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Effect of Different Nozzle Hole Orifice Diameter on Performance, Combustion and Emissions in a Diesel Engine

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Abstract: In this study, experimental tests were carried out to explore the performance, combustion and emissions by modifying the different nozzles hole size injectors such as (3 holes×Ø = 0.20 mm (modified)), (3 holes×Ø = 0.28 mm (Base)) and (3 holes×Ø = 0.20 mm (modified)). The experiments are performed on Kirloskar 4-stroke computerized solitary cylinder diesel engine fueled with diesel at 1500 rpm, water-cooled direct injection diesel engine with eddy current dynamometer with the standard injection timing of 23° bTDC with an injection pressure of 210 bar was maintained constant throughout the experiment. From the results, it was observed that among all the three different nozzles (3 holes×Ø = 0.20 mm (modified)) improves the vaporization, atomization and air-fuel mixing which leads to shorter combustion duration and appreciable results were seen in performance, combustion and in emissions. But the only weakness was NO_x increasing with smaller orifice Nozzle Hole Diameter (NHD).

Key words: Nozzles, diesel fuel, diesel engine, performance, combustion, emissions

INTRODUCTION

The main important part of the diesel engine is the fuel injector nozzle system. For a long era, the mechanism of the injector nozzle is atomization of the fuel spray this is commonly thought to be aerodynamic atomization theory. The nozzle fuel flow in diesel engine powerfully affects the development of fuel atomization, combustion, performance and emissions. The nozzle hole numbers, increasing the injection pressure and orifice sizes severely influence the combustion and performance due to the spray parameters like penetration length and droplet size. The investigation on DI diesel engine with the combination of a different nozzle of orifice sizes and holes number such as 0.225 mm diameter with 8 holes, 0.260 mm diameter with 6 holes used 0.260 mm diameter with 8 holes and 0.300 mm diameter with 6 holes is used in the experimentation. Results illustrated that the best emissions and second best BSFC were acquired by the nozzle with the highest injection hole numbers (Montgomery *et al*., 1996). The authors have studied by a high-speed video camera in a volume combustion vessel, high temperature, high pressure on flame structure and soot formation of an impinging diesel spray by using injector hole size. The experiment was performed by using two injector nozzles with a diameter of 0.16 and 0.08 mm and 3 injection pressures of 100, 200 and 300 MPa were used. From the result, it can be concluded that with the base injector nozzle of 0.160 mm and very high injection pressure creates substantially lowering the soot formation. With the micro-hole nozzle of 0.08 mm, impinging spray flame proved much smaller size and lowering the soot formation at an injection pressure of 100 MPa. The soot formations are too frail to be noticed with the 0.08 mm hole nozzle at increasing high injection pressures of 200 and 300 MPa (Wang *et al*., 2011). The smaller diameters are more efficient in atomizing the fuel sprays compared to those higher diameters. The injection pressures of 150-200 MPa are able to reduce the injection period of smaller diameter nozzle by escalating the injection velocity. The combination of smaller diameter with high injection pressure results in better atomization of the fuel and improved fuel air mixing, spray penetration, wall impingement and air entrainment (Shimada *et al*., 1989; Shundoh *et al*., 1991). The researcher has improved the air-fuel mixing and shows the shorter duration by smaller orifices. A nozzle with smaller orifices of (NH_5, Ø 0.240 mm) has been improved in combustion for the entire test, resulting in an increase in fuel efficiency compared to the reference nozzle of (NH_3, Ø 0.28 mm). Here, smaller orifices are believed to confer smaller droplet size which leads to better fuel atomization, fast evaporation and better air-fuel mixing (Vairamuthu *et al*., 2016). The emission and performances are improved by modifying the engines with different parameters (Senthur *et al*., 2014).

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MATERIALS AND METHODS

Experimental setup

Engine setup: The experimental setup is 3.5 kW rated power computerized single cylinder diesel engine. It is Kirloskar make four strokes diesel engine with water cooled diesel engine was directly coupled with an eddy current dynamometer. It is a constant speed of 1500 rpm with an injection pressure of 210 bar. The specification of engine test specification is shown in Table 1.

The engine setup, dynamometer and airflow chamber are completely interfaced to the control panel and connected to the computer. This computerized panel setup will record observation data and give the complete summary of engine performance and combustion. The AVL emission analyser and the AVL smoke meter were used. The complete experimental setup is shown in Fig. 1.

Fuel nozzle system modification: To investigate the effects of nozzle geometry on performance, combustion and emissions with the different orifice diameters are adopted. The nozzle opening pressure is of 210 bar. The different nozzle orifice diameters holes details are shown in Table 2. For better understanding, the shapes and dimensions of nozzle hole geometries are shown in Fig. 2.

Experimental test method: The experimental were carried out by diesel fuel along with modified 3 holes nozzles of different orifice diameters. The engine was performed with stable values of engine speed 1500 rpm, compression ratio 17.5:1, nozzle hole opening of 210 bar and standard injection timing 23° bTDC. The experimental was conducted to attain the performance, combustion and emission data at various loads such as 0, 20, 4, 60, 80 and 100%. At each load 3 sets of reading were noted the air flow rate, fuel flow rate exhaust gas temperature, engine mean gas temperature, cylinder pressure, emission of CO, HC, NO_x and smoke opacity and presented the average.

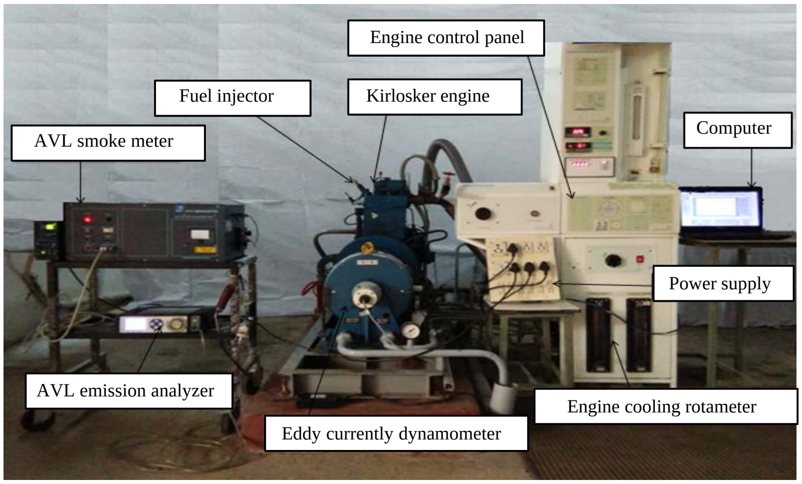

Fig. 1: Photograph of experimental setup

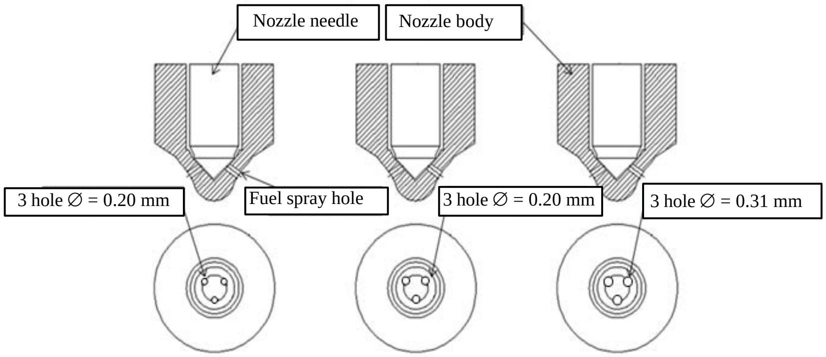

Fig. 2: Schematic diagram of 3 holes of different size diameter of nozzles

Table 1: Specification information of diesel engine

Name	Details
Make of mode	TV1-Kirloskar
Engine type	Four stroke, water cooled, single cylinder, DI diesel engine
Loading device	Eddy current dynamometer
Rated power (kW)	3.5
No. of cylinder	1
Constant speed (rpm)	1500
Stroke length (mm)	110
Cylinder bore (mm)	87.5
Swept volume (cc)	661
Compression ratio	17.5:1
Connecting rod length (mm)	234
Injection timing (°CA. bTDC)	23
Piston bowl	Hemispherical
Nozzle type	Multi-hole
Nozzle opening pressure (bar)	210
Number of nozzle hole	3
Modified nozzle spray hole diameter (mm)	0.20, 0.28 and 0.31

Table 2: Parameter details of fuel injection system

Nozzle label	No. of holes	Diameter of orifice hole (mm)
NHD (base)	3	0.28
NHD (modified)	3	0.31
NHD (modified)	3	0.20

The performance, combustion and emissions characteristics of modified nozzle fuel injection system at nozzle opening pressure of 210 bar which is fuelled with diesel were measured, analysed and compared with the base line of nozzle 3 holes with (Ø = 0.280 mm) with diesel fuel characteristics.

RESULTS AND DISCUSSION

Performance

Brake thermal efficiency and brake specific fuel consumption: The difference of primary axis BTE with respect to BP with 3 holes with each nozzle of different orifice NHD fuelled with diesel is illustrated in Fig. 3. The BTE for smaller orifice 0.20 mm NHD with diesel fuel is slightly increased by increasing the BP due to the enhanced with good atomization and vaporization due to the smaller orifice 0.20 mm NHD. In the case of 0.31 mm larger NHD with diesel the BTE has decreased due to the poor atomization. The fuel drop size particle increases with increasing the NHD.

The difference of secondary axis BSFC with respect to BP with 3 holes with each nozzle of different orifice NHD fuelled with diesel is illustrated in Fig. 3. The BSFC trend mainly depends on the fuel viscosity, fuel density and fuel chemical compositions. For 3 holes, 0.20 mm smaller orifice NHD with diesel has remarkably reduced the BSFC due to the higher mixing rate for smaller nozzle hole orifice diameter. In the case of 0.31 mm larger NHD with diesel and biodiesel, the BSFC has increased due to the poor atomization.

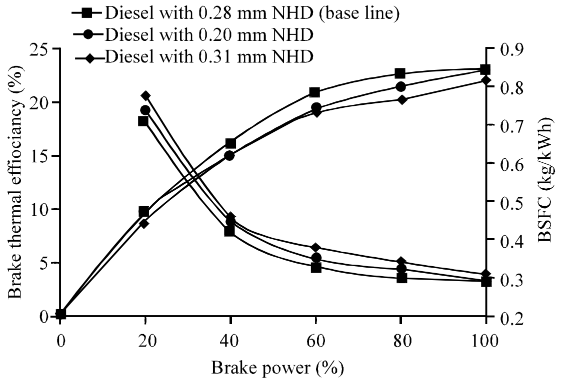

Fig. 3: Brake thermal effeciency and brake specific fuel consumption vs brake power

Combustion

In-cylinder pressure: The difference of in-cylinder pressure with respect to the crank angle at full load with 3 holes with each nozzle of different orifice NHD fuelled with diesel is illustrated in Fig. 4. The ignition delay is one of the main significant parameter in the combustion chamber. The maximum peak pressure was increased for smaller orifice 0.20 mm NHD with diesel fuel due to the increasing the gas temperature in the combustion chamber and decrease in delay period. Smaller orifice NHD results, the good atomization increase the cone angle, good fuel mixing, etc. Larger orifice NHD with diesel fuel has reduced the in-cylinder temperature and increases the ignition delay period.

Maximum in-cylinder pressure: The difference of Maximum in-cylinder pressure with 3 holes with each nozzle of different orifice NHD fuelled with diesel is illustrated in Fig. 5. The maximum in-cylinder pressure is increased as the BP is increased. Maximum pressure for diesel also increased with 0.20 mm NHD due to the improved atomization and evaporation. The pressure is decreasing for larger 0.31 mm NHD with diesel due to the particle size of fuel drop are increased and also leads to higher ID. In the case of smaller orifice NHD, the peak pressure is increasing due to the complete combustion because of proper mixing of air-fuel concentration.

In-cylinder gas temperature: The difference of in-cylinder MGT with respect to BP with 3 holes with each nozzle of different orifice NHD fuelled with diesel is illustrated in Fig. 6. From the results, it was observed that as the orifice diameter decreases the gas temperature is increased due to the proper combustion. This was due to the good atomization as well as good air-fuel mixing leads to better combustion process. If increasing the orifice NHD as seen

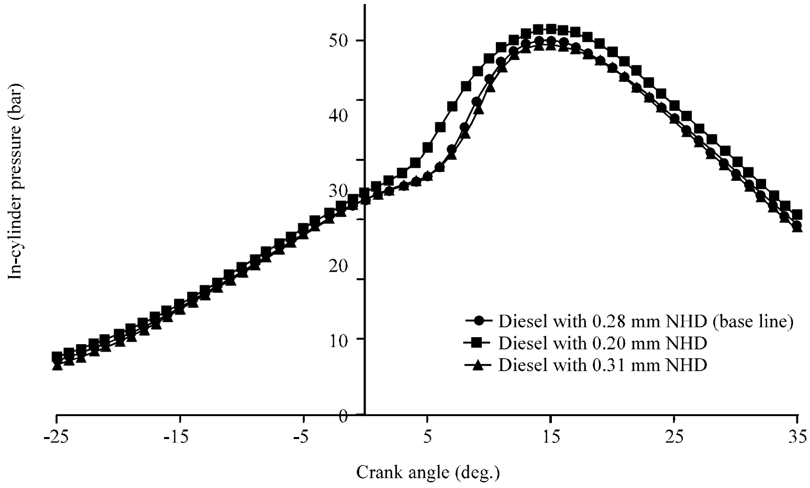

Fig. 4: In-cylinder pressure vs crank angle at full load

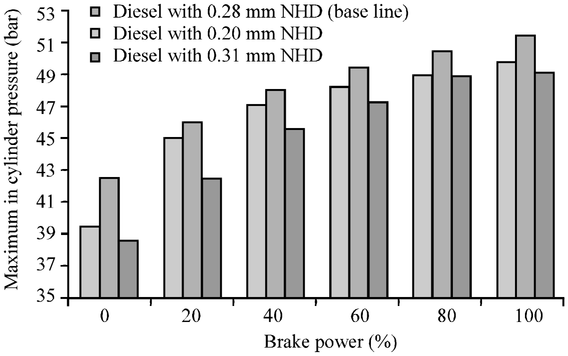

Fig. 5: Maximum in-cylinder pressure vs. brake power

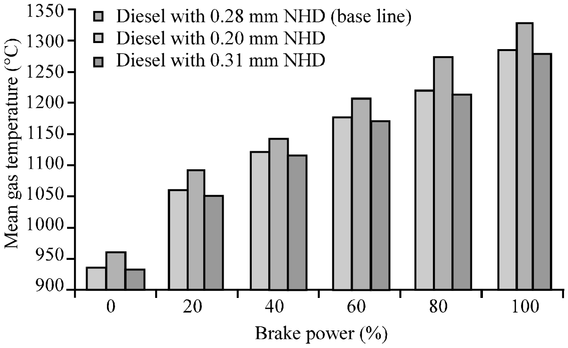

Fig. 6: Mean gas temperature vs. brake power

in the figure the gas temperature inside the in-cylinder will get reduced because of incomplete combustion and it was due to the fuel particle drop size increased.

Heat release rate: The difference of heat release rate with respect to crank angle at full load with 3 holes different orifice NHD fuelled with diesel is illustrated in Fig. 7. The 3 holes 0.20 mm NHD with diesel HHR peak is decreased due to the early SOC and shorter ID. The shorter ID due to the reducing the orifice NHD causes sluggish combustion in the premixed stage which results, lower heat release rate than the higher orifice diameter.

Emissions

Carbon monoxide: The difference of carbon monoxide with respect to BP with 3 holes with each nozzle of different orifice NHD fuelled with diesel is illustrated in Fig. 8. The CO emissions are tasteless and odourless. These CO contaminated is frequently found in engines exhaust gasses. The CO emission for smaller orifice 0.20 mm NHD with diesel fuel is greatly decreased. By reducing the smaller orifice, it has enhanced good atomization and more distribution of vaporization. For larger NHD with diesel, the CO has increased due to the poor atomization and vaporization. The fuel drop size particle increases with increasing the NHD. Here by decreasing the NHD, it helps the fuel to mix more efficiently to burn and therefore decreases the CO emission.

Hydrocarbon: The difference of Unburnt hydrocarbon with respect to BP with 3 holes with each nozzle of different orifice NHD fuelled with diesel is illustrated in Fig. 9. The formations of an unburned hydrocarbon are formed due to the improper combustion in combustion chamber. The HC emission for smaller orifice 0.20 mm NHD with diesel fuel is greatly decreased. By reducing the smaller orifice, it has enhanced the high temperature due to the proper burning in combustion chamber. For 0.31mm larger NHD with diesel the HC has increased due to the

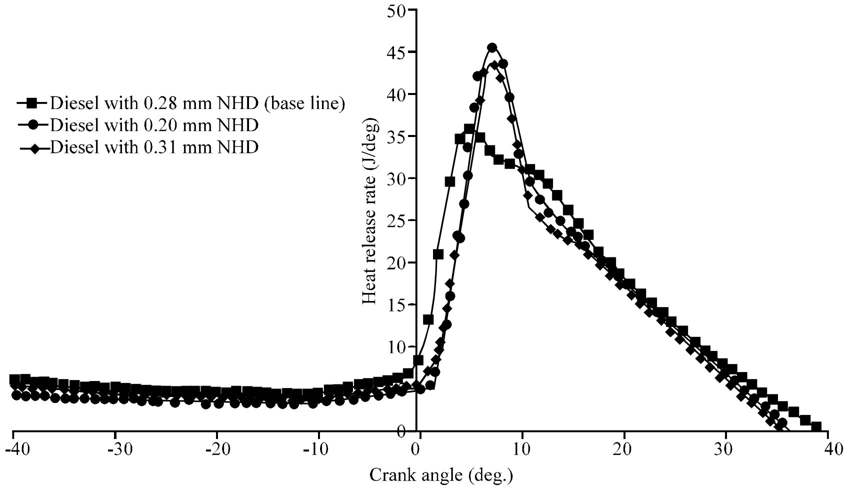

Fig. 7: Heat release rate vs. crank angle at full load

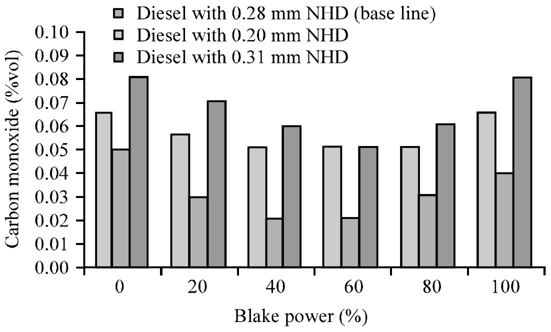

Fig. 8: Carbon monoxide vs. brake power

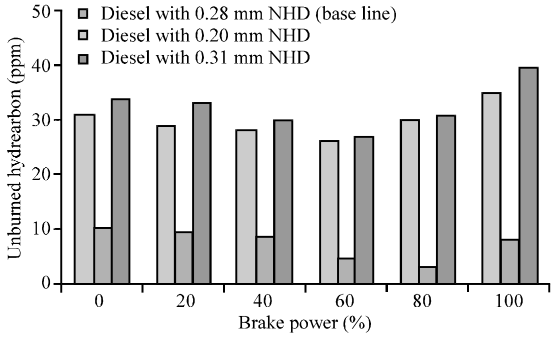

Fig. 9: Unburnt hydrocarbon vs. brake power

quenching of reaction due to the lower temperature in the combustion chamber, poor atomization and incomplete fuel evaporation.

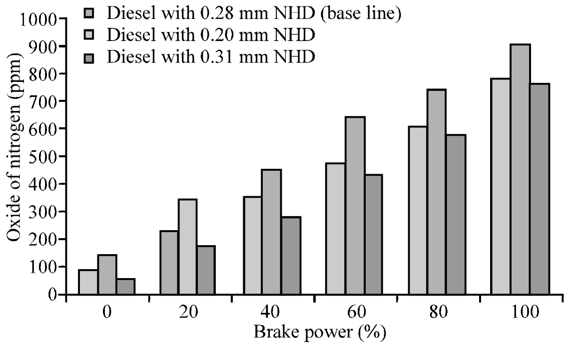

Fig. 10: Oxides of nitrogen vs. brake power

Oxides of nitrogen: Thedifference of oxides of nitrogen with respect to BP with 3 holes with each nozzle of different orifice NHD fueled with diesel is illustrated in Fig. 10. The development of the NO_X mainly depends on different factors such as oxygen content in fuels, good atomization of fuel, high cetane number fuel and increasing the fuel injection pressure. From the Fig. 10, it observed that, the NO_X emission for smaller orifice 0.20 mm NHD with diesel has deeply increased due in-cylinder gas temperature is increased. By reducing the smaller orifice, it has enhanced the high temperature in the combustion chamber due to good atomization. By increasing the NHD the NO_X is decreased due to the lower temperature in a combustion chamber, poor atomization and incomplete fuel evaporation.

Smoke opacity: The difference of Smoke opacity with respect to BP with 3 holes with each nozzle of different orifice NHD fuelled with diesel is illustrated in Fig. 11. From the results, it illustrates as the BP increases the smoke opacity is increased. It is examined that smoke opacity is vastly decreased for smaller orifice 0.20 mm NHD which was fuelled with diesel this was due to the good atomization and vaporization. The smoke opacity for

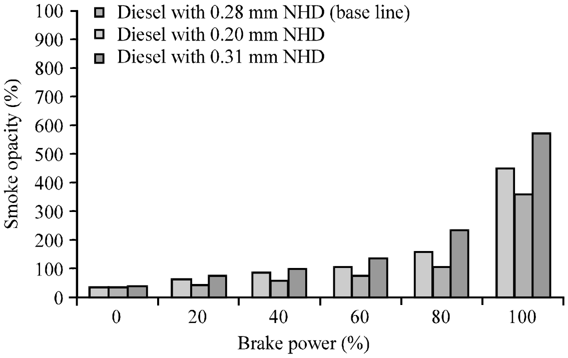

Fig. 11: Smoke opacity vs. brake power

larger orifice NHD with diesel is increased due to poor atomization and improper fixing in the combustion chamber.

CONCLUSION

The most important conclusions of experimental results are summarized as follows: the BTE and BSFC are improved with smaller orifice NHD. The HC, CO and smoke opacity exhaust emission are diminished and the NO_X is increased with smaller orifice NHD. The maximum peak pressure and MGT was seen to be increased for smaller orifice 0.20 mm NHD with conventional fuel. Smaller orifice NHD results, good atomization, increase the cone angle, good fuel mixing, etc. The HRR tells that the shorter ID generated for smaller orifice NHD, it means that SOC is earlier so less amount of fuel is mixed with air at the time of ignition. This results by decreasing the premixed combustion with reduced orifice NHD. The smaller orifice NHD produces smaller droplets particles which are evaporating and mixing faster than bigger orifice NHD.

From these conclusions, it can be concluded that the engine can be successfully run with the smaller orifice NHD which results in the better performance, combustion, and emission than the baseline diesel.

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