A Survey Paper on Effect of Nozzle Hole Geometry on Di Diesel Engine Emission

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Abstract---By optimizing spray characteristics we can minimize raw emissions from the diesel engine which are mainly NOx and PM.As engine manufacturers are under increasing regulatory pressure to reduce NOx and particulate emissions by emission governing agencies, there is need to study effect of spray characteristics. Spray characteristics such as spray angle, spray pattern, atomization, fuel droplet size and distribution, spray tip penetration and nozzle type and nozzle geometry have significant effects on Diesel engine performance parameters and emissions. Turbulent characteristics of air fuel mixing are affected by the shape and condition of the nozzle inlet that is nozzle geometry. In this paper the effects of nozzle whole geometriesare discussed in brief.

Keywords: Spray characteristics, Nozzle hole geometry, NOx, PM

I. INTRODUCTION

The key features of the direct injection (DI) diesel engine are its uniform air-fuel mixture and its combustion. Air and Fuel mixing greatly affects the engine emissions as air-fuel mixing process controls combustion nature. This mixing depends upon fuel jet nature which proportional to injection pressure and geometry of nozzle orifice. Nozzle configuration leads to fuel atomization. Various spray characteristics such as spray angle, spray tip penetration, spray pattern, droplet size, droplet distribution, initial spray break up and nozzle geometries affects fuel-air mixture formation which affects cylinder flow. It depends upon the fuel injection system which again affects liquid spray break up of fuel jet hence has effect on combustion and pollutant formation.

NOx and PM are combined effect of injection pressure and timing which depend upon various parameters like nozzle hole geometry, EGR rate, swirl formation and it's intensity, piston bowl design and combustion chamber design. We know that NOx and PM are inversely proportional to each otherso PM-NOx trade off study is important. Here effect of different nozzle hole geometries on engine emission is reviewed.

II. EFFECT OF DIFFERENT NOZZLE HOLE GEOMETRIES

A. *Elliptical Nozzle Holes[1]:*

Elliptic nozzle holes have sharp inlets and the potential to increase air entrainment into the spray, which could lead to decreased emissions from diesel combustion when compared to the circular nozzle holes. At low as well as high loads for elliptical nozzle holegeometry has low NOx and high smoke values than circular nozzle hole orifice.

According to experimental study [1] emission test results for horizontal elliptical and vertical elliptical nozzle hole geometry compared with reference circular nozzle hole geometry. For the low load tests, the engine had higher BSNOx emissions with the reference nozzle than with the elliptical nozzles only in the case of low speed. At low loads the differences were small and the curves overlap as shown in figure 1. For the high loads, the reference nozzle showed higher BSNOx values than the elliptical nozzles. Differences between the V-elliptical and the reference were slightly smaller than between the H-elliptical and the reference at high loads. At later timings the V-elliptical nozzle showed similar BSNOx emissions as the reference nozzle. The smoke emissions of the H-elliptical and the V-elliptical nozzle showed higher values than the reference nozzle, with the H-elliptical nozzle having the highest values, for all engine operating points. One explanation for the higher smoke values for the Elliptical nozzle could be the difference in umbrella angle. Five of the nozzle holes have fewer angles than the sixth. There is a study on the spray cone angle from non-circular holes where the minor axis is developed a larger cone angle than the major axis. There is a risk that the spray from the sixth nozzle hole might touch the cylinder head. This might explain the higher smoke levels for the H-elliptical nozzle. The smoke-BSNOx trade-offs are similar for all nozzles at high loads as shown in Figure 2. At lowspeed, the H-elliptical had slightly worse performance than the other two nozzles. At low loads the reference nozzle was better for the tested fuel injection timings.

The result shows that, the elliptical nozzles are characterized by slightly longer ignition delays, lower maximum rates of heat release and longer combustion durations. Also the changes in fuel injection and calculated rates of heat release are small enough not to cause increased fuel consumption. And the smoke-BSNOx emission trade-off is only slightly affected by the nozzle shape

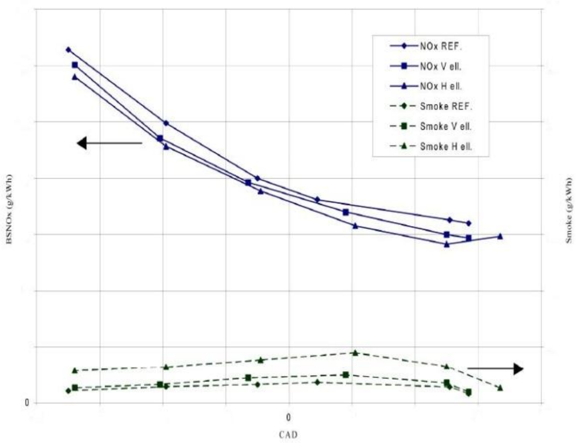

Fig. 1: BSNOx and Smoke vs. Crank Angle Degree

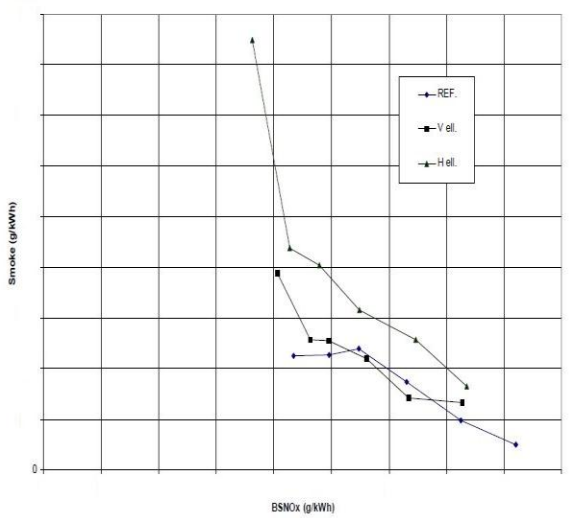

Fig. 2: Smoke vs. BSNOx

B. *Divergent Nozzle Hole Geometry[2]:*

Because of divergent nozzle hole geometry exacerbation of fuel-air mixing occurs, meaning deterioration of fuel-air mixing.This results in decrease in air entrainment rate causes decrease of peak cylinder pressure which leads to decrease in NOx and slight increase in soot. Figure 3 shows the simple construction of nozzle geometries.

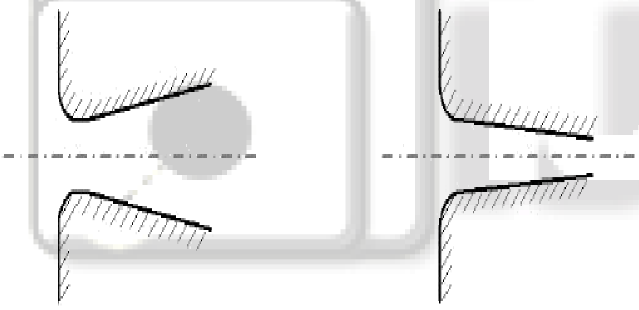

Fig. 3: Divergent and Convergent nozzle geometry

Calculated and measured [2] soot and NO tailpipe values at all operating modes examined herein are compared for the standard nozzle. A good agreement between experimentally obtained and predicted soot and NO values is observed at both low and high engine load. The effect of nozzle hole geometry on measured tailpipe soot and NO emissions is given in Figs 4. Results are given at all operating conditions examined herein. The higher values of measured soot emissions were observed for the divergent nozzle for all cases considered. At mode A50, the lower soot values were observed for the convergent nozzle. However, measured soot values for convergent and standard nozzle were similar. On the other hand, the divergent nozzle indicated the lower NO values compared to the other two nozzles at all operating conditions. It must be noted that the differences observed between the divergent and the two other nozzle types were more evident in the case of soot emissions. Results revealing the effect of nozzle hole conical shape on soot and NO emissions are in accordance with data already published in the literature [2].

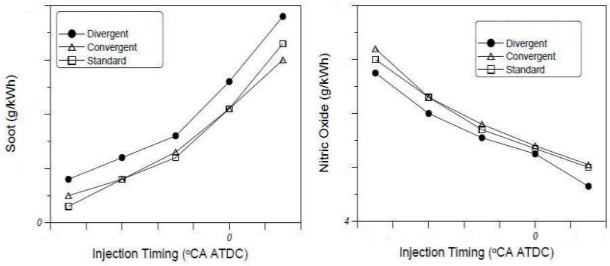

Fig. 4: Effect of nozzle hole geometries on Soot and NOx

The nozzle with divergently shaped orifices also has lower fuel consumption despite a less favourable injection rate and early burnt fraction. The nitrogen production is slightly less than the reduced orifice nozzle but much less than the circular nozzle. This contradiction of lower nitrogen oxides at the same time as the fuel consumption is lower may indicate that the heat losses are less with the nozzle with negative conisity.

C. *Valve covered orifice and minisac orifice nozzle hole geometries [3]:*

Figure 4 shows the cross-sectional view of Valve covered orifice and mini sac nozzle holes. In order to limit number of engine operating parameters here comparison between VCO and mini sac orifice type nozzles is made by keeping SOI timing, EGR percentage and injection pressure as constant.

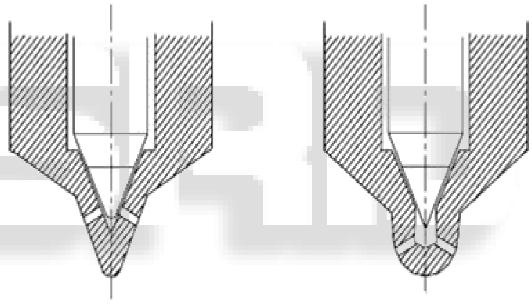

Fig. 5: VCO and MINI SAC nozzle hole geometry

At zero EGR, an increase in injection pressure resulted in an increase in NOx. In the earlier study [3], it was found that for VCO nozzle the peak of the apparent rate of heat release as well as the premixed combustion fraction dropped when the injection pressure increased. NOx dropped continuously at a decreasing rate as the EGR ratio increased. Here the reduction in the oxygen concentration at the high EGR ratios is the principal controlling parameter in NOx formation. Figures shows the NOx variation with respect to injection pressure and EGR percentage for the mini sac and VCO nozzle hole geometries. From graphs we can observe that NOx is on higher side for VCO nozzle compared to min sac nozzle.

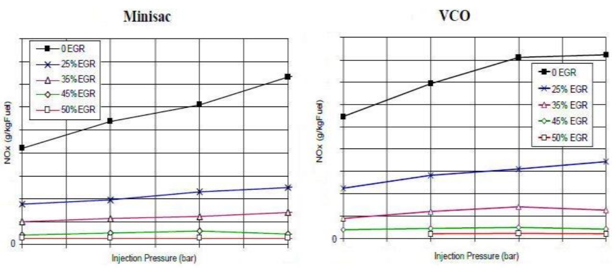

Fig. 6: Effect of mini sac and VCO nozzles w.r.t. injection pressure and EGR ratio

The larger nozzle holes produced less HC's and CO emissions where the HC's increased with EGR up to a point after which and further increase would produce a drop in HC's. Increase in the nozzle hole diameter decreases the HC emissions at all the cases.

D. *Rounded and Sharp Edged Nozzles [7]:*

We know that with increasing injection pressure and decreasing nozzle hole diameter better atomization of fuel spray occurs with better fuel and air mixing. This leads to external spray penetration, air entrainment and wall impingement causes decrease in particulates with slight increase in NOx.Sharp edged inlet nozzles have smaller droplet sizes, longer spray tip penetration and narrower spray cone angle when compared with rounded edged nozzle for the same injection velocity.

Figure 7 shows particulate vs. NOx trade-off curves comparing the round and sharp nozzles withsimilar spray angles. Here sharp nozzles have lower NOx than round edged nozzles as Rounded-edged nozzles increase the rate ofrise of the rate-of-injection profile, similar to raisingthe injection pressure, resulting in increased NOx emissions than sharp edged nozzles [7]

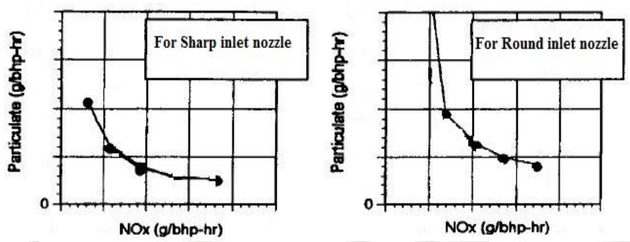

Fig. 7: Particulate vs. NOx trade off curves for sharp and round inlet nozzles at same spray angle

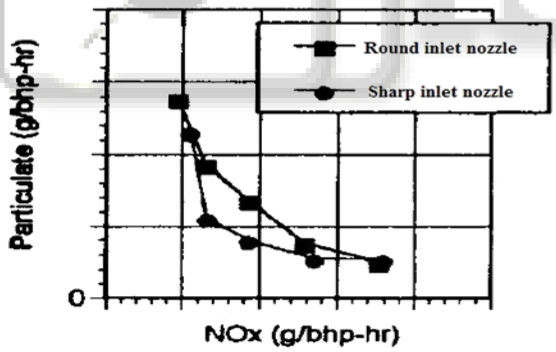

Fig.8: Particulate vs. NOx trade off curves for sharp and round inlet nozzles at same injection pressure and spray angle

Figure 8 shows particulate vs. NOx trade-off curves comparing the round and sharp nozzles withsimilar injection pressures instead of similar rates ofinjection. Here round nozzles have shorter injection duration than short nozzles due to theirhigher discharge coefficients hence sharp nozzleshave lower particulate emissions [7].

III. CONCLUSION

Injector nozzle hole geometry parameters are very important for the improvement of engine performance characteristics and reduction of diesel exhaust emissions. Through the emission analysis, we conclude that high injection pressures produce less soot emission but more NOx emission. High EGR results in less NOx but more soot emission. This confirms nature of trade-off between NOx and PM. In order to meet the emission standards, trade-off points should move closer to origin.

Many studies and experiments showed a decrease of soot and an increase of NOx emissions with the decrease of nozzle orifice diameter because as the orifice diameter decreases, the fuel flow decreases rapidly and the amount of air entrained into the fuel spray increases strongly. Earlier studies described also the role of inlet nozzle hole on fuel flow characteristics, jet penetration, spray cone angle and exhaust emissions.

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