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An Extensive Study on the Optimized Piston Bowl with Spiral Grooves for the CI Engine

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Abstract

Worldwide, internal combustion engines are in widespread usage. The rapidly growing use of fossil fuels and petroleum derivatives, which release enormous amounts of pollution, has alarmed many nations. Manufacturers are looking for better engine structures with the lowest amount of air pollution emissions as a result of rising pollution levels and the corresponding implementation of stringent emission regulations worldwide. Soot and NOx emissions are two of the most important design factors for diesel-fueled CI engines. The performance of combustion engines is enhanced by proper air-fuel mixing. Changing the form of the piston bowl is the most popular method of enhancing air-fuel mixing in a chamber cylinder. Numerous engineers have worked on different kinds of combustion chambers and piston bowl geometry. In low-utilization diesel engines like direct injection, the combustion chamber design creates the intricate interactions created by swirls and squish flows, as well as the late cycle mixing of spray-wall contacts. These interactions affected the design of the piston bowl in terms of both fuel efficiency and emission behavior. Therefore, developing a combustion process for diesel engines that reduces emissions and enhances performance is essential. An engine's piston bowl geometry can affect combustion, flow, turbulence, and mixing. Currently, a diesel engine using different piston bowl shapes will be used in an experiment to ascertain its operating and emission properties. The comparison of results shows a considerable improvement in engine performance.

Major Findings: *The major findings of the research work are to examine the effects of the best spiral groove piston bowl designs on combustion, emissions, and diesel engine performance using experimental conditions. For the thermal and static structural requirements of this investigation, Ansys 16.0 will be used to design a number of piston bowl shapes with spiral grooves. These pistons are examined using Ansys 16.0.*

Keywords: *Internal Combustion Engines, Optimization, Piston Bowl, Spiral Groove*

1.0 Overview of the Research Work

As pollution levels rise and strict emission regulations are subsequently enforced globally, engine manufacturers are becoming more conscious of the need to keep researching methods to reduce emissions. In diesel engines, air velocity is crucial for fuel-air mixing, combustion, and exhaust production during fuel injection, especially in the vicinity of the compression TDC. Air motion is influenced by diesel engine combustion, as are spray characteristics including injector-hole diameter, injection pressure, spray angle, and injection time[1,2]. In order to gain a

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better understanding of combustion in diesel engines, a number of researchers have conducted experimental and computational studies on in-cylinder processes, as discussed in the paragraphs that follow. In diesel engines, swirl, squish, and turbulence are the usual characteristics of in-cylinder air motion. These factors all have a big influence on air-fuel mixing and combustion[3,4]. Generally, the air swirls due to the intake port's configuration. A well-designed intake port will improve combustion by creating more swirl. The swirl-squish interaction creates a complicated turbulent flow pattern near the end of compression when there is swirl in the in-cylinder air. In re-entrant combustion chamber designs, this contact is significantly greater. Additionally, at the TDC of compression, swirl and turbulence increase[5,6]. The majority of the cylinder's air is squeezed into a combustion chamber with a reduced diameter at this point. Because of the conservation of angular momentum, the rotation speed increases as the radius of revolution decreases. The air around the TDC of compression is undergoing extremely turbulent squish and reverse-squish motions, which amplifies turbulence. Motion of the in-cylinder mixture and combustion are influenced by the relative positions of the injector and piston bowl axes with respect to the cylinder axis[7,8]. High HC and soot emissions are often caused by injectors having a finite sac capacity at the tip that are connected to large fuel droplets near the end of injection. Re-entrant chambers can use spray retardation to reduce NOx emissions while reducing HC and soot emissions. As a result, two turbulence peaks—one just before and one immediately after TDC—are frequently observed. Re-entrant chambers experience higher swirl and turbulence than cylindrical chambers[9,10]. As a result, combustion is more efficient, which raises NOX emissions while lowering soot and HC emissions. Better air-fuel combustion and mixing are achieved with higher injection pressures and smaller injector hole diameters. Higher injection pressures result in smaller droplets that quickly evaporate and mix with the surrounding air. Nevertheless, substantial soot emissions and flame quenching are caused by spray and vapor impingement against walls. Therefore, a longer spray route without wall impingement is desirable for improved combustion and lower emissions[11,12]. The Figure 1 depicts the combustion system.



Figure 1. Depicts combustion system[3]

2.0 Literature Review of the Research Work

The authors used a torroidal, somewhat reentrant design in place of the hemispherical combustion chamber. Furthermore, a sac-free injector was used in place of the original injector, which had a finite sac volume at the tip. But NOX and particulate matter levels need to be further reduced. Intriguingly, CO levels have also increased[13,14]. To completely comprehend the impact of engine modifications on in-cylinder flow, combustion, and emission generation, as well as to identify the optimal engine design, three-dimensional Computational Fluid Dynamics simulations are employed. The authors made four tangential grooves in a base line engine's diameter piston crown. Three different tangentially grooved pistons are used in the tests, and the base piston of a diesel engine is used to compare the emissions and performance of each piston[15].

It was discovered that the toroidal combustion chamber had a better braking thermal efficiency than the other two combustion chambers. While still less than traditional diesel, the toroidal combustion chamber's emissions of hydrocarbons, carbon monoxide, and smoke density were marginally lower than those of the other two chambers. Nitrogen oxide levels in the toroidal combustion chamber were higher than those in regular diesel, but slightly

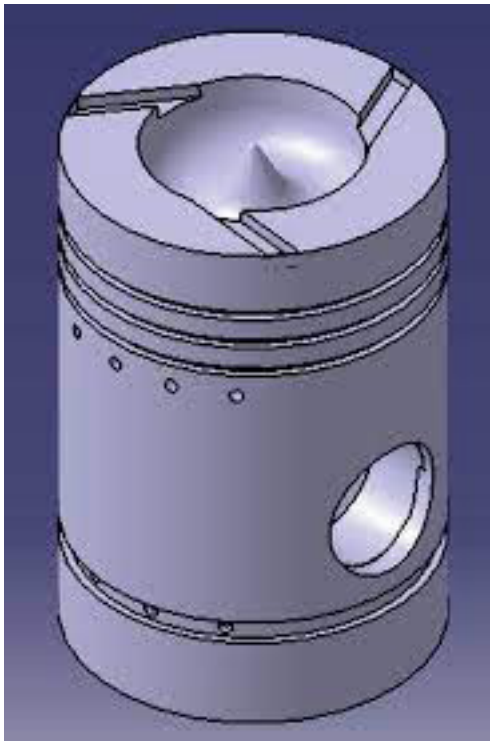


Figure 2. Piston created by CATIA V5[7].

lower than in the other two. Using Computational Fluid Dynamics, the authors examined how different piston shapes affected the air velocity and turbulence inside a Direct Injection diesel engine's cylinder[16]. The pre-processor is used to mesh the three-dimensional models of the cylinders, pistons, and manifolds created by CATIA V5 as shown in the Figure 2.

The performance and emission properties of Jatropha oil were evaluated by the authors using an air-cooled, four-stroke, direct injection diesel engine with a single cylinder and constant speed. The performance characteristics under investigation include exhaust emissions, including carbon dioxide, smoke, hydrocarbons, and nitrogen oxides, as well as braking thermal efficiency. The baseline diesel fuel statistics were compared to the experimental outcomes in each scenario. Out of all the tested fuels at full load, a lower blend of biodiesel JTME was determined to be the best alternative fuel. Diesel engines with different combustion chamber designs were tested to see how Jatropha methyl esters affected their performance, combustion, and emission characteristics[17].

The authors used genetic algorithms and artificial neural networks to develop a numerical methodology for multi-objective virtual optimization of combustion in an automotive DI Diesel engine. By evaluating three distinct piston bowls under a variety of operating conditions and identifying the Pareto-optimal individuals for each piston bowl with a limited number of calculations, the suggested methodology was utilized to support the development of a VM Motori DI Diesel engine meant for automotive applications. The best piston bowls and their set of ideal input parameters were found at the end of the project, enabling a reduction in soot emissions while keeping NOx emissions and gross-IMEP roughly the same. The best solutions were verified using real CFD three-dimensional calculations[18].

The impact of combustion chamber geometry was examined by the authors. Commonly used is the MINI-PETER Diesel Engine. The CAE CFD simulation tool is used to analyze the baseline geometry and modified geometries of the specified engine. Emission metrics like NOx, CO_2, and HC are used to compare and report the outcomes of the baseline geometry and modified geometries. Engine efficiency is raised because the whirling and turbulent kinetic energy in modified geometries is greater than in baseline geometry. Using Pro-Engineer software, the authors created three models of pistons with flat heads, concave heads, and convex heads and imported them for analysis. They tested with a variety of materials, including cast iron pistons and aluminum alloys[19].

To enhance turbulence in the fifth cylinder, the authors modified the combustion chamber and piston crown. By making grooves in the piston's crown, the swirl is made more intense. experimented with different piston configurations, such as order grooves, which improve fuel and air mixing by strengthening the swirl, and their effects on emissions and performance. The authors looked at the effects of piston bowl geometry on the emissions and performance of a direct-injection diesel engine using computational fluid dynamics. Several piston bowl shapes, including hemispherical combustion chamber, shallow depth CC, and toroidal CC, were developed using a baseline compression ratio. Together with the SAGE combustion model, the CONVERGETM CFD code was used to perform the numerical study. A better air-fuel mix is created inside the cylinder by the TCC piston bowl design[20].

Additionally, by adjusting the bowl depth, numerical experiments were performed on the shape of the TCC piston bowl. To control engine flow processes, a computer

model of a compression ignition direct injection engine was developed by fusing empirical, semi-empirical, and physical models. With varying injection times, the model might create a NOx-soot trade-off. It has been demonstrated that the EGR strategy reduces NO emissions effectively, albeit at the expense of significantly lowering engine performance. Split injection is known to slow down premixed phase combustion and significantly lower NO emissions by injecting less fuel in the first pulse. NO and soot emissions have decreased simultaneously as a result of split injection, which involves injecting more fuel in the first pulse[21].

The Figure 3 illustrates Piston Bowl Geometry. With minimal impact on engine performance, split injections were shown to be more effective in reducing NOx emissions than increasing EGR and delaying injection timings. This study investigates the effects of spray angle and piston bowl shape on a direct injection diesel engine's mixing, combustion, and emission properties. One of the most important variables affecting air-fuel mixing, combustion, and emissions in a direct injection diesel engine is the shape of the piston bowl. According to simulation data, engines with TRCC type combustion chambers operate best when the compression ratio and chamber volume are the same in all three scenarios. The blends' compositions were selected to correspond with fossil diesel's cetane numbers. Four operating points on the European Stationary Cycle were used for engine trials, and no modifications were made to the engine's settings during fuel changes[22].



Figure 3. Illustrates Piston Bowl Geometry[11].

The wave piston improved the combustion of diesel and fossil fuel-free blends, especially diffusion combustion, as compared to the conventional piston. The two most important design factors for a diesel-powered CI engine are soot and NOx emissions. Properly balancing the air and fuel content improves a combustion engine's performance. A chamber cylinder's air-fuel mixing can be improved in a number of ways, but changing the piston bowl's form is the most popular method. Complex interactions created in the combustion chamber geometry of low-utilization diesel engines, like direct injection engines, are caused by swirls and squish flows, which result in late cycle mixing of spray-wall contacts[23].

In addition to examining the effects on performance, emissions, and combustion characteristics, this study examines the impact of squish on the piston bowl of a single cylinder 4 S compression ignition engine powered by jojoba biodiesel. By altering the piston bowl cross-section while maintaining a fixed piston bowl volume, the squish area and associated velocity are optimized to maximize performance, emission, and combustion characteristics. The velocity and squish effects of a traditional piston are investigated using CFD. The outcomes are contrasted with those of a modified piston whose combustion chamber has an octagonal bowl shape. Brake specific fuel consumption, brake thermal efficiency, pressure versus crank angle, and heat release rate are among the performance and combustion factors that are examined[24].

At the tail end of the exhaust pipe, emission metrics such as NOx, hydrocarbons, and carbon monoxide were measured. The purpose of this study is to evaluate the performance of an octagonal bowl combustion chamber design to that of a standard hemispherical chamber. The braking heat efficiency is greatly increased by the octagonal piston bowl. The octagonal bowl piston reduces HC and CO in comparison to the regular piston. An engine's flow, turbulence, mixing, and combustion can all be impacted by the geometry of the piston bowl. Moreover, the ideal shape could vary depending on the fuel. This study uses AVL FIRE software to computationally investigate the impact of piston bowl shape modification on Dimethyl Ether combustion in a compression ignition engine[25].

Utilizing DME's non-sooting characteristics and learning about the re-entrant geometry are the objectives in order to minimize NO while preserving efficiency. The findings show that efficiency and pressure traces are

not much impacted by form. However, fuel/air mixing is impacted by geometry, which also affects flow at TDC. Faster combustion and higher NO emissions were the outcomes of the form with the largest bowl diameter. The design with the smallest bowl diameter, on the other hand, had the lowest NO emissions and a more noticeable tail in the heat release rate. The re-entrant structure with a smaller bowl diameter is preferred in light of this research[26].

The overall objectives of the research project are as follows:

- Using several piston bowl shapes with spiral grooves, an experimental configuration was created for squish and swirl effects.
- Choose a piston bowl form with spiral grooves for the best swirl and squish.
- Examine how squish and swirl affect diesel engine performance and operation.

3.0 Proposed Methodology of the Research Work

Using experimental settings, this study will investigate how diesel engine performance, emissions, and combustion are affected by the best piston bowls with spiral groove designs. Several piston bowl shapes with spiral grooves will be constructed using Ansys 16.0 for this study's thermal and static structural demands. Ansys 16.0 is used to examine these pistons. Enough air and fuel mixing is ensured by the ideal squish and swirl provided by the piston bowl with spiral grooves. The combustion process will increase as a result. A diesel engine will be used for the testing in order to compare the ideal piston shape and assess different attributes. The performance of a diesel engine with an ideal piston bowl shape compared to a simple spherical bowl will be investigated through experiments. To ascertain the performance boost brought about by ideal piston bowl shapes with spiral grooves in terms of full fuel combustion, studies will be conducted employing a variety of piston bowl designs. Figure 4 depicts the flow chart of proposed methodology.

4.0 Implication of the Research Work

Proper mixing of air and fuel improves combustion engine performance. In a chamber cylinder, the most

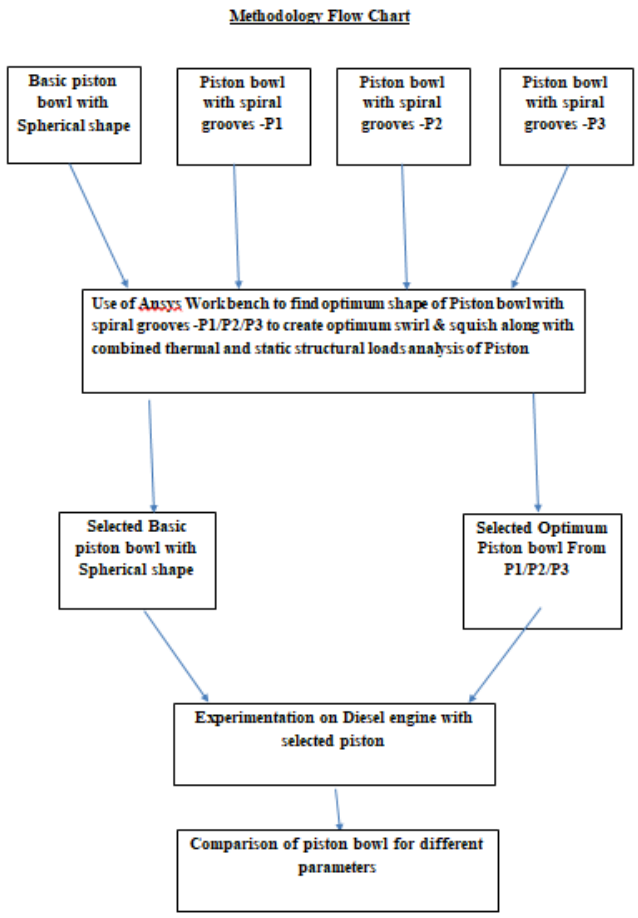


Figure 4. Depicts the flow chart of proposed methodology[13].

common way to improve air-fuel mixing is to modify the shape of the piston bowl. The geometry of piston bowls and various types of combustion chambers have been the subject of several engineering projects. The combustion chamber design in low-utilization diesel engines, such as direct injection, produces the complex interactions resulting from squish flows and swirls, as well as the late cycle mixing of spray-wall contacts. These interactions had an impact on the piston bowl's design in terms of emission behaviour and fuel efficiency. For diesel engines, it is crucial to establish a combustion process that improves performance while lowering emissions. The shape of the piston bowl of an engine can have an impact on mixing, turbulence, flow, and combustion. Currently, an experiment will be conducted to determine the operating and emission parameters of a diesel engine employing various piston bowl forms.

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