Experimental Investigation On Combustion and Emission Characteristics of Single Cylinder Diesel Engine Modified with Fuel Injector Geometry

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Abstract— Fuel injection parameters play an important role in diesel engine performance for obtaining proper combustion. The performance and emission characteristics of diesel engine depend on many parameters. An experimental study was conducted on a DI diesel engine at three hole (0.28mm diameter) and four hole (0.23mm diameter) fuel injector nozzle to study its effect on performance and emission by using conventional diesel fuel on the single cylinder four stroke engine with the engine working at different engine loads at compression ratio 16.5. The results obtained revealed that the performance, combustion, and emission characteristics of the modified engine (4-hole nozzle with an orifice diameter of 0.23 mm) were improved except NOX in comparison with those of the conventional diesel engine (3hole nozzle with an orifice diameter of 0.28 mm). The combustion in a diesel engine is governed mainly by spray formation and mixing. Important parameters governing these are droplet size, distribution concentration and injection velocity. Smaller orifices are believed to give smaller droplet size, with increase injection nozzle hole, which leads to better fuel atomization, faster evaporation and better mixing. The performance and emission characteristics were presented clearly to determine that they were found better with four-hole nozzle for the single cylinder diesel engine.

Index Terms—*Emission Characteristics, Fuel injector geometry, Injector nozzle, CI engine combustion.*

I. INTRODUCTION

Due to their relative simplicity, low capital cost, higher power density and higher efficiency, diesel engines have more popularity. From small single-cylinder generator to super-tankers, diesel engines are often the best choice for use as prime movers or at least considered as alternatives. The engine manufacturers constantly trying to further develop the CI engine technology to improve the efficiency and to control the emissions. The traditional diesel engine suffers from relatively high nitrogen oxide and particulate emissions. Thus, there is an increased focus in diesel engine research on reduction of such emissions. Some research works have been focused on investigating the effects of various engine modification, e.g. compression ratio, injection timing, fuel injector holes, orifice diameter etc. on diesel engines. The injection technology is also a main issue for the realization of recent diesel combustion technologies such as homogeneous charge compression ignition (HCCI) and stoichiometric diesel combustion. In case of combustion the fuel spray needs to be injected with smaller droplet size in order to generate a homogeneous charge within a short duration. Much research have been done on fuel injectors for diesel engine, mainly focused on low pressure swirl injectors and narrow spray included angles for preventing wall wetting. At the same time, the nozzle hole size has been reduced to produce smaller droplets. By reducing the nozzle hole size the spray tip penetration is reduced due to the low spray momentum. M Vijay Kumar, A. Veeresh Babu [1] presented the combustion characteristics of diesel engine modified with EGR and nozzle hole orifice diameter. The engine modification done by reducing orifice diameter of 0.28 mm to 0.2 mm diameter with 3 number of holes. Break thermal efficiency was slightly increased by using 0.2mm nozzle hole orifice diameter. This modified nozzle also improved the fuel vaporization and atomization. Cenk Sayin, Metin Gumus [2] presented an article based on effect of injector hole number on the performance and emission of diesel engine. The diesel engine using biodiesel and its blends and also modified with injector hole number where experimentally investigated by running the engine by different load. The result verified that the break specific fuel consumption (BSFC) and break thermal efficiency (BTE) values at higher percentage biodiesel blends (B50 and B100) produce the best results with the increased injector nozzle hole number. B.H Lee, J.H Song [3] presented the article based on the effect of the number of fuel injector holes on characteristics of combustion and emission in diesel engine. The present study considers multi hole injector with 6, 8 and 10 number of nozzle holes were used to perform the experiment. This numerical study shows that the sauter mean diameter is decreased as the number of holes increased. The local penetration of a liquid spray decreased with increasing number of holes. It is observed that amount of NOX found to be the smallest with ten hole injector due to reduced local temperature from poor mixture formation. Shijun Dong, Can Yang [4] presented an article based on investigation on the effect of nozzle hole number on combustion and emission characteristic of dual fuel engine. It has been observed that the fuel nozzle hole lead to more concentrated diesel distribution and larger orifice diameter result in poor fuel atomization. When the ethanol proportions are 0.33 dual fuel operation exhibits single stage combustion with intense heat release rate for all the nozzle cases.

The objective of the present project is to study the performance and emission characteristics of single cylinder diesel engine with the following parameters

- To study the performance parameters by increasing the injector nozzle hole number and also by decreasing the nozzle hole diameter.
- To study and compare the emission characteristics of modified fuel injector nozzle with base fuel injector nozzle

II. METHODOLOGY

A. Experimental setup

The experiment is conducted on TV1-KIRLOSKAR Single Cylinder Four Stroke Diesel Engine. A computerized single cylinder diesel engine was employed to study the effect (performance and emission characteristics) of reduced nozzle orifice diameter. The engine is coupled to an eddy current dynamometer for loading the engine. The TV1KIRLOSKAR Engine test rig is as shown in the figure2.1. Experiment was conducted on a Single-cylinder, water cooled, DI Diesel engine developing a power output of 3.7 KW at 1500 rpm connected with water cooled eddy current dynamometer. The engine was operated at standard injection pressure 210 bar, constant compression ratio 16.5:1 and constant speed of 1500 rpm. The emissions from the engine were studied at different engine loads. After the engine reach stabilized working condition, emissions like carbon monoxide, Hydrocarbon, Nitrous Oxide, carbon dioxide and sulphur oxides were measured using exhaust gas analyzer. The specification of the engine is given in the table 2.1.

Table 2.1 Engine specification

Name of the description	**Details or Value**
Model	TV1-KIRLOSKAR
Engine type	4-stroke,water cooled, Single cylinder DI diesel engine
Loading device	Eddy current dynamometer
No. of cylinders	1
No. of strokes	4
Rated power in KW	3.7 KW
Constant speed in rpm	1500
Compression ratio	16.5:1
Nozzle operating pressure	180 bar
Fuel	Diesel
Cylinder Bore	80mm
Stroke Length	110mm
Connecting rod length	234mm
Swept Volume	522cc
Rated Torque	24 N-m
Cooling	Water Cooling

Fig. 2.1 Engine test rig

B. Fuel Injector

The function of a fuel injector is to spray atomized fuel into the combustion chamber of an internal combustion engine. Fuel injection became the primary fuel delivery system in automobile engine. The spray from a fuel injector can be continuous or intermittent. A fuel pump sends the fuel to the engine bay, and it is then injected into the inlet manifold by an injector. There is either a separate injector for each cylinder or one or two injectors into the inlet manifold. The main types of injection system include pump line nozzle, unit injector and common rail. The engine performance and emission characteristics using 3 hole fuel injector nozzle is tested and the obtained values are compared with modified 4 hole nozzle fuel injector. Parametric details of the injection system used including the differences between the base and modified nozzle orifice diameters are presented in the table 2.2.

Figure2.2 Fuel injector

Table 2.2 Nozzle description.

Nozzle label	No. of holes	Diameter of the orifice hole	Standard nozzle operating pressure
Nozzle hole diameter (base)	3	0.28 mm	180 bar
Nozzle hole diameter (modified)	4	0.23 mm	180 bar

C. *Experimental procedure*

Switch on the mains of control panel and set the supply voltage from servo stabilizer to 220 volts. The main gate is opened, the pump is switched on and the water flow to the engine cylinder jacket (300 liters/hour), calorimeter (50 liters/hour), dynamometer and sensors are set. Engine is started by hand cracking and allowed to run for a 20 minute to reach steady state condition. The engine has a compression ratio of 16.5:1 and constant speed of 1500 rpm controlled by the governor, an injection pressure of 180 bars is used for the study of performance as a manufacturer. The engine is first run with base fuel injector nozzle with diesel at loading conditions 2, 4, 6, 8 and 10 N-m. Between two load trials the engine is allowed to become stable by running it for 3 minutes before taking the reading. At each loading condition performance parameter namely for the speed, exhaust gas temperature, break power etc. are measured under the steady state conditions. The engine is next run with modified fuel injector nozzle and the engine is started by hand cracking. The engine is allowed to become stable by running it for few minutes and then the engine is loaded using eddy current dynamometer and at each loading condition performance parameters namely speed, exhaust gas temperature, break power etc. are measured under steady state condition and are tabulated. With the experimental result, the parameters such as total fuel consumption, break specific fuel consumption, break mean effective pressure, break thermal efficiency and break power are calculated. Finally, graphs are plotted for BSFC, BTE and BP with respect to different loading conditions for base and modified fuel injectors. From these plots, a Performance and emission characteristic of the engine is determined.

III. RESULTS AND DISCUSSIONS

The result of experiments and analysis concerning the engine investigations carried out with diesel operation in a single cylinder diesel engine. With the observed experimental results for 3-hole nozzle (0.28mm orifice diameter) and 4-hole nozzle (0.23mm orifice diameter), performance parameters such as BP, BSFC, BTE, IThE, ME and emissions parameters such as NOX, CO2 and CO are plotted and discussed.

A. *Brake Thermal efficiency vs. Load*

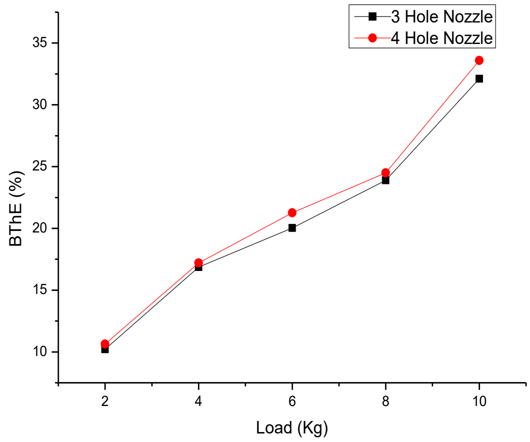

Figure 3.1 Variation of Brake Thermal Efficiency vs. Load

The variation in Brake thermal efficiency vs. load for different combinations of nozzle orifice diameter is shown in the figure 3.1. It is noticed that rise in thermal efficiency when the nozzle hole is increased. This was due to increase in nozzle hole was responsible to rise in air fuel mixing, fuel vaporization and improved combustion and heat release rate (HRR). It also been observed that the smaller the orifice, shorter the ignition delay. The smaller orifices also improves the mixing which results in reduction of heat and time losses, resulting in higher brake thermal efficiency i.e. lower brake specific fuel consumption. Thus in view of this BTE (Brake thermal efficiency) rises with number of holes.

B.Brake specific fuel consumption (BSFC) vs. Load

Effect of nozzle hole geometry for NH1 (3-Hole nozzle of 0.28mm diameter) and NH2 (4Hole nozzle of 0.23mm diameter) on Brake specific fuel consumption at different loads is as shown in fig 4.3 respectively. BSFC is a measure of fuel efficiency of any prime mover that burns fuel and produces rotational or shaft power.

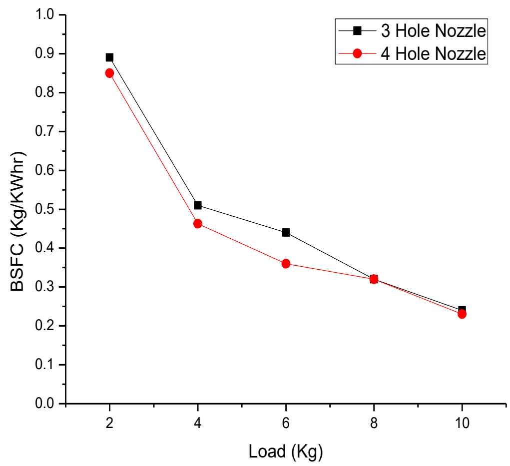

Figure 3.2 Variation of BSFC vs. Load

It is the rate of fuel consumption divided by the power produced. From the graph it is observed that BSFC is reduced as load increases for both the nozzles. It is also noticed from the figure 3.2. BSFC are lower for 4 hole nozzle when compared to 3-hole nozzle because the smaller orifice diameter reduces the size of the droplets and increases the momentum of the droplets. It can be observed that BSFC at the lower loads is reduced for 4 hole nozzles. This is indicating the fact that smaller nozzle orifice requires lower load condition to ensure the complete combustion and to bring down fuel consumption.

C.Indicated Thermal Efficiency vs. Load

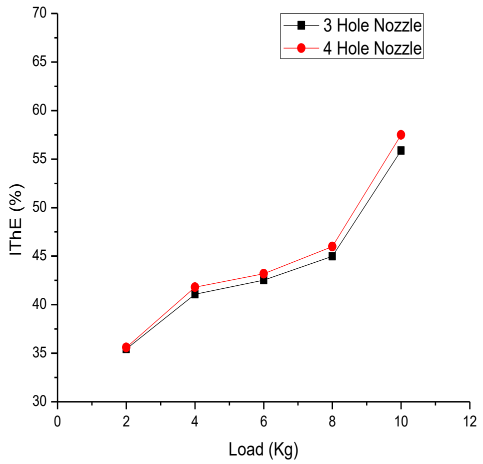

Figure 3.3 Variation of Indicated thermal efficiency vs. Load

Effect of nozzle hole geometry and load on Indicated thermal efficiency is as shown in fig 3.3 respectively. The indicated thermal efficiency gives an idea of the power generated by the engine within the cylinder with respect to heat supplied in the form of fuel. It was noticed that rise in thermal efficiency with increase in nozzle hole. This is due to the increase in nozzle hole is responsible to rise in air fuel mixing, fuel vaporization and improved combustion. Thus in view of this Indicated thermal efficiency rises with number hole. At lower loads indicated thermal efficiency is minimum due to improper combustion. It has also been observed that the smaller the orifice, shorter the ignition delay. The smaller orifices also improve the mixing, which leads to the complete combustion of the fuel.

D.Oxides of Nitrogen vs. Load

The variation of NOX at different load conditions for different combination of fuel injector nozzle orifice diameter and nozzle hole are shown in figure 3.4. NOX is generally formed when nitrogen and oxygen react at high temperatures in the combustion process. At any nozzle hole operation with increase in load, NOX emission was found to be increasing due to faster combustion and higher temperature reached in the cycle as shown in the figure 3.4. Higher NOX emissions were observed with increased number of holes.

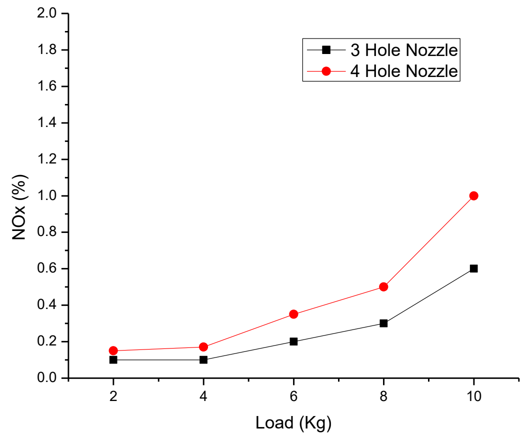

Figure 3.4 Variation of Oxides of Nitrogen vs. Load

The 4-Hole nozzle provides better air fuel mixing and hence higher premixed combustion occur leading to higher NOX emissions. The NOX emission measured for the modified fuel injector nozzle stood higher and it can decreased by introducing Exhaust Gas Recirculation system.

E. Carbon monoxide vs. Load

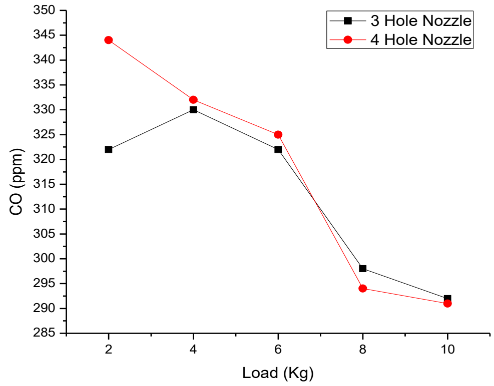

Figure 3.5 Variation of Carbon monoxide vs. Load

Effect of nozzle hole geometry and Load on Carbon monoxide emission as shown in fig 3.5 respectively. When carbon atoms bond with only one oxygen atom carbon monoxide forms. Carbon monoxide emission is nothing but behavior of incomplete combustion due to rich air-fuel mixture. Thus, due to increase in load carbon monoxide emission for all tests was found to be decreased. In addition carbon monoxide emission was found to be increased with increase in nozzle hole. Also it has been observed that at higher loads carbon monoxide emission was found to be reduced for higher number of nozzle hole. This is due to the proper air-fuel mixing and complete combustion of the fuel.

IV. CONCLUSIONS

Experiments were conducted with neat diesel for both base and modified fuel injector nozzle with different load conditions. Emission characteristics of different combination of fuel injector nozzle were recorded and the obtained data was compared with baseline data.
Accordingly, the following conclusions could be drawn:

1. The modified orifice fuel injector nozzle was beneficial in improving the engine performance parameters, i.e., Break thermal efficiency (BTE), Break specific fuel consumption (BSFC) and brake power (BP). However the modification implemented led to increased NOX at different load condition which is a major drawback. These results were mainly attributed to the more efficient atomization and proper mixing of air-fuel mixtures in response to modified fuel injector nozzle.
2. Brake thermal efficiency for four hole nozzle at higher loads was found increased and Brake specific fuel consumption found decreased. So increasing number of holes gave considerable effect on engine performance.
3. NOX emission for four hole nozzle was found increased at higher loads. Also the Carbon dioxide emission was found increased at higher loads.
4. At present scenario environmental protection is more important than fuel economy. So, decreasing emission is a primary concern which required moderate injector nozzle hole for a light duty diesel engine

REFERENCES

[1] M. Vijay Kumar, A. Veeresh Babu (2018), "Experimental investigation of the combustion characteristics of Mahua oil bio diesel-diesel blends using a DI diesel engine modified with EGR and nozzle hole orifice diameter", *Biofuel Research Journal,* 19, 863-871.

[2] Cenk Sayin, Metin Gumus (2013), "Influence of injector hole number on the performance and emissions of a DI diesel engine fuelled with biodiesel-diesel fuel blends", *Applied Thermal Engineering,* 61, 121-128.

[3] B. H. Lee, J. H. Song (2010), "Effect of the number of fuel injector holes on characteristics of combustion and emission in a diesel engine", *International Journal of Automotive Technology,* 11, 783-791.

[4]Shijun Dong, Can Yang (2018), "Experimental investigation on the effect of nozzle hole number on combustion and emission characteristics of ethanol/diesel dual-fuel engine", Fuel, 217, 1-10.

[5] Sung Wook Park, Rolf D. Reitz (2008), "Modelling the effect of injector nozzle hole layout on diesel engine fuel consumption and emissions", Journal of engineering for gas turbine and power, 130, 1-10.

[6] Fedrico Brusiani, Stefania Falfari (2014), "Influence of the diesel injector hole geometry on the flow condition emerging from the nozzle", Energy Procedia, 45, 749-758.

[7] A. V. Tumbal, N. R. Banapurmath (2016), "Effect of injectrion timing, injector opening pressure, injector nozzle geometry and swirl on the performance of a direct injection, compression ignition engine fuelled with Honge oil methyl ester", International journal of Automotive Technology, 17, 35-50.

[8]Seoksu Moon, Suhan Park (2015), "Effect of the number and position of the nozzle hole on in-and near-nozzle dynamic characteristics of diesel injection", Fuel, 10, 01-11.