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Mapping the structure of a liquid spray by means of neural networks

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Abstract

This paper presents the results of a study aimed at mapping the structure of a liquid spray system along the spray cone. Experimental results obtained by phase-Doppler anemometry (PDA) consisted of the number distributions of droplet size, velocity, and interparticle arrival time at different locations within the spray cone. The experimental data were analyzed by means of multivariate statistical techniques, in order to identify different regimes in the spray. Neural network models (NN) were fitted to the experimental data, resulting in good agreement between experimental and calculated results for most locations within the spray cone. However, in some parts of the cone the agreement was poor, and the general trends could not be well predicted by the NN models. The mismatch is due to unsteady spray conditions or incomplete atomization (e.g. existence of non-spherical particles). This fact was adopted as a criterion to identify the regions where the spray is fully established, corresponding to the regions of the spray where PDA measurements can be successfully performed. This criterion has been applied along the spray cone for different operating conditions, and can be used as a tool to map the fluid dynamic characteristics in liquid sprays.

Keywords: Spray process; Multiphase flow; Particle measurement; Neural network modeling

1. Introduction

Knowledge about the structure of liquid sprays is a key factor in the development of spray processes, which find important applications in several industrial sectors, as well as in agriculture and environment protection. Properties like droplet size distribution (DSD), droplet velocity distribution (DVD), and droplet concentration are determining variables in heat and mass transfer processes and affect the efficiency of spray systems in all applications. Liquid droplet formation from nozzles can take place by different processes, depending on fluid properties, nozzle geometry, and operating conditions. However, there is no generally accepted model that can be used to predict the spray characteristics, and, for this reason, the design of spray systems normally is based on existing experience, involving the use of empirical correlations developed for specific sets of conditions (nozzle type, fluid properties, fluid flow rate, pressure and temperature). The characteristics of fluid flow from nozzles can be estimated, e.g., by using diagrams that correlate dimensionless relevant entities like Weber and Ohnesorge numbers. Examples of such correlations, as well as a collection of empirical and semi-empirical correlations to estimate mean droplet size from these dimensionless numbers are presented, e.g., by Walzel [1], Bayvel and Orzechowski [2] and Lefebvre [3].

The development of phase-Doppler anemometry (PDA) about 20 years ago has enabled the attainment of important information on the structure of sprays. Even though, there is still some controversy regarding the limitations of the method and the conditions for obtaining unbiased results (see, for example, Gillandt et al. [4] or Albrecht et al. [5]) the technique has been adopted by a number of researchers interested in studying the distribution of key characteristics of spray systems along the spray volume.

In this study experimental results consisting of PDA-based measurements were used in mapping the flow structure of a liquid atomization system using a static nozzle. The experimental data were used in the fitting of a neural network model to simulate the structure of the spray system, based on the velocity, droplet size, and interparticle arrival time distributions. A criterion is proposed to detect limiting conditions for existence of correctly detectable (spherical) droplets based on the deviation between NN model-predicted values and experimental values of

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the measured variables (i.e. the boundary for ligament disintegration), which corresponds to the limit of application of PDA measurements in the system.

2. Experimental

The laboratory spray setup is shown in Fig. 1. It consists of a reservoir with a volume of 15 l that supplies liquid (water) to the spray nozzle. In order to prevent influences of pressure variations from the liquid supply system, the liquid is supplied at a constant pressure from the reservoir. This is accomplished by connecting the reservoir to an air supply operating at controlled pressure. A laboratory scale pressure atomizer (Spraying Systems, Type: SS650017) with an equivalent nozzle exit diameter of 0.28 mm, generating a flat jet profile was used in the experiments. Fig. 2 shows front and side views of the resulting spray cone. By operating the atomizer system at different values of the supply pressure leading to different liquid mass flow rates, different spray characteristics are achieved.

A phase-Doppler anemometer system (PDA) was used to perform measurements at the various axial and radial positions in the spray (Fig. 3). PDA is a laser-optical measurement technique for simultaneous measurement of particle velocities and sizes. The method is based on the detection of light scattered by an individual particle in its path through the interference volume of two intersecting laser beams. Detailed descriptions of the PDA methodology are presented in the literature (e.g. Bauckhage [6], Gillandt et al. [4], and Aísa et al. [7]. The system was used in the collection of data concerning droplet size, velocity, and arrival time. The evaluation of the PDA data took place in post-processing mode, where first the complete signal was continuously recorded and afterwards the evaluation concerning the measured particle velocity, diameter and arrival time was performed offline by signal evaluation in the frequency space. In relation to conventional on-line evaluation, this method has the advantage that much more particles can be validated, even at low signal-to-noise ratios. The PDA as shown in Fig. 3 was set up in forward scattering or refractive mode with the receiver positioned at 30° from the transmitter axis. The collimating lens focal length was 700 mm, and the transmitting lens focal length was 1200 mm. The information obtained by the treatment of data generated by the phase-Doppler anemometer are the distributions of droplet size, droplet velocity and interparticle (interdroplet) arrival time at a certain location in the spray.

The experiments were carried out at liquid pressures ranging from 3 to 5 bar. PDA measurements were performed in the near

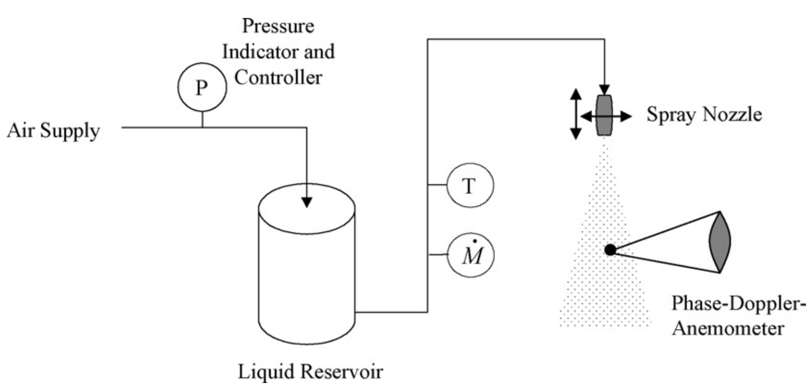

Fig. 1. Simplified scheme of the laboratory spray setup.

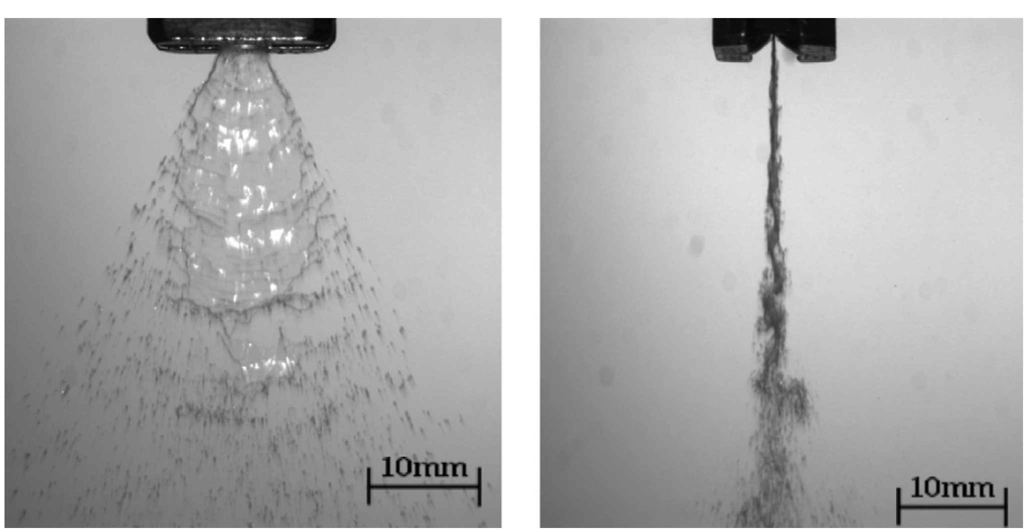

Fig. 2. Front and side views of the spray cone (operating pressure at the nozzle: 5 bar).