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EFFECT OF MICRO-HOLE NOZZLE IN THE PARTICULATE MATTER EMISSION FROM DI DIESEL ENGINES.

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Abstract. *In this work the use of micro-hole Diesel injectors was investigated as a strategy to reduce de particulate matter. This study examined the use of injector tip with 18 micro holes of 0.13 mm diameter in comparison with a conventional EURO III (CONAMA P5) injector with 6 holes of 0.226 mm diameter. The micro holes were grouped in 6 groups of 3 holes. The alignment angle between the three orifices was also varied from 0 degrees (parallels orifices) to 12 degrees. The objective of this angle is to avoid the coalescence with the droplets from multiple orifice nozzle sprays. These studies were conduced in a research single-cylinder Diesel engine with 1.991 liter displacement, derived from an in-line six-cylinder 12 liters EURO III engine with electronic injection control. The particulate matter emission was evaluated in full and partial loads maintaining, for comparison, the nitrogen oxide (NO_X) emission in the constant limit value of 5,0 g/kWh for all measurements. With the constant NO_X emission, and approximately 1% penalty in fuel specific consumption, reductions in particulate matter were clearly observed. The limit of 6 degrees for the holes alignment angle must not be exceeding.*

Keywords. *Particulate Matter, Micro-Hole Nozzle, Diesel Engine, Particulate Emission, Fuel Injection.*

1. Introduction

Diesel engines are extensively used in automotive systems due to their significant fuel consumption advantage and high reliability. In recent years, the environmental consciousness of the industrialized nations has increased, and as a result, emissions control has become more important. Because oxides of nitrogen and the particulate matter can not be easily reduced simultaneously without degrading the engine performance, they are the most critical pollutants. Some of the most significant improvements in Diesel engine emissions and efficiency in recent years have resulted from increases in injection pressure and reductions in injector tip orifices sizes. Rapid and well-controlled fuel-air mixing must be achieved to reduce the emissions. The injection pressure and the size of the injection orifice determine the mixing times in a diesel spray.

In this research our aim is, according to Iida *et al.* (1997), to combine a micro-hole nozzle with high pressure fuel injection to make the equivalence ratio distribution more uniformly lean over the whole combustion chamber, which should reduce soot by advancing fuel oxidation, while not losing de NO_X reduction effects of high pressure injection. In a previous study of Argachoy and Pimenta (2005), was made a comparison between two Diesel injectors showing that the injector with smaller orifices diameter produced droplets with smaller Sauter Mean Diameter (D_{32}) and consequently, produced smaller values of particulate matter in an EURO III (CONAMA 5) engine at emission test bench. In the present work the use of micro-hole Diesel injectors was investigate, according Dodge *et al.* (2002), as a strategy to reduce the particulate matter as a possible base for a combustion system using EGR (Exhaust Gas Recirculation) but with low particulate matter.

2. The Micro-Hole Nozzles

To evaluate the improvement in the mixture formation in a comparative manner, it was prepared a set of injection nozzles drilled in particular manner: the conventional six injection orifices of the reference injection nozzle, with diameter of 0.226 mm, were replaced through 18 small holes of 0.130 mm diameter. In the Fig. (1) is shown a picture of the micro-hole nozzle detail. The micro holes were grouped in six groups of three holes in the same positions of each hole of the original injector. In this research work, the alignment angle between the three orifices (θ) was also modified from 0 degrees (parallels orifices) to 12 degrees. The objective of this angle is to avoid the coalescence with the droplets from multiple orifice nozzle sprays. Each sample has different alignment among the holes of each group of three orifices. This is a different feature in order to complement the work of Iida *et al.* (1997).

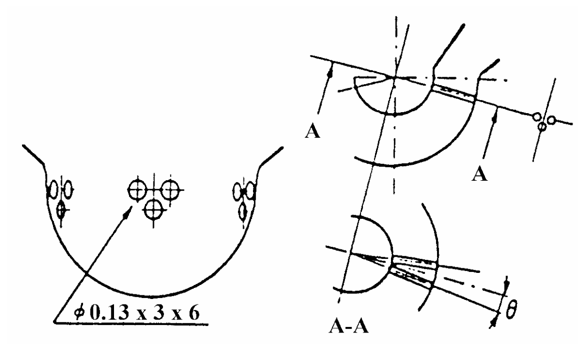

Figure 1. Enlarged detail of nozzle cone with micro-holes and angles representation.

Considering the different orientations of each jet related to the others, represented by the alignment angle, it is possible to change the shape of spray. While with the widest alignment angle (θ = 12°) we have a virtually independent spray generated by each orifice, with a narrower alignment angle takes place an influence in the shape of the resulting spray. The outline of a spray generated from three orifices with narrower alignment angle corresponds to a bigger volume; witch probably could generate a higher air penetration.

The flow through the injector samples could be characterized by a standard test, with the prescribed calibrating oil defined by ISO standard 4113, in the fixed temperature of 40 °C. In the test, with a nozzle holder without the pressure pin and under a pressure drop of 100 bar, the delivered oil volume in cm^3 is measured in a glass gage for 30 seconds. This standard test gives a well know injection nozzle characteristic by the injection equipment and Diesel engine suppliers as hydraulic flow. In terms of units, this quantity is given in cm^3/30 seconds by 100 bar. In Tab. (1) could be seen the measured hydraulic flow of each micro-hole sample. The actual hydraulic flow values must be taken into account with the comparison of the alignment angle as well.

Table 1. Hydraulic flow of each injection nozzle sample

Alignment angle of the sample - 18 holes (degree)	**Hydraulic Flow (cm^3/30 seconds by 100 bar)**
0	733
3	699
6	724
9	772
12	758
Reference nozzle - 6 holes	**742**

3. Test Methodology

This study was conduced in a research single-cylinder Diesel engine with 1.991 liter displacement, derived from an in-line six-cylinder 12 liters EURO III engine with electronic injection management. This single-cylinder engine is a special feature used exclusively for research proposes, avoiding the influence of the other cylinders and reducing the instrumentation costs. The main specifications of the research engine employed in the experiments are given in Tab. (2). According to Kobori *et al.* (1996), to evaluate just the influence of the micro-hole nozzles with different alignment angles on particulate matter emission (PM), the quantity of fuel injected per injection pump stroke (V_E in mm^3) stayed constant for all the test conditions for each sample. Eq. (1) shows the basic expression to calculate V_E according Bosch Handbook (1996).

$$V_E = \frac{1000 \, . \, P_{eff} \, . \, b_e}{60 \, . \, \rho \, . \, n_p \, . \, z} \qquad (1)$$

Where P_{eff} is the net power in kW, b_e is specific fuel consumption in g/kW.h, ρ is the fuel density in kg/m^3, n_p is the injection pump speed in min^{-1} and z is the number of cylinders.

Besides, to evaluate comparatively the influence of the micro-hole nozzle on the specific fuel consumption, the NO_X specific emissions were staying in the constant value 5 g/kW.h (the limit of the CONAMA P5/EURO III legislation) by the injection timing electronic adjustment.

According to Kobori *et al.* (1996), a line filter with the mesh size of 5 µm was installed in the fuel supply system so as to prevent the micro-hole from choking.

For the analysis on the engine test bench were considered the most critical engine speed in terms of particulate matter and NO_X emissions, especially for the possible future necessity of an Exhaust Gas Recirculation (EGR) system. Firstly an engine emissions map was made to identify such point, and them an engine speed of 1420 min^{-1} was adopted for the micro-hole nozzle evaluations. The NO_X emissions were measured by the Heated Vacuum CLD (Chemiluminescence Detector) and the particulate matter was gravimetrically measured by the AVL mini-tunnel (Smart Sampler SPC 472).

Table 2. The engine specifications.

Engine model	**Mercedes-Benz**
Type	Diesel, direct injection, 4 stroke
Number of cylinders	1 (research engine)
Combustion chamber	Quiescent
Combustion chamber diameter	90 mm
Number of intake valves	2
Number of exhaust valves	2
Injection system	Electronic, Unit Pump (UPS)
Total Displacement	1.991 dm^3
Bore/Stroke	130 mm / 150 mm
Connecting rod length	254 mm
Number of nozzle orifices (standard version)	6
Nozzle orifices diameter	0.226 mm
Hydraulic flow	742 cm^3/30 s (100 bar)
Aspect ratio of the orifices	3.54 (length/diameter of orifices)
Temperature of the fuel injected	308 K
Spray angle	154°
Compression ratio	17.25

4. Experimental Results

Figure (2) shows the results of the particulate matter evaluations of the micro-hole nozzles in comparison with the reference nozzle in four conditions of load (25%, 50%, 75% and full load). As mentioned before, the quantity of fuel injected per injection pump stroke (V_E in mm^3) stayed constant for all the test conditions. The particulate matter values of the examined micro-hole nozzle with different alignment angles are clearly under the values of the basis nozzle. Only in the 75% load has the reference nozzle (without micro-holes) a little small value of particulate matter for the same fuel injected per injection pump stroke. The diagram of Fig. (2) shows that the optimum condition for particulate matter, for almost all load conditions, is reach with alignment angle (θ) of 3 degrees, however, is important to consider the influence of the low hydraulic flow of this nozzle sample.

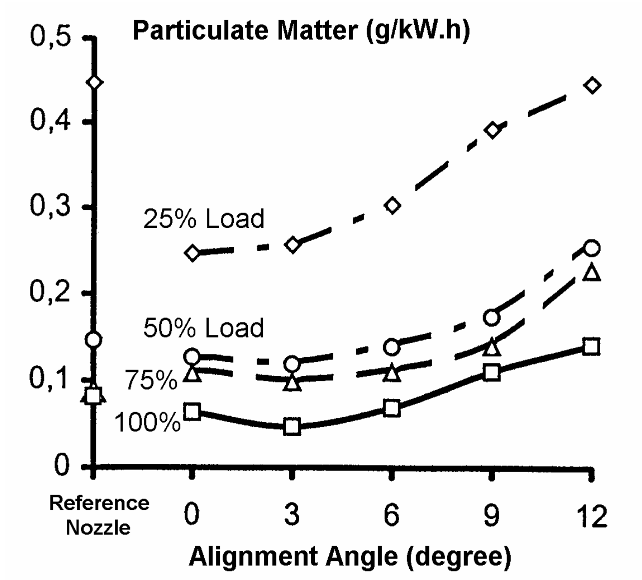

Figure 2. Effect of micro-holes alignment angle on the particulate matter profiles.

Figure (3) shows the results of the specific fuel consumption evaluations of the micro-hole nozzles in comparison with the reference nozzle in four conditions of load (25%, 50%, 75% and full load). As mentioned before, the NO_X specific emissions stayed in the constant value of 5 g/kW.h by the injection timing electronic adjustment, for all the test conditions. The fuel consumption behavior shows that the micro-hole nozzles did not have a strong influence on it. Until 6 degrees of alignment angles the consumption is, in average, approximately 1% higher than the reference nozzle. Specifically the specific fuel consumption values for the micro-hole nozzle sample with $\theta = 3$ degrees are higher, because the necessity of using a later begin of injection timing due the lower hydraulic flow value of this sample.

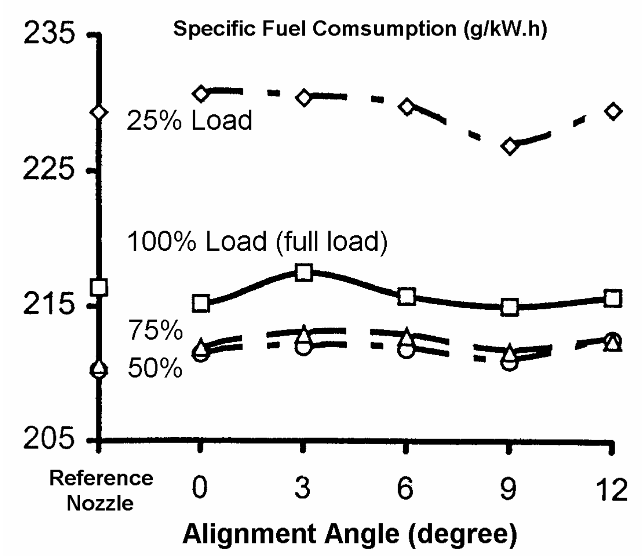

Figure 3. Effect of micro-holes alignment angle on the specific fuel consumption.

5. Conclusions

A series of engine measurements with micro-hole nozzles with commercially produced diesel injection system have been performed. The major focus of this preliminary work was to demonstrate that there is an advantage in the use of micro-holes to the particulate matter emissions reduction. This objective was satisfied without significant increase in the specific fuel consumption.

The results show that the most favorable alignment angle for the compromise between particulate matter and fuel consumption stay in the range from 0 degrees until 3 degrees, when the nitric oxide emission is held in 5.0 g/kWh. From 6 degrees of alignment angle, the particulate matter values become clearly worse.

6. Future Developments

Next step in the investigation will be to perform a fuel spray analysis of the micro-hole nozzles using an optical-access chamber and a high-speed digital camera from the company named NAC, recently bought by the FEI Mechanical Engineering Department. The micro-hole nozzles could be used as a possible base for low particulate matter EGR (Exhaust Gas Recirculation) combustion in order to achieve the future emissions-limits demands. According Dodge *et al.* (2002) will be interesting to make an analysis of the total particulate matter emissions in order to know the dry soot portion and the soluble organic fraction of the particulate matter. After-treatment for soluble organic fraction of PM may be much easier to deal with using an oxidation catalyst, as opposed to a Diesel Particulate Filter (DPF) required for dry soot.

7. Acknowledgment

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8. References

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