

EXPERIMENTAL ANALYSIS OF THE DISTRIBUTION OF DROPS IN THE LOW PRESSURE AREA GENERATED BY TWO SPRAY

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ABSTRACT

In order to obtain an appreciable effect of extinction of the heat from a heat source (eg a fire) it is necessary that the water flows are high (20- 30 liters per minute) and the droplet diameters are between 20 and 100 microns. To achieve both of these two features are the nozzles of the type used multi hole and supply pressures exceed 80 bar. In these conditions there are strong interactions between the individual holes that generate particular phenomena such as entrainment's air and the generation of areas where the drops tend to stagnate. To understand the physics of this second phenomenon, in this paper the interaction of two spray is studied. It defines the regions of interaction between the two sprays and then these are characterized using a PDA system.

INTRODUCTION

A spray is generally considered as a system of drops immersed in a gas continuous phase. Most practical atomizers generate drops in the size range from a few micrometers up to around 500 μm . Owing to the heterogeneous nature of the atomization process, the threads and the ligaments formed by the various mechanisms of jet and sheet disintegration vary widely in diameter, and the resulting main drops and satellite drops vary in size correspondingly. Practical atomizers do not produce sprays of uniform drop size at any given operating condition; instead, the spray can be regarded as a spectrum of drop sizes distributed about some arbitrarily defined mean value. In addition to mean drop size, another important parameter of importance in the definition of a spray is the distribution of drop sizes it contains.

A simple method of illustrating the distribution of drop sizes in a spray is to plot a histogram where each ordinate represents the number of droplets whose dimensions fall between the limits $D-\Delta D/2$ and $D+\Delta D/2$. As ΔD is made smaller, the histogram assumes the form of a frequency distribution curve. Because the graphical representation of droplet size distribution is laborious and not easily related to experimental results, many workers have used to replace it with mathematical expressions and their parameters can be obtained from a limited number of drop size measurements. The most widely used expression for drop size distribution is Rosin –Rammler, it may be expressed in the form

$$1-Q = \exp[-(D/X)^q]$$

Where Q is the fraction of the total volume contained in drops of diameter less than D , and X and q are constants that are determined experimentally; the exponent q provides a measure of the spread of drop size. The higher the value of q , the more uniform the spray. If q is infinite, the drops in the

spray are all the same size. For most practical sprays the value of q is between 1.8 and 3.0. From analysis of a considerable drop size data obtained with pressure-swirl nozzles, Risk and Lefebvre rewritten the Rosin-Rammler equation in the form

$$1-Q = \exp[-(\ln D / \ln X)^q]$$

Mean Diameters

In many calculations of mass transfer and spray evaporation it is convenient to work only with mean or average diameters instead of the complete drop size distribution. One of the most common mean diameters is D_{10} [1].

$$D_{10} = \frac{\sum_{i=1}^N D_i}{N}$$

The most important mean diameter for combustion applications is the Sauter mean diameter, which is usually abbreviated to SMD or D_{32} . This diameter is a number used to express the average droplet size in terms of the average ratio of volume to surface area of the droplets:

$$D_{32} = \frac{\sum_{i=1}^N N_i D_i^3}{\sum_{i=1}^N N_i D_i^2}$$

So:

$$D_{ab} = \left[\frac{\sum_{i=1}^N N_i D_i^a}{\sum_{i=1}^N N_i D_i^b} \right]^{1/(a-b)}$$

where i denotes the size range considered, N_i is the number of drops in size range i , and D_i is the middle diameter of size range i . For example, D_{30} is the diameter of a drop whose volume, if multiplied by the number of drops, equals the total volume of the sample.

Characterization Pressure Swirl Atomizers

Pressure swirl atomizers [2] rely on the conversion of pressure into kinetic energy to achieve a high relative velocity of the liquid and the surrounding gas. In pressure swirl atomizer, a swirling motion is also imparted to the liquid so that, under the action of centrifugal force, it spread as a conical sheet as soon as it leaves the orifice. There are two basic types of pressure nozzles. In the first one, the *solid-cone pressure atomizer*, the spray is consists of drops that are distributed fairly uniformly throughout its volume (Figure 1) the second one, the *hollow-cone pressure atomizer*, produces a

hollow-cone spray, in which most of droplets are concentrated at the outer edge of a conical spray pattern. The main drawback of solid-cone nozzle is a coarse atomization, the drops at the center of the spray being larger than those near the periphery. Hollow-cone nozzles provide better atomization and their radial liquid distribution is also preferred for many industrial processes, especially for combustion applications. The simplest design of the hollow-cone nozzle is the simplex atomizer. Liquid is fed into a swirl chamber through tangential ports that give it a high angular velocity, thereby creating an air-cored vortex. The outlet from the swirl chamber is the final orifice, and the rotating liquid flows through this orifice under both axial and radial forces to emerge from the atomizer with the shape of a hollow conical sheet, the actual cone angle being determined by the relative magnitude of the tangential and axial components of exit velocity.

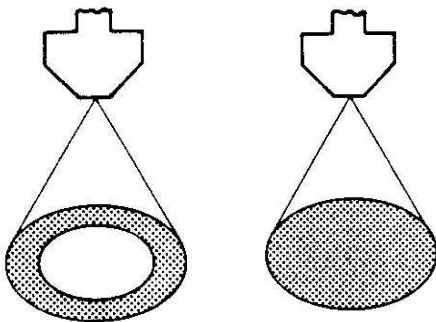


Figure 1- Spray produced by pressure-swirl atomizer: a) hollow cone, b) solid cone

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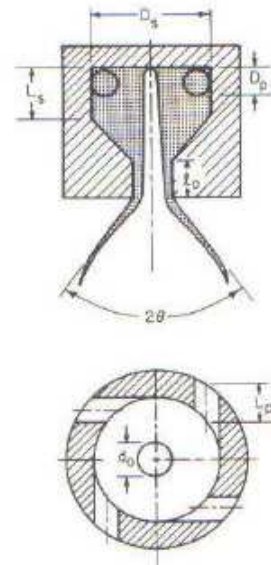


Figure 2 - Schematic view of a simplex swirl nozzle

Since Sauter mean diameter deals with surface area, it is a good way to describe a spray that is to be used for processes involving evaporation. Because of the complexity of the physical phenomena involved in atomization by pressure swirl nozzles, the study of atomization has been performed principally by empirical methods, resulting in correlations for SMD of the following general form:

$$SMD = 2.25 \sigma^{0.25} \mu_L^{0.25} m_L^{0.25} \rho_A^{-0.25} \Delta P_L^{-0.5}$$

where:

σ is the surface tension.

ν is the kinematics viscosity.

m_L is the mass flow rate.

ΔP_L is the injection pressure differential across nozzle.

This formula takes no account of spray angle, which is known to affect mean drop size. To overcome some of the deficiencies of this relation, and to explain some of the apparent anomalies that careful measurements often reveal, Lefebvre has proposed an alternative form equation for the mean drop sizes produced by pressure-swirl atomizers. This equation is not the result of a mathematical treatment of the subject, but is based on considerations of the physical process involved in pressure swirl atomization. Several different mechanisms have been proposed to describe the atomization process, it is generally agreed that the disintegration of a liquid jet or sheet issuing from a nozzle is not caused solely by aerodynamics forces, but must be result of turbulence or other disruptive forces within the liquid itself. These disturbances are very important for the sheet disintegration, especially in the first stage of atomization. Subsequently, the relative velocity between the liquid and the surrounding air has a profound effect on atomization through its influence on the development of waves on the initially smooth surface. Any increase in this velocity causes a reduction in the size of the ligaments that disintegrate and become smaller drops. The process of atomization in pressure swirl atomizer is complex so it is useful to divide it into two main stages. The first

represents the generation of surface instabilities due to the combined effects of hydrodynamic and aerodynamic forces. The second stage is the conversion of surface protuberances into ligaments and then drops.

INTERACTION BETWEEN TWO SINGLE HOLE SPRAY

When droplets are expelled at a high velocity by a spray, a strong vertical air jet is induced throughout which the smallest droplets are dispersed (their Reynolds numbers associated with their relative motion being small). In our analysis we focus on the interaction between quiescent air and this spray jet. The impulsive ejection of the liquid phase is due to the conversion of the pressure energy in kinetic energy causes the pressure reduction close to the boundary layer in the region far from the tip of the spray. The atomizing characteristics investigated in this research include the spray droplet size distribution and behavior out the boundary layer between liquid phase and quiescent air.

The atomizer are used in a lot of industrial field [5] like gas turbine, internal combustion engine, agricultural. In several of these fields the atomizer used are multi hole atomizer. In the fight fighter field a typical multi hole atomizer is shown in the fig 3.

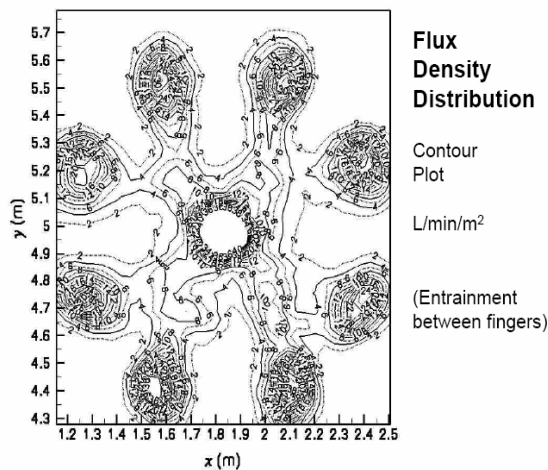


Fig.3 Flux density distribution in a multihole watermist pressure swirl atomizer

The picture represents the flux density distribution and the lines between the central hole and each periferical hole show the presence of regions where the distribution of the droplets depends on the fluidodynamics field created by their interaction.

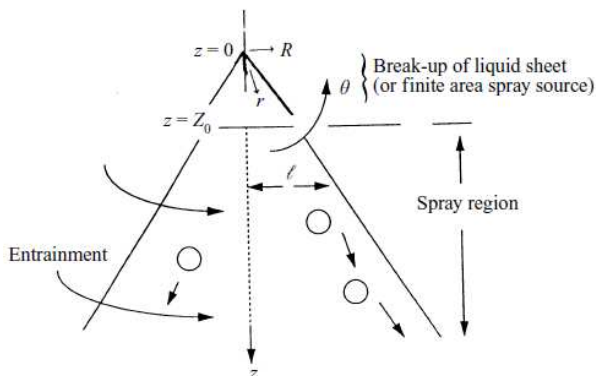


Fig. 4 Gas liquid interaction in the liquid break-up region of Twin-fluid atomization [3]

The figure 3 and 4 shows the dynamic mechanisms respectively theoretical and experimental that arise when a single hole pressure swirl nozzle is used. The liquid film generates a drop of static pressure close to the boundary layer of a liquid phase. In this region it is possible that some droplets detach from the liquid boundary layer and are call back from the external region. If a secondary singlehole exists will arise an interaction between the two sprays. This interaction depends on the the supply pressure of the atomizers and on the distance of the holes.

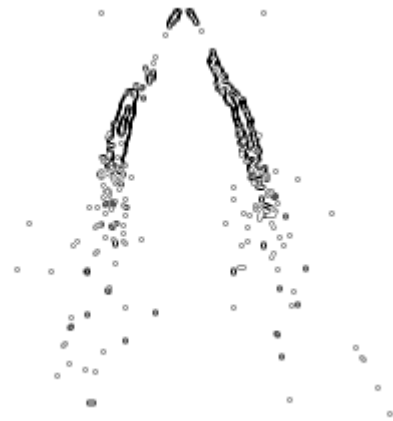


Fig 4. Experimental image of gas liquid interaction in the liquid break-up region of a single hollow cone nozzle

In this paper will be studied and characterized the behavior of the droplets along the regions generated by the fluid dynamics of the interaction of two sprays

EXPERIMENTAL APPARATUS

Two Danfoss pressure swirl atomizer 7 l/min 60° HC 7 bar supply pressure are been used to create the interaction between two sprays like shown in fig.5

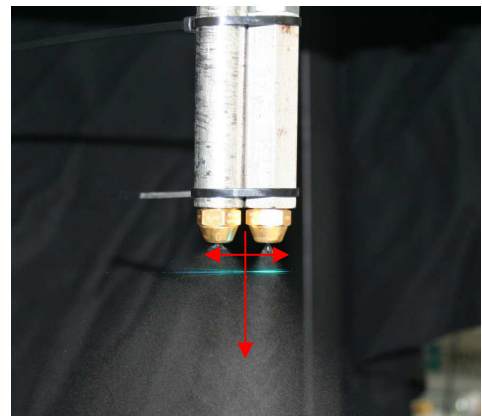


Fig.5 Nozzles interacting

The configuration of the two sprays gives the following schematic distribution of the interaction of the two sprays Fig 6.

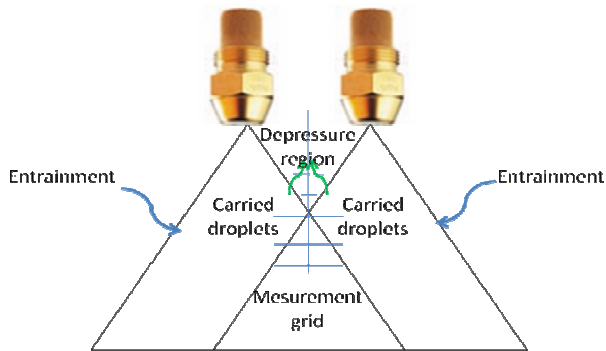


Fig 6. Schematic flow field generated by the interaction of two nozzle

The figure shows that the interaction of two sprays, or two holes of a spray head, creates three region. The first is situated between the two tips of the nozzles and it's called depressure region or empty region. The second region is also called "free zone". In these part of space the nozzle can be analyzed like a single nozzle because the fluxes don't between them . The third region is called "intersection zone" because the overlapping of the two spray. The figure 6 shows also that the grid of the measurements crosses through the all three regions.

Depressure or empty zone.

The depressure zone is far from the tip of the nozzle about 12 mm. This region develops itself along the break-up of liquid sheet length like shown in fig. In this space two phenomena arise. The first phenomenon is due to the interaction of the two phases liquid and gaseous. Close to the tip of the nozzles the energy of pressure is quickly converted in kinetic energy so the liquid injected interacts with the surrounding quiescent gas (air) and the breakup of the ligaments begins. The interaction of the two phases creates, on the their boundary layers, e shear stress and some droplets leave the liquid phase and are callback by the depressure generated between the two nozzles.

Intersection zone

In the intersection zone the droplets generated by the two nozzles interacts among them and can coalesce. In this region we will expect droplets with large diameter due to the interaction o droplets in a low velocity flow field.

Free zone

It is the region where the n behavior of the spray is the same of the single spray.

Devices and Controls

The tests to characterize the droplet distribution are carried out using the apparatus shown in the following figures:

The volumetric Haskel pump has been used to have a constant supply pressure. The volumetric pump is supplied by compressed air in a range of 1-10 bar corresponding to a pressure of the liquid phase of 10-350 bar. In the fig. 7 the air line (supply circuit of the pump) and spray line (supply circuit of the atomizer) are shown.

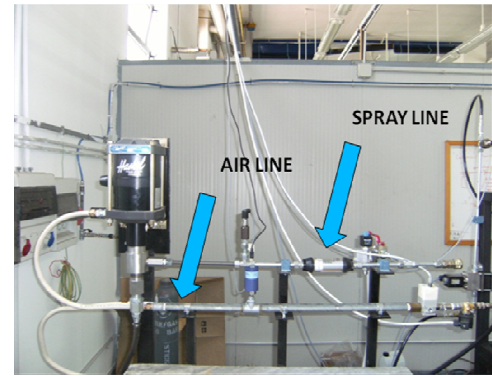


Fig.7 Volumetric pump, air and spray line

The test bench and it's sensors are controlled by a data acquisition system. The fig. 8 shows the control panel designed in Labview language

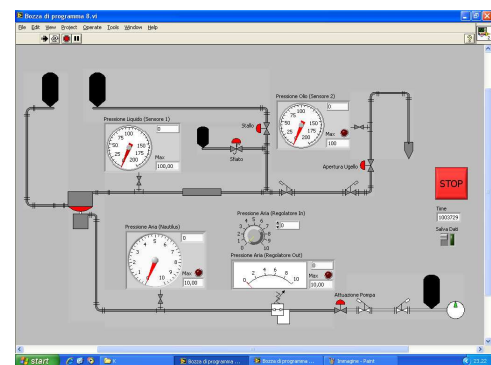


Fig. 9 Remote control panel and data acquisition system

The atomizer is set up on a vertical test stand which allows the atomizer itself to translate both in vertical and horizontal directions relative to a fixed. control volume to within 0.1 mm, in order to make the measurement possible in several points in the vertical plane. Liquid, coming from a storage tank, and it is vertically injected into the environment.

Droplet sizes and velocities as well as drop concentration have been measured by two component phase Doppler anemometer [7] [8] [9][10] [11][12][14] The latter is composed of a Ar- ion laser, as a light source, and a PDA system (Dantec) which includes a Bragg cell, transmitter and receiver probes, and BSA flow to analyze the signals and to acquire the interested output quantities. As said previously, the Bragg cell is used to shift the Doppler frequency, in particular the frequency imposed is 40 kHz. The focal length is 310 mm. The laser power was typically 25 mW per beam. The laser beams wavelength is 514.5 nm and 488 nm, for the vertical and horizontal component of the velocity measurement, respectively. Drop sizes assuming spherical particles have been measured in first order refraction.

RESULTS AND CONCLUSIONS

The measurements start from the centre of the two nozzle and move in horizontal and vertical direction. The first valid line of the measurement is the one where the geometrical and spherical validation [14] of the PDA was realized . The validation limit has been chosen when the droplets processed by the PDA were about 30.000. In fig. 9 is represented the D10 [4] [15][16] diameter along the entire field of measurements. On the x axis the zero point represents the

origin of the coordinates like shown in fig.5. The colored lines represent the distance from the tip of the nozzles. The fig. 10 represents instead the SMD. It is possible to divide the diagram in three diagrams representing the three regions, empty, intersection and free zone

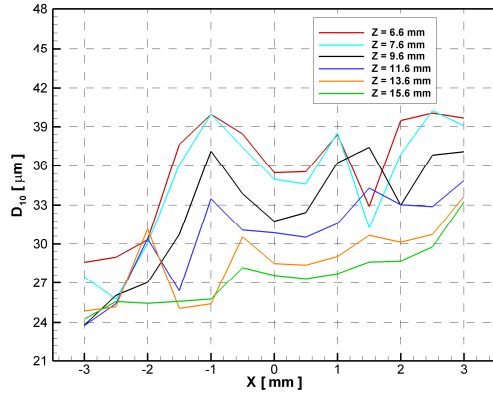


Fig. 9 Representation of the mean diameter to several radial and axial coordinates

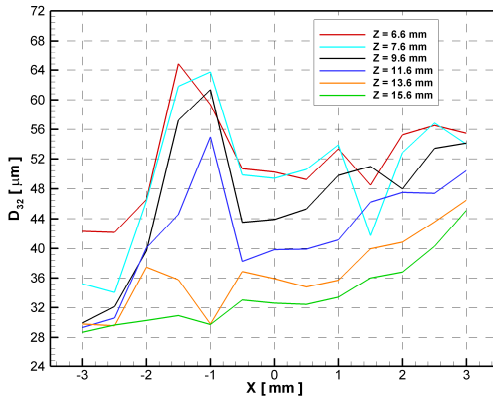


Fig. 10 Representation of the SMD to several radial and axial coordinates

The figure11 represents the characterization of the empty zone only. It shows that in the empty zone are present some droplets coming from the boundary layer of the two atomizers. In particular the diagram shoe the trend represented by the dashed line. The dashed line represents the D_{10} of a perfect symmetrical position of the two sprays.

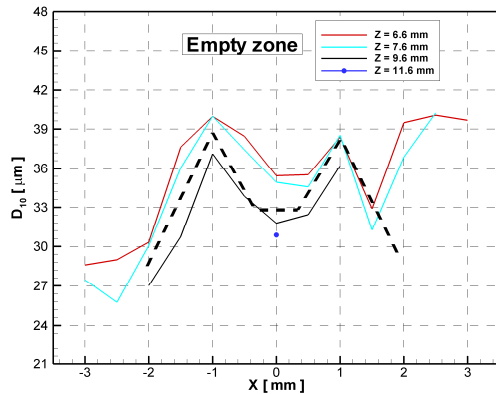


Fig. 11 Representation of the mean diameter to several radial and axial coordinates in the empty region

The value of the common mean diameter is low close to the boundary layer and it increase along the horizontal direction and achieves a minimum on the 0 point of the x axis. This trend is the same for each distance from the y axis.

In fig the trend of the D_{32} is represented. Also in this diagram the SMD diameters increase coming from the gas liquid interface and achieves a maximum before of the $x=0$. In this point all the D_{32} distributions achieve a minimum and then have another maximum going to the other gas liquid interface.

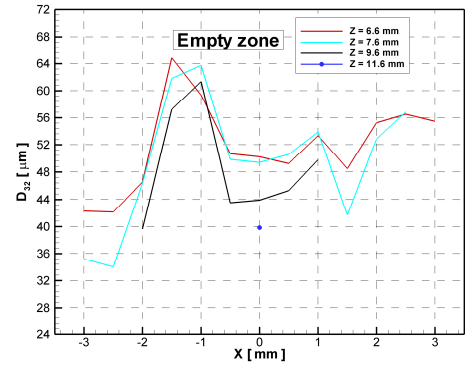


Fig. 12 Representation of the SMD to several radial and axial coordinates in the empty region

The measurements done and the related diagrams have put in evidence that the empty zone interacts with the two spray and in the region between the two spray arises a “fog” due to the callback of the droplets from the gas liquid interface that has kept suspended by the depressure inside the empty zone.

These statements are supported by the following diagrams where the volume fraction distribution is represented.

The fig 13 shows the volume fraction distribution of the droplets in the empty region measured in the three points, $x = -1,5$ mm, $x=0$ mm, $x=1.5$ mm and far from the tip of the nozzles 7,6 mm. This distribution show that most of the droplets have a diameter between 55 and 100 μm and only few small droplets (10-15 μm).

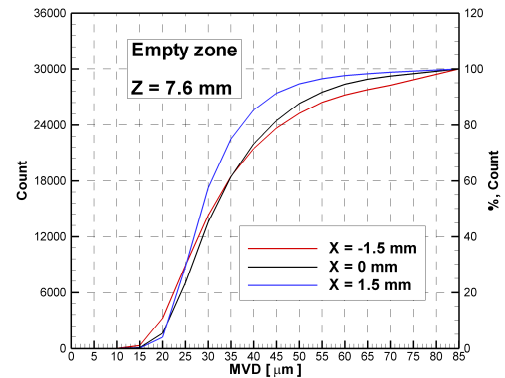


Fig. 13 Volume fraction distribution in the empty region

It is interesting to compare the distribution of drops of the empty region with that of the other two regions defined in the publication. The fig.14 shows the MVD inside the free region that is the same distribution of a single spray.

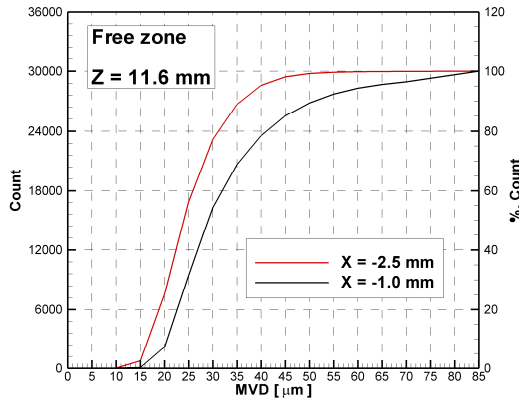


Fig. 14 Volume fraction distribution in the free region

The diagram shows that at $x=2,5\text{mm}$ the most of the droplets has a diameter between 50 and 80 μm . The following picture represent the volume fraction inside the intersection zone.

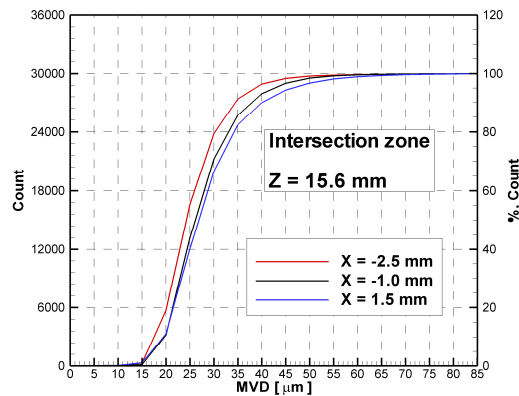


Fig. 15 Volume fraction distribution in the intersection region

It is interesting to note that the, in this case, volume fraction distribution is quite independent of the radial coordinate. The most of the droplets has a diameter between 50 and 85 μm . This is due mainly to the exchange of momentum and to the phenomenon of coalescence among the droplets.

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