AEROSOL GENERATION DEVICES SUITABLE FOR SIMULATING FOGS IN LABORATORY CONDITIONS

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Abstract: The current work is related to development of sensors for contamination detection, and systems, which use fog as a cleaning agent, in order to prevent disasters and accidents, and to help acting against terrorist attacks and weapons of mass destruction. Investigations in laboratory conditions of several types of mist generators are presented. For this purpose, various products, which create aerosols, were researched. The diameter distributions of the droplets, produced by them, were experimentally determined. For development purposes, several simple devices for easy fog generation are chosen. This study is related to the development of sensors for fog with different characteristics. The obtained results allow a proper selection of sprayers to be made, so that the necessary conditions for the development of sensors are ensured.

Keywords: FOG GENERATION, SENSORS, SPRAYER, AEROSOLS, DIAMETER DISTRIBUTION

1. Introduction

The sensors under development are based on the surface photo charge effect (SPCE) [1], [2]. This effect reflects the interaction of any solid with an electromagnetic field, which induces an electric, alternating potential difference with the same frequency as the frequency of the incident field [3]. An important feature of the SPCE is its significant dependence on the specific properties of the irradiated sample. This fact reveals vast opportunities for rapid and contactless analysis of solids, liquids and gasses [4-6].

A laboratory study on fog requires an apparatus, which can generate aerosols with fog-like characteristics and behavior. Consistency and repeatability of the properties of the generated experimental fog are required as well, as they are used for calibration of the sensor components.

Visualization of airflows for fluid mechanics and aerodynamics studies is of crucial importance and one of the most common solutions is to include a fine aerosol (particle tracer) in the airflow [7]. The development of a particle sizing apparatus requires monodisperse aerosols with exact size distribution and concentration to be generated, for proper calibration to be achieved (aerosol standards) [8]. Due to the practical importance, various methods for generating fine aerosols with preset size distribution have been developed [9].

Atomizing nozzles, specially designed for generation of fine aerosols are available and can be used for fog generation. The latter can be done in laboratories to simulate real-life fogs and study them in a controlled environment, such as an isolated chamber (fog chamber) [10], [11].

The property that characterizes an aerosol as a fog is the droplet diameter distribution – the typical mean droplet diameter of fog is less than 100 µm [12]. Aerosols with a mean droplet diameter of less than 10 µm are called dry fogs (dry mist) since droplets of this diameter bounce off a surface when in contact, without wetting it, while droplets with greater diameter splash and wet the surface. Typical fog is usually dry.

Another property, used for characterizing fogs, is the liquid water content (LWC), which is expressed as the mass of water in a volume of 1 cubic meter.

Three distinct stages can be observed during the life cycle of fog. The first stage, formation, involves a gradual increase in the mean droplet diameter and number concentration of the aerosol. The second stage, called maturation, is a relatively stable state of the fog, where the mean diameter and number of droplets remain seemingly unchanged. The final stage, dissipation, is a gradual decrease in the number concentration, while the mean droplet diameter increases, due to droplets merging [13].

2. Atomization methods

Different approaches to aerosolization of fluids exist. According to the methods they use, they can be classified into several categories.

- ***Pneumatic atomization***

This approach uses a combination of gas and liquid; the gas is fed under high pressure through one end of a tube (Fig. 1). So, the pressurized gas creates a low-pressure region at the end of the tube, which is due to the Bernoulli effect, and this draws liquid from a reservoir and into the air stream. Due to the great pressure difference between the gas and the liquid, strong forces arise and cause shearing of the liquid. In such a way, a polydisperse spray is formed, which is ejected through a narrow orifice at the end of the tube.

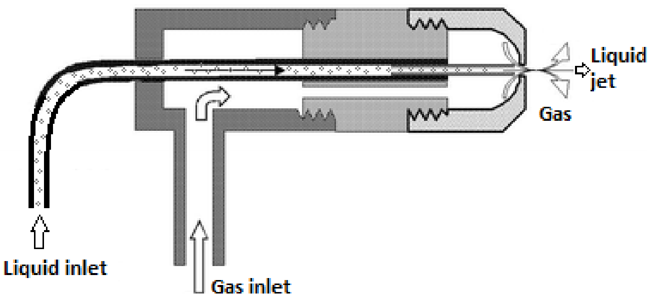

Fig. 1 *A scheme of a pneumatic atomizing nozzle (source: http://pubs.rsc.org/)*

- ***Vibrating orifice atomization***

This approach is based on Rayleigh's studies of laminar flow instabilities. An excitation electric signal is used to generate mechanical deformations in a piezoelectric material, at a frequency proportional to the signal frequency (Fig. 2). The contractions of the piezoelectric material cause an oscillating vertical movement of the orifice plate, which is constrained in the other 2 directions. By selecting the excitation frequency and orifice diameter, the desired droplet diameter with accuracy to a micron can be acquired [8]. The method can also be used to acquire solid particle aerosols by atomizing a solution and providing the conditions, necessary for the solvent to evaporate, leaving solid particles with the required diameter [14]. The aerosol, produced by this method, is a straight stream of uniform droplets, not a fog-like cloud, which renders the method useless for generating artificial fogs. Nevertheless, such precise droplet generators can be used for calibration and study of the dependence of the SPCE signal on the droplet diameter.

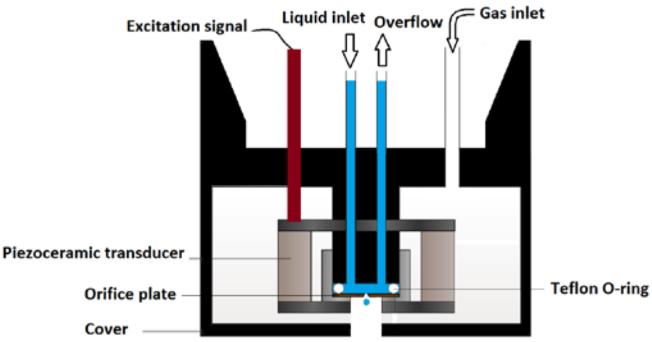

Fig. 2 *A scheme of a vibrating orifice atomizer [3]*

- ***Spinning disc (top) atomization***

This method relies on centrifugal force for production of liquid droplets. A liquid is fed at a slow rate through a hypodermic needle on the top of a disc, or top, which is spinning at a very high speed. The liquid spreads over the disc's surface in an asymmetrical thin film, accumulating at the rim, until the centrifugal force, acting to discharge it, exceeds the capillary force, which holds the liquid together and a droplet is thrown off. The centrifugal force is equal to the product of the mass of the liquid in the drop and the centrifugal acceleration at the rim. The capillary force is proportional to the product of the surface tension of the liquid and the droplet diameter [15]. The scheme of the device is shown in Fig. 3.

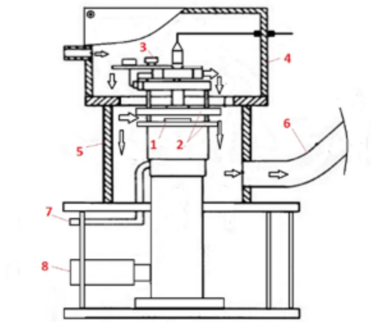

Fig. 3 *Setup scheme of a spinning disc atomizer [16]*
1 - spinning top; 2 - annulus extension rings; 3 - liquid feed needle adjustment mechanism; 4 - top cover and air inlet chamber; 5 - aerosol mixing cylinder; 6 - aerosol transit tube; 7 - compressed air supply; 8 - satellite particle exhaust tube

- ***Ultrasonic atomization***

This technique for producing micron-sized droplets relies on ultrasonic vibration. The mechanical energy, applied from a piezoelectric crystal to the system, agitates the surface of the solution, thereby creating capillary waves, which break up into micron-sized droplets (Fig. 4).

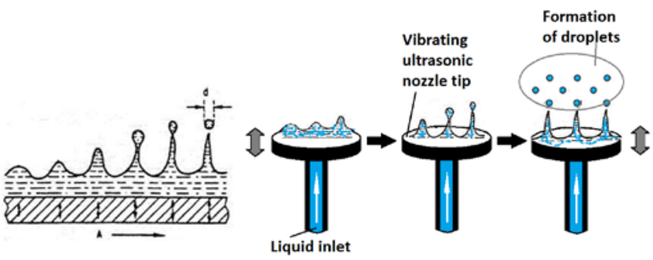

Fig. 4 *– Illustration of the operating principle of a vibrating orifice atomizer*
(sources: www.sono-tek.com ; www.activeultrasonic.com)

A particle-free air stream is passed over the solution to take away the generated airborne particles. The diameter of the primary droplets produced is a function of the frequency of vibration and the physical properties of the solution, i.e. surface tension and density. Compared to pneumatic atomizers, ultrasonic atomizers could produce monodisperse particles at a higher level.

Commercial nebulizers, used for medical purposes, often operate on this principle and are an economical solution. They are alternative means for aerosol generation, as they produce fine, monodisperse aerosols with high repeatability. The mean diameter of droplets, generated with these devices, is usually between 2 and 10 µm.

- ***Electrohydrodynamic atomization***

This method is also called electrospraying and it could produce very fine monodisperse droplets from a liquid, under the influence of electrical forces. By controlling the liquid flow rate and the electrostatic potential between the liquid and the counter electrode, the droplets' diameters could be controlled in a narrow range – from several nanometers up to several micrometers. Different spraying modes can be obtained, depending on the strength of the electric stresses, relative to the surface tension stress on the liquid surface and on the inertia of the liquid leaving the nozzle (Fig. 5).

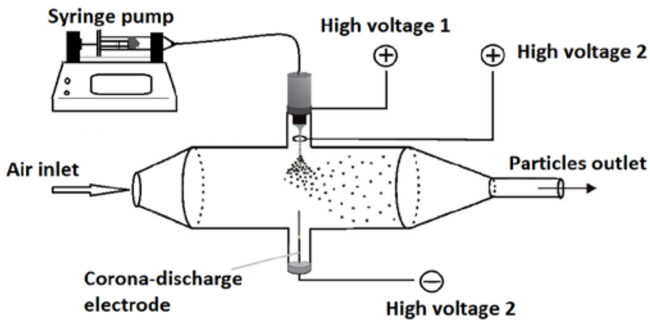

Fig. 5 *Setup scheme of an electro-hydrodynamic sprayer [13]*

- ***Condensation***

In a volume of oversaturated vapour, droplets start to condense spontaneously. The rate of condensation, droplets concentration and size distribution strongly depend on the vapour pressure, the environmental temperature and the presence of condensation nuclei. A precise control over these is required, in order to obtain an aerosol with custom properties, which makes the practical application of this method rather difficult. Theatrical smoke and fog machines often rely on condensation, for example, by introducing vapourized oil droplets as condensation nuclei in a highly humid environment. A major drawback is that the droplets evaporate more quickly in a dry atmosphere [9]. There are two distinct types of aerosol generators, based on the condensation method [15]:

✓ ***Sinclair-LaMer generator*** – in this generator liquid droplets are formed in a narrow size range. It includes a nuclei source, a boiler, a reheater and a cooling chimney. The boiler, which contains a quantity of the material, which is to be aerosolized, is maintained at a constant temperature in the range 100-200°C. The reheater is maintained at a temperature exceeding that of the boiler by an amount, sufficient to ensure the complete vapourization of all aerosol material, which enters it. The nuclei are produced by an electric spark or by heating a wire coated with an inorganic salt, such as sodium chloride. A flow of clean air carries the nuclei into the boiler, where they are mixed with droplets and vapour produced by a second flow of clean air, which has bubbled through the boiler liquid. The droplets are vapourized in the re-heater and finally, the vapour condenses on the nuclei in the Cooling chimney, at a relatively low rate, so the desired monodisperse aerosols are produced.

✓ ***Rapaport-Weinstock generator*** – This generator utilizes a nebulizer in place of a heater, as in the upper case, to generate initially polydisperse aerosols, which subsequently evaporate when passing through a heating column. The aerosol vapour condenses on the residue nuclei in the aerosol material in the cooling column and forms monodisperse aerosols. The substances used for generation of condensation aerosols are: DOP (dioctyl phthalate); esters of sebacic acid; stearic acid; menthol; rosin. These types of generators are mainly used to produce test aerosols for instruments calibration purposes.

In practice, we tried to find the most efficient and economical aerosol generators, in regard to the purpose of our research. Various companies, that produce and sell customized nozzles for industrial applications, were contacted, in order to find a suitable option [18-36].

As mentioned above, medical nebulizers can generate monodisperse aerosols with high repeatability. Their cost is also fairly low, but due to the size distribution of the droplets they produce (mean diameter of 3-4 microns), the lifetime of the droplets in conventional lab environments is pretty short.

3. Measurements of droplet size distributions of selected sprayers

The droplet size distributions of some of these (*Gardena* and *Guala dispensing* trigger sprayers, *FERM* paint gun) have been acquired by an image analysis technique, which uses the *DepositScan* algorithm for *Image J* [37]. The results are given below.

- ***"Gardena" Premium trigger sprayer***

The nozzle of this aerosol generating device can be adjusted to produce different pressures, thus generating various droplet sizes with distinctive density of the aerosols. 4 nozzle settings were tested, in the interval where the spray is a cloud of fine droplets. For each setting, 5 measurements were made, at a fixed range of 1 meter, in order to monitor the repeatability. There were no significant inconsistencies between samples exposed to aerosols, generated at identical nozzle settings.

On the first three graphs (Fig. 5), the accumulation of droplets with the minimum diameter is obvious. We have concluded, that there are many fine droplets with diameters below the minimum one, which is detectable by this technique. Information about the size distribution in this region cannot be acquired with the available equipment. Still, the curve peak is in the detectable area, and it gradually tends to move from 100 µm for the lowest settings (most tightened nozzle) to 200 µm for the lower pressure settings.

The Gardena Premium sprayer can be used to generate aerosols with relatively identical droplet diameter distributions. These are in the range 100-200 µm. A considerable amount of small droplets can also be found at higher pressure settings, but exact information of their diameter cannot be acquired by using the available equipment. By decreasing the pressure (settings 3-4), larger droplets are formed, and the spray has more polydisperse characteristics.

Fig. 5 *Size distribution curves for 4 different nozzle settings of Gardena Premium sprayer. The droplet size in µm is depicted on the abscissa*

- **"Guala Dispensing" TS1 series trigger sprayers**

We have received a free sample of 3 different types of nozzles for sprayers from *Guala Dispensing*. It is claimed, that they were able to generate aerosols with consistent and fixed size distribution. The median droplet diameter claimed was 65-70 µm for the green, 80-100 µm for the blue and 150-170 µm for the red nozzle. We have also tested them, in order to ascertain that the droplet diameter distribution is fixed and relates to the one claimed by the producer. 7 samples have been sprayed using each nozzle, from a fixed distance of 1 meter. The distribution graphs are shown in Fig. 6.

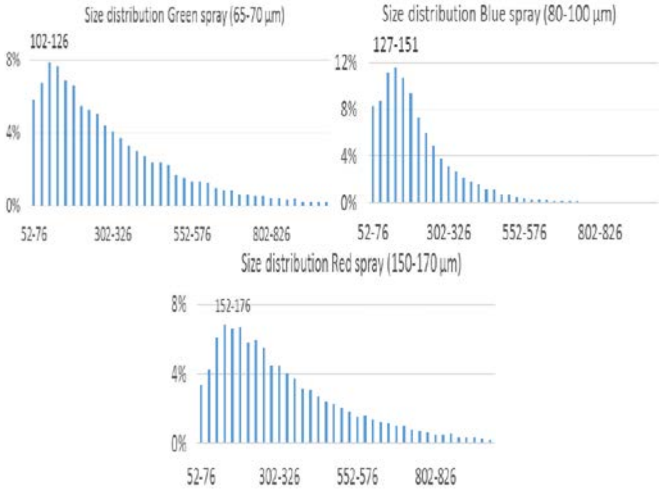

Fig. 6 *Size distributions of different Guala dispensing sprayers. The sizes of droplets in µm are depicted on the abscissa*

The data we acquired relates closely to the size distributions claimed by the company on their website. The curve maximum is usually greater than the given value for the nozzle. This was related to the inaccuracy of the image analysis technique, and the claimed distributions were taken into consideration, as we were informed by a company representative, that a laser diffraction analyzer was used for calibration and production control. Overall, each individual sample had almost identical distribution graph. The distribution of the blue spray nozzle had an exceptionally sharp peak, which means that the droplet diameters were concentrated heavily around the mean diameter. The size distributions of the other nozzles were less precise.

Therefore, we have concluded, that these sprayers can be used to efficiently generate fogs with predetermined and consistent size distributions, as it is claimed in their descriptions.

- ***FERM SGM1008 electric paint gun***

We have also bought an electric paint gun for fog generation. As the pressure, created when pushing the trigger, varies, the droplet diameters may also vary heavily, depending on the force exerted. An automatic paint gun uses an electric pump, which ensures that the operating pressure is identical and constant for each aerosol, and respectfully the diameter distribution fluctuates less. The model, chosen by us, offers the possibility of adjusting the amount of water dispersed. Six different settings were tested, and 5 measurements were taken for each of them.

The size distributions for these aerosols are almost identical, with a sharp peak in the lower values – around 100 µm. The adjustment valve controls the amount of water dispersed, and therefore, the aerosol density is increased at higher number settings, while preserving the diameter relatively constant.

At higher number settings, the spray changes its nature almost instantaneously, which can be seen in the diameter distribution of setting VI, where 2 peaks are observed – one around 100 µm and the other around 350 µm. One possible explanation of this is that as the amount of water increases, droplets merge, thus forming larger ones, in addition to the finely dispersed. This effect is clearly visible.

Other settings have not been tested, due to the formation of even larger droplets in the stream, which are not usually found in fog. The diameter distribution data is shown in Fig. 7.

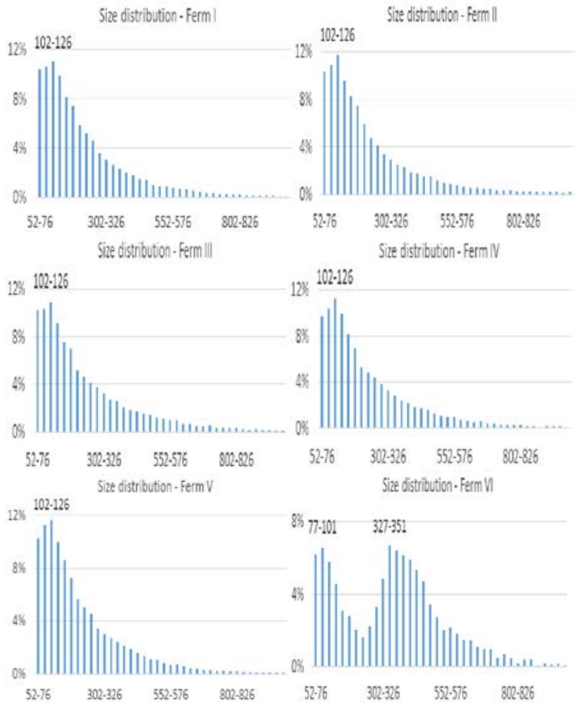

Fig. 7 *Size distributions of sprays generated using the FERM Paint gun. The droplet diameter in μm is depicted on the abscissa*

In summary, it could be concluded, that the FERM paint gun can be effectively used to generate identical aerosols with a dominant droplet diameter in the 100 μm region. At the same time, the number of droplets generated can be controlled via a valve at the back of the gun, which provides a method to test the SPCE signal dependence on fog density.

4. Conclusions

Methods for generating fogs with pre-set droplet diameter have been reviewed. Products of companies that produce such devices were studied. For the initial stage of our work, several simple devices for easy mist generation have been selected. The droplet diameter distributions of the fogs, generated with these devices, were investigated. It was concluded, that they generate fogs with repeatable and controlled droplet diameters.

Acknowledgements

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

Special gratitude to “Guala Dispensing” for the provided free 150 units of trigger sprayers.

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