9.0 COMBUSTION CHAMBER DESIGN FOR 4-STROKE AND 2-STROKE ENGINES

9.0.1 Combustion Requirements for Diesel Engines

The various processes combustion in diesel engine undergoes, are dependent of the configuration of the combustion chamber, the characteristics of the fuel, the fuel injection system and the operating conditions of the engine.

Operational characteristics of the compression-ignition engines:

a. As opposed to a spark ignition (SI) engine, combustion starts in compression ignition (CI) engines, shortly after the injection of fuel. This gives room for the running CI engines at higher compression ratios. This provides the platform for improved engine's efficiency compared to SI engines.
b. Combustion timing in CI engines is controlled by injection timing and the delay period is expected to be short. A short delay period ensures that the engine maximum pressure does not go beyond the engines maximum pressure limit. This is realised by ensuring that diesel fuel with high cetane numbers are used as fuel.
c. In CI engines, torque is varied by varying the amount of fuel injected per cycle with the amount of air approximately unchanged. As a result CI engines are not throttled. Since pumping work requirement is low or throttle losses are eliminated, the mechanical efficiency of the engine is higher compared to SI engines at part-load.
d. Total combustion of injected fuel in CI engines becomes a problem with increase in injection of fuel and this leads to the formation of soot which are incomplete combusted fuel. This is why the maximum IMEP of a naturally aspirated CI engine is lower than the value of an equivalent size of an SI engine.
e. The effective value of the specific heat ratios γ for CI engine is higher compared to that of SI, because CI engines always operate with lean fuel-air mixture. this gives the CI engine a higher fuel conversion efficiency compared to the SI engines.

Achieving quick and appropriate mixing of diesel fuel and air within the appropriate crank angle interval close to the Top Dead Centre has been the major challenge of diesel combustion chamber design. The chamber design plays a significant role in the mixing rate and fuel burning rate. The bore sizes of commercial diesel engines vary from about 70 to 900mm. To achieve high fuel conversion rate in larger diesel (CI) engines, which operates at lower engine speeds, the crank angle interval for combustion in diesel engines is between 40 to 50 crank angle degrees. Smaller diesel engines, operates at high engines speeds, therefore, the mixing of the air and fuel must take place at shorter crank angles compared to the larger engines.

In smaller bore diesel engines, more vigorous air motion is required for air-fuel mixing and this can be achieved from the combustion chamber design. As a result of the desire for optimum performance of different sizes of engines, different combustion chamber designs are required to achieve this.

9.1 Diesel Combustion Chamber Design

Diesel engines are divided into two broad groups according to the combustion chamber design: (i) Direct-Injection (DI) engines and (ii) Indirect-Injection (IDI) engines

9.1.1 Direct Injection Diesel Engine

This type of engine has a single open combustion chamber where fuel is injected into directly. In smaller diesel engines, increase in swirl in the combustion chamber is required for rapid fuel-air mixing and the swirl is generated by the suitable design of the **inlet port**. The piston crown is usually design in bowl shape. In very large diesel engines (with large bores), the rapid fuel-air mixing is not an issue of serious concern as in smaller diesel engines. The needed fuel-air mixing is achieved by the injection of fuel with momentum and energy. The piston crown is usually design in small bowl shape and a centralized multi-hole injector is used.

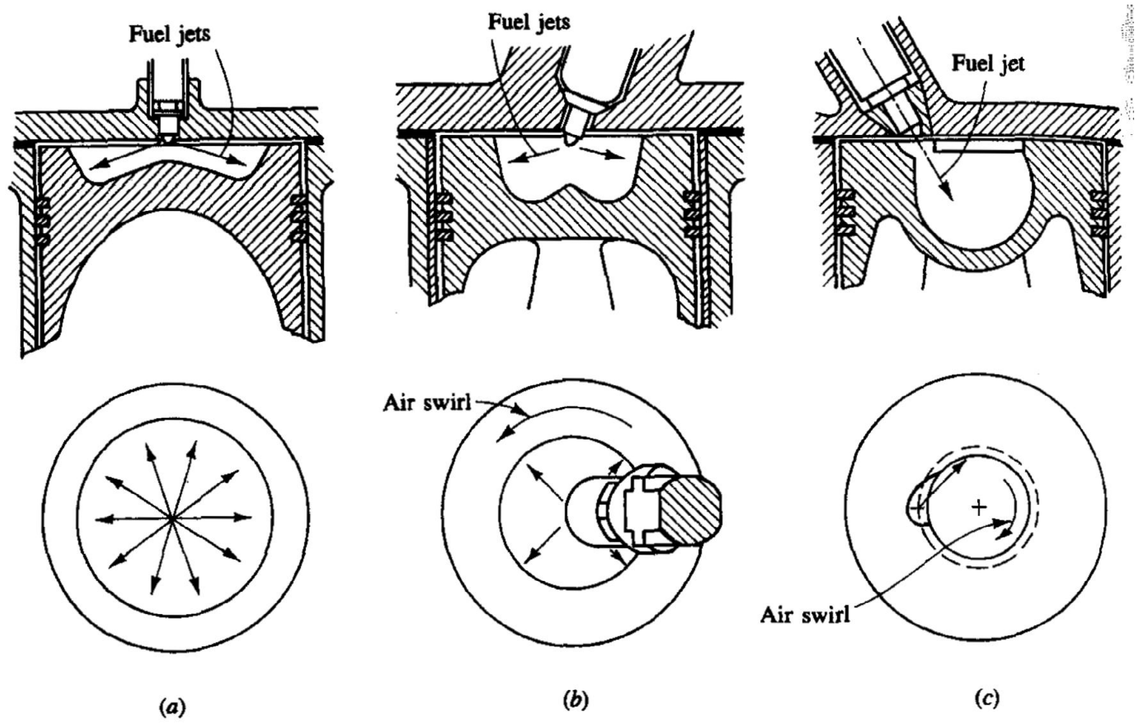


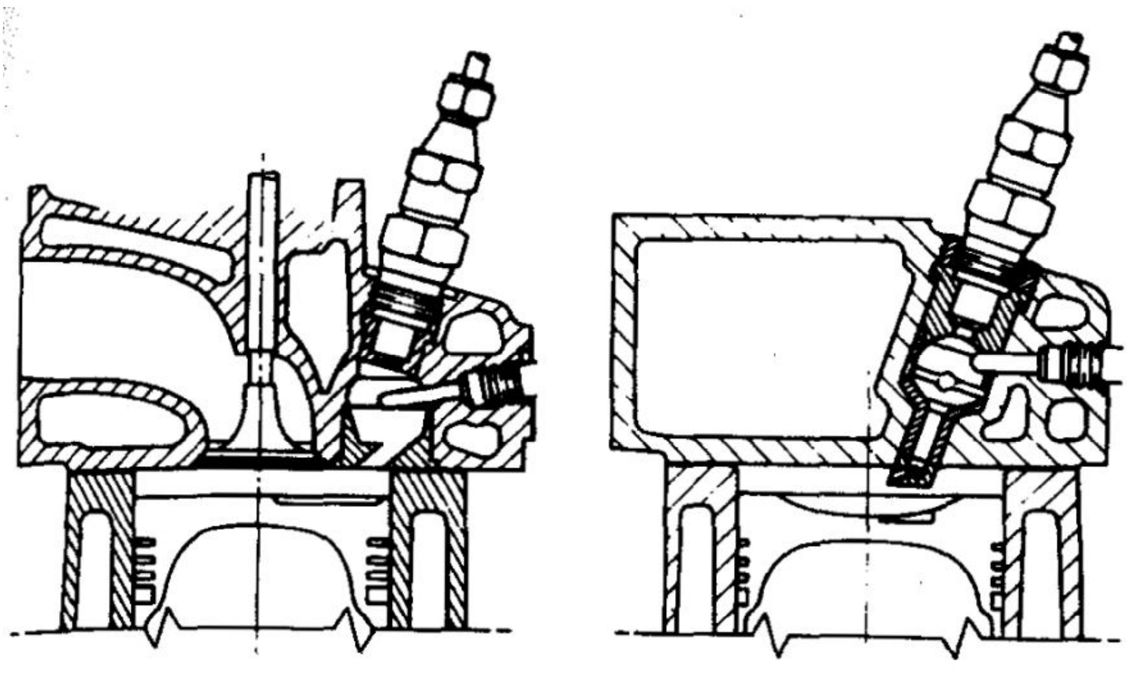
Figure X-1: Direct Injection combustion systems (a) Large engine combustion chamber with multi-hole injector nozzle (b) Bowl-in-piston chamber with swirl and multi-hole nozzle (c) bowl –in-piston chamber and single-hole nozzle.

Note: b and c are used in medium to small size DI engines.

9.1.2 Indirect-Injection Diesel Engine Systems

In spite of, the increase in fuel-air mixing as a result of the bowl-in-piston design, adequate mixing is still an issue in small high-speed diesel engines. Other forms of combustion chamber design known as the **Indirect-injection** or **divided-chamber** are used instead, where **vigorous charge motion** during fuel injection is generated during the compression stroke. The indirect-injection combustion chamber is classed into two broad groups:- (i) Swirl chamber systems and (ii) Pre-chamber systems. As shown in Figures X-2. During compression, some of the air in the main combustion chamber is forced into the auxiliary chamber, through a set of nozzles or orifices and this generates a vigorous flow in the auxiliary combustion chamber and swirl is generated and maintained by the shape of the combustion chamber.

The indirect injection system, allows the of lower pressure injection-systems as opposed to the DI engines, through a pintle nozzle as a single spray. Combustion starts at the auxiliary chamber, as the pressure rises, the expanding gas and fuel are forced into the chamber, where the injected fuel mixes with air in the main chamber (entrains air) and combusts. Glowing plug is installed in the pre-chamber and it is a cold-starting aid.



(a) (b)

Figure X-2: IDI engine combustion system (a) swirl prechamber (b) turbulent pre-chamber

9.2 Characteristics of Common Diesel Engine Combustion Systems

Over the years, various combustion chamber designs have been proposed and tried in diesel engines and the objectives have been to improve the physical and chemical processes involved. The important characteristics of these chambers now most commonly used are summarized in Table X.

System	Direct injection				Indirect injection	
	Quiescent	Medium swirl	High swirl "M"	High swirl multispray	Swirl chamber	Pre-chamber
Size	Largest	Medium	Medium—smaller	Medium—small	Smallest	Smallest
Cycle	2-/4-stroke	4-stroke	4-stroke	4-stroke	4-stroke	4-stroke
Turbocharged/supercharged/naturally aspirated	TC/S	TC/NA	TC/NA	NA/TC	NA/TC	NA/TC
Maximum speed, rev/min	120–2100	1800–3500	2500–5000	3500–4300	3600–4800	4500
Bore, mm	900–150	150–100	130–80	100–80	95–70	95–70
Stroke/bore	3.5–1.2	1.3–1.0	1.2–0.9	1.1–0.9	1.1–0.9	1.1–0.9
Compression ratio	12–15	15–16	16–18	16–22	20–24	22–24
Chamber	Open or shallow dish	Bowl-in-piston	Deep bowl-in-piston	Deep bowl-in-piston	Swirl pre-chamber	Single/multi-orifice pre-chamber
Air-flow pattern	Quiescent	Medium swirl	High swirl	Highest swirl	Very high swirl in pre-chamber	Very turbulent in pre-chamber
Number of nozzle holes	Multi	Multi	Single	Multi	Single	Single
Injection pressure	Very high	High	Medium	High	Lowest	Lowest

9.3 Two-Stroke Engine Configurations

The expulsion of burned gases and induction of fresh fuel-air mixture (or air) into the combustion chamber of an engine (the intake-exhaust process) is known as SCAVENGING.

In two-stroke cycle scavenging flows, different designs exist and this done by the arrangement of the ports (and valves). The different designs exist and they are classified as follows: - (a) Cross-scavenged (b) loop-scavenged and (c) uniflow-scavenged configurations.

The cross and loop-scavenging systems use exhaust and inlet ports in the cylinder wall, which is open and closed by the piston’s motion. The uniflow system, comprising of ports and valves arrangements, has the ports as the inlet channels while the exhaust channel is controlled by the exhaust valves, which is controlled by the valve-train in the cylinder head.

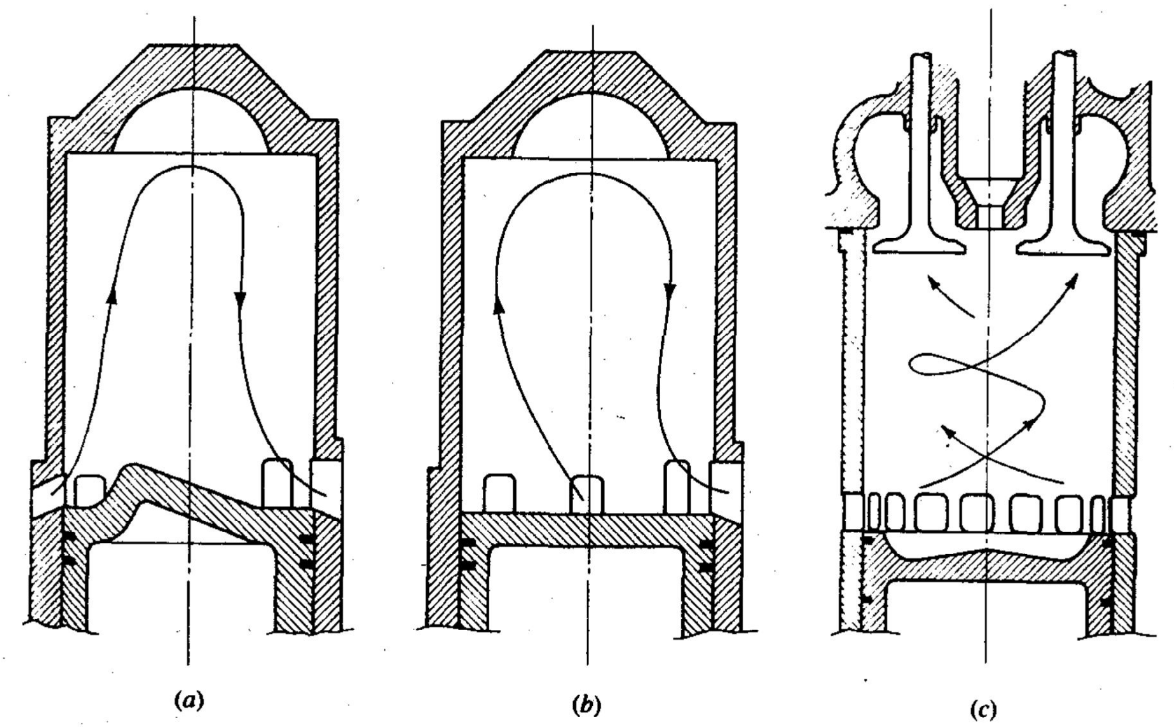


Figure X-3: Two-stroke cycle engine configurations (a) cross-scavenged (b) loop-scavenged and (c) uniflow-scavenged.