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COMPARATIVE ANALYSIS OF ATOMIZATION'S CHARACTERISTICS IN A NEW, USED AND RECONDITIONED DIESEL SPRAY NOZZLES OF COMMON RAIL SYSTEM

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Abstract. *This study involves the operation of the Common Rail Diesel Injection, atomization characteristics of fuel and reconditioning of diesel engine nozzles. The nozzles of the Common Rail system were repaired in order to give them optimum operation conditions. For it be confirmed, the volume of Diesel injected was measured as a function of injection pressure, injection angle, the cone angle and the velocity field of the jet fuel atomized into new nozzles (control), used and reconditioned. In the evaluation of the volume, it was used a circuit consisting of a high pressure pump, a source of pulses and a reservoir of fuel oil. For the geometric characteristics of the fuel spray was used a high speed filming, 4000 frames per second, applying shadowgraphy techniques for measuring these angles. The kinetic characteristics of the jet fuel were measured by particle image velocimetry (PIV). The experimental results allowed evaluating the types of changes in the nozzle after the reconditioning process. It was observed that the reconditioning process of nozzles does not modify the operation of the nozzle or diesel engine. There are no losses in the combustion of fuel and no change in performance, consumption of fuel, efficiency and emissions of the vehicle.*

Keywords: *atomization, Common Rail, Diesel, nozzle, PIV, reconditioning.*

1. INTRODUCTION

With prolonged use the nozzles, in general, lose their initial properties. In the case of diesel engine nozzles these properties provide a standard spray and hence a good combustion. With the increased use the vehicle begins to fail due to a typical combustion deficient (excessive smoke expelled by the exhaust, reduction of its efficiency and increase of the fuel consumption), due to wear of the seat and needle nozzle, clogging the outlets of the fuel and/or carbonization of the nozzle tip. Such failures are usually a result of poor atomization of the diesel oil, or when one or more of the following spraying parameters are compromised: volume of injected fuel, the quantity and drop size, velocity field of the jet, the jet penetration and cone angle of atomized jet fuel (HIROYASU, H and ARAI, M., 1990).

In the Brazilian market it is possible to find reconditioned nozzles which underwent a process of recovery of its properties that were lost due to use of contaminated Diesel oil and the long-term use. These properties are recovered in most of the time redoing the angle and seating of the needle of the nozzle, clearing outlets of the injection and trimming sealing surfaces of nozzles, stanching leaks due to mechanical wear. In the case of nozzles of the Common Rail system, in addition to the standard procedure in the recovery of nozzles, an assessment is also made in the volume of oil injected in certain regimes of injection pressure, since this system stands out for the separation of systems pressure generation and injection. Thus, each injector provides individually and accurately fuel to the respective engine cylinder. Many techniques of microscopic and macroscopic measurements of the characteristics of the atomization of fuels are used, with a variety of techniques, including optical, electrical and mechanical. The optical techniques are more common because they are not invasive. This is the case of methods such as PIV (particle image velocimetry), LDA (Laser Doppler Anemometry) and PDA (Phase Doppler Anemometry). Such methods provide microscopy information, as the drop diameter and the velocity field. The geometrical or macroscopic characteristics of the atomization can be achieved with an experimental technique based on direct analysis of frames, obtained by photography or high speed filming. The quality of the results obtained in this way is dependent on method of analysis used.

Thus the main objective of this study is to measure the volume of fuel injected as a function of injection pressure, velocity field of spray a certain pressure and the global macroscopic characteristics (injection angle and cone angle) of the atomized Diesel jet into new nozzles (control), used and reconditioned of Common Rail injection system to compare them and get a better understanding of the structure of atomized fuel spray in reworked nozzles.

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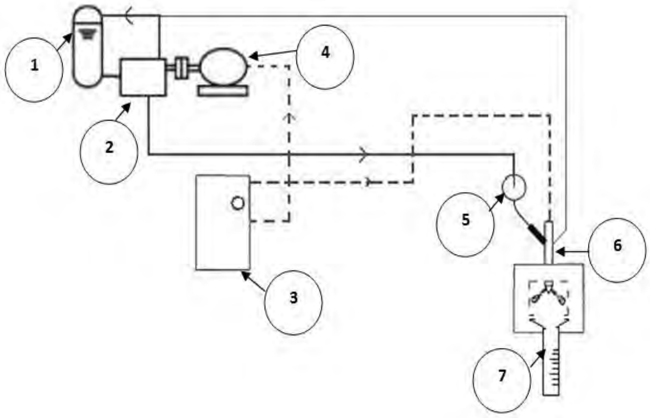
2. METODOLOGY

2.1 Volume of Diesel Injected vs. Presseure Injection

The Fig. 1 shows a schematic of the experimental setup used in this study to measure the amount of fuel injected as a function of injection pressure and is composed of three main parts: a supply (test fluid), generation of pulses and atomizer. The fluid supply line consists of three components, including a liquid reservoir with a capacity of 7.0l, an electric motor driving the pump, a piston pump CP1 (Bosch 0 445 010 002) high-pressure with pressure regulator 0-1650 bar. The generation of the pulses are composed of a source which is controlled pressure pump CP1 through its pressure regulating valve and where also controls the pulse rate and time of opening the nozzle. The line of the atomizer consists of three elements, an accumulator, a nozzle of the Common Rail system (Bosch 0445110190) and a cylinder (0-150cm³ ± 1.0) to record the volume of fluid that came out of the nozzle.



1-fuel tank, 4-electric motor 7-cylinder
2-high pressure pump CP1, 5-accumulator;
3-source generating pulses; 6 - nozzle;

Figure 1: Schematic of experimental setup

For testing the injected volume were chosen three nozzles Fig. 2 of the same model: a new (to control), a used and refurbished nozzle. The characteristics and conditions which these nozzles were tested are presented in Tab. 1.

Figure 2: Injector Bosch 0445110190

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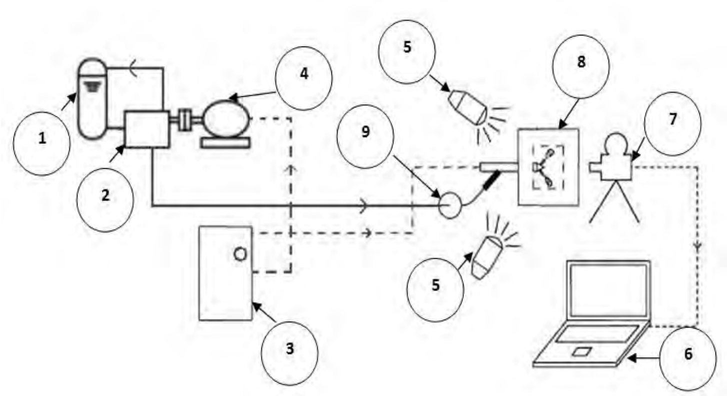
Table 1: Experimental conditions

Injector	CRI Bosch 0445 110 190
Nozzle	Bosch DSLA 154 P.1320
No. of nozzle holes	6 holes
Diameter of the injector holes	160-170μm
Injection angle	77degrees
Number of pulses	500
Pulse time used	1,0ms
Pulse Frequency	25,0Hz
Simulacrum oil	ISO 4113
Oil temperature simulacrum	46-50°C
Test pressure	300 to 1200bar

2.2 Vizualization of Fuel spray

To measure the injection angle of nozzles is necessary to obtain images at the exact moment of injection, with the oil jet fully developed and it was used the same equipment used in the evaluation of the volume, but with two amendments, one was the change in position nozzle and adding a high speed camera (CCD, f = 105mm, shooting 4kHz rate, resolution (400x296 pixels) Fig. 3.



1-fuel tank, 5 - light source; 9-accumulator;
2-high pressure pump CP1, 6 - microcomputer;
3-source generating pulses; 7-high speed camera;
4-electric motor; 8-nozzle;

Figure 3: Schematic of experimental setup.2

Using the apparatus shown diagrammatically in Fig. 3, the images of the jet were separated and processed for analysis. Filming was used in the technique of shadowgraphy, i.e. contrary to the lighting CCD images thus generated both to assess the injection angle Fig. 4 and for evaluating the cone angle of the fuel jet Fig. 5.
In the treatment of the images were used the following steps: First the images were converted to grayscale and then the spray was normalized after the subtraction. Showing only the atomized spray, thus helping to analysis of angles.

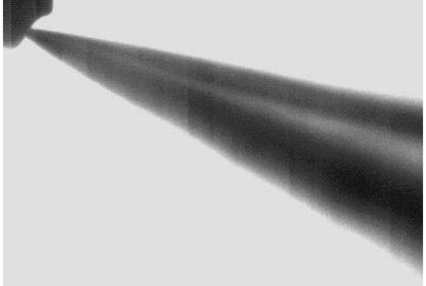


Figure 4: Jet fuel to the normal CCD

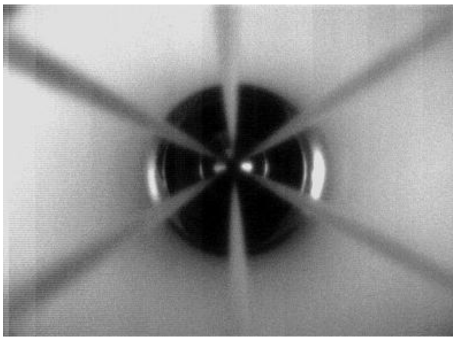


Figure 5: Jet fuel to the front CCD.

2.3 Injection Angles

Comparing macroscopic characteristics of spray, because a search of change values can cause much damage to complete combustion and to the vehicle engine. With the images treated fuel jet this angle can be measured as shown in Fig. 6. Using as the images Fig. 4, and treating them with the aid of a CAD software, then the Solid Works, the angles were measured and stored for comparison between the nozzles.

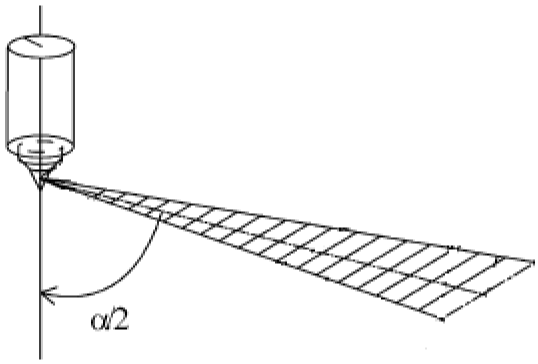


Figure 6: Injection angle

In this configuration can be evaluated through the values of the angles of injection, if the holes in the fuel injectors reconditioned and used are in some kind of anomaly, leading to an exaggerated increase or decrease of this angle or even a scattering of the jet itself.

2.4 Cone Angle of Atomized Jet

The cone angle spray (θ) is the angle which is formed by the outer limit of the cone of atomized fuel, taken from the outlet nozzle, to somewhere on the axis of atomization. This location can be defined in several ways depending on the macroscopic structure of the cone being examined (BAE, C.H, YU, J, KANG, J, KONG and J, LEE, K.O, 2002), Fig. 7 shows the angle of macroscopic dispersion defined (HIROYASU, H and ARAI, M., 1990).

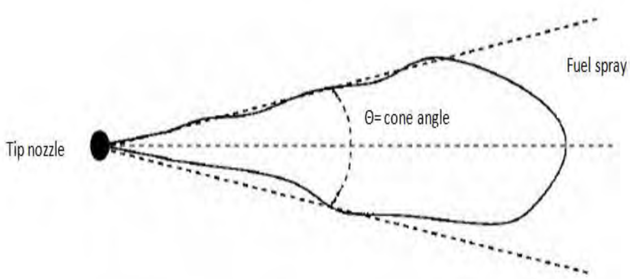


Figure 7: Cone angle of atomized jet.

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Other parameters that have an effect on the angle of spray cone are the hole length and hole diameter of the nozzle. These effects have been reported by several authors such as (LAOONUAL, Y., YULE, A.J and WALMSLEY, S.J., 200), (CHAVES, H., KNAPP, M and KUBITZEK, A., 1995) and (SCHMIDT, D.P., RUTLAND, C.J and CORRADINI, M.L., 1999). Thus these parameters are relevant to an evaluation of the spray cone angle, and may compare the angles between different nozzles or angles between same nozzle, determining whether these holes are in compliance or not.
The procedure for measuring the cone angle was the same procedure for measuring the angle of injection, as in this case one has to view all jets of the nozzles they were listed in Fig. 8.

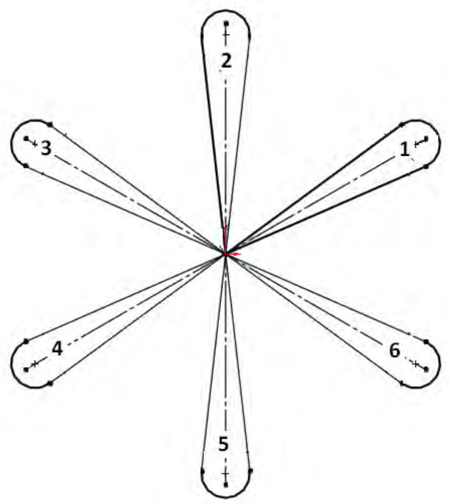

Figure 8: Cone angles listed

2.5 Velocity field of Atomized Jet

We used the technique of PIV (particle image velocimetry) for measuring the speed of fuel jet, testing each nozzle at a time (new, refurbished and used), respectively, at a pressure of 300 bar, as this pressure was the only one in which the level of speed is compatible with the software and with a delay of 1.3 ms from the start of injection and the aperture of the camera, a spray obtained with fully developed can be seen in Fig9.

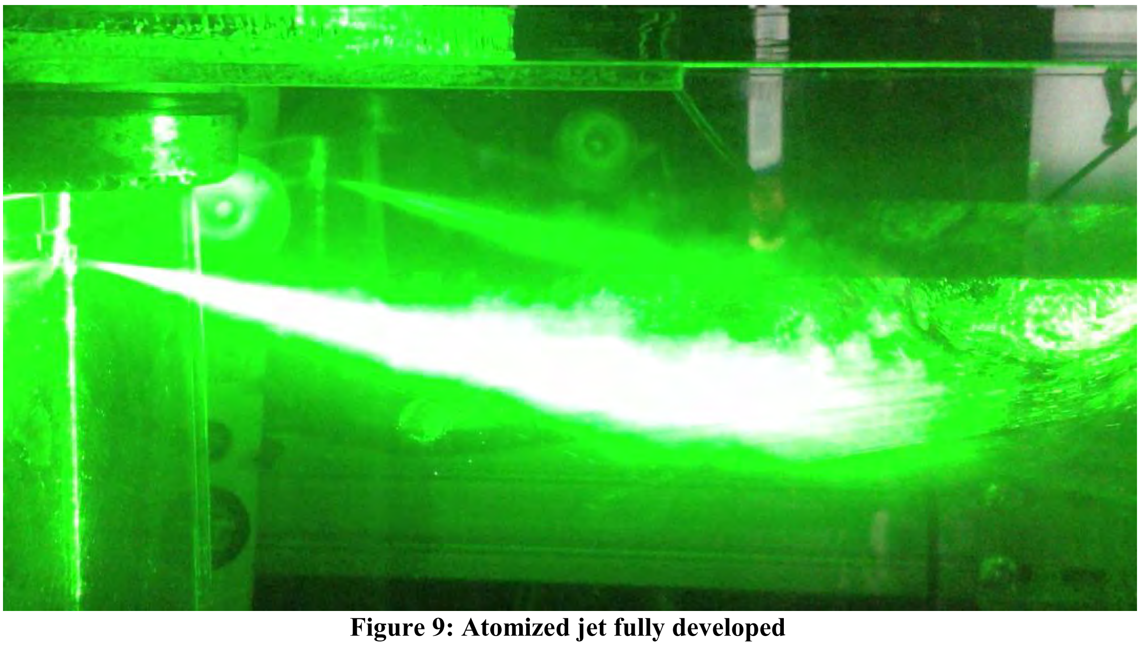

Figure 9: Atomized jet fully developed

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From Figure 9 the software generates a pair of spaced images with a set Δt, Shown in Figure 10 and thus the velocity field of the jet fuel is created.

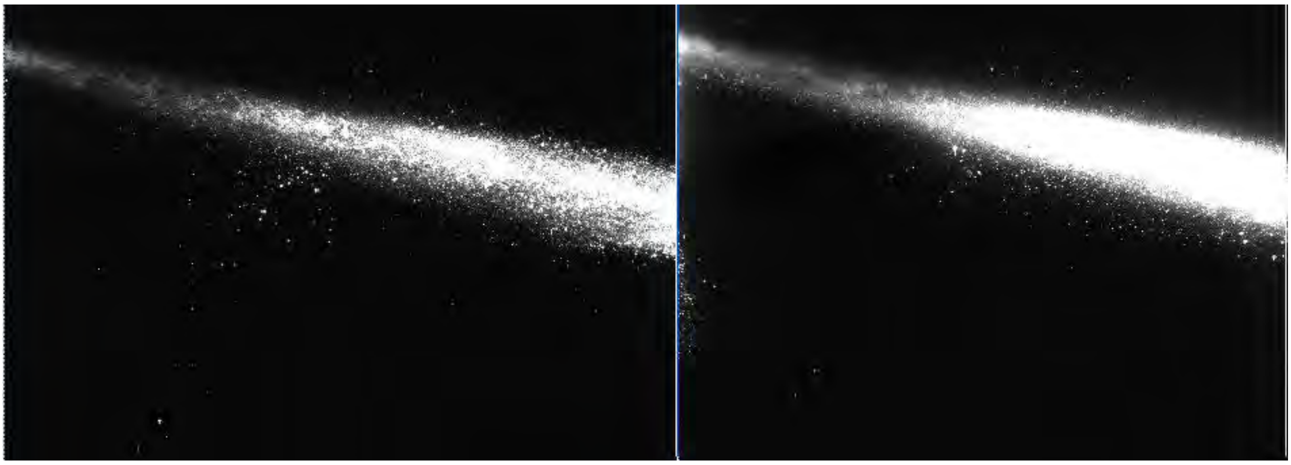

Figure 10: Pair of images to analyze the velocity field

3. RESULTS AND DICUSSIONS

3.1 Volume of Diesel Injected vs. Presseure Injection

As a result, we obtained values of the volumes of the injection of nozzle control (new nozzle), rectified nozzle and used nozzle respectively in the graph shown Fig. 11.

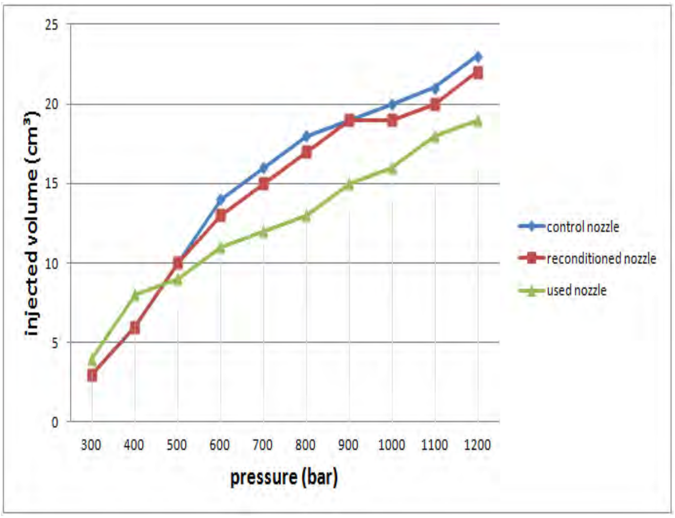

Figure 11: Injection volume of nozzles

It is noted a decrease in the volume injected, as expected, the nozzle used, as this decrease is due to the fact that a possible blockage or obstruction of one or all injection holes due to contamination of the vehicle Diesel, the carbon deposit on the tip of the nozzle or the modification of the regulation, caused by mechanical wear, seen that the nozzle has been working on the vehicle before.
By comparing the volumes between the nozzles, recovered and control (new) note that a difference in the order of 1.0cm ³ in the values, this is because when you retrieve a nozzle is used as a reference new nozzles or table with values of measurement provided by the manufacturer.

3.2 Vizualization of Fuel spray

Shown below in the Fig. 12 and Fig.13 the sequence of frames in the image processing to show only the jet of atomized fuel.

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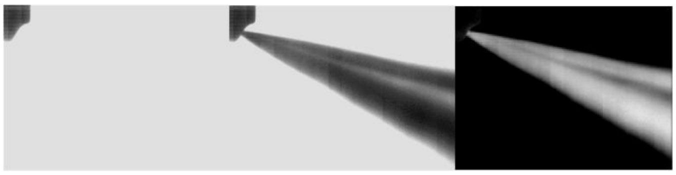

Figure 12: Frames of atomized jet normal to the CCD

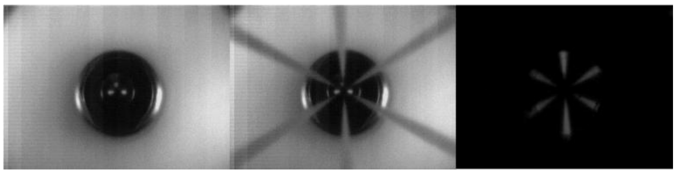

Figure 13: Frames of atomized jet frontal to the CCD

Showing the jets, after the processing of images, it becomes easier to obtain the angle of injection and the cone angle and generate data for comparison however, in the nozzles used, it wasn't possible to identify the injection angle, due to an exaggerated scattering of fuel jets impairing the visualization of the jets as seen in the Fig. 14.

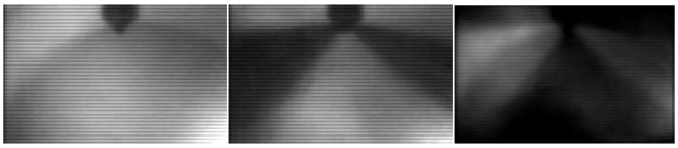

Figure 14: Used nozzle (injection angle)

3.3 Injection Angles

From the analysis of the frames there is a dispersion of oil to be injected by the used nozzle and shows as atomization, on a macroscopic scale, in this case is affected.

With the aid of graphs Fig. 15 and Fig 16, the injection angle values shown below.

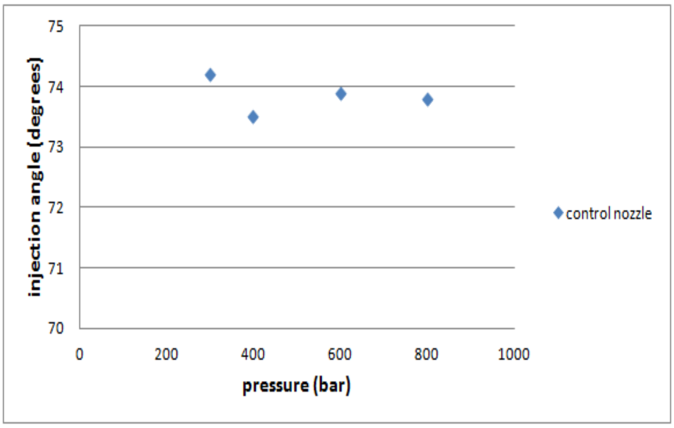

Figure 15: Injection angle x injection pressure (control nozzle)

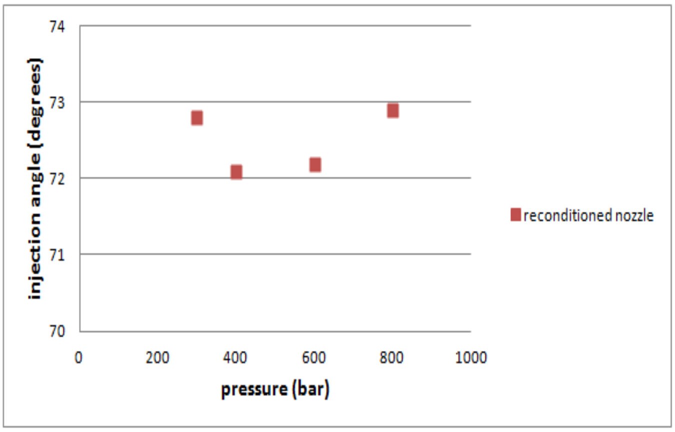

Figure 16: Injection angle x injection pressure (reconditioned nozzle)

Through the values of the angles shown in the graphs, it is noticed that the reconditioned nozzle approaches the control nozzle, it shows that the recovery process returns almost completely to the values of the injection angles, since the differences between these angles are of the order of 2.0degrees.

3.4 Cone Angle of Atomized Jet

The results in this case are also presented through the images Fig. 17 for a visual analysis of the jets and by the graphics Fig. 18, Fig 19 and Fig 20, for doing the comparison of the cone angle between the holes of the same nozzle and between the nozzle orifices, hole-hole and between nozzles. Since there is no obvious link between the cone angle and injection pressure (CRUA, C., 2002) this study was interesting, because it got more points for comparison. This optional section must be placed before the list of references.

Figure 17: Sprays of control, reconditioned and used nozzle, respectively

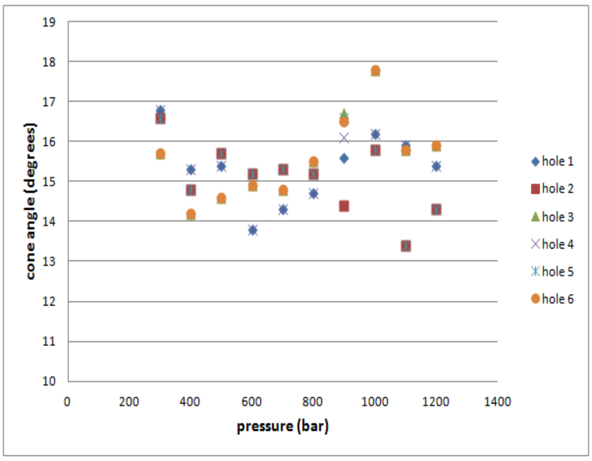

Figure 18: Cone angle (control nozzle)

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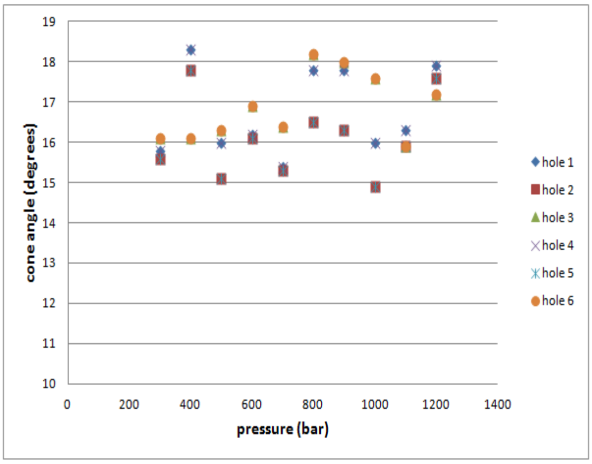

Figure 19: Cone angle (reconditioned nozzle)

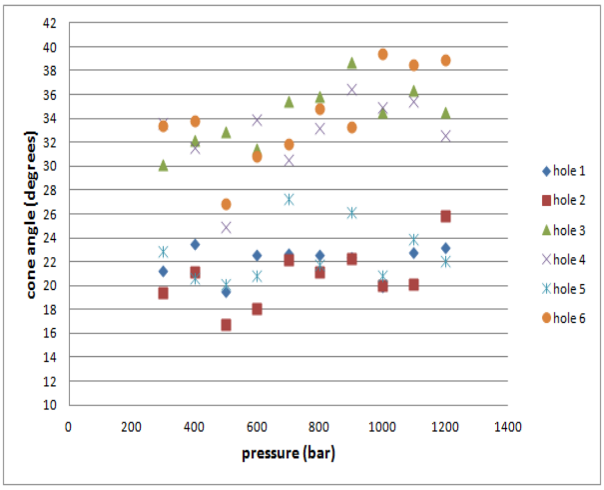

Figure 20: Cone angle (used nozzle)

3.5 Velocity field of Atomized Jet

Separating the pairs of images obtained with and making the PIV necessary correlations had as a result the velocity field of the jet of atomized fuel and its velocity profile, measured 1.5 cm from the exit nozzle which can be seen in figures 21, 22 and 23, representing the injectors new, refurbished and used, respectively.

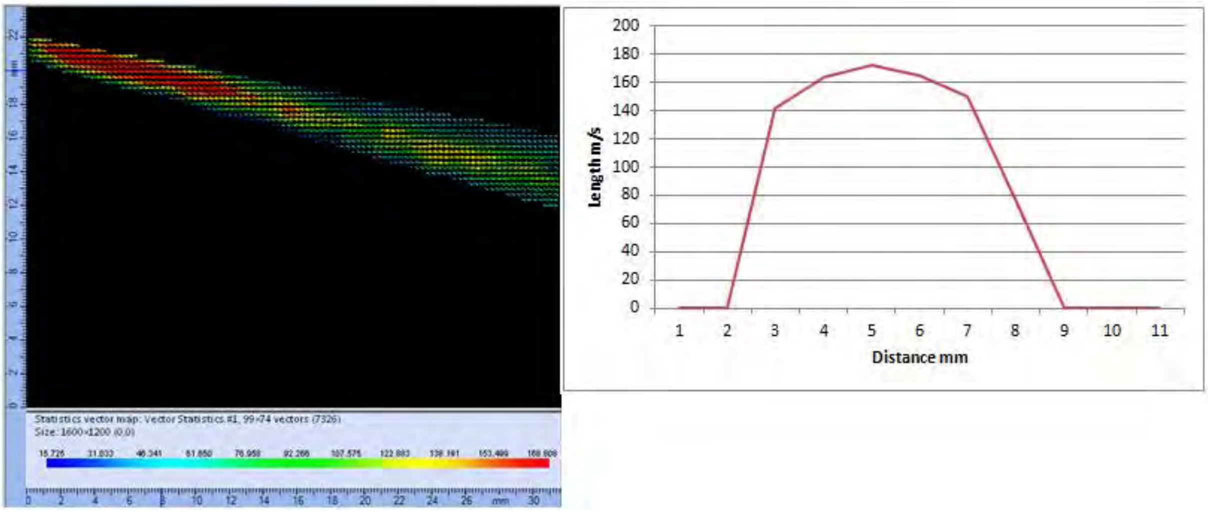

Figure 21: Velocity field and velocity profile of new nozzle injector

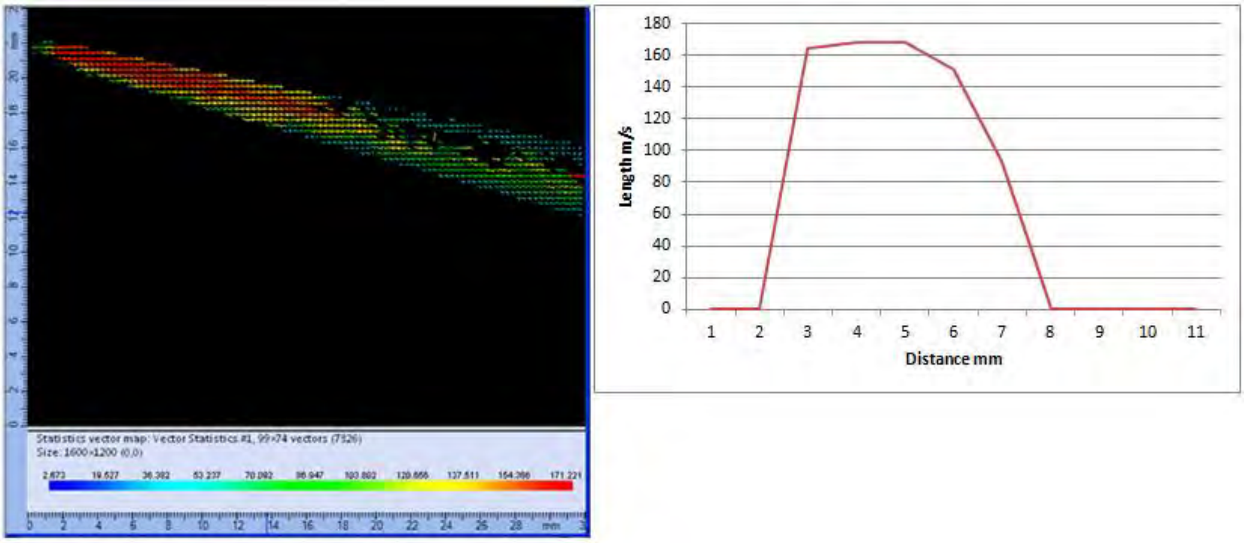

Figure 22: Velocity field and velocity profile of refurbished nozzle injector

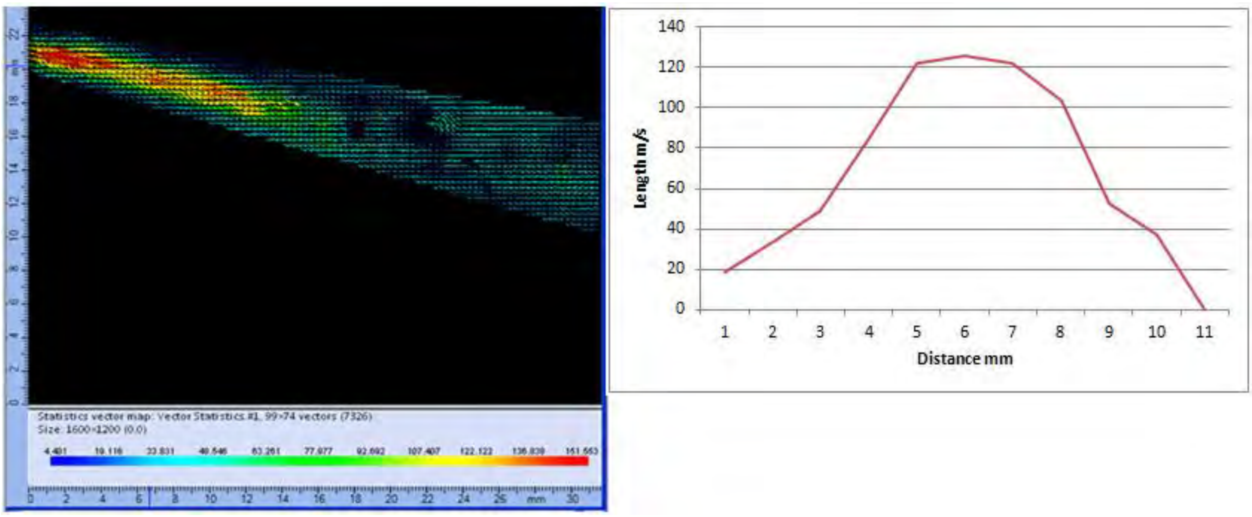

Figure 22: Velocity field and velocity profile of used nozzle injector

Note a similarity between the new refurbished nozzles, both the velocity field, the format and values of speeds, but the speed of the injector level used is lower than the other two, possibly caused by the considerable increase in the cone angle and the increase in droplet diameter of the atomized fuel.

4. CONCLUSION

Comparing the control nozzles and refurbished the test results injected volume as a function of injection pressure did not show much difference, because these values are different in a few tracks of pressures in order of 1.0 cm ^{3}, and some tracks are the same values. Thus, with regard to the quantity of fuel injected in an engine it is known that the nozzle recovered is practically equal to the new nozzle, i.e. does not contribute to a wrong operation of the vehicle motor and not to increase emissions. When comparing the same parameter between the control and used nozzles realizes that in some pressure ranges the volume of the injection, in nozzle used is larger than the new nozzle and other tracks is smaller, showing non-conformity in the injection pattern of these nozzle.

Under macroscopic (geometric) atomization of the diesel, says that when the oil spray is already fully developed there is little difference, both between the injection angle and the cone angles, comparing the control and remanufactured nozzle and this difference increases much to compare with the nozzle used.

Comparing the velocity field e profile, it was concluded that the characteristics of the spray nozzle formed by a refurbished is similar to that of a new (control) nozzle. In view of the need for the formation of the jet pattern to be formed, the nozzle used not fulfill this role, which necessitates its replacement in a vehicle.

Thus, from the results of this study, it was observed that the reconditioning process in nozzles is well run, it reproduces the atomization characteristics lost due to the use and at least in this aspect ensures that these nozzles may be another option for consumers.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] HIROYASU, H., ARAI, M., 1990. Structure of fuel spray in diesel engines. SAE Paper 900475

[2] BAE, C.H., YU, J., KANG, J., KONG, J., LEE, K.O., 2002. Effect of nozzle geometry on the common-rail diesel sprays. SAE Paper 2002-01-162

[3] LAOONUAL, Y., YULE, A.J., WALMSLEY, S.J., 2001. Internal fluid flow and spray visualization for a large scale valve covered orifice (VCO) Injector. ILASS Europe 2001, Zurich 2-6

[4] CHAVES, H., KNAPP, M., KUBITZEK, A., 1995. Experimental study of cavitation in the nozzle hole of diesel injectors using transparent nozzles. SAE Paper 950290

[5] SCHMIDT, D.P., RUTLAND, C.J., CORRADINI, M.L., 1999. Cavitation in two dimensional asymmetric nozzles. SAE Paper 1999-01-0518

[6] CRUA, C., 2002. Combustion processes in a diesel engine. Thesis PhD, University of Brighton, United Kingdom.