SPRAY CHARACTERIZATION FOR LEAN PREMIXED-PREVAPORIZED COMBUSTION (LPP) AND PRELIMINARY ANALYSIS OF INSTABILITIES SPRAY

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ABSTRACT

Lean and premixed combustion is a successful method for reducing NO_x and CO emissions from gaseous and liquid fuel combustion. However, premixed combustion of liquid fuels is much more complicated since liquid fuels have to be first atomised and completely evaporated and then they should be mixed homogenously with the air in the premix duct before the auto-ignition time elapses. In the present work, drop size distribution and droplet velocities of a kerosene spray produced by different hollow-cone atomizers in terms of the angle spray are presented.

A Phase Doppler Anemometer (PDA) measures droplet sizes and velocities of kerosene spray. Results indicate droplet diameters and velocity values are the smallest at the spray centreline and grow with radial distance from the centreline at the spray periphery; to parity of height above the nozzle, the mean diameter obtained with spray angle 60° turns out to be greater of that one with angle of 80°.

Preliminary investigation using high speed imaging allowed to estimate the spray sheet oscillation frequency.

INTRODUCTION

Environmental constrain presses gas turbine manufacturers to develop new project for combustion chamber in order to decrease pollutant emissions. The emission control technologies emerging consist in lean premixed prevaporized combustion for reduction of NO_x emissions.

LPP relies on a lean, homogeneous fuel/air mixture burning at low temperature and therefore low formation rates of thermal NO_x. The fuel has to be completely evaporated and should be mixed homogeneously with the air in the premix duct before the time of autoignition elapses. The first important step for an efficient combustion also for LPP technology is the fuel atomisation, because the droplet evaporation and dispersion are strongly influenced by the initial drop size of the spray produced [1] The atomisation of liquid fuel is a process of the great practical importance, in which a liquid jet or sheet is disintegrated by the kinetic energy of the liquid itself, or by exposure to high velocity air o gas, or a result of mechanical energy applied externally through a rotating or vibrating device. Because of the random nature of the atomisation process the resultant spray is usually characterized by a wide spectrum of drop sizes.

Combustion of liquid fuels in diesel engines, gas turbine, rocket engines and industrial furnaces is dependent on effective atomisation to increase the specific surface area of the fuel and thereby achieve high rates of mixing and evaporation. In most combustion system, reduction in mean fuel drop size leads to higher volumetric heat release rates, easier light up, a wider burning range and lower exhaust concentrations of pollutant emissions. A typical spray includes a wide range of drop sizes; some knowledge of drop size distribution is helpful in calculations of heat or mass transfer between the dispersed liquid and the surrounding gas. The difficulties in specifying drop size distributions in sprays have led to use of various mean diameters. For combustion system and other applications involving heat and mass transfer to liquid drops, the Sauter mean diameter, which represents the ratio of the volume to the surface area of the spray, is often preferred [2-3].

The aim of this work is to characterize drop size distribution and the velocities of a kerosene spray produced by two different hollow cone atomizers, which differ for the spray angle.

Hollow cone nozzle is a pressure swirl atomizer; in this device the angular momentum is imposed on the liquid to form a swirling motion; under the action of centrifugal force, the liquid spreads out in the form of a conical sheet as soon as it leaves the orifice. In the hollow cone spray the most of the drops are concentrated in the periphery of a cone; atomisation performance is good, so it is being increasingly favoured for use in modern LPP gas turbines [4].

A PDA system was used to measure liquid fuel particle diameter and velocity [5-8] and a high-speed CCD is employed to study spray instabilities.

PDA AND CCD SET-UP

Phase Doppler Anemometer (PDA) measured droplet sizes and velocities of the liquid fuel spray with a processor BSA flow (an optical system of DANTEC). This system is a development of a classical Laser Doppler Anemometer; the emission optics is the same as in a normal LDA system only reception optic differs. At least two detectors are used at different angles in order two collect the light scattered by the particle passing through the probe volume. As in LDA, the frequency of the intensity of the light collected by both detectors is proportional to the velocity of the particle. But it may also be shown that the phase shift $\Delta\phi$ (=70°) between the signals is proportional to the particle diameter. We have characterized and confronted two different sprays. The sprays are generated by two hollow cones, commercial nozzle (Delavan), with angle of 80° and 60°, which were operated at a pressure of 7 bar for kerosene flow rate of 11.2 l\h.

In the Table 1 are reported the features of the two nozzles.

Table 1

Atomizer	Hollow cone
Hole size	d_0(mm) = 0.46
Pressure	P(bar) = 7
Mass flow	m(l\h) = 10.2
Spray angle (1)	θ = 80°
Spray angle (2)	θ = 60°

The operative conditions and the characteristics of the fuel are given in Table 2.

Table 2

Atomised Liquid	Kerosene Jet A-1
Temperature	20°C
Surface tension	σ(N\m) = $26.8\cdot10^{-3}$
Density	ρ(Kg\m^3) = 800
Kinematic viscosity	ν(mm^2\s) = 3.5
Dynamics viscosity	μ(Kg\m·s) = $1.5\cdot10^{-3}$
Refraction index	n = 1.46

The instability depends on several conditions and it changes the characteristic parameters (geometrical and dynamic) completely. It is important to verify if and how can be source instability conditions. In some cases the start of the instability phenomena depends on the fluid dynamics conditions inside the nozzle chamber. It can verify pressure oscillation, starting cavitation and other parameters of the nozzle. Furthermore, it is important to correlate the spray oscillation with the pressure field inside the nozzle chamber. In fig 1 the experimental set-up to analyse the instability phenomenon is showed.

A laser sheet generated by a laser source (λ = 514 nm, and optimised for a clean response of the CCD photo electronic sensor) and opened by a divergent lens intercepts the hollow cone spray. The cross of the laser, inside the hollow cone, generates a pattern on the plane parallel and including the nozzle axis. The pattern is due to the scattering of the droplets crossing through the light plane. The scattering droplets are recovered by a CCD high-speed camera (30 – 10000 frames/s). The numerical analysis of the recorded sequences and the correlations with the pressure field inside the nozzle chamber give an interesting answer related to the instability phenomena.

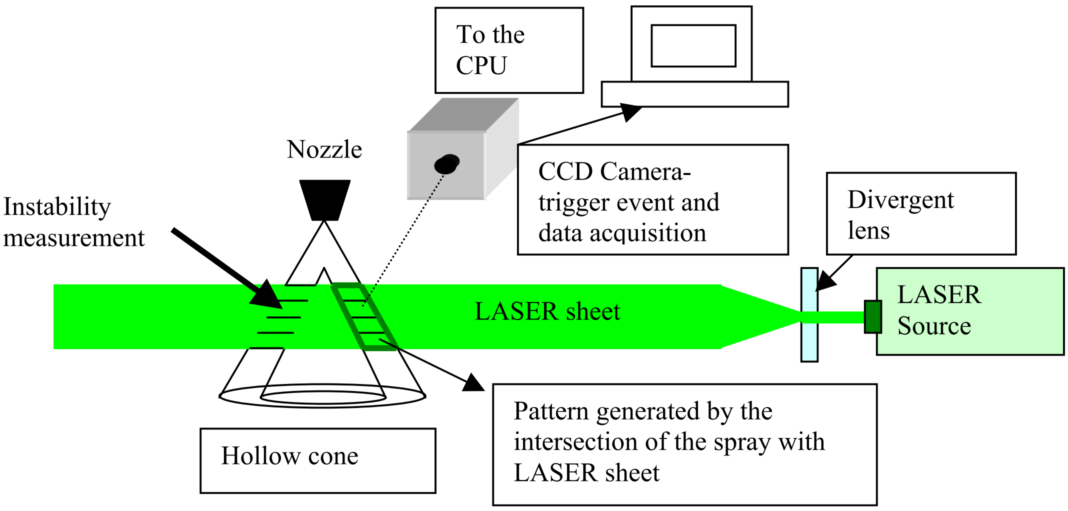

Fig.1 Experimental set up for spray instabilities

RESULTS AND DISCUSSION

The mean diameter D_{10}, the Sauter diameter D_{32} and the velocities, at different heights above the nozzle, are plotted as function of the radial coordinate for both of the atomizers. Before 7mm above the nozzle the PDA is not able to valid date due to the spray density. All graphs show an axial symmetry. PDA system gives obviously diameter measurements in steady-state spray conditions. In this way, is correct to measure the mean Sauter diameter along the spray axis.

The evolution of the mean drop diameter well underlines the spray angle and the droplet density. It is possible to note on fig.2, on the right for spray angle 60°, and on the left, for spray angle 80°, the centreline the radial profiles of size drop keep the very small diameters.

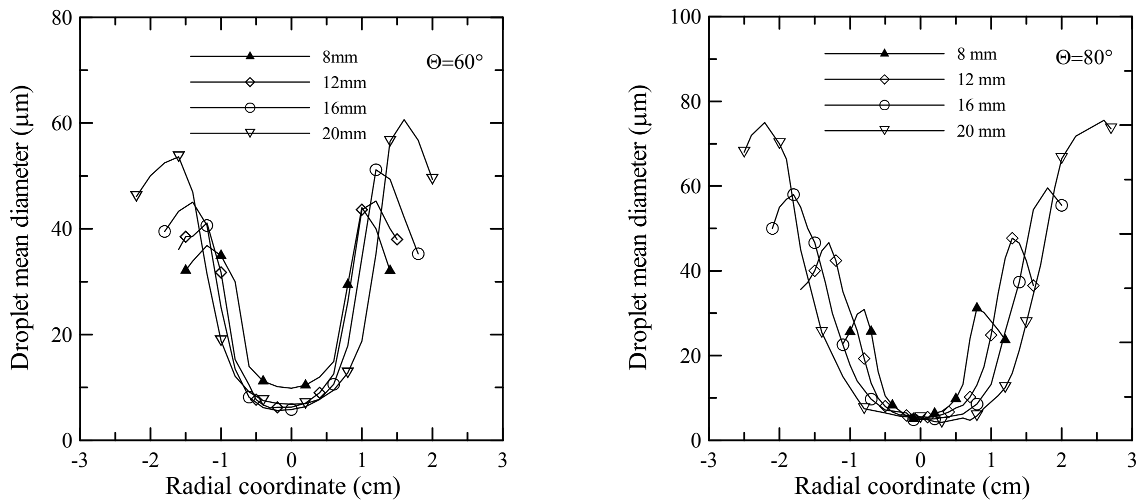

Fig.2 Radial profiles of droplet mean diameter

In fig.3 is plotted Sauter mean diameter for both nozzles, at different heights. We can see that the trend is the same.

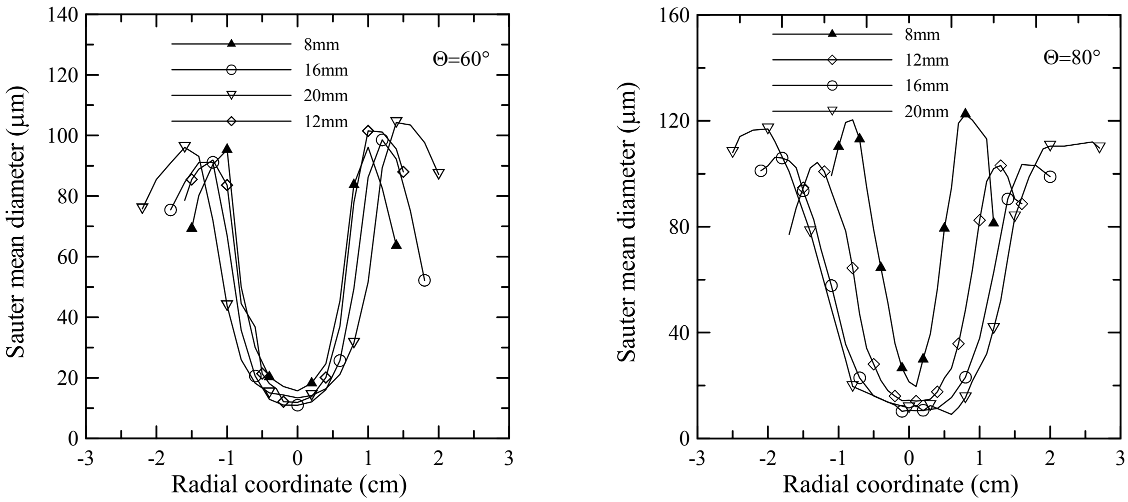

Fig.3 Radial profiles of measured Sauter diameter.

For both the atomizers the velocity plot, in fig.4, exhibits a minimum in the centre of the spray and it increases in the external part of the spray; this behaviour is not surprising and was already observed [9]. In figure 4, we can see the effect of the extractor on the right side for the spray angle of 60°.

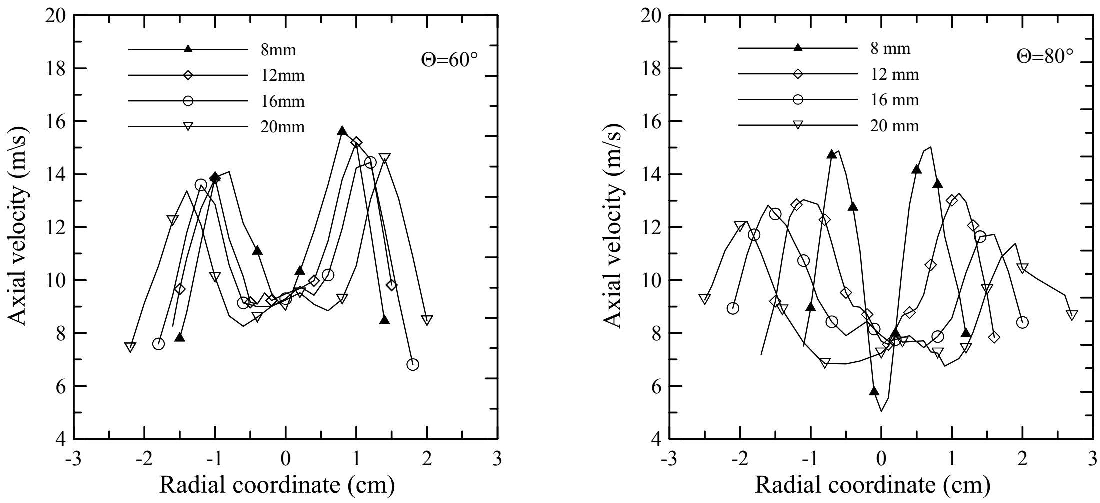

Fig.4 Axial Velocity profiles in the spray.

On fig.5 are reported Sauter mean diameters and axial velocity for both nozzles at 20 mm above the nozzle and we can see that the Sauter mean diameters of spray (1) are smaller than mean diameters of spray (2). It seems that so the hollow cone atomizer with spray angle of 80° is chosen for LPP.

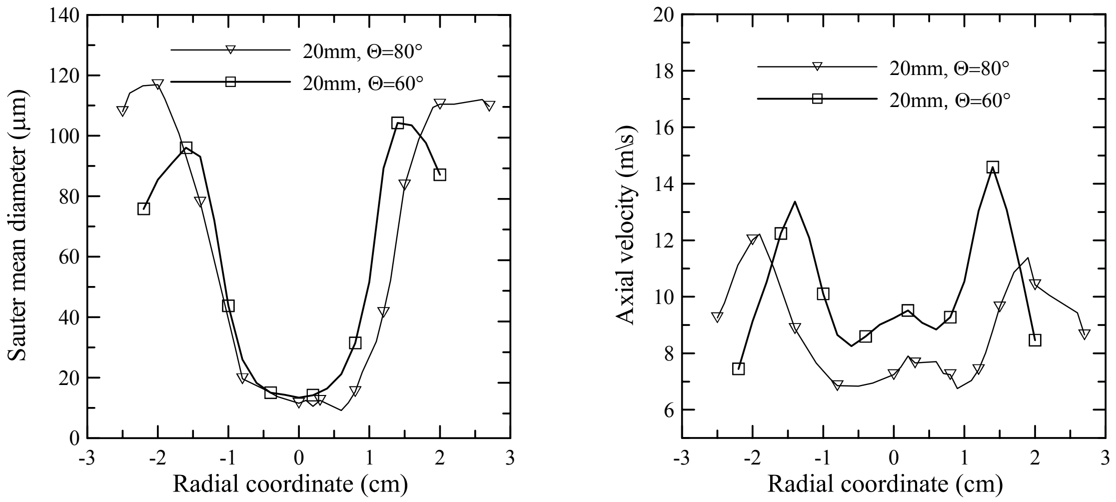

Fig. 5

A preliminary study using this technique is carried out in this work. It is possible to notice by using high speed CCD camera, the spray behaviour due to local instability. Two different instants of a running spray are showed in figure 6; the frame rate of the scan is 3000 Frame/s and laser sheet crosses the hollow cone. In this way only the external droplets of the spray are excited. The temporary sequence of the picture is 3 frames. It is possible to put in evidence the variation of the open cone angle along this elapsed time. In first approximation it is possible say that the frequency of the spray between maximum and minimum open con angle is about 1kHz.

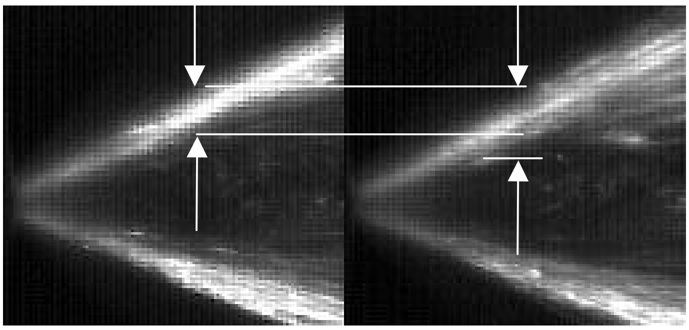

Fig.6 Sequence of two spray images separated by ~1 ms.

CONCLUSIONS

Complete PDA measurements were performed on hollow cone kerosene spray. As expected, the main part of the droplets is present at the outer part of the spray, even though a large number of small droplets are present inside the spray cone.

A preliminary analysis of the spray instability is pointed out with the laser and CCD high speed camera technique; this approach permits to observe the density variation of the hollow cone along the radius and the main axis. Following and optimising these techniques will be studied the oscillations of density and so of the mass fluxes that are very important for a correct working of a LPP nozzle

REFERENCES

1 Gabriel Roy, *Propulsion Combustion Fuels to emissions,* Combustion: An International Series, 1997.
2 A.H. Lefebvre, Norman Chigier, *Atomization and Sprays*, Combustion: An International Series.
3 G.G. Nasr, A.J. Yule and L. Bending, *Industrial Sprays and Atomization: design, analysis and applications*, Springer, 2002.

4 L. Bayrel, Z. Orzechowski, *Liquid Atomization*, Combustion: An International Series, 1993.
5 K.K. Hoinghous, J.B. Jeffries, *Applied Combustion Diagnostics*, Combustion: An International Series, 2002.
6 M. Sommerfeld, Analysis of isothermal and evaporating turbulent sprays by phase-Doppler anemometry and numerical calculations, *International Journal of Heat and Fluid Flow,* vol.19, pp. 713-186, 1998.
7 F. Lacas, J.C. Rolon and D. Veynante, Droplets size and velocity measurements in a laminar counterflow spray flame with Phase Doppler Anemometry, In *Joint Meeting of the French, Italian and Swedish sections of the Combustion Institute*, Capri, Italy, September, p. II-3, 1992.
8 H.E. Albrecht, M. Borys, N. Damaschke, C. Tropea, *Laser Doppler and Phase Doppler Measurement Techniques*, Springer, 2003.
9 F. Beretta, A. Cavaliere, A. D'Alessio, Drop size and concentration in a spray by sideward laser light scattering measurements*, Combustion Science and Technology*, vol. 36, pp. 19-37, 1984.