# Effect of Piston Geometry on Diesel Engine Performance and Emission Characteristics with Varying Injection Pressure

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*Abstract*— Engine performance improvement and exhaust emissions reduction are the two most important issues to develop a more efficient engine with less environmental impact. For diesel engine piston geometry, injection timing and injection pressure are one of the major parameters that affect the engine performance and emissions. These issues can be sought out by geometry modification of piston and variation of pressure. In this study, engine performance improvement and exhaust emissions reduction was carried out with the help of some modification in piston bowl in a single cylinder Direct Injection (DI) diesel engine. The piston bowl geometry was modified to have piston-B (Hemisphere Combustion Chamber With Circular Arc on Periphery of Piston Crown @ 120°) from the standard piston-A(Hemispherical open type Combustion Chamber).The test result shows that Brake Specific Fuel Consumption was decrease by 5.98% and brake thermal efficiency was increase by 1.93% with piston B at 185 bar pressure when compare with the baseline of engine. Due to the expense of increase the exhaust gas temperature (EGT) and oxide of nitrogen (NOX) emission by 4.52% and 4.22% respectively. The exhaust gas emission of hydrocarbon (HC) was decrease by 2.12%and carbon monoxide (CO) was similar to the baseline condition.

***Key words:*** DI, Piston Crown, Combustion Chamber, Fuel Consumption, Hemisphere Combustion

## I. Introduction

The compression ignition engine is an internalcombustion engine that uses the increase intemperature in the compression stroke to ignite a fuelcharge (fuel-air mixture). This is also calledauto-ignition. These engines are always fuel injected.Air is drawn into the cylinder through the intakemanifold and compressed by the piston. The mostimportant function of the CI engine combustionchamber is to provide proper mixing of fuel and airin a short time to lessen theignition lag phase. In order to achieve this, anorganized air movement called air swirl is provided toproduce high relative velocity between fuel dropletsand air. When the liquid fuel is injected into thecombustion chamber, the spray cone gets disturbeddue to the air motion and turbulence inside. The onsetof combustion will cause an added turbulence that canbe guided by the shape of the combustion chamber. [22]

In the history of engine development, engine manufacturers are very keen to design the combustion chamber meticulously, as it is the key component ascertaining the engine combustion, performance and emission. Typically, combustion chamber design will have an effect on air/fuel mixing process and an improved air/fuel mixing will help achieve enhanced fuel burning rate. Therefore, in the design process, care should be taken to develop combustionchamber, which could enhance the air/fuel mixing and the subsequent combustion process. [1]

The combustion and emission formation processes in diesel engines have a close relationship with the piston bowl geometry which can strongly affect the air fuel mixing before the combustion starts. [2]

### A. Importance of Combustion Chamber:

The performance and emission characteristics of CI (compressionignition) engines mainly depend upon the combustion process. Combustion of the fuel inside the cylinder, in turn depends onvarious factors like, fuel injection timing, fuel injection pressure,engine design such as shape of combustion chamber and positionof injector, fuel properties, number and size of injection nozzlehole, fuel spray pattern, air swirl, fuel quantity injected, etc. [5] Most important function of CI engine combustion chamber is to provide proper mixing of fuel and air in short possible time[23]. In CI Engine there is only air enters inside the combustion chamber during suction stroke. After that air gets compressed inside the combustion chamber during compression stroke, near the end of compression stroke fuel enters the combustion chamber by means of injector so there is heterogeneous mixture in CI engine. After injection of fuel inside the combustion chamber, fuel and air mixed with each other but it take certain time for mixing so to increase the rate of mixing turbulence is required in CI Engine. If turbulence is applied inside the combustion chamber the fuel mixes with the air completely and it passes throughout the chamber. The temperature and pressure of the air inside the chamber is high so the injected fuel reaches to its self-ignition temperature and start burning. Due to turbulence the flame propagate throughout the combustion chamber and because of this complete combustion of mixture may occur inside the chamber.

### B. Objective of Piston Geometry:

Our environment is polluted day by day from industrial emissions and road vehicles emissions. Petrol engine and diesel engine produced different types of harmful gases during combustion like $NO_x$, CO, $CO_2$, HC and some quantity $SO_x$ due to poor fuel quality. These gases are produced by different engine factor such as piston bowl geometry, injection timing, compression ratio etc. This entire factor also affects the combustion efficiency, fuel consumption and engine brake power. [10]To reduce the emissions engine manufacturers try to best design the combustion chamber and other level. At combustion chamber geometry design to reduce the NOx many researchers studied the different piston bowl geometry. So, in current scenario every researcher and manufacturers try to reduce the exhaust emissions by combustion chamber design as well as other method like EGR (Exhaust Gas Recirculation),SCR (Selective Catalytic Reactor) and HCCI (Homogeneous Charge Compression Ignition). Here in present work NOx and other gases are reduced by the modification of piston bowl geometry for direct injection diesel engine.

### *C. Air Motion within the Cylinder:*

Air motion plays a significant role in fuel-air mixing, combustion and emission processes. Along with air motion, spray characteristics, spray angle, injection pressure and injection timing also have a significant role in diesel engine combustion. The air motion inside the cylinder greatly influences the performance of diesel engines. It is one of the major factors that control the fuel-air mixing in diesel engines. Air-fuel mixing influences combustion, performance and emission level in the engine. The air motion inside the cylinder mainly depends on manifold design, inlet and exhaust valve profile and combustion chamber configuration. The initial in-cylinder intake flow pattern is set up by the intake process, and then it is modified during the compression process. The shape of the bowl in the piston and the intake system, control the turbulence level and air-fuel mixing of the DI diesel engine. [7]The variation of shape of intake system, shape of piston cavity, etc. lead to a change in the flow field inside the engine.

### *D. Effects of Air Motion:*

The air motion inside the cylinder:

- Atomizes the injected fuel into droplets of Different sizes.
- Distributes the fuel droplets uniformly in the air charge.
- Mixes injected fuel droplets with the air mass.
- Supplies fresh air to the interior portion of the fuel drops and there by ensures complete Combustion.
- Reduces delay period.
- Reduces after burning of the fuel.
- Better utilization of air contained in the cylinder.

## II. LITERATURE SURVEY ON PISTON GEOMETRY

S. Vedharaj, R. Vallinayagam, W.M. Yang , C.G. Saravanan b, P.S. Lee wascarried outoptimize the combustion bowl geometry of a single cylinder stationary diesel engine for the effective operation of KME (kapok methyl ester) diesel blends. Two different combustion chamber geometries such as TRCC (trapezoidal combustion chamber) and TCC (toroidal combustion chamber) were chosen in addition to the convention design of HCC (hemispherical combustion chamber).Based on the results obtained from this study, TCC was shown to exhibit better performance and emission than TRCC and HCC for all test blends. Categorically, B50 showed a 5.2% increase in BTE than diesel with TCC.

J. Li, W.M. Yang, H. An, A. Maghbouli, S.K. Chou Was analyzed the effects of piston bowl geometry on combustion and emissioncharacteristics of a diesel engine fueled with biodiesel under medium load condition. Three differentbowl geometries namely: Hemispherical Combustion Chamber (HCC), Shallow depth Combustion Chamber(SCC), and the baseline Omega Combustion Chamber (OCC) were created with the same compressionratio of 18.5. The biodiesel is made from waste cooking oil whosemain composition is palm oil. To simulate the combustion process, computational fluid dynamics (CFD) modeling basedon KIVA-4 code was performed. It isfound that the narrow entrance of combustion chamber could generate a strong squish, especially at highengine speed, hence enhancing the mixing of air and fuel.

HadiTaghavifar, ShahramKhalilarya, SamadJafarmadar the simulation was carried out based on 1.8 L Ford diesel engine and the geometrical modification in structure of piston were considered in terms of bowl movement and the bowl size in four equal increments. A new version of Coherent Flame Model’s sub-model (ECFM-3Z) was adopted during the calculations to shed light into the combustion chemistry and reaction rate in detail. Engine structure was modified in two ways. Firstly, the bowl ofpiston was shifted outward and secondly the radius of the bowlwas incremented evenly. The effects of these two parameters weretaken into account as to explain the flow and combustion behaviorwithin the cylinder.It was found that increasing outward bowl movement (D1–D4 configuration) provides better uniformity in air/fuel mixtureeither qualitatively (equivalence ratio) or quantitatively(Homogeneity Factor) which results in higher peak pressureand HRR.it was demonstrated that smaller bowl size induces better squish and vortexformation in the chamber, although lesser spray penetration and flame quenching owing to the spraywallimpingement reduces ignition delay.

S. Prasanna Raj Yadav, C.G. Saravananwas investigateIn this regard, three combustion bowl geometry shapes are preferred viz Piston 1 (shallowdepth combustion chamber), Piston 2 (toroidal combustion chamber) and Piston 3 (hemisphericalcombustion chamber). In the pursuit of experimental investigation of B25 (HCF e 25% and diesel e 75%)and B100 (HCF e 100%), piston 2 showed enhanced engine performance and emission than the other twoconfigurations. Notably, BTE for B25 with piston 2 is increased by 10.2%, while the emission such as HC, CO and smoke are reduced by 13.3%, 11.7% and 10.1%, respectively, than the conventional piston bowl geometry (piston 3) at the expense of increased $NO_X$ emission.

S. Jaichandar,K. AnnamalaiWas find that Improved thermal efficiency, reduction in fuel consumption and pollutant emissions from biodiesel fueled diesel engines are important issues in engine research. To achieve these, rapid and perfect air-fuel mixing are the most important requirements. The mixing quality of biodiesel spray with air can be improved by selecting the best injection parameters and better design of the combustion chamber.Then the experiments were carried out at different injection opening pressures of 185, 200, 210, 220, and 230 bar.Experiments were performed using a DI diesel engine equipped with a conventional jerk type injection system and pistons having HCC (hemispherical combustion chamber) and TRCC (toroidal re-entrant combustion chamber) geometries. The combined effect of varying, injection pressure and combustion chamber geometries, on the combustion, performance and exhaust emissions, using a blend of 20% POME (pongamia oil methyl ester) by volume in diesel was evaluated. The test results showed that improvement in terms of brake thermal efficiency and specific fuel consumption for TRCC operated at higher injection pressure. Substantial improvements in the reduction of emissions levels werealso observed for TRCC operated at higher injection pressure.

 

S. Jaichandar, P. Senthil Kumar , K. Annamalaiwas done experimental studyaims to optimize the combination of injection timing and combustion chamber geometry to achievehigher performance and lower emissions from biodiesel fueled diesel engine. in a singlecylinder Direct Injection (DI) diesel engine equipped with pistons having Hemispherical and Toroidal ReentrantCombustion Chamber (TRCC) geometries Thestandard engine was fitted with three shims to give standardinjection timing of 23_ before Top Dead Center (BTDC). By changingthe no of shims, the injection timings were varied to 20, 21, 22and 24 BTDC.The test results showed an improvement of 5.64% inbrake thermal efficiency, a reduction of 4.6% in brake specific fuel consumption and a 11% increase ofoxides of nitrogen (NOx) level for TRCC compared to baseline engine operated with ULSD due to betterair-fuel mixing and retarded injection timing.

C.D. Rakopoulos, G.M. Kosmadakis, E.G. Pariotis was, investigate using three piston bowlgeometries for three engine rotational speeds of 1500, 2000 and2500 rpm. These alternative geometries are produced by changingthe ratio of piston bowl diameter to cylinder diameter (d/D) from64% (which is the standard case) to 54% and 44%, increasing correspondinglythe piston bowl height in order to keep the compressionratio constant. Comparing the results, it can be concluded that both modelspredict quite similar mean cylinder pressure and temperaturetraces, over the whole closed part of the engine cycle. Comparing the predictedmean axial and radial velocities, as they have been calculatedby the two models, it can be concluded that the results arequite similar for all piston bowl geometries examined, over thewhole closed part of the engine cycle.

## III. RESEARCH METHODOLOGY

### A. *Piston Geometry:*

The shape of the combustion chamber and the fluid dynamics inside the chamber are important in diesel combustion. As the piston moves upward, the gas is pushed into the piston bowl. The geometry of the piston bowl can be designed to produce a squish and swirling action which can improve the fuel/air mixture formation before ignition takes place. The main goals desired from the design of chamber geometry are to optimize the mixing of the fuel and air, before and during ignition, and to improve the flow of the exhaust products once combustion is complete.

The piston C means the hemisphere combustion chamber with circular arc providing on the periphery of piston. The photographic view of piston-C is shown in figure 3.1.

The piston crown of 85 mm diameter of base line engine is modifying by producing three circular arc at 120° on the piston. In the present experiment, three circular arc of a 14 mm radius will produced on pistons of 85 mm diameter and maintaining constant depth of 2 mm in piston.

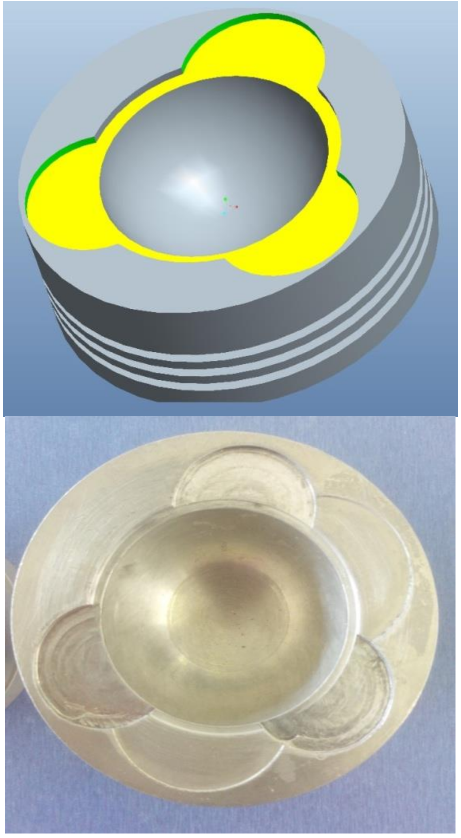

Fig. 1: Combustion Chamber of Piston B

### B. *Injection Pressure:*

Tests were also performedat different injection pressures of 200 & 170 bar andtheir results were compared and analyzed with standard injection pressure of 185 bar. In order to have a meaningful comparison ofemissions and engine performance, tests were performed at sameoperating conditions, i.e. engine speed, torque and peak conditionswere maintained.
The injector opening pressure was varied byadjusting the spring tension of the injector by screwing orunscrewing the screw provided on the top of the injector. Then theexperiments were carried out at different injection opening pressures of 170,185 & 200 bar.

### C. *Step Wise Methodology:*

1) An experiment was carried out using pure diesel.
2) To start with, the performance and emissions tests was carried out using pure diesel at various loads for the standard engine having HCC with manufacturer recommended fuel injection pressure and fuel injection timing of 185 bar and 26° BTDC respectively. This performance and emissions values are considered as baseline values throughout the experimentation for comparison with the results obtained from the modified engine with diesel.
3) The engine tests was Carried on at 0%, 20%, 40%, 60%, 80% and 100% load.
4) The experiments are conduct with these two different pistons and their performance and emissions are compared with base line piston of diesel engine.
5) The experiments are conduct with these two different injection pressures and their performance

and emissions are compared with base line pressure of diesel engine.

## IV. EXPERIMENTAL SETUP AND ARRANGEMENT

To evaluate the performance and emission characteristics, the specific type of engine is used in this project, single cylinder, water cooled, HSDI diesel engine used. Set up of the experimental engine is illustrated in fig 4.1 and its specifications are listed in Table 4.1. The engine is coupled with an electrical dynamometer with load bank acting as a variable load system. Various instruments and gauges are used to obtain different measurements. The engine speed measure with the help of digital tachometer, fuel tank connected with calibrated glass burette to measure mass of fuel for experiment, engine intake air supply is connected to air box for measure mass of air consume during the experiment-type thermocouple with digital temperature indicator was used to measure exhaust temperature. In this engine using with/without the coated piston & valves to measure engine performance & emission in C.I engine.

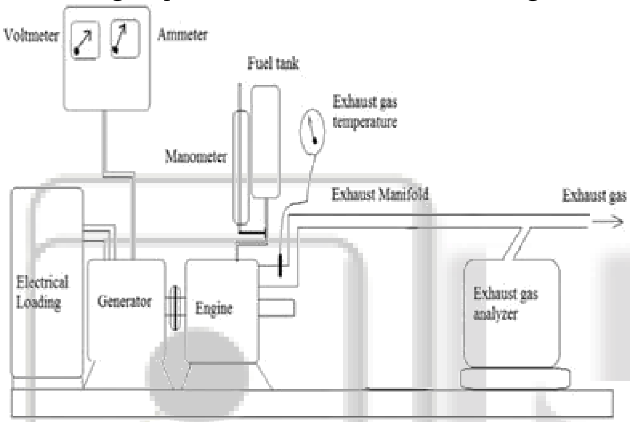


Fig. 2: Schematic Diagram of Experimental Set Up

| Parameters | Specification |
|---|---|
| Model | New JaiKishan diesel engine |
| RPM | 1500 |
| No. of cylinder | Single cylinder |
| No. of stroke | Four stroke |
| Engine Power | 4.5 KW |
| Cylinder bore | 85 mm |
| Stroke length | 110.80 mm |
| Injection timing | 26ºBTDC |
| Injection pressure | 185 bar |
| Compression Ratio | 18:1 |
| Lubricating oil | Yantrol 32 |

Table-1: Engine Specification

## V. RESULTS AND DISCUSSIONS

### *A. Performance Results:*

#### *1) Effect of Brake Power on Brake Thermal Efficiency:*

The brake thermal efficiency of the engine is one of the most important parameter for evaluating the performance of the engine. It indicates the combustion behavior of the engine to a greater extent. The variations of brake thermal efficiency with brake power of the engine with various condition are shown in Fig 5.1 and compared with the brake thermal efficiency observed with base data. It is noticed that the BTE of the engine increased with increasing loads.

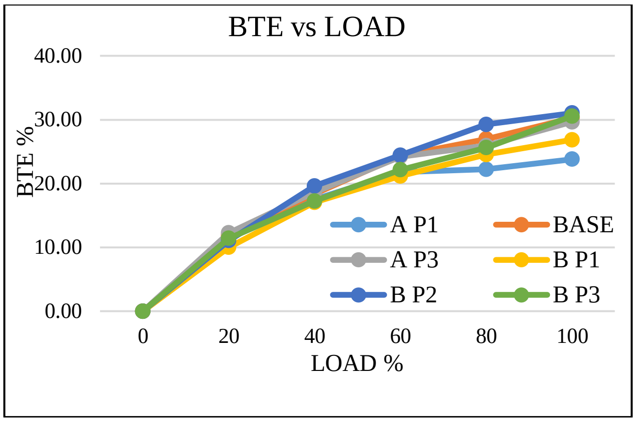


Fig. 3: Variation of Brake Thermal Efficiency with Brake Power

It can be observed from the figure that the thermal efficiency is highest for engine with**B** piston. The brake thermal efficiency of piston B was increased by 1.93% when compare to the base line engine the increased and decresed of pressure give negative effect on brake thermal efficiency.

#### *2) Effect of Brake Power on Brake Specific Fuel Consumption:*

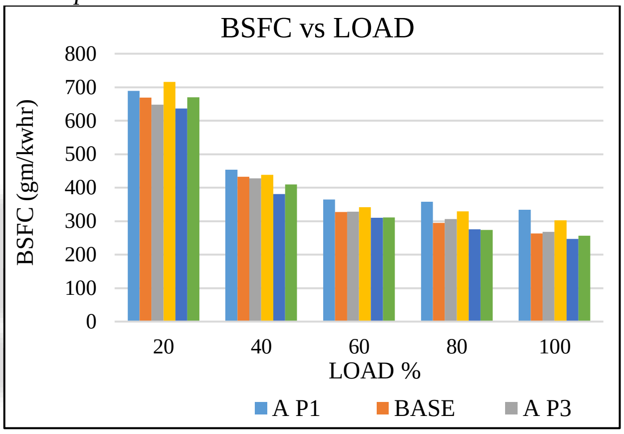


Fig. 4: Variation of BSFC with Brake Power

Fig.4 shows the variation in BSFC (brake specific fuel consumption) with respect to brake power. It can be seen from the Fig 5.2 that fuel consumption decreases with increase in load. One possible reason for this reduction is that the brake power increases in higher percentage compare to fuel consumption. Fuel consumption decreases about 5.98% compare to baseline condition.

#### *3) Effect of Brake Power on Exhaust Gas Temperature:*

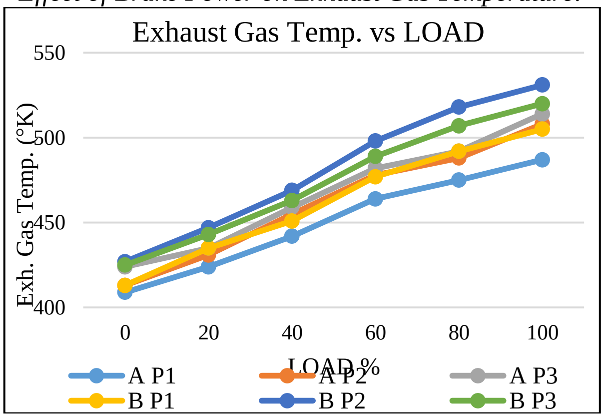


Fig. 5: Variation of Exhaust Gas Temperature with Brake Power

Fig.5 shows the variations of exhaust gas temperature for standard engine and modified engine with circular arc on periphery of piston crown at different injection pressures at no load to full load condition. Exhaust gas temperature increased with engine load for both the combustion chambers used. It was observed that the exhaust gas temperature of the modify piston B was increase by 4.52% compare to base condition of engine at full load operation which is shown in fig 5.3.This may be due to more complete combustion as a result of better air fuel mixing.

### *B. Emission Parameters:*

#### *1) Effect of Brake Power on Carbon Monoxide (CO):*

Carbon monoxide emissions from internal combustion engines are controlled mainly by the fuel/air equivalence ratio. Usually diesel engines work with lean mixtures, but local conditions may be rich and lead to the formation of CO. The emission of carbon monoxide for different loads and also for different condition has been shown in Fig.6 Compares the CO emission of engine at varying brake power and at different conditions. It is seen that, CO emission decreases with increase in load for any condition and also different values at even same load. The CO emission is 0.08% at baseline and 0.07% at modified piston condition.

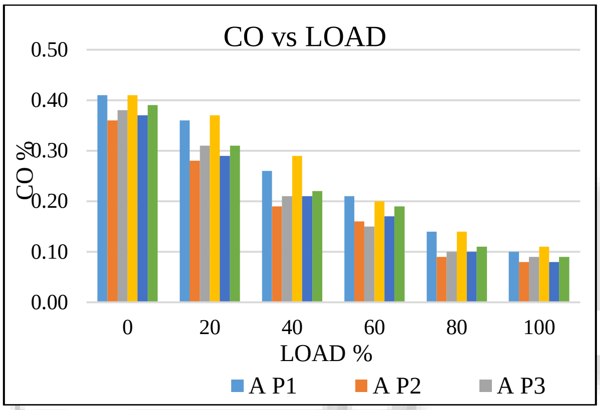


Fig. 6: Variation of Carbon Monoxide (CO) with Brake Power

#### *2) Effect of Brake Power on Hydrocarbons (HC):*

The comparisons of Hydrocarbon (HC) emissions for both piston A and piston B with different injection pressures at no load to full load are shown in fig.7

From fig.7 shows that the HC emission of modifying piston B is reduced by 2.12% at same injection pressure when it is compare to baseline engine. It is apparent that the hydrocarbon emission is decreasing with the increase in the turbulence, which results incomplete combustion.

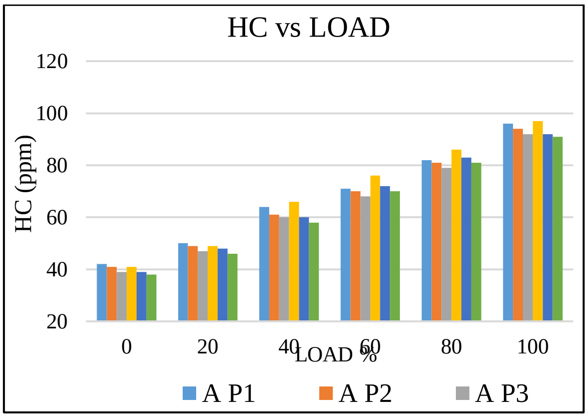


Fig. 7: Variation of Hydrocarbons (HC) with Brake Power

#### *3) Effect of Brake Power on Oxides of Nitrogen (NOx):*

Nitrogen oxides are known as an air contaminants formed through the combustion of fossil fuels and other fuels that contain nitrogen. Combustion of nitrogen-free fuels at high temperatures in the presence of air oxidizes the nitrogen in the air, producing nitric oxide.

Fig.8 shows the variations of oxides of nitrogen emissions for standard engine and modified engine with hemisphere combustion with circular arc on periphery of piston crown at different injection pressures at no load to full load condition.

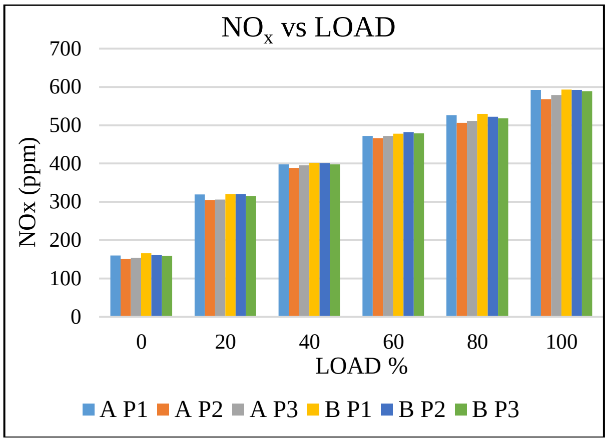


Fig. 8: Variation of Nitrogen Oxide (Nox) with Brake Power

It was measure that emission of $NO_X$of modify piston B was increased by 4.22% at 185 BAR injection pressure when compare to baseline engine at full load condition. Thereason for the increase in NOx may be attributed to higher combustion temperatures arising from improved combustion due to better mixture formation in piston B.

## VI. CONCLUSION

The combined effect of injection pressure and combustion chamber geometry on the performance and emission and characteristics of a naturally aspirated single cylinder four-stroke DI diesel engine was studied and the conclusions of the test results are given below.

Brake Specific Fuel Consumption was decrease by 5.98% and brake thermal efficiency was increase by 1.93% with piston B at 185 bar pressure and injection timing 26° BTDC when compare with the baseline of engine condition which that hemisphere combustion.

Due to the expense of increase the exhaust gas temperature (EGT) and oxide of nitrogen ($NO_X$) emission by 4.52 and 4.22% respectively.

The exhaust gas emission of hydrocarbon (HC) was decrease by 2.12% and carbon monoxide (CO) was similar to the baseline condition.

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