Methodology for Assessing Spray Droplet Diameter Distributions

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Abstract: *The nature of the SPCE phenomenon and the possibility to employ it for analysis of fluids are discussed. The droplet diameter distribution function and its properties are presented as a means to describe a spray qualitatively and quantitatively. A methodology that can be used to assess it is also presented and experimental results from an investigation conducted in our laboratory are given.*

Key words: *spray, surface photo charge effect, droplet diameter distribution*

INTRODUCTION

The spray is a multiphase fluid, consisting of dispersed water droplets (discrete phase) in a gas (continuous phase). It can be characterized by its various parameters, such as droplet size, number concentration, charge, chemical composition. Although these parameters are insufficient to fully describe the dynamic behavior of the spray, they affect it to a large extent. For example, the optical properties are highly influenced by the particle composition, shape, size distribution and number concentration. In industrial applications, the efficiency of various filters is also heavily dependent on the properties and behavior of the aerosols. [1] In agriculture, the efficiency of a pesticide spray is determined by its area coverage, which is inversely proportional to droplet size. [2]

The use of high-precision modern instrumentation allows for an accurate and express determination of these parameters, but in most cases the cost of such analyses is not economically beneficial. Therefore, for analyses where great precision is not required, alternative less expensive methods are employed.

SURFACE PHOTO CHARGE EFFECT AND ITS APPLICATION FOR FLUID ANALYSIS

The Surface Photo Charge Effect (SPCE) phenomenon is observed when a solid is illuminated with frequency modulated light. An alternating potential difference is induced between the illuminated solid and another arbitrary solid with constant potential (electrode). The setup is schematically represented in Fig. 1.

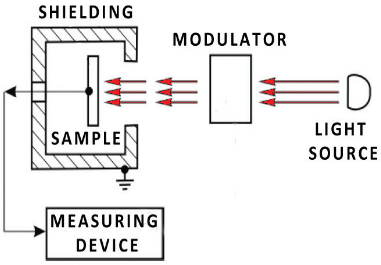

Fig. 1.
Setup for inducing and detecting SPCE-generated signal

It has been proven that the generated voltage is not due to external photoelectric effect by using light with frequency that would not induce the latter. In fact, the SPCE is present only when frequency modulated light is used for the illumination, if non-modulated light is used, there is no potential difference between the two solids. [3]

A very important peculiarity of this effect is that the generated voltage is heavily dependent on the properties of the illuminated solid sample. This makes it possible to analyze different features of the studied sample by observing the change in the SPCE-generated signal. The analysis is fast and contactless, and with a suitable measurement setup, it is possible to analyze liquids and gasses.

Some of the applications of SPCE for analysis include: determination of surface features [4], composition analysis of bricks [5], detection of counterfeit coins [6], investigation of liquids and determination of petrol octane number [7], detection of contaminants in milk [8] and others.

Our current project is engaged with the application of SPCE for analysis of fluids, in particular. Various reports show the possibility to build optical sensors for multiphase fluid analysis, often operating in the infrared region [9]. During our studies we needed to provide means for measuring the parameters of these fluids. In the rest of this paper, a methodology we employed for assessing the droplet diameter distribution is discussed.

THE DROPLET SIZE DISTRIBUTION FUNCTION

The spray contains droplets of different size and cannot be accurately described in terms of a single value. In order to characterize a spray in regard to the size of its droplets, a specific statistical distribution function is employed – the droplet size distribution. [1] As the droplets' shape is roughly spherical it can be defined in terms of their diameter only, and the function is converted to a droplet diameter distribution for convenience. Graphically, the function plots the percentage of droplets as a function of their diameter, usually in the form of a Gaussian distribution. As in a typical distribution function, a maximum can be found, which signifies the droplet mean diameter (DMD).

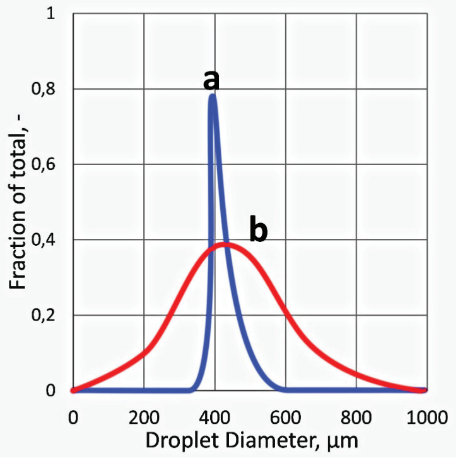

Fig. 2.
Examples of a monodisperse (a) and a polydisperse (b) droplet diameter distribution plots

In regard to the homogeneity of the diameter of droplets present in sprays, the latter can be classified as monodisperse (all droplets have relatively identical diameter) and polydisperse (the droplets' diameter varies in a wide range). The distribution function plot of a monodisperse spray has a sharp peak centered at the distribution mode (the DMD value), while the polydisperse spray's diameter distribution is spread over a wide interval and its peak is not as distinct. Examples of mono- and polydisperse diameter distribution plots are given in Fig. 2.

Sometimes, two maxima may be observed in a spray diameter distribution plot (Fig. 6). Such distributions are called bimodal, and the presence of the second peak, which is found at larger diameter values can be related to droplet coalescence processes.

ASSESSMENT OF THE DROPLET DIAMETER DISTRIBUTION BY ANALYZING SPRAY DEPOSITS

Determination of various fluid properties, and especially multiphase fluid properties is still a serious technological problem as it requires an environment with strictly controlled parameters, which is difficult and expensive to acquire. [10] An article written by Heping Zhu describes a fast, portable method for spray deposition analysis. [2] It is based on measuring the area of stains formed by spray droplets that have settled on a water sensitive layer. When in contact with water, the material that constitutes this layer changes its color and the spot becomes highly contrasting and easily distinguishable. The methodology uses paper strips covered with this water sensitive material. A region of a sample strip that had been exposed to a spray is shown in Fig. 3.

There is a known empirical dependence (1) between the spot area and the diameter of the droplet before it settled. ***d*** represents the droplet diameter and ***A*** – the area of the stain on the paper strip. [2]

$$d = 1.06 * A^{0.455} \tag{1}$$

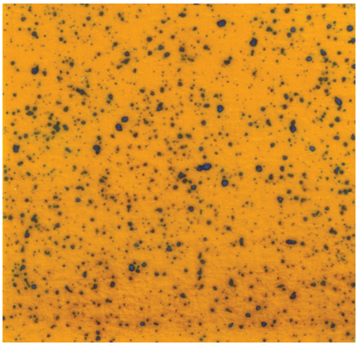

Fig. 3.
Water sensitive paper strip, exposed to a spray.

The stained strips are scanned and the acquired images are analyzed in an image analysis software, Image J. The preprocessing consists of converting the image into 8-bit grayscale mode and then adjusting the threshold by analyzing the contrast levels. The threshold level can also be adjusted manually. The area of each spot is then measured by counting the number of pixels it occupies, and the diameter of the droplet that formed it is calculated from (1).

The authors used a handheld portable business card scanner and a custom developed “Deposit Scan” plugin for the Image J software. The method simplifies and automates the task of analyzing the water sensitive paper strips. The handheld scanner, coupled with a laptop, provides a portable station for spray deposition analysis. The Deposit Scan plugin prompts the user to scan an image, which is then instantly processed and the data is given in a clear form with the option to be exported as an Excel table. A complete list of all the spots found on the image along with their area and the respective droplet diameter is given. [2]

There are two main disadvantages to this method – the lower range is limited and the scanning resolution has a great impact on the accuracy.

The reason for the lower size limitation is that the smallest stain that can be detected on the scanned image will have an area of 1 square pixel (px^2). Even if the actual spot's area is smaller, it will be measured as 1 px^2 by the software which sets the limitation to the diameter of the smallest droplets. Moreover, small droplets are most often detected on the border of several pixels (visual example is given in Fig. 4.), which increases the error by a large factor. Due to this the program algorithm sets the minimum droplet diameter to be the one corresponding to a spot whose area is detected as 4 px^2. Depending on the resolution used when scanning, the actual size of 1 pixel varies, for example, at 1200 dpi (the resolution used by us), 1 px^2 equals approximately 448 μm^2. The minimum droplet diameter calculated via (1) is then equal to 32 μm.

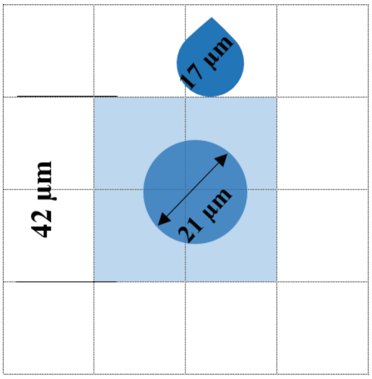

Fig. 4.
Visual representation of the error sources in the method

The decreased accuracy when measuring small droplets is also due to spots, overlapping neighboring pixels, and being measured as larger by the program, which introduces a positive error. Generally, this error decreases at higher scanning resolutions and for larger droplet diameters values the relative error is lower.

EXPERIMENTAL RESULTS

We have acquired a pack of 50 76mm x 52mm water sensitive cards and a set of protective plastic sleeves, which are used to store the cards after exposure to the spray and protect them from moisture. For spraying, we have used several portable trigger sprayers and an electric paint gun with adjustable flow rate.

The paper samples were placed at a fixed distance of 1m from the sprayer nozzle. Several samples were used for each sprayer, but each sample was sprayed only once. After waiting approximately 30 s for the stains to develop on the surface, each piece was placed in a plastic sleeve and scanned with our scanner at a resolution of 1200 dpi.

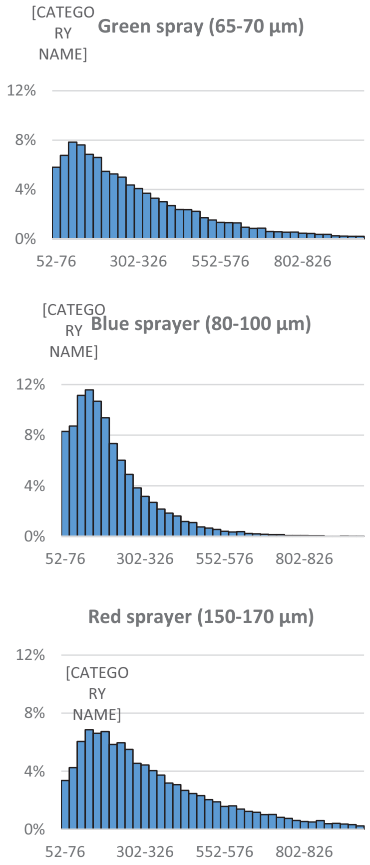

Fig. 5.
Diameter distribution plots of sprayers with constant DMD.

The processing of the results begins with conversion of the image to 8-bit grayscale mode and adjustment of the threshold levels. The automatic counting and measurement of the spot's area is then carried out by the program. The data was exported as an Excel .xls table. For each sprayer, the average size distribution from several sprayings was plotted in discretized mode. The diameter values are in the range 50-1000 µm, where water spray droplets usually belong. Initially, three trigger sprayers with different nozzles were tested. These were claimed to generate identical sprays with DMD in the range 65-70 µm, 80-100 µm and 150-170 µm, respectively (tested during production with a high-precision laser diffraction analyzer). Plots of the diameter distributions we acquired are given in Fig. 5. The size interval of the bins is given on the horizontal axis and the relative frequency – on the vertical axis. The labels above the maxima in the plot signifies the mode bin interval.

The data we acquired relates closely to the size distributions claimed by the manufacturer of the sprayers. The mode value is usually greater than the given for the nozzle. The reason for this positive error is due to the inaccuracy of the method, described above. It can be seen in the diameter distribution of the Red sprayer that as the size of the droplets increases, the measured DMD matches the claimed one. The distribution of the Blue spray nozzle has an exceptionally sharp peak, meaning that the diameter of most of the droplets is close to the mean diameter. The size distributions of the other nozzles have a more polydisperse characteristic.

Fig. 6. shows the droplet diameter distributions of sprays, generated using the paint gun at different flow rate settings. Pure tap water was used as the working liquid at 25%, 50%, 75% and 100% of the maximum flow rate.

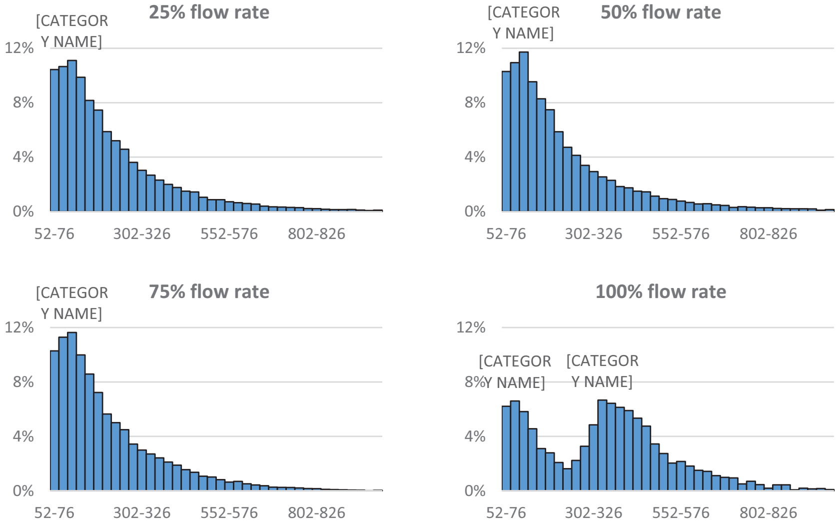

Fig. 6.

Diameter distribution plots of electric paint gun sprays at different flow rates

It can be easily seen that the droplet diameter distribution remains relatively unchanged and the DMD is the same in the first three plots. The difference is that the amount of droplets increases proportionally with the flow rate. When it is increased to its maximum value, the distribution becomes bimodal. This is due to overlapping spots on the sample's surface and droplet mid-flight coalescence, both of which result from the increased number concentration of droplets in the spray.

CONCLUSION

An alternative, simple and low-cost methodology for studying spray droplet diameter distributions has been studied and applied. The materials and apparatus required are water sensitive paper strips, a document scanner and a computer for data acquisition and processing.

The droplet diameter distributions of sprays generated using conventional trigger sprayers and an electric paint gun have been assessed. They provide both qualitative (dispersity of the droplets) and quantitative (droplet mean diameter) information regarding the spray. The droplet mean diameter of the sprays that were generated using portable trigger sprayers, relate closely to the values that were acquired in production testing, using a laser diffraction analyzer. The distribution functions for the sprays generated using the paint gun show that the dispersity and DMD of the sprays generated with it are identical at different settings, while the amount of droplets increases proportionally to the flow rate. At high droplet concentrations the distribution changes due to coalescence and spot overlapping.

Having knowledge regarding the properties of the sprays we generate is of crucial importance for developing an SPCE-based multiphase fluid analysis system. The methodology we have adopted allows us to assess the necessary information easily and at an affordable cost.

ACKNOWLEDGEMENT

This work has been funded by EU FP7 Security program under contract 312804.

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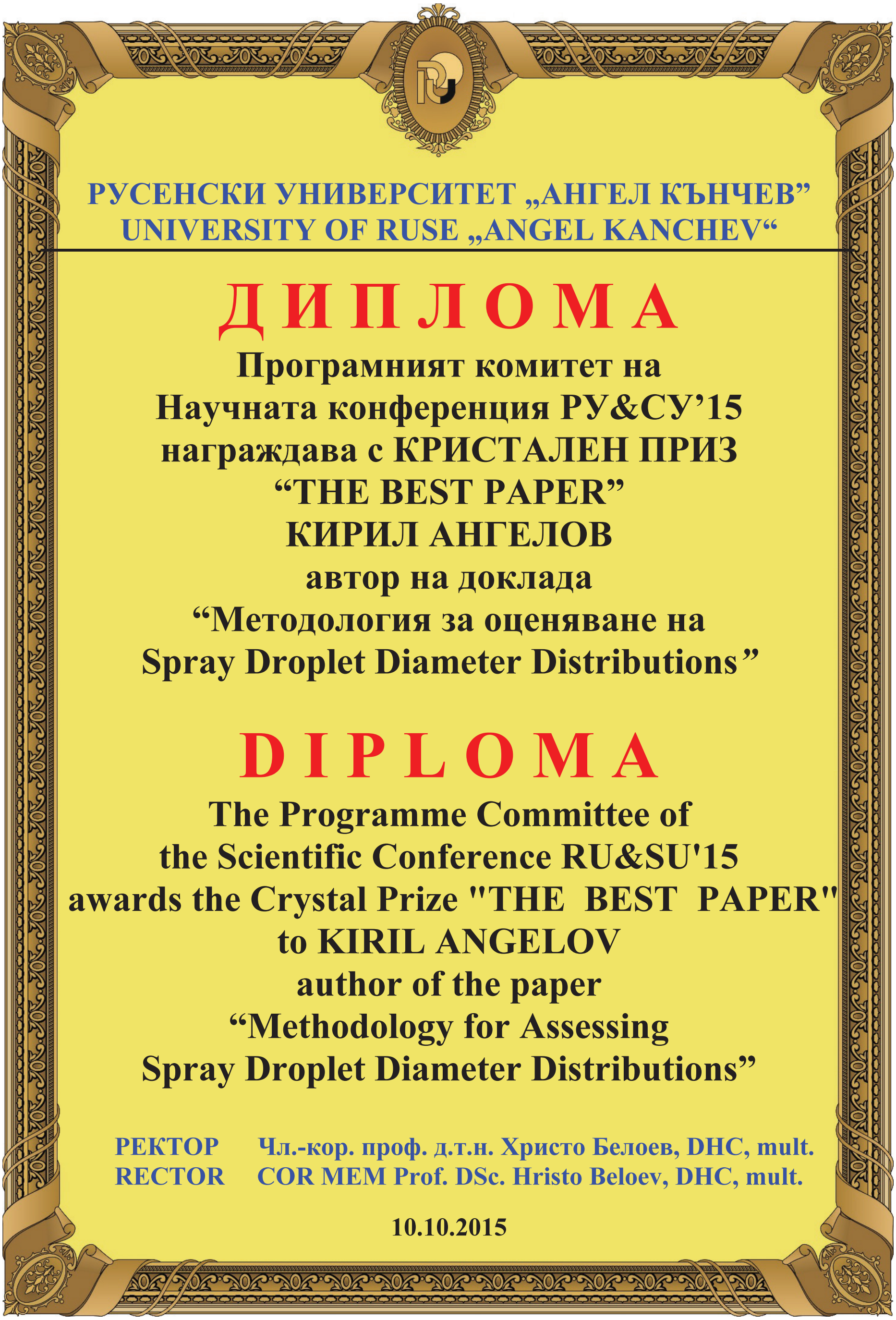

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10.10.2015