A Review: - Effects of Combustion Chamber Geometry and Injection Parameters on Diesel Engine Parameters

Vishal Markad[1], Prof. R. L. Karwande[2], Prof. M Javed[3]
[1]*M. Tech Student Mechanical Engineering, MSS CoE Jalna*
[2]*HOD Mechanical Engineering, MSS CoE Jalna*
[3]*Asst. Prof. Mechanical Engineering, MSS CoE Jalna*

Abstract—The increasing demand for diesel-powered transportation and industrial applications has raised concerns regarding fuel consumption, depletion of fossil fuels, and environmental pollution. Stringent emission regulations have motivated researchers to develop advanced combustion technologies that improve fuel efficiency while reducing harmful emissions. Among the various approaches, optimization of combustion chamber geometry, in-cylinder air motion, and fuel injection characteristics has emerged as a promising solution. This review paper examines the influence of combustion chamber design, particularly re-entrant combustion chambers, along with air swirl, squish, turbulence, injection pressure, injector nozzle geometry, and injection timing on diesel engine performance and emission characteristics. The findings indicate that enhanced air-fuel mixing achieved through optimized combustion chamber geometry and injection strategies can significantly reduce soot and hydrocarbon emissions while improving thermal efficiency. The review also highlights the need for further investigations on small and medium-sized diesel engines using advanced computational and experimental techniques.

Index Terms—Diesel engine, Combustion chamber geometry, Re-entrant piston bowl, Swirl, Turbulence, Injection pressure, Emissions, CFD.

I. INTRODUCTION

Diesel engines are widely used in transportation, agriculture, power generation, and industrial sectors because of their superior fuel efficiency and durability. However, increasing environmental concerns and stricter emission regulations have necessitated the development of cleaner and more efficient diesel combustion systems. The major pollutants emitted from diesel engines include nitrogen oxides (NOx), particulate matter (soot), hydrocarbons (HC), and carbon monoxide (CO).

Engine combustion performance is strongly influenced by in-cylinder air motion and fuel injection characteristics. Parameters such as swirl, squish, turbulence, injection pressure, nozzle hole diameter, spray angle, and injection timing determine the quality of air-fuel mixing and combustion efficiency. Researchers have focused on optimizing these parameters to achieve lower emissions and improved fuel economy.

This review paper discusses the role of combustion chamber geometry and fuel injection characteristics in enhancing diesel engine performance and reducing emissions.

II. IN-CYLINDER AIR MOTION OF DIESEL ENGINES

The combustion process in diesel engines is highly dependent on the movement of air inside the cylinder. The three major components of in-cylinder air motion are:

2.1. Swirl Motion

Swirl is the rotational movement of air around the cylinder axis generated primarily by intake port design. Higher swirl intensity improves fuel-air mixing and combustion efficiency. Appropriate swirl levels promote complete combustion and reduce soot emissions.

2.2. Squish Motion

Squish occurs when air is forced radially inward toward the combustion chamber as the piston approaches Top Dead Centre (TDC). This motion enhances turbulence and promotes rapid mixing of fuel and air.

2.3. Turbulence

Turbulence increases the rate of fuel evaporation and combustion. Studies have reported two turbulence peaks near TDC, one before and one after TDC, due to squish and reverse-squish effects. Increased turbulence generally improves combustion efficiency but may increase combustion temperatures and NOx formation.

III. INFLUENCE OF COMBUSTION CHAMBER GEOMETRY

Combustion chamber geometry significantly affects air motion, mixture formation, combustion quality, and emissions.

3.1. Conventional Combustion Chambers

Traditional cylindrical combustion chambers provide moderate swirl and turbulence levels. Although they offer stable operation, their combustion efficiency is lower compared to advanced chamber designs.

3.2. Re-Entrant Combustion Chambers

Re-entrant combustion chambers contain a lip or throat at the bowl entrance, which intensifies swirl and turbulence during compression.

Advantages

- Enhanced air-fuel mixing
- Improved combustion efficiency
- Reduced soot emissions
- Lower hydrocarbon emissions
- Improved brake thermal efficiency

Limitations

- Increased combustion temperature
- Higher NOx emissions under certain operating conditions

IV. DESIGN CONSIDERATIONS FOR A PISTON

In designing a piston for I.C. engine, the following points should be taken into consideration:

1. It should have enormous strength to withstand the high gas pressure and inertia forces.
2. It should have minimum mass to minimize the inertia forces.
3. It should form an effective gas and oil sealing of the cylinder.
4. It should provide sufficient bearing area to prevent undue wear.
5. It should disperse the heat of combustion quickly to the cylinder walls.
6. It should have high speed reciprocation without noise.
7. It should be of sufficient rigid construction to withstand thermal and mechanical distortion.
8. It should have sufficient support for the piston pin.

V. EFFECT OF FUEL INJECTION PARAMETERS

Fuel injection characteristics play a crucial role in diesel combustion.

5.1. Injection Pressure

Higher injection pressure produces finer fuel droplets and improves atomization.

Benefits

- Faster evaporation
- Better fuel-air mixing
- Improved combustion efficiency
- Reduced smoke emissions

However, excessively high injection pressure may increase NOx emissions due to higher combustion temperatures.

5.2. Injector hole Diameter

Smaller nozzle hole diameters generate finer sprays with larger surface area.

Advantages include:

- Improved atomization
- Better combustion efficiency
- Reduced particulate emissions

5.3. Spray Angle

The spray angle affects fuel distribution within the combustion chamber. Proper spray angle ensures effective utilization of available air and prevents wall impingement.

5.4. Injection Timing

Injection timing significantly influences combustion and emissions.

- Advanced injection timing generally increases NOx emissions.
- Retarded injection timing reduces NOx but may increase fuel consumption and soot emissions.

In re-entrant combustion chambers, optimized injection timing can simultaneously control NOx and soot emissions.

VI. COMBINED EFFECT OF SWIRL AND INJECTION CHARACTERISTICS

Research studies indicate that combustion performance depends on the combined optimization of:

- Swirl ratio
- Combustion chamber geometry
- Injection pressure
- Nozzle hole diameter
- Injection timing

An optimum swirl level exists at which emissions are minimized and combustion efficiency is maximized. Excessive swirl may increase heat losses and NOx formation, whereas insufficient swirl leads to poor fuel-air mixing.

VII. APPLICATION OF COMPUTATIONAL FLUID DYNAMICS (CFD)

Modern engine development increasingly relies on Computational Fluid Dynamics (CFD) to analyze in-cylinder processes.

Benefits of CFD

- Visualization of air flow patterns
- Prediction of combustion behavior
- Optimization of combustion chamber geometry
- Reduction in experimental costs
- Evaluation of emission characteristics

CFD studies have demonstrated the effectiveness of re-entrant combustion chambers in improving swirl intensity, turbulence generation, and combustion efficiency.

VIII. RESEARCH GAP

A review of existing literature reveals that:

1. Most investigations have focused on large-capacity diesel engines.
2. Limited studies are available on small and medium-sized diesel engines.
3. The combined effects of re-entrant combustion chamber geometry and injection parameters require further investigation.
4. More experimental validation of CFD predictions is needed.

Therefore, research on small single-cylinder diesel engines operating under practical conditions remains an important area for future study.

IX. CONCLUSION

Combustion chamber geometry and fuel injection parameters significantly influence diesel engine performance and emissions. Re-entrant combustion chambers enhance swirl, squish, and turbulence, leading to improved air-fuel mixing and combustion efficiency. Higher injection pressures and smaller nozzle diameters further improve atomization and combustion quality. However, achieving a balance between NOx and soot emissions remains a major challenge. Optimizing combustion chamber design together with injection characteristics offers a promising approach for developing cleaner and more fuel-efficient diesel engines. Future studies should focus on small and medium-capacity engines using advanced CFD and experimental techniques to identify optimum design parameters.

REFERENCES

[1] J. B. Heywood, *Internal Combustion Engine Fundamentals*. New York, NY, USA: McGraw-Hill.

[2] R. Stone, Introduction to Internal Combustion Engines. Warrendale, PA, USA: SAE International.

[3] F. Payri, J. Benajes, X. Margot, and A. Gil, “CFD Modeling of Diesel Combustion Chamber Design,” Applied Thermal Engineering.

[4] J. E. Dec, “A Conceptual Model of DI Diesel Combustion Based on Laser-Sheet Imaging,” SAE Technical Paper.

[5] C. D. Rakopoulos et al., “Effect of Combustion Chamber Geometry on Diesel Engine Performance

and Emissions," Energy Conversion and Management.

[6] A. K. Agarwal, "Biofuels and Diesel Engine Emissions: A Review," Progress in Energy and Combustion Science.

[7] B. Kegl, "Influence of Biodiesel on Engine Combustion and Emissions," *Applied Energy*.