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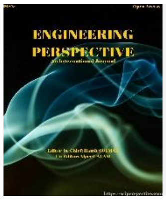

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Review Paper

Performance Optimization of Compression Ignition Engines: A Review

O. A. Towoju[1]

[1] *Mechanical Engineering Department, Faculty of Engineering and Technology, Lead City University, Ibadan, Nigeria*

ABSTRACT

A catalyzing factor for the continuous search to optimize the compression ignition engines is the impact it has on the environment. The compression ignition engines find applications in the transportation sector, agriculture, energy, and construction sectors, and the optimization of its performance will thus not be an effort in futility. Many studies have focused on the optimization of the performance of compression ignition engines. The ones of interest reviewed herein can be broadly categorized as combustion chamber geometry studies, fuel studies, and advanced combustion modes studies. The combustion chamber geometry poses an impact on the in-cylinder fluid motion. This influences the combustion process which in-turn affects the engine performance and emission characteristics. The fuel type is also an influencer of the engine performance and emission characteristics drawing its impact from its properties. The combustion mode also poses an impact on the combustion process and can influence the engine performance and its emission characteristics. While it is difficult to pinpoint a particular intervention means that can completely resolve the challenges created by the use of ignition compression engines, the combustion chamber geometry optimization tends to bring along emission reduction and efficiency boost. A combination of the different methods will however, make a huge impact.

Keywords: Advanced Combustion Mode; Combustion Chamber Geometry; Emission; Fuel

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Author Contacts
**Corresponding Author*
e-mail addresses : olumidetowo@yahoo.com
Orcid numbers : 0000-0001-8504-2952

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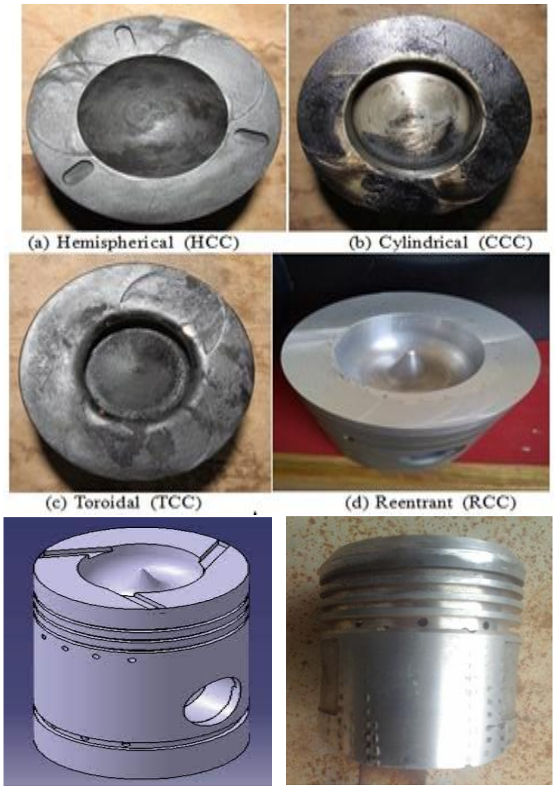
1. Introduction

Internal combustion engines have proved their worth. The transportation sector enjoys its development by the invention of these engines that eased movement [1,2]. The transportation sector was not the only sector that was positively impacted by the internal combustion engines. The energy, agriculture, and construction industry also, benefited immensely from the invention [3-4]. It is, therefore, not an understatement to say that the internal combustion engines were in part responsible for globalization. However, the glaring adverse impact of the engines' emissions on the environment when powered with fossil fuel derivatives has continually put them in the spotlight. The emissions from these engines are fingered to be critical contributors to global warming responsible for Climate change [2-7]. Considering the importance of internal combustion engines to humans and the adverse impact it has on the environment, many studies focus on their optimization. The methods of optimizing the performance of the internal combustion engines is based on the following areas; combustion chamber geometry, fuels, injection mode, and advanced combustion modes [4, 8-13]. These interventions contribute to better fuel efficiency and reduced emissions. This study is, thus, designed to review some of the intervention methods in the optimization of the performance of the internal combustion engine.

Section 2 discusses the impact that the combustion chamber geometry interventions have on the performance and emission characteristics of the Engine. Section 3 discusses the different fuels intervention impact, and section 4 discusses the impact of advanced combustion modes interventions on the performance and emission characteristics of the Engine. The conclusion is presented in section 5.

2. Combustion Chamber Geometry

One of the highly researched means of optimizing the performance of internal combustion engines is through the modification of the combustion chamber geometry [4,9,11-12]. The combustion process in the engine is determined by the in-cylinder fluid motion which is governed by the combustion chamber geometry [14-16]. Studies on the combustion chamber geometry were undertaken to optimized the engine performance because of its effect on the combustion process which weighs a great impact on physical properties like temperature and pressure. The pressure determines the output power and the temperature influences the combustion products. The pivotal parameters in the formation of emission products in the internal combustion engines are impacted by its combustion chamber geometry and engine speed [14]. The proper mixing of the fuel and air is determined by the swirl motion [17]. While most studies have been conducted using cylindrical shaped pistons, a few have focused on non-cylindrical shaped pistons like the truncated cone [4,9,11]. Some of the performance optimization interventions carried out on the internal combustion engine combustion chamber geometry are spelt out in Table 1. Some of the geometries are shown in Fig. 1.



(e) Trapezoidal (f) Truncated cone

Figure 1. Selected piston bowl geometry

3. Fuels

Of prominence in the study of engines performance and emission optimization is the consideration of fuels. The properties of the fuels utilized for combustion in engines is a determinant of the engine performance. Properties like density, viscosity, heat content, and Oxygen content pose a great impact on the performance and emission characteristics of an engine [3,23-26]. The viscosity of the fuel affects its delivery and power output, the brake specific fuel consumption is dependent on its heat content, and the brake thermal efficiency shows a correlation with the fuel's Oxygen content [3, 23-26]. The Oxygen content of a fuel also weighs an impact on the emission of particulate matters (PM), Carbon II Oxide (CO), and Oxides of Nitrogen (NO_x) [23].

Table 1. Impact of Combustion Chamber Geometry on Engine Performance

Intervention	Outcome
Toroidal shaped piston bowl	The performance characteristics of internal combustion engines is improved with the use of toroidal shaped piston bowl in comparison to standard piston bowl. The emission from the engines were also found to be reduced in comparison to a standard piston crown except for NO_x emissions [8,14,16,18-20].
Re-entrant piston bowl	The performance characteristics of the engines records a decline as it was also for the emission performance except for the oxides of Nitrogen [14]. Improved performance and increased NO_x emission however, been earlier reported in literature with the use of the re-entrant piston bowl in comparison with cylindrical piston bowl [21].
Hemispherical piston bowl	The engine recorded reduced performance and emission characteristics in comparison to the cylindrical piston bowl except for NO_x emissions where it performed better [8,16]. The performance and emission characteristics of engines using the hemispherical piston bowl fared lesser to that using the toroidal piston bowl except for NO_x emissions [8,14,16,18-20].
Trapezoidal piston bowl	The engine recorded reduced performance and emission characteristics in comparison to the cylindrical piston bowl except for NO_x emissions where it performed better [8,16]. The trapezoidal piston bowl fitted engines recorded the least performance characteristics of the many studied combustion chamber shapes [8, 14,16].
Shallow depth piston bowl	The performance and emission characteristics of the engine is improved with the use of the shallow depth piston bowl except for NO_x emissions [8]
Grooved piston crown	The performance and emission characteristics of the engine was enhanced with the use of tangential grooved piston crown [17,22].
Multi-Chambered piston crown	The use of multi-chambered piston crown led to improvement in performance and emission characteristics of the engine over standard piston crown [23].
Truncated cone piston crown	At optimized cone base angles, the performance and emission characteristics were enhanced with the use of truncated cone piston crown in comparison to standard piston crown [4,9,11].

Table 2. Alternative Fuel Impact on Engine Performance

Intervention	Outcome
Di-Methyl Ether (DME)	Improved engine performance and emission characteristics is witnessed with the use of DME [27,28]
Canola biodiesel	The use of Canola biodiesel as a blend with petroleum diesel at appropriate ratio results in reduced emission of hydrocarbons (HC) smoke, and CO [25,29-30]. Studies have also proven increased brake thermal efficiency for blend ratios B40 and B50 [31], and when it is emulsified [32]..
Jatropha biodiesel	A B30 blend of Jatropha biodiesel with petroleum diesel gives improved engine thermal efficiency at compression ratio values of 17.5:1 and above [33]. The use of appropriate blends of Jatropha biodiesel with petroleum diesel results in increased engine thermal efficiency and reduced NO_x but with attendant increased CO and HC emissions [34-35]
Pongamia biodiesel	In dual fuel mode with liquefied petroleum gas, engine performance and was improved with reduced emission except for HCs [36]. Blends of Pongamia with petroleum diesel results in better emission characteristics except for NO_x, although the engine performance parameters like thermal efficiency and specific fuel consumption showed slight reductions [37-40].
Waste Oil biodiesel	The use of waste oil biodiesel in compression ignition engines results in improved emission characteristics with the exception of NO_x and CO_2. [41-43]. The brake thermal efficiency can be improved with the use of waste oil biodiesel in small volumes [44].
Karanja biodiesel	For blend ratios of B20, the engine performance characteristics are comparable to that fueled with petroleum diesel, with an advantage of reduced emissions of CO, HC, and smoke [45-49]. In blends with Diethyl ether, the engine performance parameters like brake thermal efficiency and brake specific fuel consumption can exceed that of petroleum diesel fuel [50].
Palm Oil biodiesel	Palm oil biodiesel blends with petroleum diesel results in improved engine emission characteristics [51-54]
Soybean biodiesel	Increasing the ratio of Soybean biodiesel in its blend with petroleum diesel results in increased NO_x emission, but in the reduction of other emission products [26,56-57]. The brake thermal efficiency and specific fuel consumption of an engine can also be improved over that of petroleum diesel with the use of soybean biodiesel blend B20 and B30 [56,58]

The impacts of the fuel properties on engine performance is huge and hence the reason for conducting studies on it. Many of the interventions on engines with the use of fuels are being done with alternative fuels (biofuels). Synthetic fuels technology is still in the development phase [2], however, Di-Methyl Ether (DME) a type of synthetic fuel has been available for long. Some of the fuels which have been utilized in optimizing performance of engines are spelt out in Table 2.

The study has focused more attention on the use of biodiesels as an alternative fuel because it is the commonly used alternative fuel in compression ignition engines. However, alcohols are also used to reduce engine emissions [59-60].

The use of metallic additives in biodiesels is also gathering momentum among scholars due to the positive results obtained from earlier studies. These metallic additives have been reported to increase the engines performance and reduce emissions based on the stability of blends and heat transfer rate improvement [61-63].

4. Advanced Combustion Modes

The continuous search for an economical and environmental friendly engine brought about the advanced compression ignition engines. These engines evolved along two fronts; the Homogeneous Charged Compression Ignition (HCCI) and the Low Temperature Combustion (LTC). These combustion process types are tailored such as to reduce the emission of toxic pollutants like NO_x and particulates which are major mitigating factors against the use of compression ignition engines. The technology of the use of Exhaust Gas Recirculation (EGR) is also an accepted means of increasing the fuel efficiency and reduction of the emission of toxic wastes from internal combustion engines [64-65]. Some of the interventions which have been undertaken based on advanced combustion modes is as depicted in Table 3.

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Table 3. Advanced Combustion Mode Impact on Engine Performance

Intervention	Outcome
Homogenous Charge Compression Ignition	Low-load combustion efficiency and high-load limit was improved with the adoption of HCCI process type through temperature stratification [66-67]. Reduction in the amount of NO$_x$ and particulate matters emission is also made possible with the adoption of the HCCI process type [66,68-69]. The use of fuels other than the conventional petroleum fuels is also made possible with the adoption of the HCCI engines a plus for the use of alternative fuels in the face of the dwindling fossil fuels [68]. The HCCI is however, still being taken aback by the effect of rapid pressure rise and combustion timing [65].
Exhaust Gas Recirculation	The brake thermal efficiency can be improved and the NO$_x$ emission levels can be reduced with the use of appropriate volumes of EGR [64,70-71]. Slight increment in the emission of HC and CO is however, to be expected with the use of EGR [70-71].
Reactivity Controlled Compression Ignition	Improved thermal efficiency and reduced NO$_x$ and soot emissions levels are obtained with the use of this intervention [72-74]. It is however, plagued with increased UHC [73], and its increasing susceptibility to knocking [74].
Premixed Charged Compression Ignition	This intervention process is reported to have led to an improvement in engine performance and reduction in the emissions of NO$_x$ and particulates [75-77].

5. Conclusions

The importance of the compression ignition engines to several sectors of countries economy cannot be overemphasized. Also, the adverse impact of its emission products on the environment is a major cause of concern. The positive output of some of the interventions on these engines is a major impetus to do more. Interventions through combustion chamber geometries, fuels, and process types were reviewed in this work. The performance and emission characteristics of compression ignition engines can be improved through these intervention methods. The studies on combustion chamber geometry has proved;

i. Improvement in the performance parameters of the engine like thermal efficiency, brake specific fuel consumption, and brake power except for the re-entrant, hemispherical, and trapezoidal piston bowls.
ii. Emission characteristics of the engine witnessed an improvement

Studies on fuels have generally shown the potentials of reducing the emissions from the engines and this was documented for all the fuel types mention in this study. The brake thermal efficiency of the engine also witnessed improvements with the use of some of the alternative fuels like DME, Canola, Jatropha oil etc.

The studies on process types shows that;

i. NO$_x$ emission is reduced
ii. Thermal efficiency is improved with EGR process, and the HCCI allows the use of alternative fuels.

The impacts of some of these interventions are still steps away from achieving the desired reduction of greenhouse gases from the compression ignition engines. Great hope however, lies with the fuel interventions. The availability of synthetic fuels in commercial quantities will result in Carbon neutral fuels and is much needed to check the dreaded climate change attributable to emissions from the internal combustion engines. While it is difficult to make a straight forward conclusion on the single best intervention method, the combustion chamber geometry optimization brings along improvement in emission reductions and engine power output. Combining the intervention methods will ensure better results.

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Conflict of Interest Statement

Author declares that there is no conflict of interest in the study.

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