for two-stroke cycle engines. (a) Cross scavenged with intake ports and exhaust ports on opposite sides of the cylinder. (b) Loop scavenged with intake ports and exhaust ports on the same side of the cylinder. (c) Uniflow scavenged (or through-flow scavenged) with intake ports in cylinder walls and exhaust valve in head. Other variations and combinations of these types exist, depending on the placement of slots and/or valves.

9. INTAKE FOR TWO-STROKE CYCLE ENGINES

For the same power generation, more air input is required in a two-stroke cycle engine than in a four-stroke cycle engine. This is because some of the air is lost in the overlap period of the scavenging process. A number of different intake and performance efficiencies are defined for the intake process of a two-stroke cycle engine. Volumetric efficiency of a four-stroke cycle engine can be replaced by either delivery ratio or charging efficiency,

$$\text{delivery ratio} = \lambda_{dr} = m_{mi}/V_d\rho_a \tag{22}$$

$$\text{charging efficiency} = \lambda_{ce} = m_{mt}/V_d\rho_a \tag{23}$$

where

m_{mi} = mass of air–fuel mixture ingested into cylinder
m_{mt} = mass of air–fuel trapped in cylinder after all valves are closed
V_d = displacement volume (swept volume)
ρ_a = density of air at ambient conditions

with typical values $0.65 < \lambda_{dr} < 0.95$
$0.50 < \lambda_{ce} < 0.75$

9. INTAKE FOR TWO-STROKE CYCLE ENGINES

Other efficiencies include:

$$\text{trapping efficiency} = \lambda_{te} = m_{mt}/m_{mi} = \lambda_{ce}/\lambda_{dr} \quad (24)$$

$$\text{scavenging efficiency} = \lambda_{se} = m_{mt}/m_{tc} \quad (25)$$

$$\text{relative charge} = \lambda_{rc} = m_{tc}/V_d\rho_a = \lambda_{ce}/\lambda_{se} \quad (26)$$

where m_{tc} = mass of total charge trapped in cylinder, including exhaust residual with typical values:

$$0.65 < \lambda_{te} < 0.80$$
$$0.85 < \lambda_{se} < 0.95$$
$$0.50 < \lambda_{rc} < 0.90$$

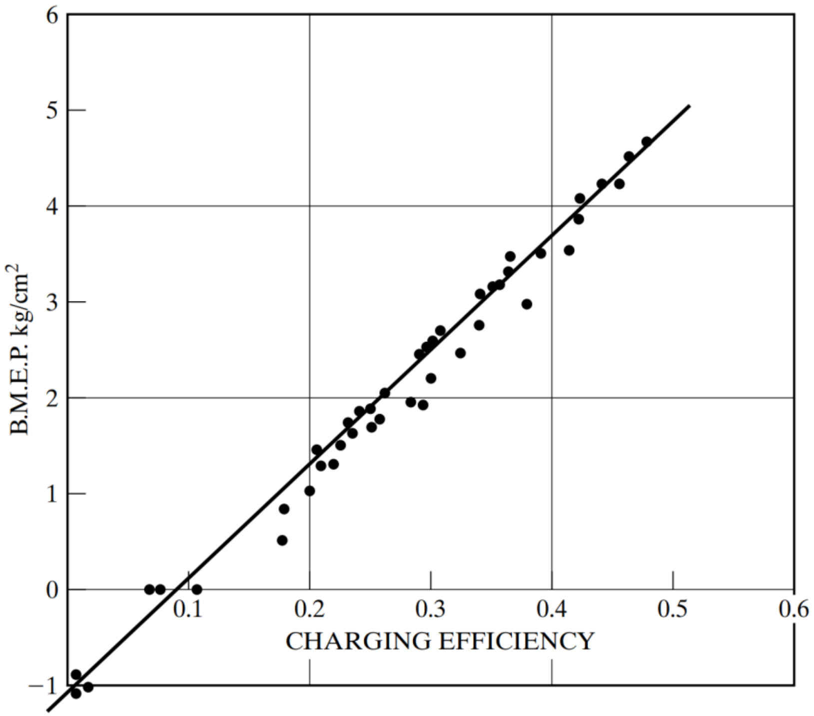


FIGURE 24

Brake mean effective pressure as a function of charging efficiency for two-stroke cycle SI motorcycle engine of 0.347 L displacement. Reprinted with permission from SAE Paper No. 750908 © 1975 SAE International, [229].

10. INTAKE FOR CI ENGINES

- Injection pressure for CI engines must be much higher than that required for SI engines.
- The cylinder pressure into which the fuel is first injected is very high near the end of the compression stroke, due to the high compression ratio of CI engines.
- By the time the final fuel is injected, peak pressure during combustion is being experienced.
- Pressure must be high enough that fuel spray will penetrate across the entire combustion chamber.

10. INTAKE FOR CI ENGINES

During injection, the mass flow rate of fuel through an injector is

$$\dot{m}_f = C_D A_n \sqrt{2\rho_f \Delta P} \tag{27}$$

The total mass of fuel injected into one cylinder during one cycle is

$$m_f = C_D A_n \sqrt{2\rho_f \Delta P}\,(\Delta\theta/360N) \tag{28}$$

where

C_D = discharge coefficient of injector
A_n = flow area of nozzle orifice(s)
ρ_f = density of fuel
ΔP = pressure differential across injector
$\Delta\theta$ = crank angle through which injection takes place (in degrees)
N = engine speed

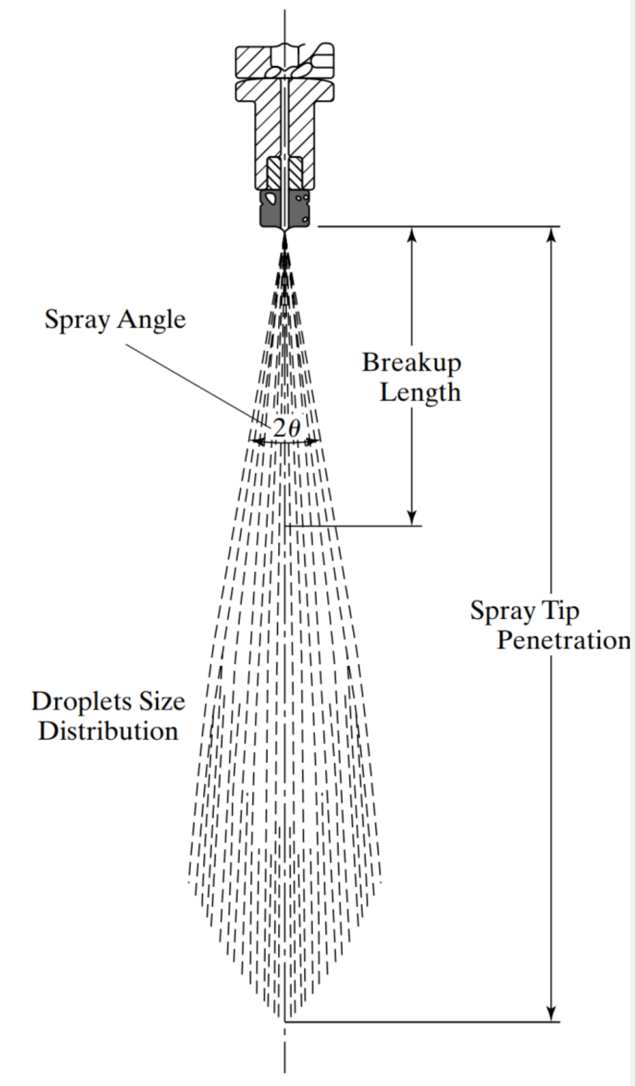
Pressure differential ΔP is about equal to the injection pressure:

$$P_{\text{inj}} \approx \Delta P \tag{29}$$

10. INTAKE FOR CI ENGINES

FIGURE 27

Fuel spray from injector in CI engine. The liquid spray breaks into individual droplets of varying sizes in the breakup length. The droplets then atomize, vaporize, and mix with air that has been pulled into the spray by the liquid flow. It is generally desired for the spray tip penetration length to reach the farthest distance in the combustion chamber. In most engines, spray will be distorted by swirl and tumble. Reprinted with permission from SAE Paper No. 840275 © 1984 SAE International, [144].



11. NITROUS OXIDE

- A unique way of ingesting a greater amount of oxygen into an engine, and thus producing more power, is to input the oxygen in the form of liquid nitrous oxide.
- By injecting oxygen as a liquid, a much greater amount can be input during each cycle without the normal restriction of limited volumetric efficiency.
- With more oxygen added, it is a fairly simple process to add more fuel, with a net result of a greater amount of combustible mixture in the cylinder to produce power during each cycle.
- One of the major problems of using nitrous oxide in a reciprocating engine is that it can produce enough power to destroy the engine.
- Power increases of 100–300% are possible, and unless the mechanical structure of the engine is reinforced, most engines would not survive this kind of operation.
- When a burst of power is desired, such as during a quarter mile drag race, a charge of liquid as well as a corresponding charge of liquid fuel, are injected into the engine cylinders.
- This produces a short-term surge of power output

EXAMPLE PROBLEM 1

A 2.8-liter four-cylinder square engine (bore = stroke) with two intake valves per cylinder is designed to have a maximum speed of 7500 RPM. Intake temperature is 60°C. Calculate:

1. intake valve area
2. diameter of intake valves
3. maximum valve lift

EXAMPLE PROBLEM 2

A six-cylinder, 4.8-liter, supercharged engine operating at 3500 RPM has an overall volumetric efficiency of 158%. The supercharger has an isentropic efficiency of 92% and a mechanical efficiency in its link with the engine of 87%. It is desired that air be delivered to the cylinders at 65°C and 180 kPa, while ambient conditions are 23°C and 98 kPa.

Calculate:

1. amount of aftercooling needed
2. engine power lost to run supercharger

EXAMPLE PROBLEM 3

An experimental six-cylinder, two-stroke cycle, SI automobile engine has a delivery ratio of 0.88 when operating at 3700 RPM. At this speed, when the exhaust slots close during the cycle, there is an air–fuel mass of 0.000310 kg in each cylinder, plus a 5.3% exhaust residual from the preceding cycle. The engine has a bore of 7.62 cm and a stroke of 8.98 cm.

Calculate:

1. charging efficiency
2. trapping efficiency
3. scavenging efficiency
4. relative charge

EXAMPLE PROBLEM 4

A fuel injector in a CI automobile engine has an orifice diameter of 0.31 mm, a discharge coefficient of 0.85, and an operating pressure differential of 110 MPa. Density of the diesel fuel is 750 kg/m^3.

Calculate the mass flow rate of fuel through the injector using Eq. (27):

END OF THE LECTURE