Properties of sprays created by an ultrasonic nozzle.

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This paper is devoted to the study of spray characteristic created by ultrasonic nozzles. The major advantages of such nozzle are to create a spray with small size, narrow distribution and low velocity. Several optical techniques are applied to extract information close and far from the orifice.

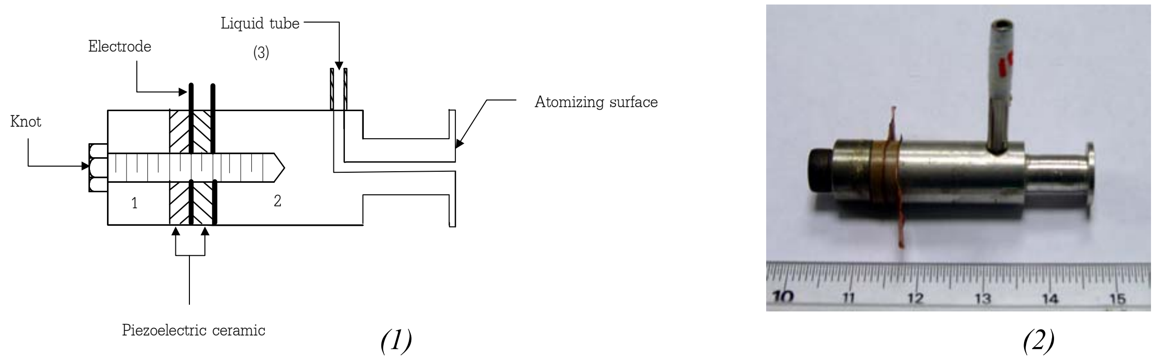
1. Introduction

Ultrasonic nozzles use the ultrasonic vibrations to generate the liquid atomization. In contrast to conventional spraying mechanisms which rely on relatively high hydraulic pressure or high velocity gas streams for atomization of liquid media, ultrasonic nozzles could produce very fine droplets with a relatively uniform diameter, while no requiring high air compressor or high pressure pump to produce such small droplets. The atomization by the ultrasonic nozzle is possible even with a low liquid flow rate. Moreover, there is no problem of clogging because of the relative large aperture of the orifice. Therefore, ultrasonic nozzle spray technology is used in a wide range of industrial and research applications such as medical nebulizers, combustion and drying, paint spraying systems, encapsulation and surface coating [1,2,3]. Nevertheless, a better understanding of the characteristics of the spray produced by such ultrasonic nozzles is necessary to improve their use. The objective of this research is to study the behavior of a spray produced by such a nozzle.

The paper is organized as follow. Section 2 describes the nozzle used and its working conditions. Section 3 is devoted to the measurements. These measurements characterize the spray just at the orifice output (size, velocity, temperature) and far from the orifice (size and velocity). The section 4 consists of a conclusion where the behavior of the nozzle for other working conditions and liquids is considered.

2. Experimental set up

Figure 1 shows that an ultrasonic nozzle structure is an acoustically resonant device consisting of a pair of piezoelectric ceramic rings sandwiched between a backing piece (1) and a mechanical transformer (2). The atomization take place at the free end of the mechanical transformer forms called atomizing surface. The liquid is delivered to this surface through the hole (3).



(1) (2)

Fig. 1 : 1.1) Scheme of the ultrasonic nozzle. 1.2) Photography of the studied nozzle.

Ultrasonic nozzle used piezoelectric ceramic to generate ultrasonic energy by transforming electrical energy to mechanical energy in order to vibrate an atomizing surface. At the resonance frequency, which is a function of geometrical characteristics of the nozzle, the direction of vibration is perpendicular to the atomizing surface. When a liquid is introduced on to the atomizing surface, it spreads and forms a thin liquid film. The liquid film adsorbs a fraction of the vibration energy creating a unique wave pattern on the surface, known as capillary wave. When the amplitude of the underlying vibration is increased, the amplitude of the capillary waves increases correspondingly. Finally, when the critical amplitude is reached the height of the capillary wave exceeds that required to maintain its stability. The wave collapses and tiny drops of liquid are ejected from the top of the degenerating waves [3].

3. Measurements

3.1 PDA measurements

A first experiment has been carried out, measuring the size and the velocity of the droplets at 5 mm from the orifice on the axis of the canal orifice (see figure 1). The PDA configuration used was the standard PDA configuration and the processing of the events was carried out by using the Dantec PDA (58N80-58N81) and Dantec software. The duration of the measurement was about 5 minutes for 500,000 events. The experiment starts with the excitation of the nozzle.

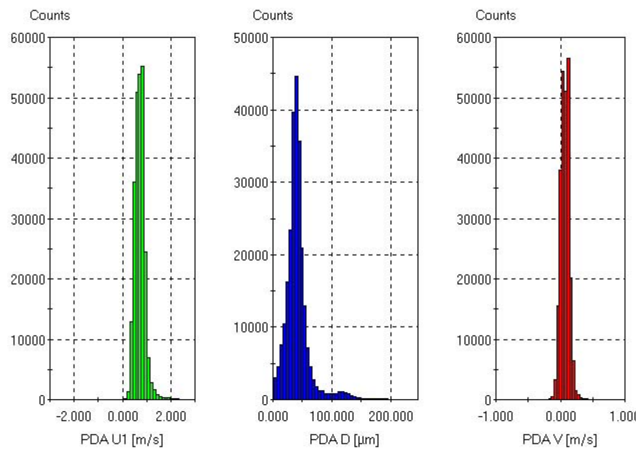


Fig. 2: Example of PDA measurement at 5 mm from the orifice.

Figure 2 displays histograms of longitudinal velocity, diameter and transverse velocity for a flow rate of 1.1 cm^3/min and excitation frequency is 46 kHz , in the case of water. A nearly perfect Gaussian distribution of the particle size characterizes the spray. The spray parameter are D_{10} = 46.68 µm and D_{32} = 63.9 µm.

Then the following post-processing has been applied to the measurement series:

1. The measurement series has been divided in windows of equal duration.
2. Each temporal window has a duration equal to 100 ms.
3. For each window, we compute and record: the number of particles, the average velocities (longitudinal and transverse), and the average diameter.

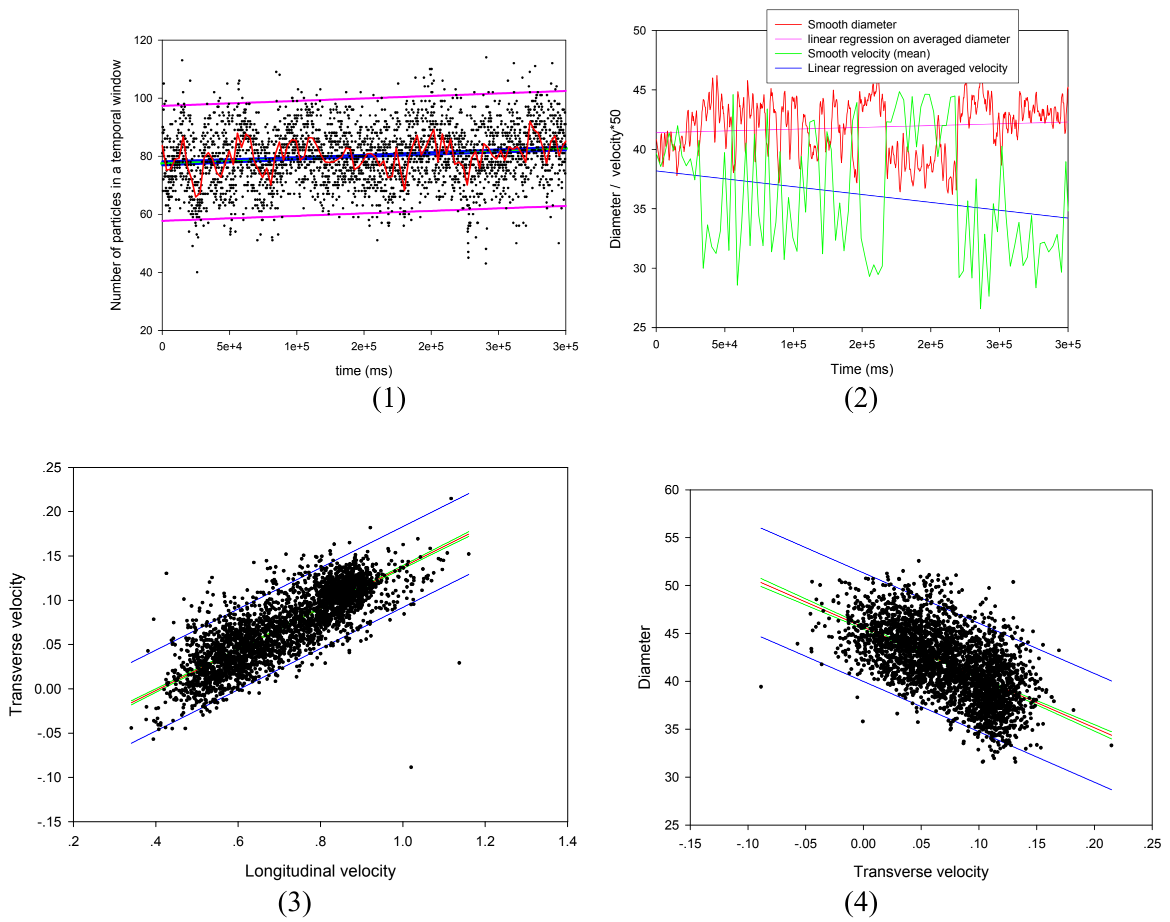


Fig. 3 *:* Processing of PDA temporal series. 3.1) number of particles versus time, 3.2) Longitudinal velocity and diameter versus time, 3.3) Transverse velocity versus longitudinal velocity, 3.4) diameter versus transverse velocity

The results are plotted in figure 3. Figure 3-1 displays the number of measured particles versus time. From this figure, it is shown that the flow of particles is essentially constant at this location (around 80 particles every 100 ms). Figure 3-2 displays the average mean velocity and the average diameter versus time. From these figures it can be conclude that:

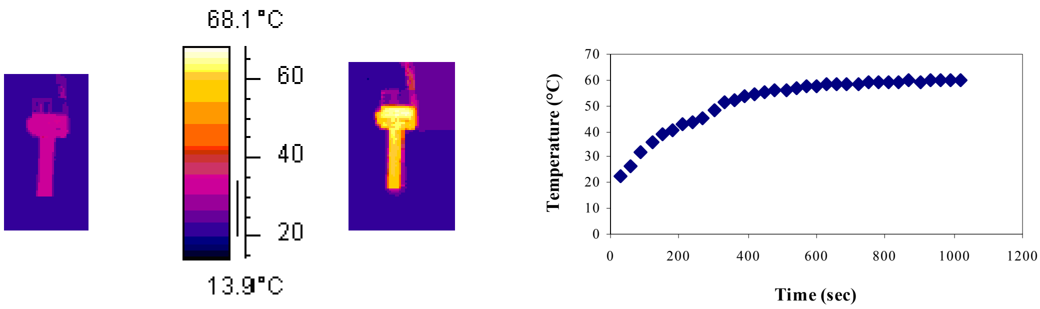
1. The longitudinal velocity is small, about 60-80 cm per second.
2. A correlation between size and longitudinal velocity exists: the biggest the particles, the smallest the velocity.
3. The correlated size/velocity evolves on a short time scale.
4. A continuous evolution at long time scale of the size and velocity appears (see the linear regressions)

In order to confirm these remarks, the transverse velocity versus the longitudinal velocity and the diameter versus transverse velocity has been plot (see figures 3.3 and 3.4). A strong correlation still exists between the longitudinal and the transverse velocity as well as between the transverse velocity and the diameter.
From these results it can be explained that the changes of size at short time scale is due to the effect of a transversally fluctuating flow, while long time evolution must have another origin. We postulate that this effect could be related to the change of the nozzle temperature due to the excitation. The study of this effect is the aim of the next section.

3.2 Temperature measurements

3.2.1 Nozzle temperature

The temperature of the nozzle has been recorded by using an infra red camera (ThermalCAM PM595 LWB with objective of 24° from FLIR Systems). Figure 4.1 displays maps of the nozzle temperature at the beginning of the excitation and 15 minutes later while figure 4.2 displays the temperature at the nozzle orifice versus time.



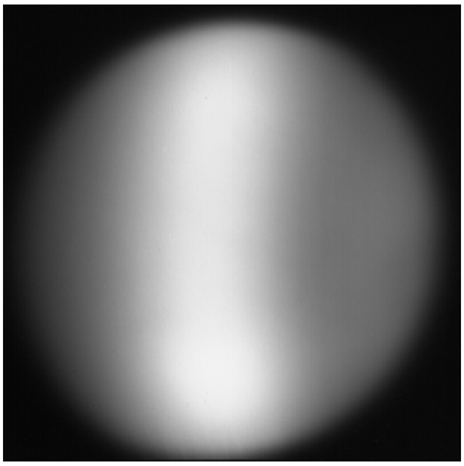
(1) *(2)*

Fig. 4 : 4.1) Maps of infrared emission for the nozzle just at the beginning of excitation and 15 minutes later . 4.2) Temperature at the nozzle orifice versus time.

A strong increase of the nozzle temperature is observed. The increase of the nozzle temperature is estimated from the infrared images (after a calibration) to be of about 40°C. This temperature change of the nozzle will induce a temperature evolution of the liquid droplets. The next section is then devoted to temperature measurements of the droplets spray near the nozzle orifice.

3.2.2 Droplets temperature

To measure the temperature of the droplets just at the orifice of the nozzle a global rainbow refractometry experiment has been carried out. The concept of the global rainbow refractometry has been introduced by van Beeck and Riethmuller [4], from whom the complete details of the technique could be obtained. Here we just recall that contrary to the rainbow refractometry on individual droplet which is very sensitive to departure from perfect sphericity, the global rainbow created by a large number of droplets is insensitive to such an effect, under the assumption that the orientation of the droplets is fully random and that the ellipticity of the particles is small enough to verify that the individual rainbow are only angularly shifted [5].



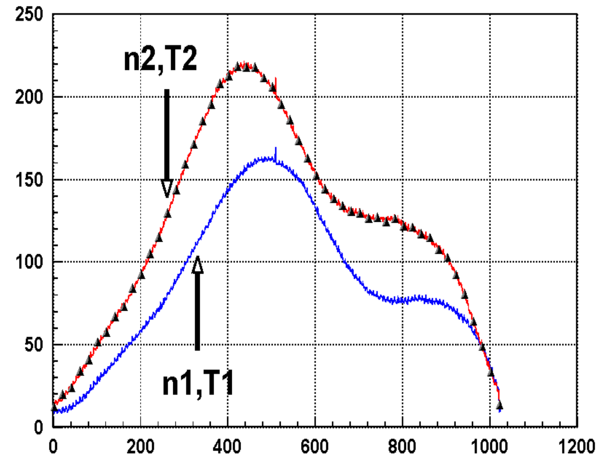


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Fig. 5 : Example of global rainbow measurement at 5 mm of the nozzle orifice. 5.1) direct record of the light scattered around the first rainbow angle. 5.2) Comparison between global rainbow signatures just at the beginning of the excitation of the nozzle and 5 minutes later. The temperature T1 and T2 are estimated to 20°C and 50°C.

Figure 5.1 is an example of a recorded experimental rainbow while figure 5.2 displays the recorded intensity versus the pixel number (scattering angle), at the beginning of the excitation and 5 minutes later. From such curves the temperature evolution of the droplet can be extracted. In this case, the temperature is estimated to 50°C, essentially in agreement with the results of the previous section.

To this increase of the liquid temperature is connected an evolution of its physical properties, which could induce the observed diameter and longitudinal velocity evolutions at long time. This is a point still under study. Nevertheless the results reported below are sufficient to demonstrate that these ultrasonic nozzles are well adapted to create a stable, well-masterized cloud of small droplets with a low velocity, which could be easily transported by an accessory flow. When the cloud of droplets dilutes, its properties (mainly its size) may evolve and could not be longer measured by PDA as the waiting time between events increases prohibitively. The next section is devoted to the presentation of some Interferometric Laser Imaging Droplets Sizing (ILIDS) results obtained at 50 cm from the orifice in a free fall configuration.

3.3 Measurement far from the orifice

To measure the characteristics of the spare spray far from the orifice, a suitable technique is ILIDS which has been introduced by Glover et al [6], and then studied and developed by several teams [7-11]. The measurement principle of ILIDS is based on the record of an off-axis, out-of-focus image. The size of the particle image is only a function of the lens aperture and the magnitude of the out-of-focus. The size information is coded in the fringes created by the interferences between the light reflected and refracted by the droplets. To study the spray at 50 cm from the orifice, a classical PIV set up (it is a classical TSI PIV set-up and the PIV processing is carried out by Matlab toolbox) is used. The only difference between a classical PIV measurement and an ILIDS measurement is that the recording camera has to be moved towards the laser sheet (by 5 cm here) to obtain out-of focus configuration. The time between two pulses is equal to 600 µs and the repetitiveness is of 10 couples of images by second. Figure 6.1 displays such a recording (one image of a couple). By analyzing such images with devoted software, the size distribution displays in figure 6.2 has been obtained (D_{10} = 50 µm). This size distribution well compares with the size distribution obtained by PDA as previously shown in figure 2. Furthermore, by applying a classical PIV processing to the couple of out-ofout-of-focus couple of images it is possible to extract a map of velocities (the arrows in figure 7). The velocity is measured to run from about 0.1 m/s to 0.3 m/s which is in agreement with the free fall velocity for drops of this size, showing that the injection velocity is not longer dominating. Furthermore, from image as the one displayed in fig. 6.1, it is evident that the particles are not uniformly or randomly distributed but are organized in assembly of drops with close characteristics (velocity and size).

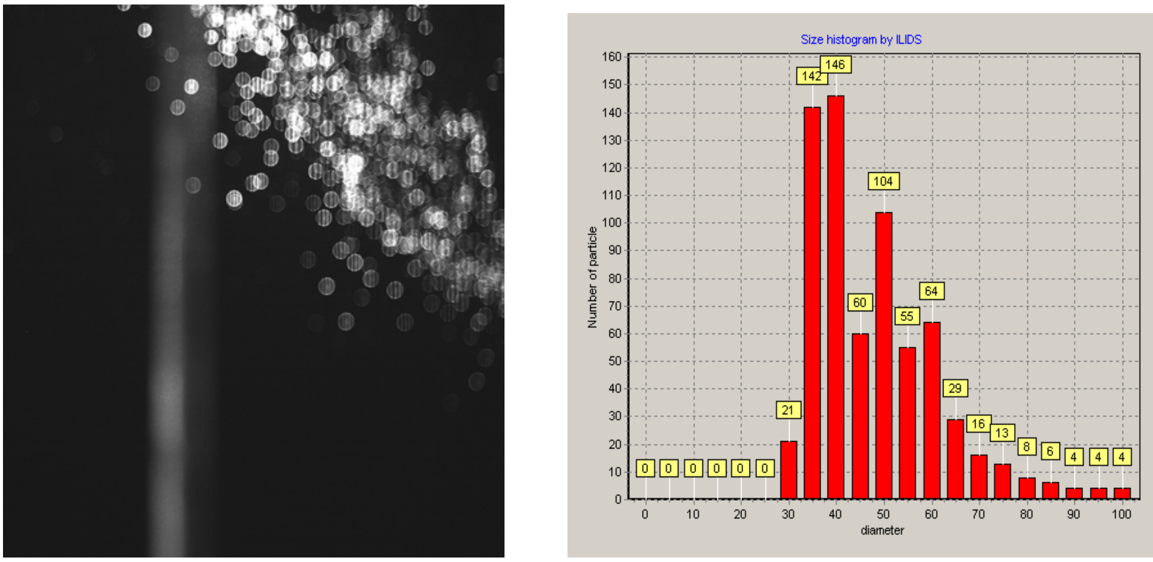

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Fig. 6: ILIDS measurements. 6.1) Example of a recorded ILIDS image, 6.2) Size histogram obtained by analyzing 50 ILIDS images

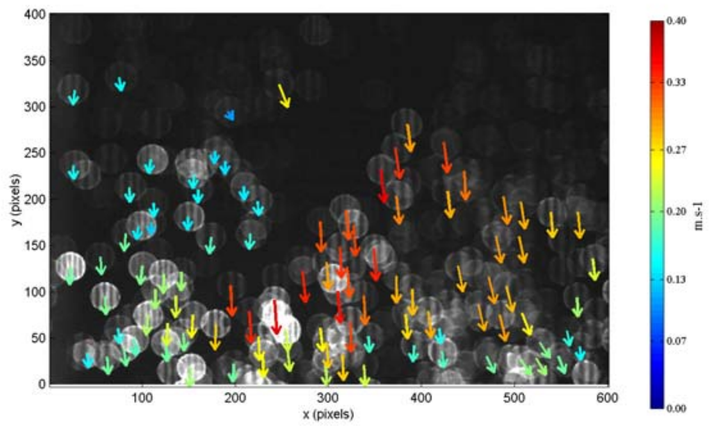

Fig. 7: Example of a PIV/ILIDS map. The arrows give the velocities (direction and amplitude). From the fringes the size of the droplets could be extracted while the velocity is obtained from standard PIV software

4. Conclusion

The behaviour of a water spray created by an ultrasonic nozzle has been studied. To reach this aim, an experimental procedure has been developed to measure the spray characteristics near the orifice (velocity, size, temperature) as well as far from it (velocity and size). The spray characteristics presented here for water droplets have also been obtained for other liquids and other flow rate.

5. Acknowledgements

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References

[1] Toop M.N. and Eisenklam, 1972, Ultrasonics, **10** 127-133
[2] Lacas F., Versaevel and Scouflaire P., 1994, Part. Part. Syst. Charact., **11** 166-171
[3] Berger H.L. 1998. Ultrasonic Liquid Atomization Theory and Application. New York: Partridge Hill Publishers.
[4] van Beeck J.P.A.J. and Riethmuller M.L, 1996, Applied Optics, **35** 2259-2266
[5] Han Y.P., Mees L., Ren K.F., Gouesbet G., Wu S.Z. and Gréhan G., 2002, Optics Communications, **210** 1-9,
[6] Glover A.R, Skippon S.M. and Boyle R.D., 1995, Applied Optics, **34**, 36 8409—8421
[7] Mounaïm-Rousselle C., Pajot O., 1999 , Particle and Particle Systems Characterization **16** 160-168
[8] Girasole T., Ren K.F, Lebrun D., Gouesbet G. and Gréhan G., 2000, Journal of Visualization, **3,** 2 195-202
[9] Kobayashi T., Kawaguchi T. and Maeda M., 2000, Measurement of spray flow by an improved interferometric laser imaging droplet sizing (ILIDS) system, 10 th International Symposium on applications of laser techniques to fluid mechanics,
[10] Calabria R. and Massoli P., 2000, Experimental study of droplets in evaporating r egime by 2D scattering analysis, , 10 th International Symposium on applications of laser techniques to fluid mechanics,
[11] Damaschke N., Nobach H., Nonn T., Semidetnov N. and Tropea C., 2002, Size and velocity measurements with the global phase Doppler technique, 11th International Symposium on applications of laser techniques to fluid mechanics,