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STUDY OF AN INJECTOR ALCOHOL/N2-LIQUID THROUGH ANALYSIS OF SPRAY BY OPTICAL TECHNIQUES

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Abstract*. In the search for more efficient rocket engines, the pressure in the combustion chamber needs to be high and appear the requirement for propellants with high energy efficiency, including the cryogenic. The development of atomizers for these propellants is quite difficult because the characteristics of the fluids involved (boiling temperature). As part to the development of a bench study of combustion using this type of propellant, a injector was designed to operate with alcohol and liquid oxygen. This study used the technique of Planar Laser Induced fluorescence (PLIF),Particle Image Velocimetry (PIV) and Laser measure of drop diameter which allows non-intrusive way of viewing the flows, the interaction between the sprays and characteristics such as opening angle of the atomizer using Water Alcohol and liquid nitrogen as a substitute for the Propellants.*

Keywords*: spray; injector; Plif; PIV; Criogenic*

1. INTRODUCTION

The instability of combustion is a major problem in a liquid propellant engine. It results from the interaction between combustion and fluid dynamics of the system and is characterized mainly by oscillation of pressure in the combustion chamber (Ito, 2004). These oscillations, depending on the frequency, can cause damage to the engine.

The mechanisms that can cause the combustion instability involve the combination of the combustion chamber's acoustics and at least one of the following processes: injection, the spray dynamics, vaporization, burning, the mixture of propellants and products, and chemical kinetics (Yang, 1995). The first five processes are directly related to injectors. The completion of these components's project is very complex because there is insufficient information about important processes to its design, such as propellant's atomization, the rate of mixing and burning of droplets.

The injector used in this study is the centrifugal bipropellant type, typically used in the liquid rocket engines. It was developed by the IAE (Institute of Aeronautics and space) for an experimental engine. To verify the characteristics of these injectors tests at ambient pressure and temperature are commonly used (Ferraro et al, 1996; Ramezani et al, 2005), using optical means (diffraction of laser, laser anemometer, photographs) for the measurement of size, speed and position of formation of the drop, as well as distributors for the analysis of spatial distribution of the liquid and the degree of mixing. Recently, options of measurement of distribution through optical techniques have emerged (Sellens et al, 2000 ; McDonel et al, 1997; Koh et al, 2006).

These tests are usually performed with water as the working fluid due to the characteristics of certain propellants (toxicity, flammability and low boiling points) that prevent the direct usage of them. However many propellants have many different physical characteristics between them, such as the pair for which the injector of the study was designed. Thus the results obtained in tests with water do not reproduce the phenomena that occur with actual propellants.

This article presents a study on the spray of a swirl injector, using alcohol and liquid nitrogen as propellants, by PLIF and PIV and compares them with tests carried out with water

2. EXPERIMENTAL

Firstly, the injector was tested using water as working fluid for both the fuel and for the oxidizer. The spray was photographed and the image manipulated to obtain the approximate angle. The distribution of liquid was found with colorimeter and patternator.

The same injector was studied using alcohol and nitrogen. The liquid nitrogen replaces the liquid oxygen as an oxidant to be used in the normal operation of the injector. The alcohol presents a mixture of 10% acetone. This is used as a tracer. The image of the spray is captured by an ICCD camera. After treating the images, the approximate angles are measured. Since it is not possible to use the physical patternator, in this case the distribution of the spray is observed only through the PLIF images.

A PIV was used to show the velocity field and explain some results from PLIF.

The SMD from the injector was measured and compared with theoretical calculations (Lefebvre 1989).

Below are the description of methods of analisys.

2.1. Measurement of droplet size by laser diffraction method.

The system of laser light diffraction of Malvern Instruments Ltd. Mastersizer X was used, as shown in Fig 1, together with the system outlined in Fig 2 which will allow the measurement of the distribution of the size of the drop.

Figure 1. Mastersizer X from Malvern Instruments Ltda

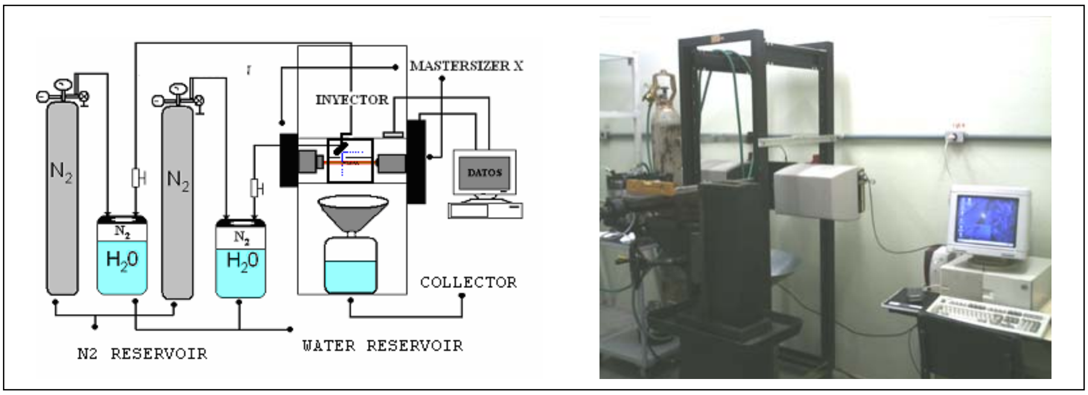

Figure 2. Layout and photo of the system for measuring the average sizes of the drops.

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The Injector is positioned in a chamber in order to limit the flow, which is very high and obscures the laser, preventing the execution of the measurement.

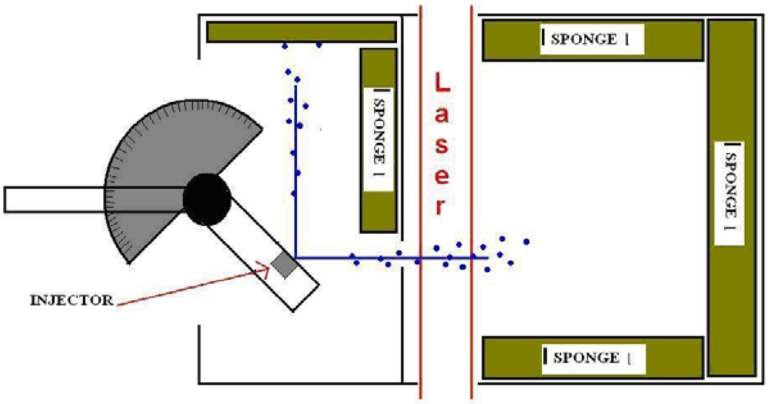

Figure 3. Scheme of the positioning of the Injector in test chambers of the laser

The chamber consists of an acrylic box with a partition. On one side, there is the injector in a holder which keeps it in the horizontal position and there is also an angle so that the surface of the cone is perpendicular to the partition. In the partition, there is a gap of 1cm-wide and 2 cm in height that allows the passage of only part of the flow. On the other side there is the laser that will measure the size of the drop.

The chamber is coated with sponge to prevent the shock of the spray with the walls from causing the appearance of a cloud of droplets that wets the lens of the equipment.

Due to the size of the canal inputs of injector and the susceptibility of clogging distilled water was used to avoid the inclusion of any particle in the cycle.

2.2. Measurement of the mass distribution.

This measurement is made in an apparatus which consists of a series of compartments with the same cross section where the water is collected. These compartments are arranged in a plan that is perpendicular to the axis of the injector. It can be arranged around a circular shaft or honeycomb, as shown in the figure below (Fig 4).

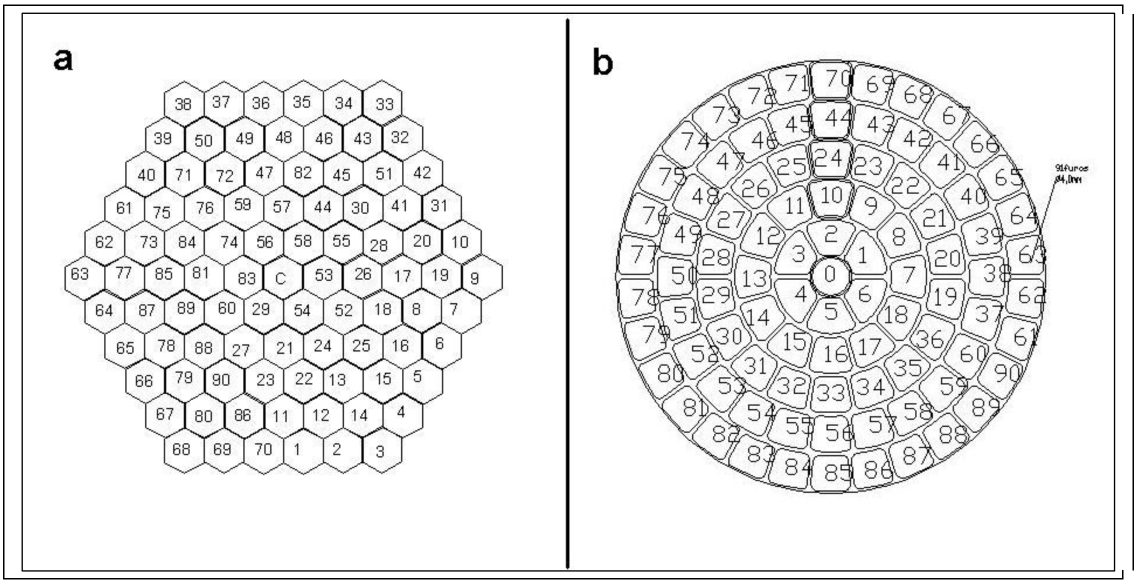

Figure 4: Schematic of collectors, a) honeycomb, b) circular

After the injector has been triggered for some time, the collectors are emptied and the amount that each one collected is measured. These values will be treated taking into consideration the effective area seen in the perspective of the injector. With these results we can evaluate the symmetry of the spray. It is also possible to calculate the coefficient of discharge.

2.3. Planar laser induced fluorescence and Particle Image Velocimetry .

A schematic of the experimental setup is shown in Fig. 5. The laser system consists of a Sirah pulsed dye-laser pumped by a Quanta-Ray Nd:YAG laser. The emitting laser pulse duration is 7 ns. Light from the Nd:YAG laser at a wavelength of 1064 nm passes through a frequency-doubling crystal producing 532 nm light which pumps the dye laser operated with Rhodamine 6G solution in ethanol. The dye laser outputs light at 566 nm region, which is frequency-doubled by a KDP crystal producing laser radiation at the 283 nm region. The dye laser radiation is narrowband (0.6 mm) and wavelength tunable by the harmonic generation unit. The output beam of the dye laser is converted into a 600 μm width and 50 mm high sheet at the flame position. The sheet is produced with two cylindrical lenses (f=-300 mm and f= +500 mm). The laser energy is approximately 5 mJ per pulse that assures a linear regime. The image is acquired by a 1024×1248 pixel intensified CCD camera (Cooke Instruments, DICAM-PRO) and a 105 mm f/4.5 quartz NIKON camera lens. A Schot W295 filter is placed in front of the lens to reject scattered residual 283 nm light and a Schot BG12 filter is also used to eliminate visible light background. The camera is held perpendicular to the excitation laser sheet direction. The Acetone chemiluminescence's images are obtained with the same experimental setup excluding the laser radiation.

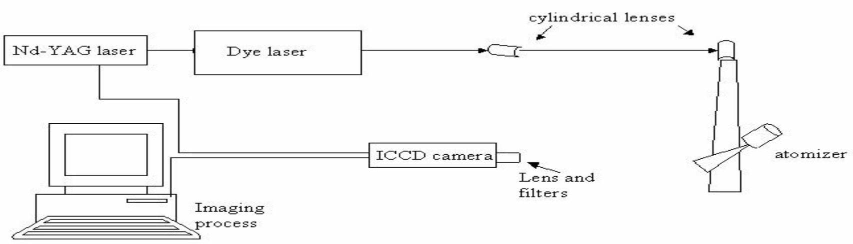

Figure 5. Diagram of the experimental Plif assembly

Piv system consists of a Nd:YAG Dual Cavity pulsed laser - Big Sky Ultra PIV 50. The emitting 2 laser pulse of 50 mJ/pulse at a wavelength of 532 nm at a rate of 15 Hz. The image is acquired by a Imager Intense cross-correlation CCD camera with 1376 x 1040 pixel resolution, at 10 frames/sec, 12-bit digital output, Peltier cooled and 6.45 x 6.45 μm pixels.

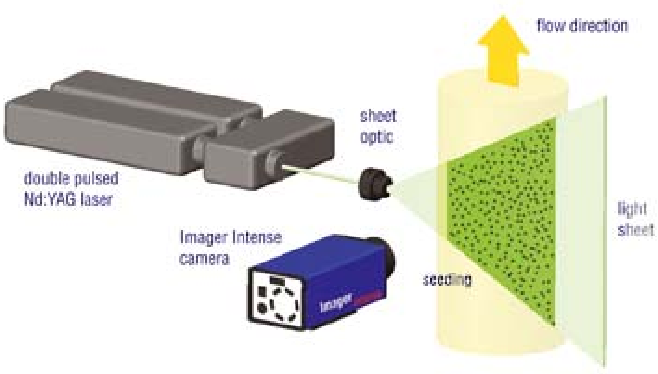

Figure 6: PIV System

The injector used is shown below

Figure 7. Swirl injectors

3. RESULTS AND DISCUSSIONS

In tests with water, there was an interference of the oxidant spray on the spray of fuel. The latter presented an angle of 126 ° (Fig. 8) when working alone at a pressure of 5 bar. In the test with both injectors, fuel and oxidant, there was the closure of the angle to about 80 ° (Fig. 9). It is believed that this behavior is due to the drag caused by the inner spray.

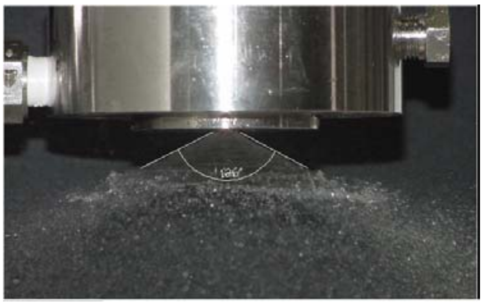

Figure 8. Fuel injector testing with water at 5 bar

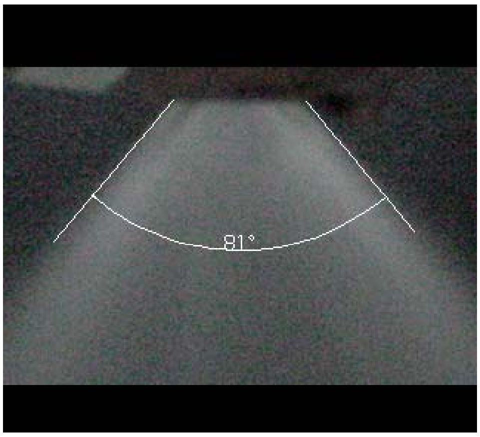

Figure 9. Fuel and oxidant injector testing with water at 5 bar

The results with colorimeter and patternators demonstrated that the injector provides an unsatisfactory mixture (Fig. 10). It presented an external area with high concentration of fuel (peaks of the figure), an inner zone with higher concentration of oxidant (valleys in yellow) and the empty center, characteristic of a spray swirl injectors.

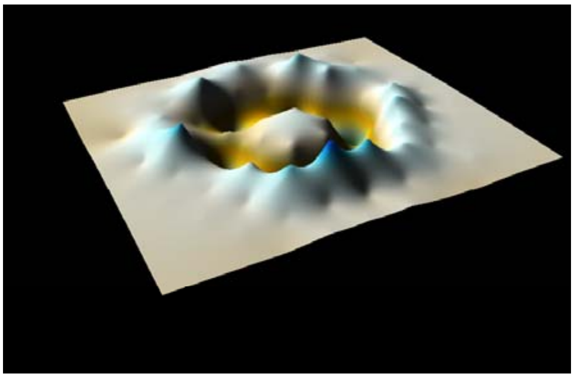

Figure 10. Performed with the mass distribution colorimeter, the valleys are poor mixture (with excess of oxidant) and the peaks, rich mixture (excess fuel)

In tests with alcohol, the angle was approximately 131 ° for the spray of the fuel injector in a pressure of 5 bar (Fig. 11). When the oxidizer injector is into operation with nitrogen, the angle of the fuel spray will also change as occurred in tests with water. However the closure of the angle is much smaller than that observed previously, the maximum amplitude is of approximately 100 ° (Fig. 12).

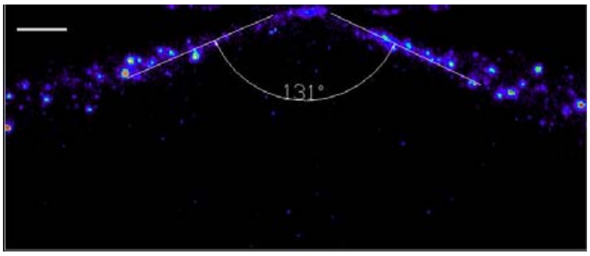

Figure 11. fuel injector testing with alcohol at 5 bar

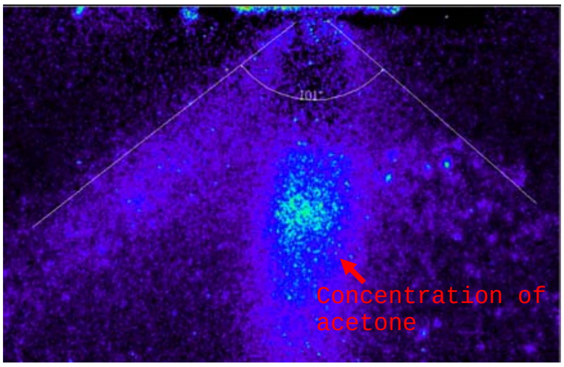

Figure 12. fuel and oxidant injector testing with alcohol and Liquid Nitrogen at 5 bar and 9 bar

The spray of nitrogen undergoes vaporization after the exit of the injector. However there was the presence of a concentration of fuel in a central jet (Fig. 12). This concentration suggests mixing the propellants due to the drag of the nitrogen spray. Thus the injector working with alcohol and nitrogen has two distinct regions. The first includes the spray of fuel which does not mix the nitrogen and is opened at an angle greater than that observed in the test with water resulting in a rich mixture. And a second region, located within the spray, where there is poor mixing of propellants, caused by the drag of the central injector spray

A PIV was used to show the velocity field and explain the behavior of spray. The figure below (Fig 13) shows the ICCD camera image from PIV. The left image is sprays of water and the right is alcohol and nitrogen.

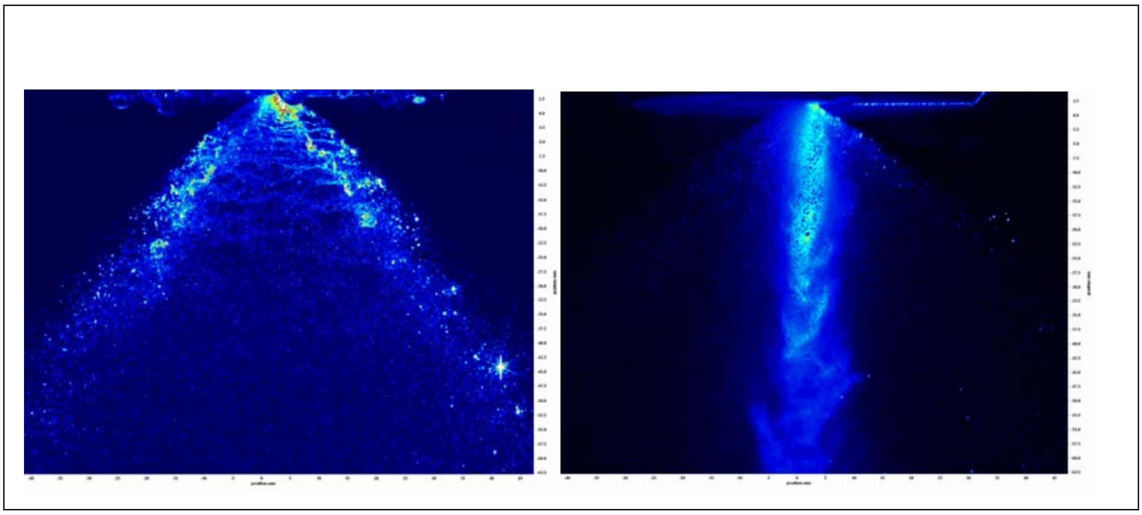

Figure 13. ICCD camera image from PIV. Left image is sprays of water and the right is alcohol and nitrogen

In spray of water it is possible to see the cone separation of the fuel spray from oxidizer spray and a later meeting of sprays caused by drag of the inner. This behavior was observed in test with colorimeter and patternators. The same is observed in sprays of alcohol and nitrogen, but as the nitrogen evaporated too fast, the fuel spray is poorly affected and isn't dragged the same way

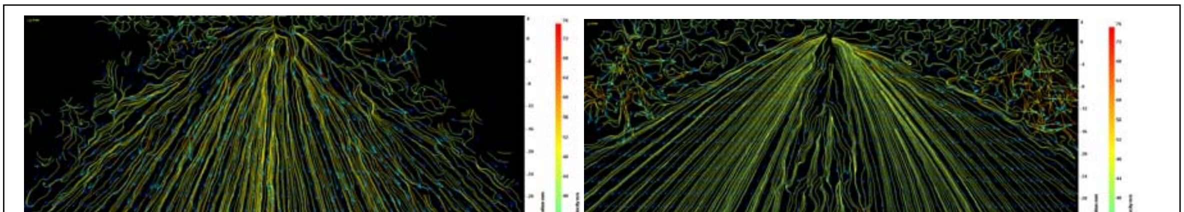

Figure 14 Spray Velocity Field from PIV system. Left is the sprays of water and right the spray of alcohol and nitrogen

However, as one can see in PLIF image, there is a concentration of fuel in the middle of nitrogen spray. That is explained by turbulent zone showed in velocity field image from PIV. This strong turbulence zone drags the fuel drops from the surroundings to the center.

The SMD from the injector was measured. When compared with theoretical calculations (Lefebvre 1989) it shows that the injector has a good atomization.

Table 1. Drop diameter (mm).

Injector	Radcliffe	Jasuja	Wang&Lefebvre	Measured
Fuel	417,48	284,67	285,02	231,59
Oxi	516,73	343,79	391,37	204,07

4. CONCLUSION

Assays were performed with sprays from a swirl injector with water, liquid N2 and alcohol. They were analyzed using the technical of photograph, mechanical patternators and colorimetry, Planar Laser Induced flourescence (PLIF) and PIV. For the PLIF with alcohol and liquid nitrogen acetone was used as a tracer mixed to fuel to distinguish the interaction between the sprays. It was shown that the behavior of sprays differ greatly between trials, depending on the working fluid used because of their different physical characteristics. The test with water indicated the existence of three zones. The first formed by a spray of fuel, a second formed by the spray of oxidant and the third being the area without the presence of propellants in the center of the spray. The two sprays interact by the drag of the fuel spray by the oxidizer spray. In tests with alcohol and nitrogen only two zones were observed. One with a rich mixture in the periphery and a central area with poor mixing. The drag is observed in sprays of alcohol and nitrogen too, but as the nitrogen evaporated too fast, the fuel spray is poorly affected and is not dragged the same way. The central zone of mixing is explained by strong turbulence showed by PIV's velocity field. The SMD from injector was measured. Comparing with theoretical calculations of SMD, the injector shows a good atomization

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