Predictive models for particles size generated by a spinning disk and their transportation.

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Introduction

Quality of encapsulation depends on many chemical factors, and also on the quality of drops that have to be encapsulated. In this way, two factors are important: size and trajectory of drops.

The Fluid and Application team of the Conservatoire National des Arts et Metiers and the company Services pour la Production et la Recherche en Aérosols Industriels – SPRAI have developed together new technological devices which produce monodispersed aerosols with high flow rates and models which can predict both the particle size and their trajectories.

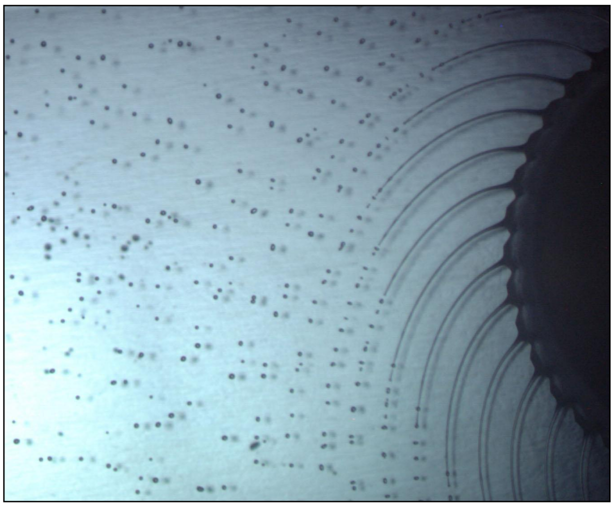

Figure 1: Without vibrations

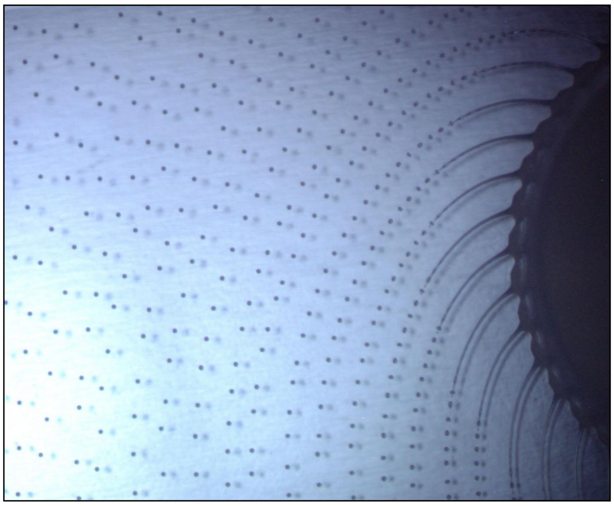

Figure 2: With vibrations

SPRAI technology

SPRAI technology is based on the good knowledge of the spinning disk method. This method is preferred to the nozzle technique, because no pressure is needed, there is no high shear stress in the liquid and no risk of clogging the nozzle. This method also allows to atomize high viscous fluids and in our case to get drops almost all of the same size.

The classical spinning disk

In the spinning disk method, a liquid is injected to the centre of a rotating disk. A liquid film takes form on the disk and can be disintegrated in droplets toward its periphery according to different physical processes. For medium flow rates, ligaments (liquid jet) are uniformly organized around the disk. An instability grows on the ligaments that break up into droplets. As this instability is random and the ligaments are not cylindrical, they cut at different distances from the disk and droplets size is heterogeneous (figure 1).

The rotating disk with vibrations

SPRAI technology is based on an artificial vibration propagating along the ligaments and constraining them to cut all at the same distance of the disk (figure 2). By modifying the vibration properties like amplitude and frequency, it is possible to obtain one mode (monodispersed aerosols), two modes or more (figure 3). Figure 4 gives the size distribution of a spray with a 0.04 relative standard deviation (σ).

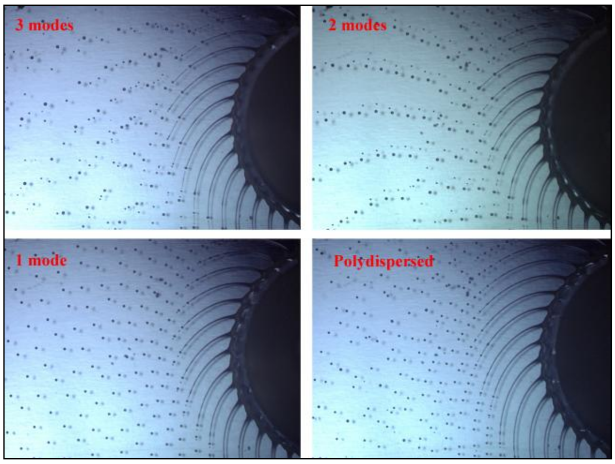

Figure 3: The different modes

SPRAI Models

CNAM and SPRAI have together developed models which predict diameters and trajectories of droplets.

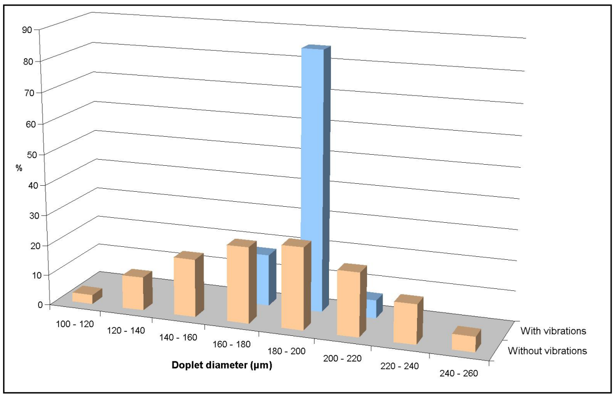

Figure 4: Size distribution

The SPRAI model of atomization

SPRAI model of atomization uses fluid mechanics laws and Rayleigh's laws [3] to predict the flow on the rotating disk and in the ligaments and to explain the amplification of the vibration in these ligaments. The ligament cuts off and forms drops when the vibration amplitude reaches the ligament radius [1] [2].

For a liquid of given density, viscosity and surface tension, the drop diameter depends on flow rate, disk diameter, rotation speed, vibration amplitude and vibration frequency.

If T is the vibration period, Q_v the injected volumetric flow rate to the centre of the disk and Z the number of ligaments, the radius of droplets is given by:

$$R_g = \left(\frac{3Q_v T}{4\pi Z}\right)^{1/3}$$

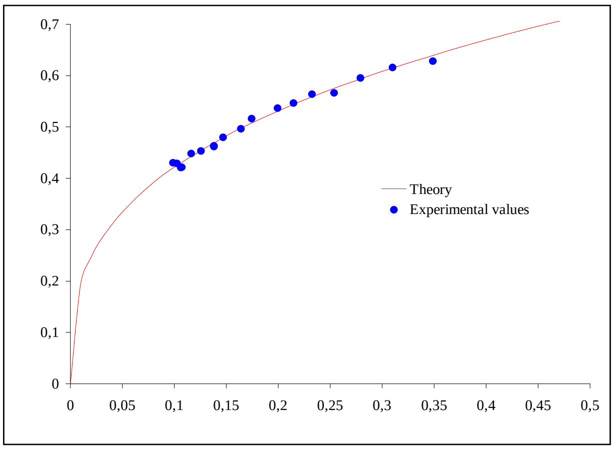

Figure 5: radius of droplet prediction

Figure 5 shows the predicted and experimental radius R_g as a function of the frequency ω and the period T. There is very little difference between the model and the experimental results obtained with our technology. Based on the theory, the droplet size can be changed by applying different frequencies of vibrations.

The SPRAI model of droplets movement

After disintegration of the ligaments, particles are submitted to two forces: the gravity force and the aerodynamic force [4].

The aerodynamic force depends on the air density (ρ_{air}), the master torque of the particle (S_g), the aerodynamic drag factor (C_x) and the relative velocity (V_{ga}) of the particle. Thus the momentum theorem applied to the particle reads:

$$m_g \frac{dV_{ga}}{dt} = -\frac{1}{2}\rho_{air} S_g C_x V_{ga}^2 \overset{\circ}{n} + m_g \overset{\circ}{g} \quad (1)$$

The aerodynamic drag factor depends on the Reynolds number Re. For Re < 0.1, the Stocke's formula can be used to calculate the factor C_x and, for Re < 1 000, the Abraham's formula. When the Reynolds number is greater than 1 000, our own approximation of the aerodynamic drag factor is used.
The system (1) has no analytical solutions. The Rung-Kutta's numerical method is implemented to solve the system and find the particle trajectory.

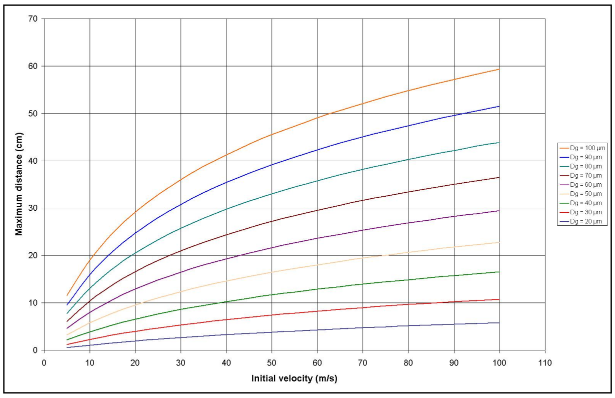

Figure 6: Maximum distance abacus

The analysis of theoretical trajectories allows one to calculate the pulverization area. An abacus (figure 6) can be drawn with the particle diameter, the initial velocity and the maximum distance relatively to the disk centre that the particles reach. This maximum distance increases with particle diameter and initial velocity. The experimental results show that we must overestimate the drag force to be closer to reality. This difference can be explained by the expression of the aerodynamic drag factor. Indeed, in the theoretical study, the expression of this factor for a perfect sphere is used.

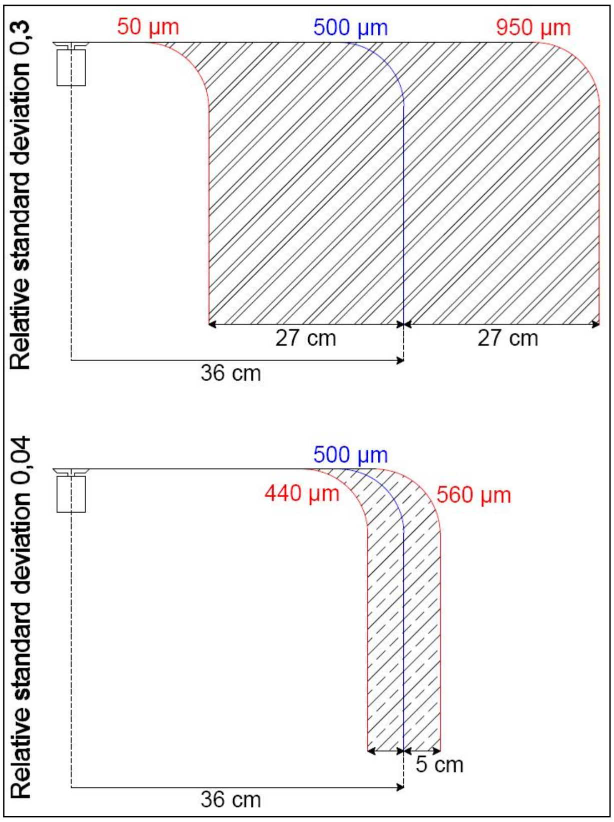

Figure 7: Pulverization areas (± 3σ)

Trajectory knowledge is useful in both powder and encapsulation applications. It allows one to predict the pulverization area that can be modified by an artificial wind. This pulverization area also depends on the relative standard deviation. Figure 7 shows the pulverization area for two relative standard deviations with the same initial conditions (flow rate, initial velocity and average diameter of droplets). The lower the relative standard deviation is, for example with a rotating disk and vibrations, the smaller the pulverization ring is.

In many applications, an artificial wind is added to modify the particle trajectories and to reduce the pulverization area. With the same disc, a smaller rotation velocity is required to generate large particles and high rotation velocity to small particles. In the area close to the disc, the big particles are more easily deviated than the small ones. These phenomena connect to the aerodynamic drag factor that is calculated with the relative velocity and the particle diameter. At the beginning, the relative velocity prevails, the diameter and this velocity is smaller for the large particles that are ejected with a smaller initial velocity ; thus, the aerodynamic drag factor is higher. To move away the disc, the relative velocities of both the small and large particles are almost equal and this is the particle diameter that influences the aerodynamic drag factor.

Conclusion

Monodispersion is a quality factor for aerosol in powders and microcapsules production. It also induces other advantages like energy reduction, facility of the process and protection of environment. The device that we have developed allows dispersal of a quantity of liquid with a flow rate from 50 to 100 times as high as ones that are obtained with the classical vibrating nozzle technique, while producing similar droplet size. To achieve this result, the liquid film shall be disintegrated at the edge in small ligaments artificially excited.

Predictive models for ligament disintegration and for particle trajectories enable better understanding of aerosols behaviour. They are also very useful to calibrate the pilot and industrial installations involved in spray. For example, they allow one to better predict the installation dimensions and the airflow that is needed to modify the trajectories and/or to dry.

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