

# Experimental Investigation of Various Piston Bowl Geometries on DI Diesel Engine fuelled with Pongam Biodiesel

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**Abstract**— Automobile sector is a growing field where there evolves a new technology every day. The recent trend in the automobile sector is to improve the efficiency and reduce the amount of pollutants. Increased pollution awareness and the consequent introduction of stringent emission norms throughout the world are forcing engine manufacturers to continue to investigate for strategies for reducing emissions which contributes to the study of air motion. The air motion plays a very important role in fuel-air mixing, combustion and emission formation. When the in-cylinder air motion is unsteady the efficiency of the engine gets reduced and emissions are increased. To investigate this type of problem, piston geometry is taken into consideration. New geometrical modification was made on the piston by making radial holes on the piston bowl for various diameters. This change in piston geometry helps in inducing swirl during compression stroke and gives a proper mixture of air and fuel. These modified pistons are tested for performance.

**Keywords**— Modified piston geometry, Air swirl, Piston Bowl, Pongam biodiesel

## I. INTRODUCTION

Energy issues along with ever-increasing demand of environmental communities to reduce the emissions, made researchers to analyze the various parameters affecting the engine efficiency and burnt gas production. In recent time, the world is facing problems with energy crisis due to depletion of conventional energy sources and increased environmental problems. This situation has led to the search for two alternate ways. The former is the application of bio-fuel, which is inexhaustible and produces lesser pollution, and the later concerns with the design of the piston geometry for achieving both efficiency and less emission. Many researchers studied the different piston bowl geometry and use of biodiesel to attain the above goals. It is well known that air/fuel mixing has drastic impact on subsequent combustion, engine efficiency, and emission production. Piston bowl modification in structure has proved to be excellent scheme in increasing efficiency and emission reduction. In DI diesel engines swirl motion is needed for proper mixing of fuel and air. This swirl motion can only be provided by change in geometry.

Li et al conducted a numerical study to investigate the role of bowl geometry on combustion and emissions of biodiesel-fueled diesel engine. Three different bowl geometries namely: Hemispherical Combustion Chamber (HCC), Shallow depth Combustion Chamber (SCC), and the baseline Omega Combustion Chamber (OCC) were created and Computational fluid dynamics (CFD) modeling was performed. Also, the simulation results indicate that in terms of performance SCC is favorable at low engine speed; whereas at high engine speed, OCC is preferred. They concluded that the application of the bowl with less surface area is preferred at low engine speed [1]. Rajashekhar et al studied the effect of combustion chamber geometry and injection pressure on performance and emissions of Jatropa fuelled multi-chambered piston diesel engine using CFD. The performance and emission characteristics were studied and it has been noticed that for the engine under consideration 200 bar injection pressure gives optimum performance. Furthermore squish and tumble flows are measured. A maximum of 13.1 m/sec squish velocity was observed at 10° crank angle before TDC. The increase in squish velocity was 31% compared to a standard engine [2].

Antony Raj et al conducted study concerning energy efficient piston configuration for effective air motion, wherein four configurations namely flat, inclined, centre bowl, and inclined offset bowl pistons were investigated. From this study, it is concluded that a centre bowl on flat piston is found to be the best from the point of view of tumble ratio, turbulent kinetic energy, turbulent intensity and turbulent length scale [3]. Pratap et al investigated effect of spiral grooves in piston bowl on exhaust emissions of direct injection diesel engine where he concluded that the fuel consumption slightly reduced by 0.1 Kg per hour. In this work to reduce the NO<sub>x</sub>, HC, CO, and CO<sub>2</sub> some modification has been done in piston bowl by cutting three spiral grooves on inner surface of hemispherical bowl. The spiral grooves in piston bowl increase the air capacity and reduce slightly the

compression ratio as well as make homogeneous mixing of air and fuel. Brake thermal efficiency for modified piston is increased near about 1.9 & 2%. NO<sub>x</sub> is reduced by 8.82 % at full engine Load [4]. C.V. Subba et al conducted an experiment on effect of tangential grooves on piston crown of D.I. diesel engine with three different sizes of tangential grooved pistons. Three tangential grooves of different widths of 5.5mm, 6.5mm and 7.5 mm were produced on three pistons of 80 mm diameter and maintaining constant depth of 2 mm in each piston. After the experiments performance and emissions are compared with base line piston of diesel engine Among the three Base line engine with tangential grooves size of width 6.5 mm and depth 2 mm on the piston crown enhances the turbulence and hence results in better air-fuel mixing process of all [5]. Karuppa Raj et al theoretically analyzed on effect of swirl in a constant speed DI Diesel Engine using Computational Fluid Dynamics. It showed that turbulent intensity at TDC is increased by 12 % from swirl ratio of 1.4 to 4.1. The peak heat release rate decreases with increasing equivalence ratio from 0.75 to 1.05. By varying the swirl ratio from 1.4 to 4.1, the peak pressures, peak temperature, peak heat release rates increase by 7 %, 8.6 % and 31 % respectively. By increasing the swirl ratio from 1.4 to 4.1, peak soot level reduces by 30 % [6].

Prathibha et al conducted an experiment on the influence of air swirl on combustion and emissions in a Diesel Engine. The intensification of the swirl is done by cutting grooves on the crown of the piston. In this work three different configurations of piston in the order of number of grooves 6,9,12 are used to intensify the swirl for better mixing of fuel and air. The conclusion makes a maximum reduction in NO<sub>x</sub>, HC and CO emissions is achieved. The smoke emission in the engine is reduced by about 5.9%. The maximum reduction in NO<sub>x</sub> emissions is about 1.8%. The maximum reduction in HC emissions is about 2.83%. The carbon monoxide emissions are found to be reduced by about 11.7% [7]. Prasad et al focused on the effect of swirl induced by re-entrant piston bowl geometries on pollutant emissions. The baseline engine with hemispherical piston bowl and an injector with finite sac volume is subjected to analysis. The second involved using a torroidal, slightly re-entrant bowl geometry, and a sac-less injector. Pollutant emission measurements indicated a reduction in emissions with this modification. CFD analysis showed a highly re-entrant piston bowl was found to be the best for swirl [8]. Agarwal et al investigated experimentally on effect of pongam biodiesel on engine performance, combustion and durability. It focused on fuel characterization and standardization of biodiesel production process for optimum yield and quality, effect of biodiesel on fuel injection system, wear of engine components upon long-term usage, and effect of biodiesel on lubricating oil life. It is verified that lower pongam biodiesel blends (20%) showed reduction in CO, HC and particulate emissions however slight increase in NO<sub>x</sub> emissions [9].

Venkateswara Rao et al conducted experimental investigation of Pongamia, Jatropha and Neem Methyl Esters as Biodiesel on C.I. Engine. Results indicated that B20 have closer performance to diesel and B100 had lower brake thermal efficiency mainly due to its high viscosity compared to diesel. However, its diesel blends showed reasonable efficiencies, lower smoke, CO and HC. Pongamia methyl ester gives better performance compared to Jatropha and Neem methyl esters. [10]. Panigrahi et al conducted performance and emission tests using a four stroke diesel engine by non-edible pongam biodiesel and confirmed BSFC reduces with increase in load. BTE shows better result than diesel. The specific gravity, Kinematic viscosity of B20 and B40 blends is much closer to diesel. CO<sub>2</sub>, HC and smoke emissions are lowered as compared to diesel [11]. Stalin et al conducted a performance test of IC Engine using pongam biodiesel blending with diesel and with various blending ratios have been evaluated. As the load increases, torque increases to the maximum at 70% load and then decreases for all the fuel samples. As the load increases, brake specific fuel consumption decreases to the minimum of at 70% load and then increases for all the fuel samples tested. This can be correlated to the conclusion that the brake power increases as the load increases [12].

## II. MODIFIED PISTON

The hemispherical bowl piston is selected for modification. Based on the previous literature of spiral grooves and tangential grooves induces swirl inside the cylinder it is expected that holes in piston crown facilitate induction in swirl for proper mixture of fuel and air. Therefore hemispherical bowl is modified by drilling radial holes of 6nos. for 2.5mm and 3mm diameters. The induction in swirl occurs when the piston reaches TDC during compression Therefore swirl flow occurs due to this modification which results in proper homogeneous mixture.



Fig. 1 Modified piston with 2.5 mm holes



Fig. 2 Modified piston with 3 mm holes

### III. PONGAM BIODIESEL

Pongam oil belongs to the family leguminaceae. Commonly known as *Pongamia pinnata*. The tree is hardy, reasonably drought resistant and tolerant to salinity. The pongam tree is of medium size, reaching a height of 15-25 meters. The tree is well suited to intense heat and sunlight and its dense network of lateral roots and its thick long tap roots make it drought tolerant. Pongam tree is one of the few nitrogen-fixing trees to produce oily seeds. The tree bears green pods which after some 10 months change to a tan color. The yield potential per hectare is 900 to 9000 Kg/Hectare. The pongam tree gives pods which are flat to elliptic, 5-7 cm long and contain 1 or 2 kidney shaped brownish red kernels. Pongam oil is extracted using soxhelt apparatus. The yield of kernels per tree is reported between 9 and 24 kg. The composition of typical air dried kernels is: Moisture 19%, Protein 17.4%. The oil content varies from 27%-39%. Chemical properties of pongam oil are shown in table 1.

Table 1 Properties of Pongam Biodiesel

Properties	Values
Color	Yellowish Red
Viscosity (mm <sup>2</sup> /sec)	38.8
Water content	0.05%
Specific gravity	0.9366
Density (gm/cc)	0.9358
Carbon residue	0.80%
Ash content	0.05%
Flash point	212°C
Fire point	224°C
Cloud point	2°C
Pour point	-4°C
Calorific value (Kcal/Kg)	8742
Cetane number	38

### IV. EXPERIMENTAL SETUP



Fig. 3 Test Engine

The experiment is conducted in D.I. diesel engine as shown in Figure 3. At first modified piston with 2.5 mm holes is assembled in the engine and allowed to run with diesel as fuel and then with biodiesel. The power is measured from the dynamometer coupled to the engine. The engine was subjected to different loads and the readings are noted with respect to fuel consumption. The AVL gas analyzer and smoke meter are installed at the exit of the exhaust port. The readings from gas analyzer and smoke meter are noted. The experiment is repeated for modified piston with 3 mm holes for diesel and biodiesel. The graphs are plotted to compare the performance and emission characteristics of the diesel engine in case of both diesel and biodiesel blends. The specification of test rig is shown in table 2.

Table 2 Test Engine Specification

Type	Vertical, water cooled, Four stroke
Number of cylinder	1
Bore diameter	87.5 mm
Compression ratio	17.5:1
Maximum power	5.2 kW
Speed	1500 rpm
Dynamometer	Eddy current type
Injection timing	23° before TDC
Injection pressure	220 kgf/cm <sup>2</sup>

V. RESULTS AND DISCUSSIONS

A. BRAKE THERMAL EFFICIENCY

In Figure 4 brake thermal efficiency is plotted against load. It is observed that brake thermal efficiency increases for increase in load for all cases. But comparing with diesel and biodiesel the former has higher thermal efficiency for modified piston with 2.5 mm radial holes. PB25 for 2.5 mm and PB50 for 3 mm holes piston has closer values to diesel for 2.5 mm modified piston.

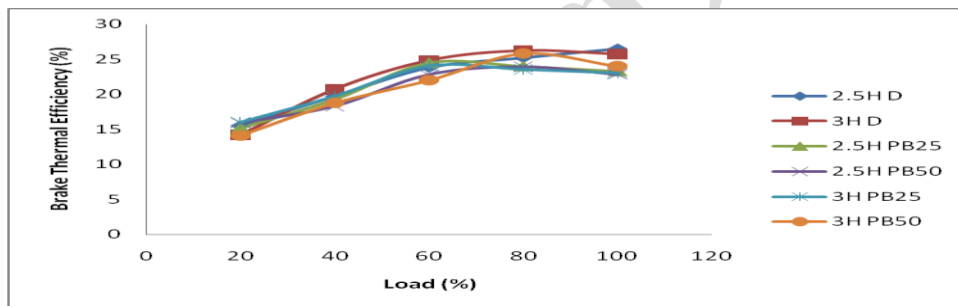


Fig. 4 Brake Thermal Efficiency Vs Load

B. BRAKE SPECIFIC FUEL CONSUMPTION

It is noted from the Figure 5 that brake specific fuel consumption (BSFC) for the biodiesel blends is higher than the diesel for both modified piston due to high viscosity of biodiesel blends. PB25 and diesel values are more or less equal for 2.5 mm modified piston.

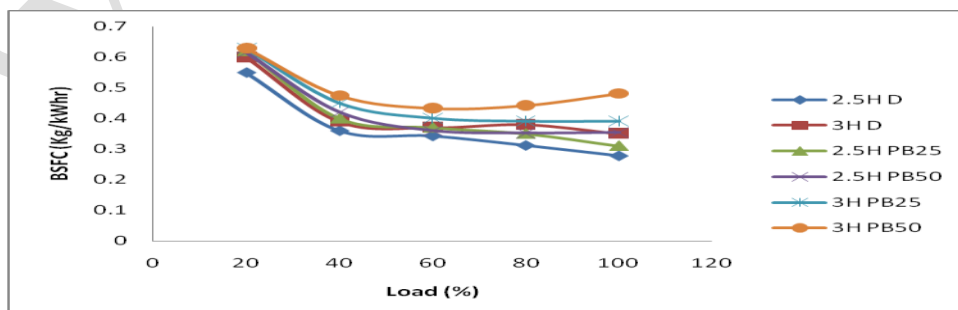


Fig. 5 Brake Specific Fuel Consumption Vs Load

The following figures from 6 to 10 represents various emissions from the engine using modified piston for both fuels like HC, CO, CO<sub>2</sub>, NO<sub>x</sub> and smoke density. The observed graphs are compared for both modified pistons.

**C. HC EMISSION**

Figure 6 shows that modified piston with 3 mm radial holes run by biodiesel has a lower HC emissions compared to other piston run by both fuels. Both modified pistons run by diesel shows higher HC emission values due to high amounts of carbon and hydrogen in the fuel.

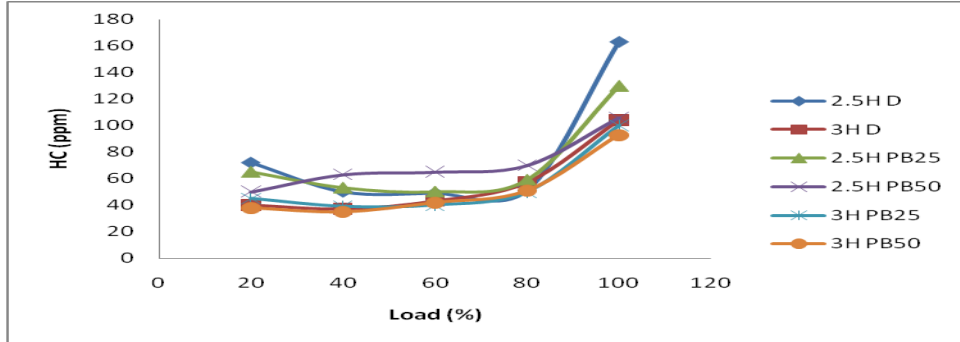


Fig. 6 HC Emission Vs Load

**D. SMOKE DENSITY**

From the Figure 7 it is observed that smoke densities of biodiesel blends are higher than diesel for both modified pistons. This is due to high specific gravity and high density of biodiesel blends than diesel fuel. Modified piston with 2.5 mm radial holes run by biodiesel shows nearly comparable values to diesel fuel.

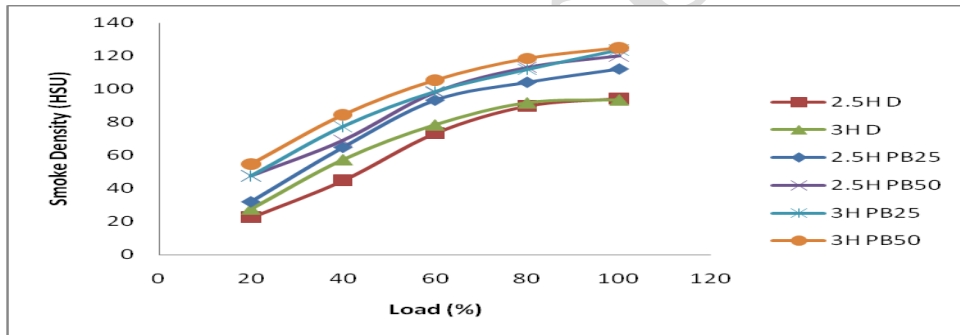


Fig. 7 Smoke Density Vs Load

**E. CO EMISSION**

Graph between CO emission and Load is shown in Figure 8. CO emission increases for increase in load. CO emission is higher for PB50 blends for both modified pistons due to incomplete combustion of blends. Modified piston with 2.5 mm holes run by PB25 shows results closer to piston with 3 mm holes run by diesel.

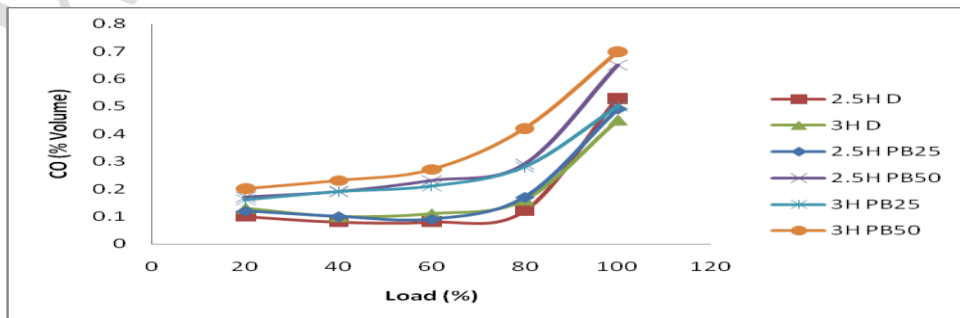


Fig. 8 CO Emission Vs Load

**F. CO<sub>2</sub> EMISSION**

Figure 9 represents variation of CO<sub>2</sub> with load. Modified piston with 3 mm holes shows higher CO<sub>2</sub> due to more elemental oxygen presence in the fuel and more induced swirl lead to homogeneous mixture of air and fuel. Modified piston with 2.5 mm holes run by both diesel and biodiesel blends shows less CO<sub>2</sub> emissions.

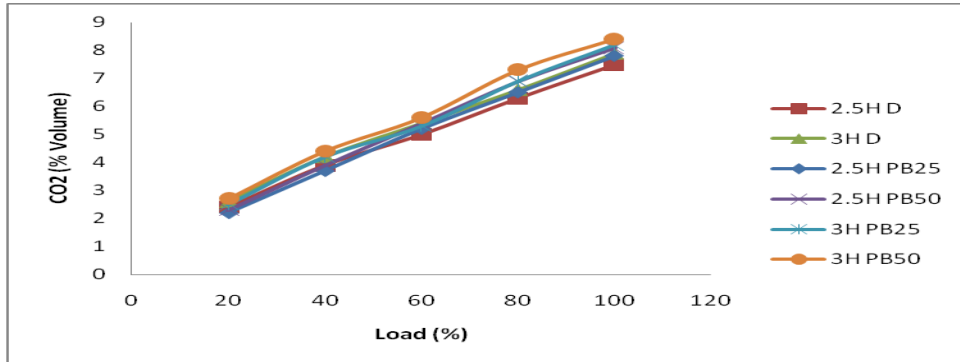


Fig. 9 CO<sub>2</sub> Emission Vs Load

**G. NO<sub>x</sub> EMISSION**

NO<sub>x</sub> emissions are drawn with respect to load as shown in Figure 10. NO<sub>x</sub> emissions are less for modified piston with 2.5 mm radial holes run by biodiesel compared to the other piston.

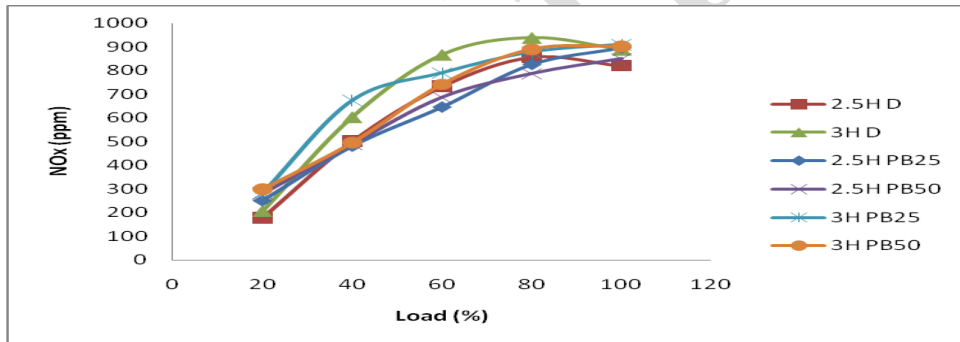


Fig. 10 NO<sub>x</sub> Vs Load

**VI. CONCLUSION**

From the experimental results it is concluded that modified piston with 2.5mm radial holes has better efficiency and reduction in emissions using biodiesel comparing to modified piston with 3 mm radial holes. But comparing with neat diesel fuel, modified piston with 2.5 mm radial holes have comparable values for biodiesel. So pongam biodiesel with lower blends can be used to meet the efficiency requirements and emissions for the notified piston

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