Short Research Article

Numerical Investigation of the Use of Some Piston Crown Geometry on CI Engine Performance

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ABSTRACT

Performance enhancement of internal combustion engines is basically achieved through process type, fuel use, injection mode and, combustion chamber geometry modification. Extensive studies are being undertaken to optimize the performance of compression ignition engines by combustion chamber geometry modification, however, this is largely executed with experiments. Numerical results on the effect of piston crown geometry as a means of combustion chamber modification on the performance characteristics of a compression ignition engine are presented in this short paper. The impact of in-cylinder fluid flow velocity was used to evaluate the performance of the engine. The in-cylinder motion of the fluid was positively impacted using the conical, hemispherical and dual hemisphere indented piston crowns, which is in agreement with previous experimental studies.

Keywords: Combustion Chamber Geometry, Engine Performance, In-Cylinder fluid motion, Piston crown

1. INTRODUCTION

The enhancement of the performance of internal combustion engines is being usually achieved through any of the following means; fuels, process types, injection mode, and combustion chamber geometry type.

The importance of the internal combustion engines in the transportation sector is unquantifiable, as it is basically the driving force in the sector. It finds application in the road, rail, marine, and even in some aircrafts.

Better fuel efficiency and reduced emission of engines have been proven to be a reality from results of studies on combustion chamber geometry which ultimately determine the fuel mixture formation, in-cylinder flow, and the combustion process achieved using different piston crown geometries [1, 2, 3]. Some of such piston crown geometries include; toroidal, hemispherical, truncated cone, re-entrant, trapezoidal etc. These geometries result in the redesign of the combustion chamber. The use of dual fuels in engines results in improved engine performance and reduced emissions [4, 5]. The improved performance criteria are in terms of brake thermal efficiency, brake specific fuel consumption, and brake power [6, 7]. Improved performance of these engines is essential for the reduction of the much talked about global warming resulting from the emission of CO_2 gas and other greenhouse gases like NOx and PMs [8, 9, 10]. The need for a reduction in the emission of greenhouse gases from internal combustion engine is the reason for the search of sustainable fuels which synthetic fuels promises to fill [11]. The percentage contribution of the transportation sector to the total for greenhouse gas emission stands at about 14% [12] making it a subject for critical consideration.

More of the studies reported in literature have been based on experimental studies, and it is imperative to develop models to make further studies easier, faster and less costly. This study is therefore concerned about the numerical studies of the performance enhancement of the compression ignition engine. It focusses on the performance characterization of a compression ignition engine using selected piston crown geometry to provide a redesigned combustion chamber. The simulation results showed an agreement with previous experimental studies of performance improvement with redesigned combustion chamber using hemispherical and conical piston crown. The next section discusses the methodology employed, third section is a presentation of the results and discussion, while the last section is the conclusion.

2. METHODOLOGY

The different piston crown geometries investigated in this numerical studies are cylindrical, conical, hemispherical, dual cone, and dual hemisphere indented piston crowns as shown in figure 1. All the pistons were dimensioned towards the kirloskar TV1 compression ignition engine with a bore D of 0.0875 m, stroke S of 0.11 m, and compression ratio CR of 17.5:1. The connecting rod length L_c was 0.238 m, crank arm length L_a was 0.055 m and the utilized initial pressure and temperature for the simulation were 1e5 N/m^2 and 313 K respectively. The engine performance was simulated using COMSOL Multiphysics 5.0 software which employs the finite element solution method. The turbulence in the engine cylinder was modelled using the Reynolds Average Naiver Stokes (RANS) equation with the kinetic energy-eddy dissipation (k-ε) model because of its ease of convergence to simplify the Naiver Stokes equation.

The RANS equation;

$$\rho\frac{\partial u}{\partial t} + \rho\, u.\nabla\, u = \nabla.\left[-\rho 2I + (\mu+\mu_T)\,(\nabla u + (\nabla u)^T\,) - \frac{2}{3}\,(\mu+\mu_T)\nabla(\nabla\,.u)I - \frac{2}{3}\rho k I\right] + F \tag{1}$$

K equation;

$$\rho\frac{\partial k}{\partial t} + \rho(u.\nabla)k = \nabla.\left[(\mu + \frac{\mu_T}{\sigma_k})\nabla k\right] + p_k - p_\varepsilon \tag{2}$$

ε equation;

$$\rho\frac{\partial \varepsilon}{\partial t} + \rho(u.\nabla)\varepsilon = \nabla.\left[(\mu + \frac{\mu_T}{\sigma_\varepsilon})\nabla\varepsilon\right] + C_{\varepsilon 1}\frac{\varepsilon}{k}P_k - C_{\varepsilon 2}\rho\frac{\varepsilon^2}{k} \tag{3}$$

The RANS equation (1) is closed using equations 2 and 3 which are the kinetic energy and the eddy dissipation equations respectively.

The turbulent modelling parameters are spelt out in Table 1

Table 1. Turbulent Modelling Parameters

Parameters	$C_{\varepsilon 1}$	$C_{\varepsilon 2}$	C_μ	σ_k	σ_z	k_v	B
Value	1.44	1.92	0.09	1	1.3	0.41	5.2

The adopted boundary conditions for the cylinder wall and piston head was the moving wall function making use of its velocity in the radial (r) and axial (z) components, while the wall function was adopted for the cylinder head being that it was stationary.

The performance criteria; thermal efficiency, brake power and, brake specific fuel consumption were calculated using equations 4, 5 and, 6 respectively.

$$\eta_{Th} = \frac{W_{net}}{Q_{in}} \tag{4}$$

$$P = \frac{P_m LAN}{n_c} \tag{5}$$

$$\text{BSFC} = \frac{\rho_f q}{P} \tag{6}$$

W_{net} is the net work output from the engine, and Q_{in} is the heat energy generated by the combustion of the fuel-air mixture, both obtained from the simulation results.
A is the area of the engine cylinder;
N is the number of revolutions per minute;
n_c is the number of cycles required to make a complete revolution;
P_m is the mean effective pressure;
ρ_f is the fuel density.

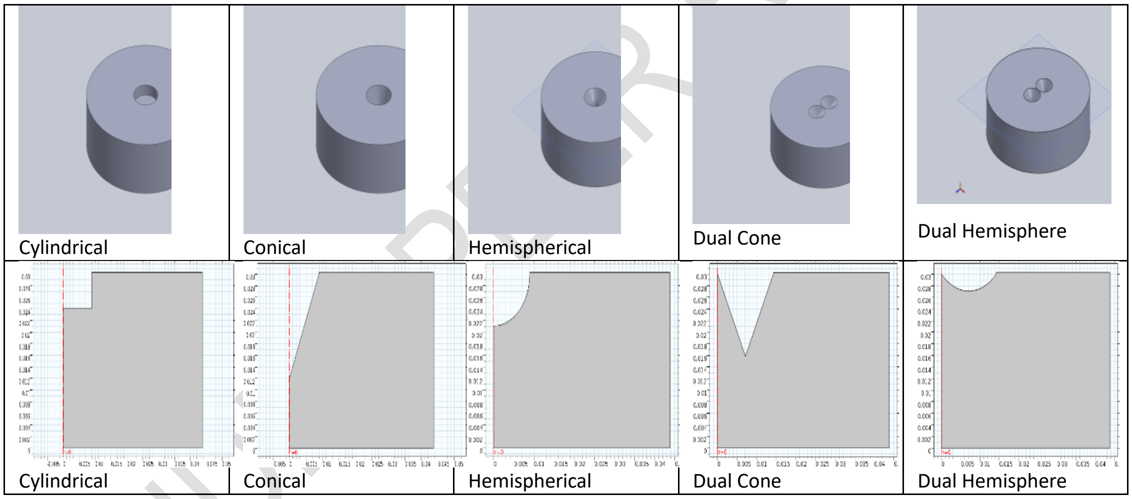


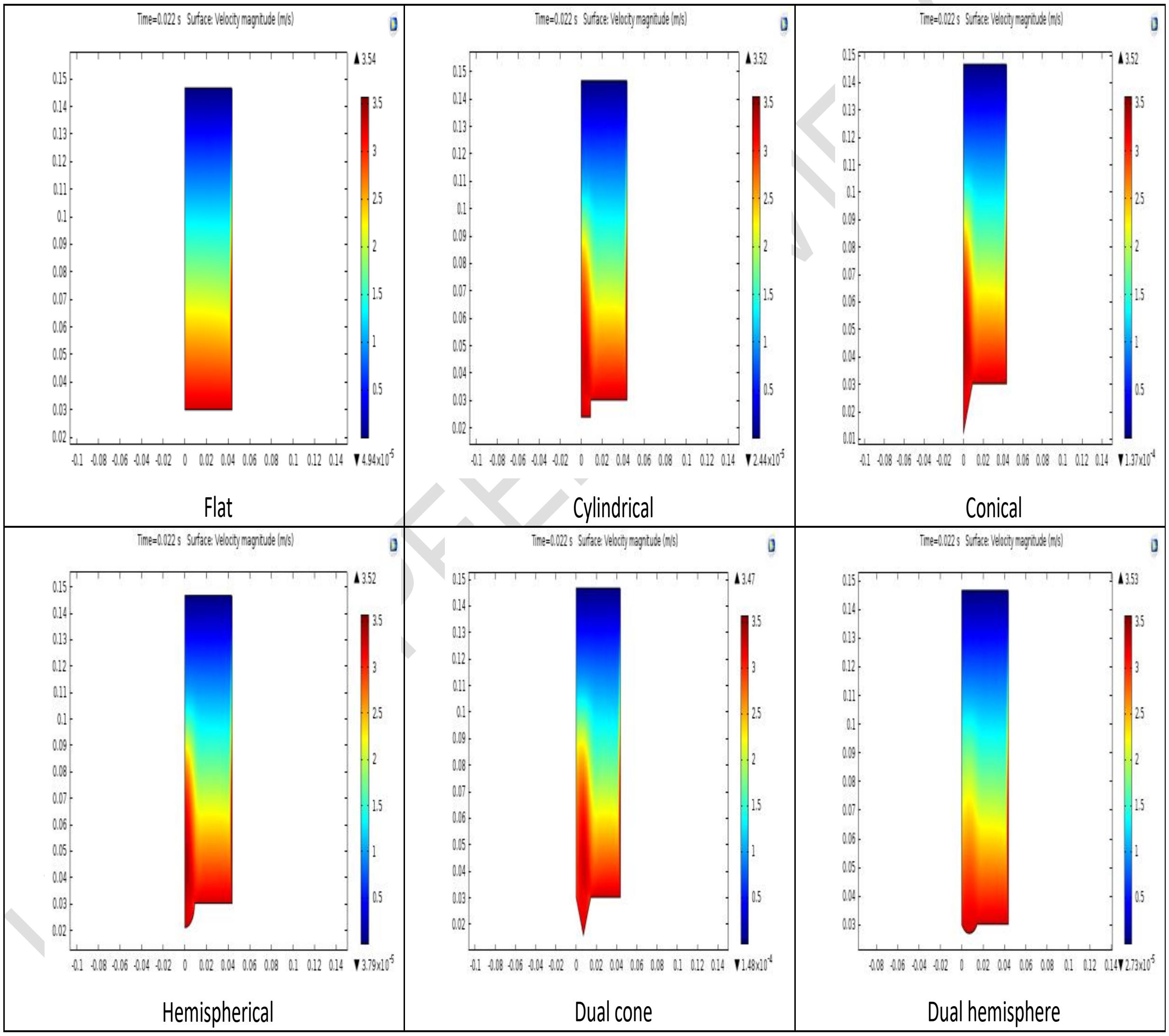
Fig. 1. Geometry of the investigated cases in 3D and 2D axisymmetric views

3. RESULTS AND DISCUSSIONS

The in-cylinder fluid motion is dependent on the combustion chamber geometry which for this study was effected with the use of different piston crown shapes. The combustion process is to a great extent dependent on the in-cylinder fluid flow and this determines the combustion rate and the extent. The in-cylinder fluid mobility is capture by its velocity distribution. The velocity distribution for the studied cases are depicted in figure 2.
The piston crown geometry did have notable impact on the simulated engine performance. The performance of the engine was negatively affected with the use of the cylindrical indented and the dual cone indented piston crown signaling that the in-cylinder motion of the

fluid was negatively impacted using these dimensioned combustion chamber and this is evident in their lower fluid velocity in figure 2.

The more mobile the fluid particles, the greater the generated pressure which is available for doing work. The effect of the use of the different piston crowns on the engine performance; thermal efficiency, brake power, and the brake specific fuel consumption in comparison to that of an ideal flat piston crown is tabulated in figure 3, as derived with the use of equations 4, 5 and 6 in each of the considered case; cylindrical, conical, hemispherical, dual cone, and dual hemisphere.



Flat

Cylindrical

Conical

Hemispherical

Dual cone

Dual hemisphere

Fig. 2. Velocity distribution of the in-cylinder fluid

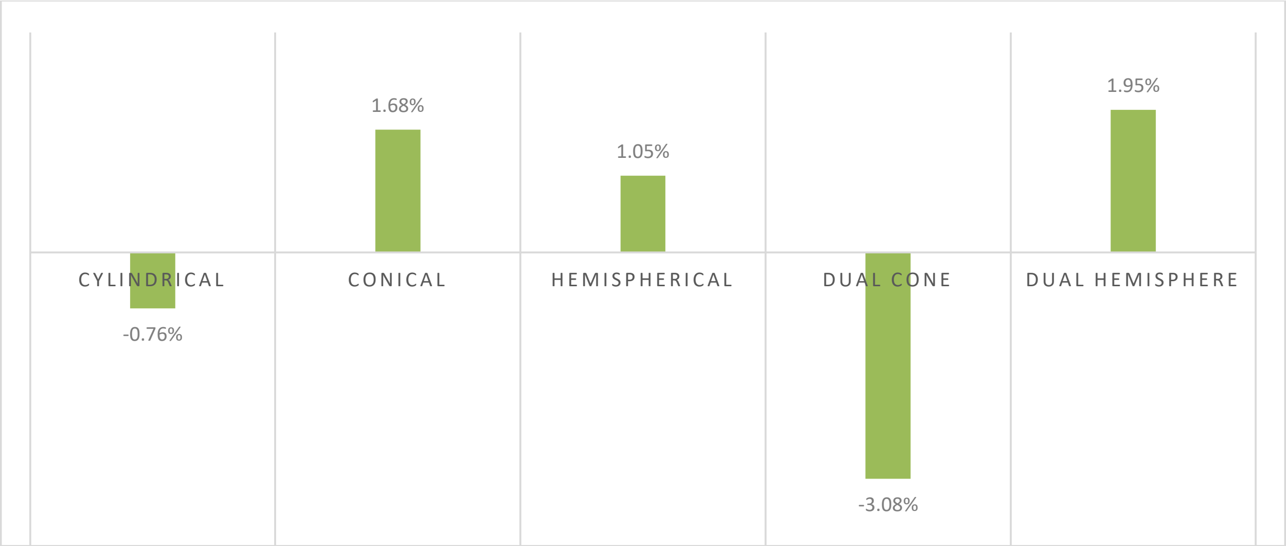


Fig. 3. Percentage Difference in Engine Performance in Comparison with Flat Face Piston Crown

4. CONCLUSION

The performance of a compression ignition engine equipped with different piston crown geometry was numerically determined and compared vis-à-vis that of a flat faced piston crown. The piston crown geometry did have notable impact on the simulated engine performance.

- The performance of the engine was negatively affected with the use of the cylindrical indented and the dual cone indented piston crown
- The in-cylinder motion of the fluid was negatively impacted using the cylindrical and dual cone indented piston crowns
- The in-cylinder motion of the fluid was positively impacted using the conical, hemispherical and dual hemisphere indented piston crowns

The results showed an agreement with previous experimental studies where the use of hemispherical indented piston crown and cone shaped piston crown led to an improvement in the engine performance.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

REFERENCES

1. Jafarmadar, S. and Khanbabazadeh, M. A Computational Study of the Effects of Combustion Chamber Geometries on Combustion Process and Emission in a DI Diesel Engine". *Journal of Fuel and Combustion*, 2008; 1-16.
2. Towoju, O. A. and Dare, A. A. Impact of Conical Piston Crown Equipped Compression Ignition Engine on Performance. *European journal of engineering and technology*, 2018; 6(1): 13-25.
3. Towoju, O. A., Dare, A. A. and Fashogbon. S. K. Experimental Investigation of the Performance and Emission Characteristics of a CI Engine Equipped with a Modified Truncated Cone Piston Crown Operated on Diesel and Shea-Butter Biodiesel *European Journal of Engineering Research and Science*, 2018; 3(10): 126-131. (DOI: http://dx.doi.org/10.24018/ejers.2018.3.10.954)
4. Argakiotis, C., Mishra, C. Stubbs, C. and Weston, W. The Effect of using an Ethanol blended fuel on Emissions in an SI Engine. *International Conference on Renewable Energies and Power Quality (ICREPQ'14)* Cordoba: Renewable Energy and Power Quality Journal (RE&PQJ), 2014; 1-6.
5. Balki, M. K., Sayin, C. and Canakci, M. The effect of different alcohol fuels on the performance, emission and combustion characteristics of a gasoline. *Meeting at the SAE Congress,* 2014;1-8. Detroit: SAE.
6. Ghazali, W. M. W., Mamat, R., Masjuki, H. H. and Najafi, G. Effects of Biodiesel from different Feedstocks on Engine Performance and Emissions: A Review. *Renew and Sustain Energy Reviews*., 2015; 51: 585-602.
7. Towoju, O. A. and Jekayinfa, S. O. Compression Ignition Engine Performance as a Function of the Fuel Properties. *Journal of Engineering Sciences,* 2019; 6(1): G1-G5. DOI: 10.21272/jes.2019.6(1).g1
8. IPCC. Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change" [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, L. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. Von Stechow, T. Zwickel and J. C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014.
9. Allen, M. R. Dube, O. P., Solecki, W., Aragón-Durand, F., Cramer, W., Humphreys, W., Kainuma, M., Kala, J., Mahowald, N., Mulugetta, Y., Perez, R., Wairiu, M. and Zickfeld, K. Framing and Context. In: Global Warming of 1.5^{0}C. An IPCC Special Report on the impacts of global warming 1.5^{0}C above pre-industrial levels and related greenhouse gas emission pathways, in the context of strengthening the global response to threat of climatic change, sustainable development, and efforts to eradicate poverty" [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. 2018.
10. Ritchie, H. and Roser, M. CO_2 and other Greenhouse Gas Emissions. *Published online at OurWorldInData.org.2019.* Retrieved from: 'https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions' [Online Resource] on 15/04/2019.
11. Towoju, O. A. Fuels for Automobiles: The Sustainable Future. *Journal of Energy Research and Reviews*, 2021; 7(3): 8-13.

12. Towoju, O. A. and Ishola, F. A. A Case for The Internal Combustion Engine Powered Vehicle, *Energy Reports,* 2020; 6S2: 315-321. https://doi.org/10.1016/j.egyr.2019.11.08