ANALYSIS OF COMBUSTION CHAMBER PROFILE EFFECT ON DIESEL ENGINE PERFORMANCE AND EMISSIONS

Dr. S. Periyasamy, Associate Professor, Department of Mechanical Engineering, Government College of Technology, Coimbatore, India : speriyasamy@gct.ac.in
Dr. A. Sasikumar, Assistant Professor, Department of Production Engineering, Government College of Technology, Coimbatore, India : sasikumar@gct.ac.in
Dr. S. Kumar, Assistant Professor, Department of Production Engineering, Government College of Technology, Coimbatore, India: kumar.sgm@gmail.com

ABSTRACT
The present work describes an experimental investigation of the performance and emissions of a diesel engine with different combustion chamber profiles. The internal flow characteristics of the working medium depend on the shape of the combustion chamber. Parameters such as squish, tumble, and flow patterns vary with different combustion chamber profiles, which significantly affect the combustion process. Combustion efficiency was correlated with indicated thermal efficiency and the emission of unburned hydrocarbons in the exhaust gas. Emission parameters, including CO, CO_2, NO, and NOx, were compared for four different piston crown profiles. The Rankine half-body profile exhibited the best flow pattern for efficient combustion. However, this profile is not currently used in internal combustion engines, as it is neither a hemispherical profile nor a standard design. Among the four piston profiles tested, one was identified as providing superior performance compared to the others.

Keywords:
Combustion Chamber Profile, Efficiency, Emissions, Specific Fuel Consumption.

1. Introduction
Engine performance indicates the degree of success in converting the chemical energy contained in the fuel into useful mechanical work [1 - 3]. To achieve better performance, numerous numerical, theoretical, and experimental investigations are still ongoing. A brief review of previous studies is presented here before delving into the current work. The numerical simulation of different combustion chamber profiles began in the late 20th century, but detailed experimental records for similar profiles are limited. The effect of combustion chamber geometry on engine performance and exhaust emissions has been extensively investigated by researchers [4 - 8]. Proper combustion chamber design can offer significant benefits in reducing pollutant emissions without severely compromising engine performance. Recent studies have continued to explore the optimization of combustion chamber geometry to enhance diesel engine performance and reduce emissions. Advanced computational methods, such as CFD have been instrumental in these investigations. Prasad et al., [9] investigated the impact of re-entrant piston bowl geometries on pollutant emissions in a diesel engine using detailed CFD simulations. They identified an optimal geometry that enhances in-cylinder swirl and turbulence, with emission reductions primarily attributed to the use of a sac-less injector. Punukollu et al., [10] employed surrogate model-driven multi-parameter optimization to assess four distinct piston bowl designs. The research demonstrated the effectiveness of CFD in optimizing piston bowl shapes to improve combustion efficiency and lower emissions. Another recent experimental investigation by Temizer et al., [11] introduced a novel combustion chamber geometry and compared it with a standard design under various operating conditions. The findings indicated that the new geometry reduced hydrocarbon (HC), carbon monoxide (CO), and soot emissions, although nitrogen oxide (NOx) emissions saw a slight increase. Additionally, Guo et al., [12] focused on optimizing piston bowl geometry for heavy-duty diesel engines using CFD-guided design optimization. The research aimed to achieve low emissions and high efficiency, underscoring the critical role of piston bowl design in engine performance. An extensive literature survey on engine performance and emissions reveals that

most studies utilized CFD to simulate flow patterns, while some researchers focused on engine parameters for performance analysis. However, the use of piston profiles as a variable has been rare. Therefore, this study investigates performance and emissions using four different combustion chamber profiles, all with the same volume.

2. Experimentation

A single-cylinder compression ignition engine was used to generate the test data. This directly injected 4-stroke diesel engine, equipped with fixed valve timing and speed control, was coupled to a mechanical dynamometer for testing. The experimental program was divided into four categories, where the engine was loaded using the dynamometer with loads incrementally increased from 0 kg to 15 kg in steps of 5 kg, and the engine speed was varied from 1100 rpm to 1500 rpm in steps of 100 rpm for each load condition. In the first category, the engine was fitted with a double-convex profile piston and operated under normal conditions. In the second category, the hemisphere profile piston was installed, and the engine was run with varying loads and speeds under typical conditions. In the third category, the elliptical profile piston was used, and the engine was operated in a similar manner. Finally, in the fourth category, the ellipsoid profile piston was fitted, and the engine was tested under normal conditions. For all test conditions, various performance parameters and emission values were recorded, and the engine specifications are listed in Table 1.

Table 1: Specification of the engine

Engine Parameters	Value
No. of Cylinder	One
Bore (mm)	85
Stroke (mm)	110
Speed (rpm)	1500
Connecting rod length (mm)	235
Compression ratio	18:1
Intake pressure (bar)	1
Intake temperature (K)	300

3. Results and Discussion

The performance and emissions of an engine depend significantly on the combustion process, which is influenced by injection parameters, fuel type, operating conditions, and the physical geometry of the piston crown, where the combustion chamber is formed. In this study, all conditions except the combustion chamber profile were kept constant, making the influence of other parameters negligible. The air/fuel ratio for different piston engines, as shown in Figure 1, indicates that the hemispherical piston engine draws in more air or less fuel under no-load conditions. However, at load conditions, its air/fuel ratio becomes similar to that of other engines. The specific fuel consumption (SFC) for all piston profile engines, depicted in Figure 2, shows that the hemispherical piston engine consumes more fuel than the others at the same power rating. The ellipsoid piston engine consumes the least fuel, while the elliptical and double-concave piston engines fall in between. The economic speed of the elliptical and ellipsoid piston engines is higher than that of the hemispherical and double-concave piston engines, as illustrated in Figure 3. The starting specific fuel consumption of engines with Rankine-type profiles, such as elliptical and ellipsoid pistons, is lower compared to other engines.

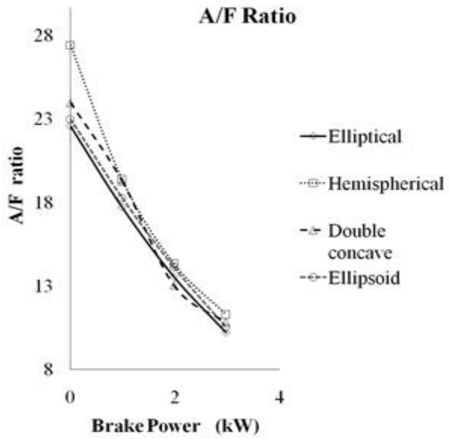

Figure 1. Comparison of air-fuel ratio of various piston engines

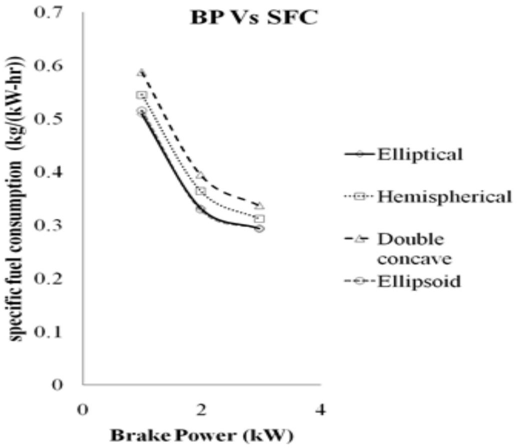

Figure 2. Comparison of specific fuel consumption of engines with various pistons

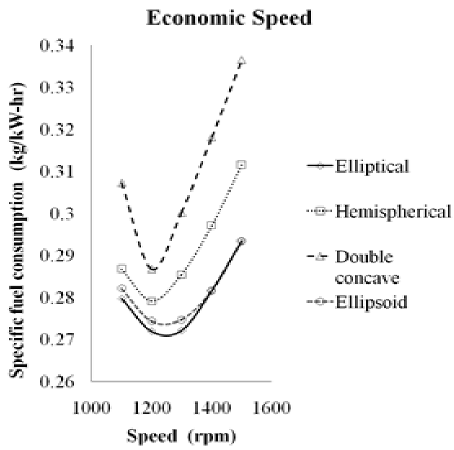

Figure 3. Comparison of economic speed of various piston engines

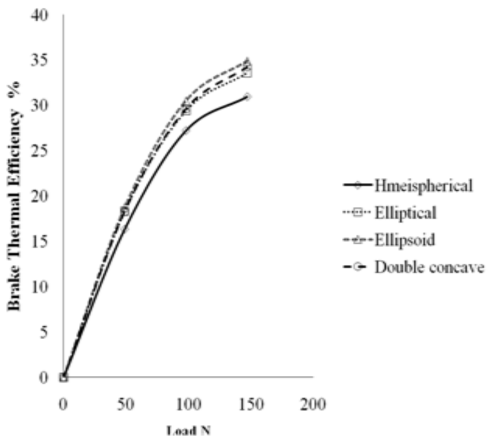

Figure 4. Comparison of Brake Thermal Efficiency for different piston engines

The brake thermal efficiency of all pistons, shown in Figure 4, reveals that the ellipsoid engine has the highest efficiency, while the hemispherical engine has the lowest. This is notable even though the ellipsoid engine's fuel consumption is lower, and the hemispherical engine's is higher. The indicated thermal efficiency of the ellipsoid engine is also higher than that of the other engines, as depicted in Figure 5. The mean effective pressure and mechanical efficiency differences between the piston engines are minimal, indicating that all engines meet external power requirements with a stipulated minimum combustion process while overcoming mechanical friction. The variation in SFC and brake thermal efficiency underscores the influence of piston profile on the combustion process. The ellipsoid piston engine satisfies power requirements with minimal fuel utilization due to its superior air-fuel mixing capability. The inherent steep walls of the ellipsoid design force the air-fuel mixture into a downward spiral around the cylinder axis during compression. This reduces the squish area, violently thrusting the trapped mixture from the thin to the thick end of the chamber, leading to better combustion and improved mixing of residual charges.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 1, No.2, January : 2025

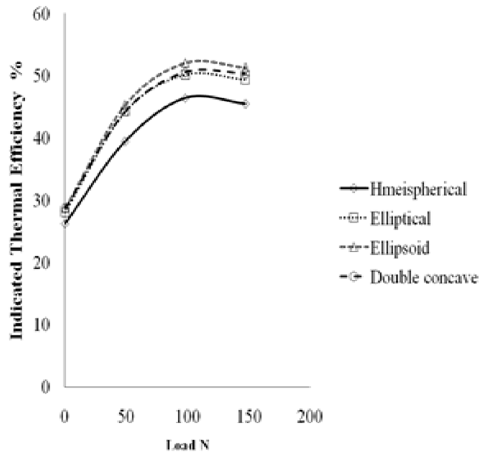

Figure 5. Comparison of Indicated Thermal Efficiency for different piston engines

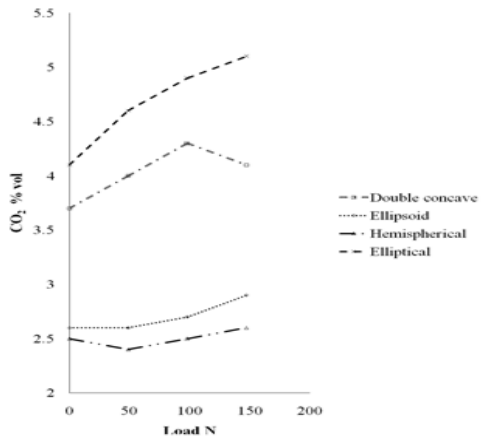

Figure 6. CO_2 emission for different piston engines

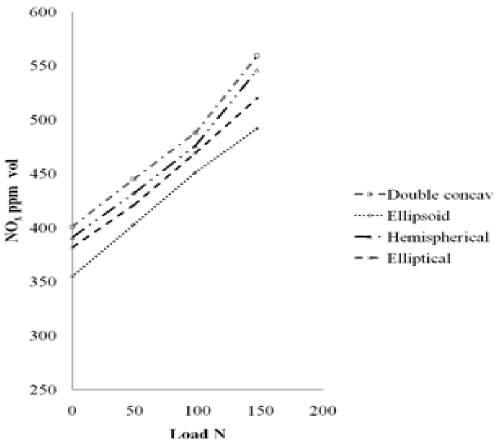

Figure 7. NO_x emission for different piston engines

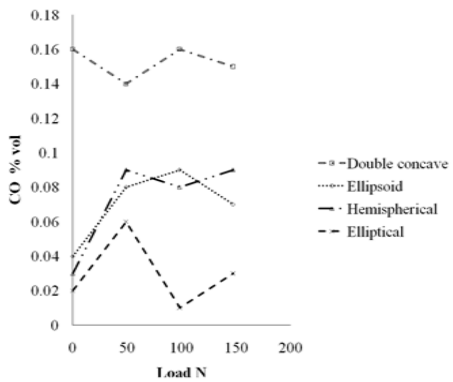

Figure 8. CO emission for different piston engines

The CO_2 emissions, shown in Figure 6, are slightly higher for elliptical and ellipsoid piston engines due to their better combustion efficiency, which results from their geometric shape and profile. The NOx emissions for all piston engines, depicted in Figure 7, are lowest for the ellipsoid engine, as its SFC is lower than that of the other engines. The remaining piston engines emit higher NOx levels because they consume more fuel for the same indicated pressure. This increased fuel consumption raises air intake, and the excess air and higher temperatures favor NOx production.
CO emissions, shown in Figure 8, indicate the level of unburned hydrocarbons in the exhaust gas. Elliptical and ellipsoid piston engines release less CO compared to other piston types. In contrast, double-concave and hemispherical piston engines exhibit incomplete combustion due to unfavorable flow conditions within the chamber during the combustion process.

4. Conclusion

Persistent and comprehensive efforts are being made in internal combustion engines to reduce emissions without introducing additional components while simultaneously improving performance. The combustion chamber and operating parameters play a dominant role in the functioning of internal combustion engines. This study focuses on the automotive sector, aiming to reduce emissions through modifications to integral components and enhance engine performance. The research involved modifying the combustion chamber with three different piston profiles and investigating the resulting performance and exhaust emission changes, comparing them with the existing hemispherical piston profile. The key findings are as follows:

- Under normal operating conditions, the ellipsoid piston engine demonstrated superior performance, consuming 12.75% less fuel for the same specific power output compared to the hemispherical piston engine. The elliptical piston engine consumed 3.92% more fuel than the ellipsoid piston engine but still less than the hemispherical engine.
- The indicated thermal efficiency of the ellipsoid piston engine was significantly higher, being 12.2% greater than that of the hemispherical piston engine. The elliptical piston engine, another modified Rankine profile model, achieved an efficiency that was 3.73% lower than the ellipsoid piston engine, attributed to its improved combustion profile compared to other piston types.
- The NOx emissions from the double-concave piston engine were 13.62% higher than those from the ellipsoid piston engine and exceeded the emissions of both the elliptical and hemispherical piston engines. The rate of internal heat buildup in the walls and interior of the chamber for the double-concave piston engine was also higher than for other piston profiles.
- Overall, the results indicate that the elliptical and ellipsoid piston engines produced better performance and emission outcomes compared to the other piston profiles.

References

[1] Sudalaiyandi, K., Alagar, K., VJ, M. P., & Madhu, P. (2021). Performance and emission characteristics of diesel engine fueled with ternary blends of linseed and rubber seed oil biodiesel. Fuel, 285, 119255.

[2] Atakan, B., Kaiser, S. A., Herzler, J., Porras, S., Banke, K., Deutschmann, O., ... & Schulz, C. (2020). Flexible energy conversion and storage via high-temperature gas-phase reactions: The piston engine as a polygeneration reactor. Renewable and Sustainable Energy Reviews, 133, 110264.

[3] Deepanraj, B., Senthilkumar, N., Mala, D., & Sathiamourthy, A. (2022). Cashew nut shell liquid as alternate fuel for CI engine—optimization approach for performance improvement. Biomass Conversion and Biorefinery, 12(5), 1715-1728.

[4] Doppalapudi, A. T., Azad, A. K., & Khan, M. M. K. (2021). Combustion chamber modifications to improve diesel engine performance and reduce emissions: A review. Renewable and Sustainable Energy Reviews, 152, 111683.

[5] Topkaya, H., Işık, M. Z., Çelebi, Y., & Aydın, H. (2024). Numerical analysis of various combustion chamber bowl geometries on combustion, performance, and emissions parameters in a diesel engine. International Journal of Automotive Engineering and Technologies, 13(2), 63-72.

[6] Chen, G., Wei, F., Zhang, K., Xiao, R., Wang, Z., & Yang, S. (2023). Investigation on combustion characteristics and gas emissions of a high-pressure direct-injection natural gas engine at different combustion modes. Energy Conversion and Management, 277, 116617.

[7] Sener, R., Yangaz, M. U., & Gul, M. Z. (2020). Effects of injection strategy and combustion chamber modification on a single-cylinder diesel engine. Fuel, 266, 117122.

[8] Khan, S., Panua, R., & Bose, P. K. (2022). Numerical investigation to explore the influence of combustion chamber modification on combustion and emission of a diesel engine fuelled with biodiesel. International Journal of Ambient Energy, 43(1), 4701-4715.

[9] Prasad, B. V. V. S. U., Sharma, C. S., Anand, T. N. C., & Ravikrishna, R. V. (2011). High swirl-inducing piston bowls in small diesel engines for emission reduction. Applied energy, 88(7), 2355-2367.

[10] Punukollu, R., Pasham, N. R., & Baliga, N. (2024). Surrogate model-driven multi-parameter optimization of four distinct combustion chambers in a four-stroke diesel engine. Journal of Engineering and Applied Science, 71(1), 1-34.

[11] Temizer, I., & Cihan, O. (2024). Experimental Investigation of New Combustion Chamber Geometry Modification on Engine Performance, Emission, and Cylinder Liner Microstructure for a Diesel Engine. Journal of Energy Resources Technology, 146(12), 121201.

[12] Guo, Z., He, X., Pei, Y., Chang, C. T., Wang, P., Sun, X., Wang, B., Liu, S., Wang, Z., & Shuai, S. (2020). Optimization of piston bowl geometry for a low emission heavy-duty diesel engine (No. 2020-01-2056). SAE Technical Paper.