Measuring local Drop Size in atomized Suspensions using Laser Diffraction Spectroscopy

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Abstract
A suspension of in water dispersed glass spheres is atomized using a twin-fluid atomizer. The drop size in the spray is measured by means of Laser Diffraction Spectroscopy (LDS) for various particle sizes and concentrations. LDS provides mean values of the drop size along the entire laser beam. Processing the LDS-data with a tomographic algorithm provides information about the local drop size in the spray.

Introduction

Twin-fluid atomizers are commonly used for spray drying applications. The pre-heated suspension of liquid and particles is mixed with gas and then atomized. The critical mass flow rate is achieved in the exit cross section of the atomizer. Due to the pressure drop upon leaving the nozzle, the temperature exceeds the saturation point and the liquid component evaporates. The produced particles form a powder. The drop size of the spray has a major influence on the particle size of the produced powder.

In a previous experiment Lörcher [1] measured that the drop size profile in water sprays is inhomogeneous but axially symmetric.

The aim of this work is to measure the local drop size in an atomized suspension. The main dependencies between drop size, particle concentration and particle size in the suspension are investigated. This leads to a better understanding of the atomization process of suspensions using twin-fluid atomizers.

Experimental setup

For the conducted experiments a pressurized suspension consisting of water and glass spheres (Ø 40-80 µm and 70-110 µm) is atomized by a twin-fluid atomizer. A photo and a microscope picture of the particles is shown in Figure **1**.

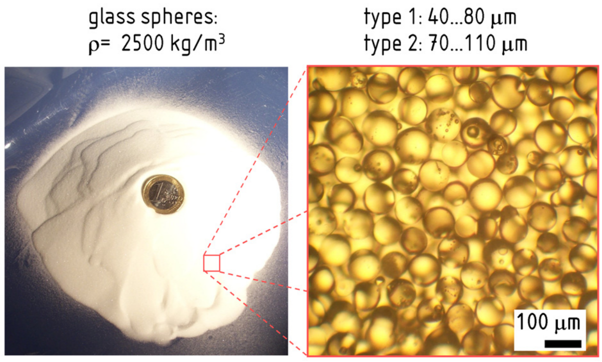

Figure 1: Glass spheres used as particles in the suspension

The gaseous component, added inside the atomizer, is air. For measuring the drop-size in the spray of non transparent drops the Laser Diffraction Spectroscope (LDS) "Helos Magic Vario" manufactured by Sympatec GmbH is used. The laser beam of the LDS crosses the spray and the drop size is calculated from the diffraction signal. Figure **2** shows the optical setup at the test rig. The atomizer is located above the optical measurement device and can be positioned relatively to it. This permits measuring at different locations in the spray.

The flow sheet of the test rig and a sketch of the atomizer is depicted in Figure **3**. The nozzle is fed from a stirred tank which holds the pressurized suspension and the pressurized gas. Flux, temperature and pressure are measured for both suspension and air. The particle concentration in the suspension is also measured.

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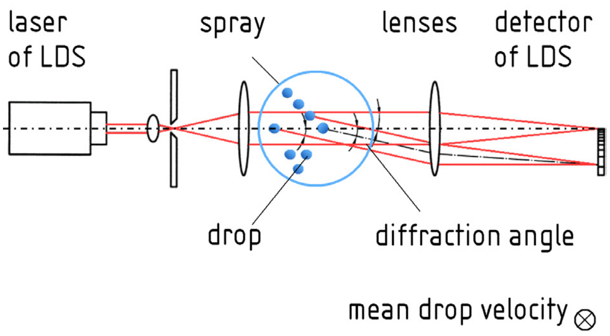

Figure 2: Optical setup at the atomizing test rig

The suspension is fed axially into the mixing chamber (Ø 5 mm) of the atomizer. The gas is then dispersed in the suspension through radial holes (Ø 0.5 mm). In the cone of the atomizer the flow accelerates and exits through the orifice (Ø 1.5 mm). The spray is oriented vertically downwards into a surrounding at ambient pressure. The operating conditions are kept stationary during the measurement.

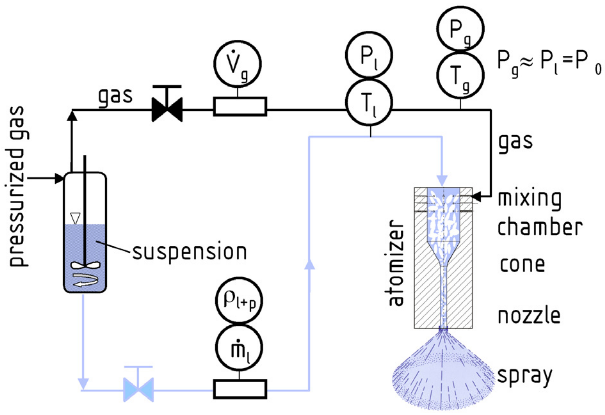

Figure 3: Flow sheet of the test rig and sketch of the atomizer

In order to measure the drop size the laser of the LDS is send along a horizontal cross section of the spray at different positions. In consequent steps of 1 mm the cross section is scanned. Figure 4 gives an overview of the way the measurements are taken. Two results are produced from each measurement: The particle size distribution as a probability density function (PDF) and the transmittance of the laser beam crossing the spray.

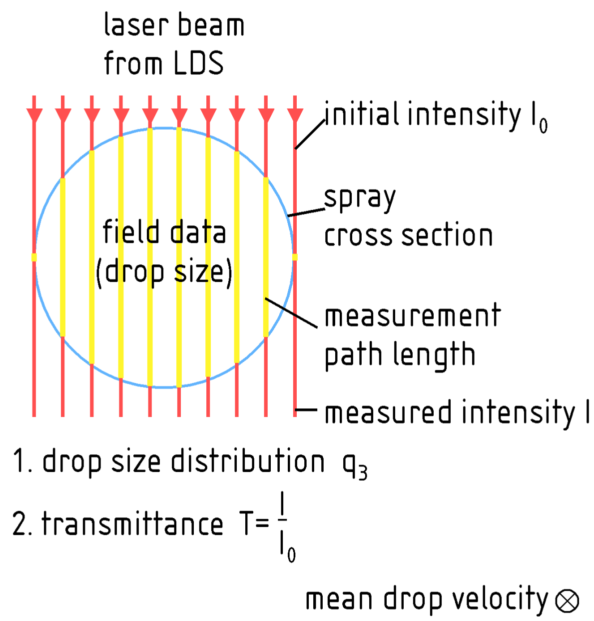

Figure 4: LDS scan of a spray cross section

Combined with the radial position of the measurement this set of results serve as input to the tomographic reconstruction. Tomographic reconstruction techniques allow to calculate local data from a set of integral measurements.

Tomographic Reconstruction

For all tomographic reconstructions it is necessary to have a summed up signal of the measured value, the integral data. The basics of various tomographic techniques are described by Reinecke [2]. According to Swithenbank [3] LDS provides the mean drop size distribution along the beam path, but not about the absolute drop concentrations. These are necessary to calculate integral data from the measured PDF's. Boeck [4] describes a method to calculate the volumetric concentration of drops crossing a laser beam. Using the Lambert-Beer's law

$$\ln T = -c_V \; A_V \; L$$

the volumetric concentration c_v can be calculated from the transmittance T, knowing the volumetric scattering area A_v and the path length L. The volumetric scattering area is calculated according to

$$A_V = \frac{3}{2} \sum_{i=1}^{k} K_i \; d_i^{-1} \; q_3\left(d_i\right) \Delta d_i$$

where i is the diameter-class index, k the number of classes, Δd the diameter-class width, d the drop diameter, q_3 the PDF and K the extinction coefficient. The extinction coefficient is calculated from the Mie-theory with a software code by Bohren [5].

Each measured PDF is multiplied with its corresponding volumetric concentration. The results are equivalent to absolute volume concentrations of drops in their classes. They are integral data and can be used for tomographic reconstruction.

The described procedure leads to integral of the data in the measurement plane only for one direction. For tomography at least three directions are necessary for reconstruction except for axially symmetric fields. In such a case the Abel Inversion can be used to reconstruct the profile across the field from integral data of only one direction.

Pretzler [6] describes the algorithm and discusses possible errors due to asymmetry. Hipp [7] implemented the Abel Inversion along with other tomographic techniques into a software code that is used in this work.

After the Abel Inversion is completed one diameter-class at time for the whole cross section for all diameter classes the local PDFs are reassembled. The Sauter-Mean-Diameter (SMD) is calculated for each PDF and gives the SMD-profile across the center of the spra.

Results and Discussion

For all experiments the pressure in the atomizer's entrance cross section is $6{,}5 \cdot 10^5$ MPa and the gas-liquid ratio is 0.51. The previously described atomizer is used in all experiments and the drop size is measured at a distance of 50 mm downstream from the nozzle exit. The diameter of the measured cross section is 30 mm which was found to capture all drops. For the LDS a measurement range of drop size from 0.5 µm to 875 µm is chosen. The temperature of all fluids is 20°C.

In order to apply the Abel Inversion the spray needs to be axially symmetric. A reproducibility is also essential for the use of the LDS-Tomography. Therefore the same spray is measured four times across the whole cross section. In Figure 5 the mean value of the transmittance is shown as a function of the absolute value of the radial position in the cross section. The transmittance of laser light is high at the spray borders and reaches a minimum of 0.36 for the beam crossing the center of the spray. Between 4 mm and 13 mm the transmittance rises roughly linearly and approaches for higher radial positions 0.81. The standard deviation for the transmittance is generally low and minimal in the center of the spray. The transmittance for the 1st and 2nd quadrant match well.

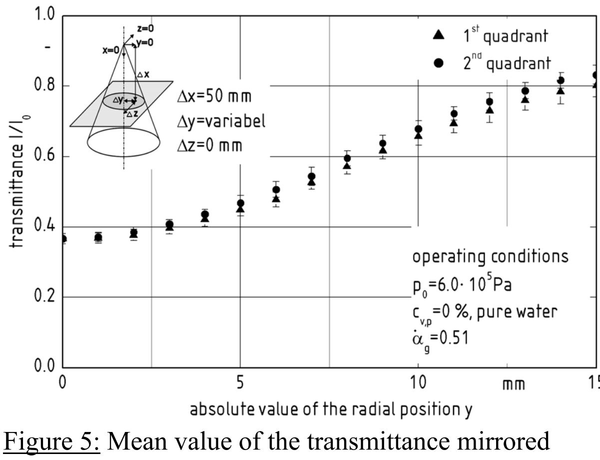

Figure 5: Mean value of the transmittance mirrored across the y-axis for four measurements

From the profile of the transmittance shown in Figure 5 and as expected the spray is most dense in the center. For high radial positions the transmittance does not reach 1 because very fine drops are traveling all around the spray. This off-set in laser absorption due to mist is corrected.

The small standard deviations and the small differences between the 1st and 2nd quadrant indicate that the measurements in the spray are not only reproducible but the spray is also axially symmetric. This is a requirement for the applicability of the Abel Inversion.

Figure **6** compares the integral Sauter mean diameter which is measured with the LDS and the tomographically reconstructed profile of local drop diameter through the center of a water spray. As expected the values at the border of the spray match very well. For the integral as well as for the tomographically reconstructed diameter the maximum drop sizes are in the center of the spray. The tomographically reconstructed diameter is in the center of the spray about 80 µm and it is higher than the integral diameter.

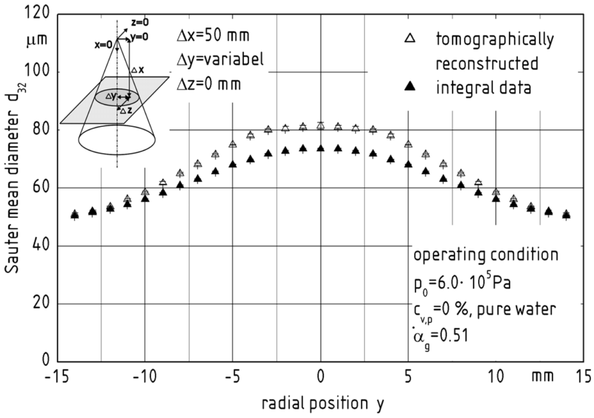

Figure 6: Integral data compared to tomographically reconstructed data for a water spray

Comparing the tomographically reconstructed drop diameter with the integral ones it is reasonable to have similar values at the border of the spray. This is because the measurements at the border of the spray have a very small measurement volume as depicted in Figure 4. The drop sizes measured there are almost the local ones. The higher diameters in the center for the reconstructed diameter are also reasonable. In the center of the spray generally bigger drops are to be found. The local drop sizes have to be bigger then the ones from the integral data because the integral diameter represents a mean value along the whole measurement volume. This volume includes both the bigger drops in the center and the small drops at the border of the spray.

Experiments with two different particle sizes (40-80 µm and 70-110 µm) at a concentration of 10% by volume in the suspension are also carried out. The measurements with no particles and with two different particle size ranges are shown in Figure 7.

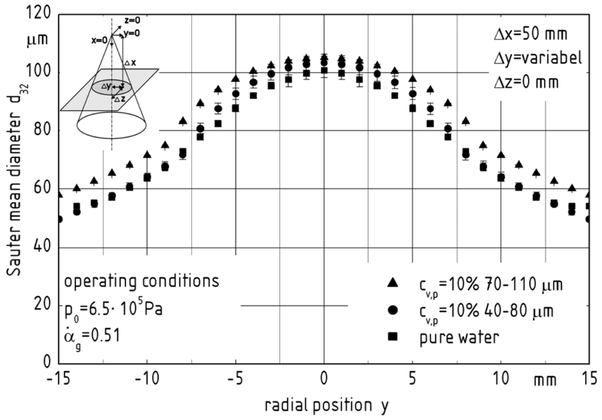

Figure 7: Sauter mean diameter for a pure water, particles of 40-80 µm and 70-110 µm in diameter

The influence of the particles on the drop diameter can be derived from the measurements presented in Figure 7. Compared to the radial differences in drop size the influence of particle load and size is relatively small. The rising diameter for a 10% by volume particle load can be explained by a higher stability of the jet. This influences the breakup. Bigger drops for bigger particles occur because the glass spheres are carrying a liquid layer. So the measured drops are bigger with bigger particles.

Conclusions

In the experiments a spray created by a twin-fluid atomizer is investigated concerning the local drop size. The liquid fed into the atomizer is a suspension consisting of water and two types of glass spheres. The gas is air.

The drop size in sprays consisting of non transparent drops can be measured by means of a Laser Diffraction Spectroscopy. The measured drop size distribution together with the transmittance of the laser light serves as input to a tomographic reconstruction algorithm. This allows to calculate local drop sizes.

The presented measurements show a good reproducibility and proof to be sufficiently of axial symmetry for the applied tomographic algorithm. The transmittance of laser light in the center of the spray is as expected at its minimum.

A particle laden liquid produces bigger drops compared to pure water. Also bigger particles lead to bigger drops in the spray. For all particle loads investigated the drop size profiles display a maximum in the center of the spray.

Acknowledgements

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Notation

c	[-]	volumetric concentration
d	[µm]	diameter
I	[-]	intensity
K	[-]	extinction coefficient
k	[-]	number of diameter classes
L	[m]	length
$\dot{m}$	[kg/s]	mass flow rate
p	[MPa]	pressure
q_3	[1/µm]	probability density function
T	[°C, -]	temperature, transmittance
$\dot{V}$	[m^3/s]	volumetric flow rate
x,y,z	[mm]	position in the spray
α	[-]	void-faction
ρ	[kg/m^3]	density

Subscripts

0	input of the atomizer, initial intensity
g	gas
i	diameter-class number
l	liquid
p	particles
v	volumetric

References

[1] M. Lörcher, Zerstäuben von zweiphasigen Gemischen aus Flüssigkeiten und Gasen, *VDI Fortschritt-Berichte*, vol. 3, issue 764, 2003

[2] N. Reinecke, G. Petritsch, D. Schmitz, D. Mewes, Tomographic measurement techniques - Visualization of multiphase flows; *Chem. Eng. Technol.* vol. 20 issue 1, pp. 15-26, 1998

[3] J. Swithenbank, J. M. Beer, D. S. Taylor, D. Abbot, G. C. McCreath,, A Laser Diagnostic Technique for the Measurement of Droplet and Particle Size Distributions, AIAA 14th Aerospace Science Meeting, pp. 76-69 1976

[4] T. Boeck, Entwicklung eines Photometrischen On-Line Oberflächen-messverfahrens für trockene, disperse Feststoffe, Fakultät für Bergbau, Hüttenwesen und Maschinenwesen, Technische Universität Clausthal, Clausthal, pp. 21-37 and pp. 43-62, 1983

[5] C. F. Bohren, D. R. Huffman, Absorption and Scattering of Light by Small Particles; Wiley, New York 1983

[6] G. Pretzler, H. Jäger, H. Philipp, J. Woisetschläger, Comparison of Different Methods of Abel Inversion Using Computer Simulated and Experimental Side-On Data, *Z. Naturforsch.*, vol. 47, issue: a, pp. 955-970, 1992

[7] M. Hipp, P. Reiterer, User Manual for IDEA 1.7 – Software for Interferometrical Data Evaluation; Institut für Experimental Physik, Technische Universität Graz, Graz, pp 64-65, 1999