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Fluids and Applications
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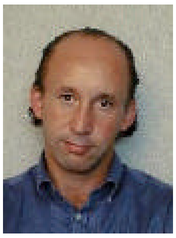

Introduction

Several physical or chemical methods are currently tested to encapsulate solid materials or liquids, biological or not. The physical methods use a process in which the active product is spayed into drops, which are then, coated, dried or solidified. The average size and the quality of distribution in size of the generated capsules are some important criterions of efficiency. The current sprays, with nozzle or spinning disk, generate droplets with a natural process of degeneration of liquid jets. However they provide polydispersed aerosols.

The general method to obtain a monodispersed aerosol consists in controlling the degeneration of a liquid jet by creating an artificial vibration on this one. This method is used in the generator with vibrating nozzle. In this case, an artificial vibration is applied to a liquid jet which passes through a cylindrical opening. The vibration is transmitted and developed along the jet, the break-up happens at a fixed distance of the opening. This process offers a very good degree of monodispersity but has its limits. First, concerning the production of very small droplet. The diameters of the drops are overall double the size of the diameter of the nozzle . As a result, the nozzle presents some risk of clogging. Second, the flow rate is low. A more important flow rate requires a vibration in parallel at the same frequency of several identical openings.

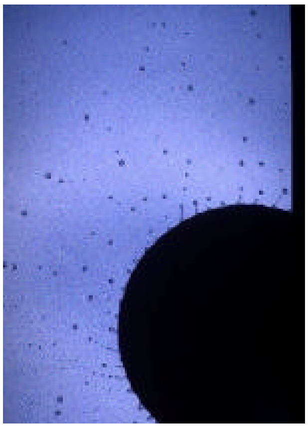

Figure 1 : Disintegration by direct drops formation

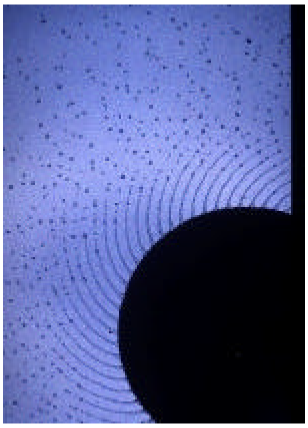

Figure 2 : Disintegration by ligaments formation

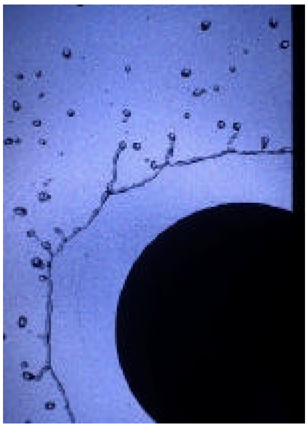

Figure 3 : Disintegration by film formation

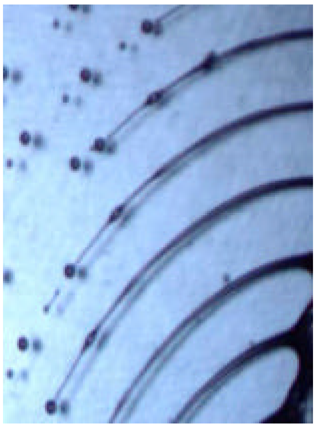

Figure 4 : generation of drop by a propagating undulation

When we inject a liquid in the center of a spinning disk with smooth edge, a liquid film is formed over the disk and can be disintegrated in droplets toward its periphery according to three different physical processes. When the flow rate is low, direct droplets are formed at the edge of the disk (fig. 1). When the flow rate is medium, ligaments (or liquid jets) are uniformly organize around the disk after which they become droplets (fig. 2). Finally with a great flow, a liquid film extends beyond the limits of the disk (fig. 3).

These processes of disintegration depend on the mechanical properties of the fluid (dynamic viscosity, density and surface tension), the radius the disk, the operating flow rate and the operating angular velocity of the disk.

In the process of disintegration by formation of ligaments, droplets are the result of a natural instability, just as described for cylindrical liquid jets **[1] [2]**. The instability is propagated and developed along the ligament until breaking it up and forming one or more drops (fig.4).

Material and methods

We know that it is possible to control the fragmentation of the liquid jets by producing a vibration. Then, the production of droplets then can be controlled perfectly. From then on several methods excitation are possible.

- The generation of a vibration by excitation of the liquid on the disk **[5]**.
Patent 914006218 **[3]** describes different methods of generation, creating capillary waves on the liquid at the level of the admission pipe or more generally at the level of the central area of the flow on the disk. In this case, the ligaments are simultaneously disturbed by a concentric undulation which is propagated from the center to the edge of the spinning disk.

- The generation of a vibration by excitation of the disk

In the last generator of a monodispersed spray that we developed (fig. 5), ligaments are excited by the vibration of the disk (1) a long its axis of rotation. The vibrator, rotating at the same speed than the disk, is composed of a recessed plate (2) over a structure (3), placed between the motor (4) and the disk and distorted by a piezo-electric cell (7) electrically driven by an amplifier up to a tension of appropriate frequency and magnitude.

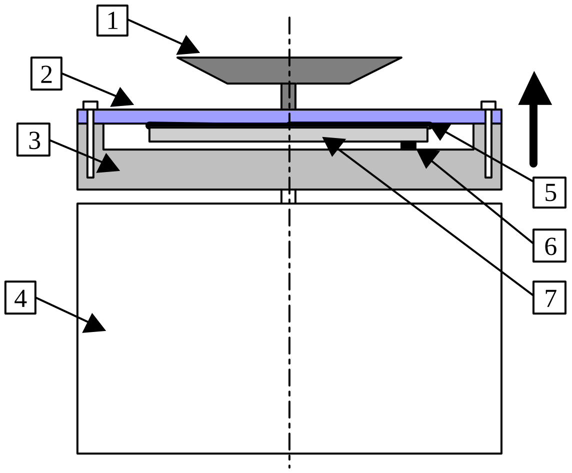

Figure 5 : Vibrating disk device

- The generation of a vibration by toothed disks

On the disks with a smooth edge, ligaments turn to an angular speed ω_j slightly weaker than the speed angular ω of the disk. The addition of teeth at the periphery of the disk has two effects according to the relative dimensions of the teeth and the diameters of the ligaments.
First, if the size of the teeth is comparable to the diameter of ligaments, we can observe a phenomenon of grapping, characterized by the fact that the number of ligaments the becomes equal to the number of teeth and the speed of ligament rotation becomes equal to the rotation speed of the disk. The presence of teeth and the existence of the grapping phenomenon don't change the mechanisms of transformation into droplets but modify somewhat the range of function. It presents the advantage of knowing the number of ligaments precisely and decreasing the uncertainty on the calculation of the radius of the drop **[5]**.
Second, if the dimensions of teeth are small, they don't allow the grapping of the ligaments that slip on the teeth. The break-up of all the ligaments seems similar to the one existing with a vibration **[3]**. In that case, as a result of the capillarity, the shape of the teeth act as a vibration. If the slipping speed is defined by $w_g = w - w_j$ and Z_d is the number of teeth, the vibration frequency created is

$$F = \frac{(w - w_j) Z_d}{2p}$$

Results and discussion

We are presenting here the results obtained by the generator with a vibrating disk. The figure (6) and (7) shows the influence of the vibrations on the break-up of the rotating filaments. On the figure (6), without vibration, the distance of break-up is uncertain ; the size of the droplets produced is polydispersed. On the figure (7) the point of ligament fragmentation is mastered, the scattering of the drops is organised and the drops are calibrated perfectly. The figure (8) shows that the size distribution becomes narrower and in the end the produced droplets are monodispersed. In this case the relative standard deviation is $a = \frac{s}{D} = .04$

on the over hand, with the hypothesis that with each period a droplet is formed, the law of conservation of the mass allows to evaluate with great precision the radius of droplets produced (fig. 9).
If T is the period of vibration, Q_v the injected volumetric flow rate to the center of the disk and Z the number of ligaments, the radius of droplets is $R_g = \left[\frac{3Q_v T}{4pZ}\right]^{1/3}$.

The currently developed generator allows to produce droplets of diameters between 50 µm and 1 mm with a relative standard deviation less than 0.1. The flow rate, that is function of the drop size, goes from $0.5\ 10^{-6}$ to $4.0\ 10^{-6}$ m^3/s. The dynamic viscosity goes from 0 to 50 mPas^{-1} and the surface tension goes from 20 to 80 N/m.

Today, the main device which allows to have monodisperse sprays is the vibrating nozzle. The mechanism of ligament break-up and the quality of droplets generated are comparable to the vibrating spinning disk, but it present two important differences :
- the flow rate is greater because of the number of ligaments formed at the edge of the disk (30 to 150 ligaments)
- with the vibrating nozzle, the liquid jets are nearly cylindrical. In monodispersed operating mode, the size of the droplets formed depends

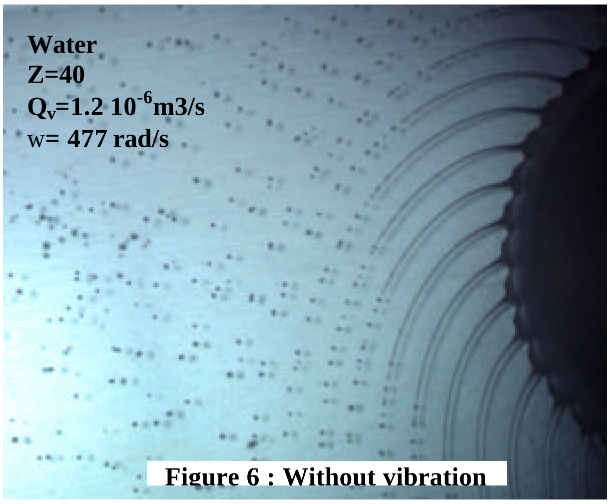

Figure 6 : Without vibration

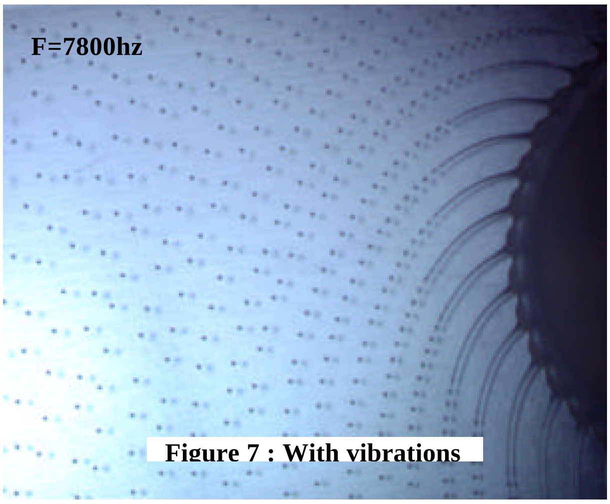

Figure 7 : With vibrations

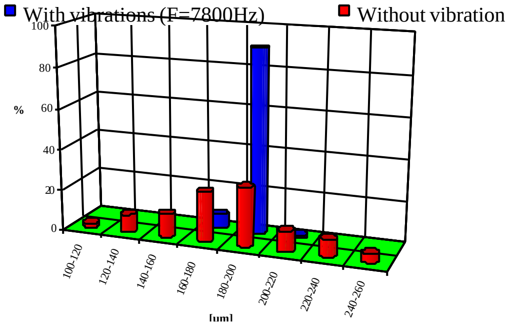

Figure 8 : Size distribution

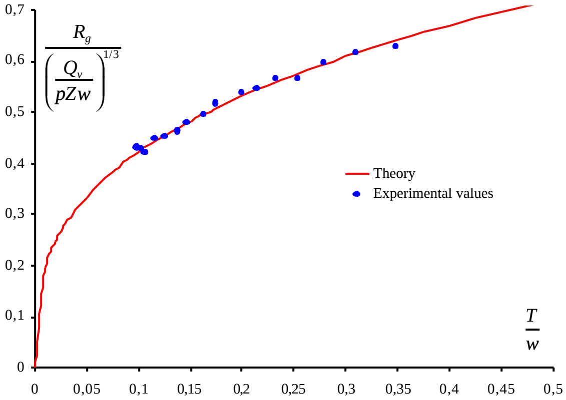

Figure 9 : Radius of droplets prediction

principally of the diameter of the opening but a little bit of the vibration frequency and even less of the magnitude. With a spinning disk, the diameter of the ligaments decrease quickly while moving away from the edge (fig. 4). The break-up distance from the edge of the disk can be modified while varying the magnitude and the frequency of vibration. The size of the spray is largely dependent on diameter of the jet. It is therefore possible to modify the size of the droplets, at the rate of 1 to 6, by simple modification of the adjustments and without changing the disk.

Some comparable results are obtained with small teeth disposed around the edge of the disk. This methodology is very interesting, because it is much simpler to activate, without requiring to vibrate the disk. However it remains limited on the one hand because to a speed of rotation given corresponds a slipping speed and therefore a frequency ; on the other hand because the magnitude of the excitation is bound to the shape of the teeth. This device can only have in advance one point of function for a given speed of rotation and only one size of droplet defined in advance. And also the slip of ligaments is a decreasing function of the viscosity. As a result, the frequency of excitation, equal to the product of the number of teeth by the speed of slip becomes too weak to get monodispersed droplets **[1] [2].**

Conclusion

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