Contactless Determination of the Number and Diameter of Fog Droplets Using Gravitational Separation and Measurement of Electrical Signals

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Abstract: *A method was developed for contactless evaluation of the number and diameter of droplets in a jet, by means of gravitational separation and measurement of an electrical signal from a laser-induced electromagnetic echo effect (EMEE), at several points of the jet. With it, only with modulated laser radiation, an electrical signal is induced. The measured value of the signal from this EMEE depends on the parameters of the fog (number and sizes of droplets). This signal is measured at several points of the jet, as the droplets must be in laminar flow. After measuring the signal at the first point, the signals at the previous points are subtracted from its value at each subsequent point, in order to separate the measured signal at each point and determine the change in fog parameters. The method represents an affordable and reliable alternative to existing fog characterization techniques.*
Keywords*: FOG PARAMETERS, ELECTROMAGNETIC FIELD-MATTER INTERACTIONS, SENSOR*

1. Introduction

Characterization of airborne particles or droplets is crucial for research in a number of fields, such as air quality research, cloud and fog characterization, cleanroom monitoring, jet research, etc. Nowadays, there are various methods for determining the number and size of particles, including droplets. Some of them use separation to segregate the particles by size, but they are not suitable for the study of droplets, as they are only applicable to solid particles [1]. There are many instruments that use optical methods based on Fraunhofer diffraction and various forms of light scattering (dynamic, static, etc.), such as laser diffraction, to determine the number and spectrum of particle diameter distribution. Optical techniques require specific statistical processing of the results, and they are greatly influenced by the specific statistical method used for the purpose [2]. More modern technologies are based on the use of high-resolution cameras and image analysis, which are also used to determine particle velocities [3]. Other imaging techniques include optical and electron microscopy, holography, and photography. With these methods, the main problem is the overlapping of the particles, they are also quite expensive.

2. Prerequisites for solving the problem

We have developed an alternative method for contactless determination of the number and diameters of droplets in a jet, by means of gravitational separation and measurement of electrical signals from laser-induced electromagnetic echo effect (EMEE), at several points of the jet. The signals are generated using only modulated laser radiation, and their values depend on the fog parameters (number and sizes of droplets). These signals are measured at several points of the jet, in which the droplets are required to be in laminar flow. After measuring the signal at the first point, at each subsequent point the signals obtained at the previous points are subtracted from the measured value, in order to separate the signal at each point and determine the change in fog parameters.

It was experimentally established that during the generation of fog, at a certain distance from the nozzle, the flow of drops is turbulent, after which the flow becomes laminar. It is from this moment on that a gravitational separation of the droplets by size is observed. The largest droplets of the stream fall to the ground first, and the rest continue forward. Then the next largest drops fall, and only the finest droplets reaching the furthest. The presented method and the corresponding device are protected by a patent issued by the Patent Office of the Republic of Bulgaria in 2020 [4].

3. Methodology for non-contact measurement of fog parameters in an artificially generated jet

Consider a small cloud of fog, for which we are interested in the spectrum of the distribution of the diameter d of the drops by the number N_d for each diameter. Let us assume that a force F acts on the cloud in the direction indicated in Fig. 1. Such a force can be created in various ways - for example, by a constant airflow or an electrostatic field. As a result of the acting force, the drops will begin to move in the indicated direction, and at the same time they will also begin to fall. The heaviest drops will travel the shortest way. They will reach point 1. All drops of size up to d_1 will settle there. Accordingly, drops of sizes up to d_2, d_3, d_4, … d_n will reach points 2, 3, 4, etc. We can measure with a suitable instrument the number N_d of drops for each point.

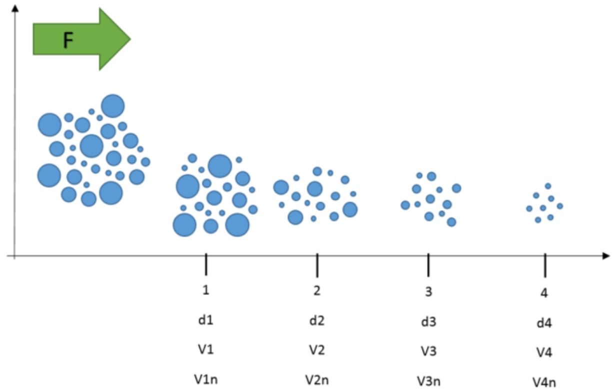

Fig. 1 *Gravitational separation of drops in laminar flow.*

Fog Detector 6 is a device that we developed and through which we implement our method. It works on the basis of EMEE and is very sensitive to the number and diameter of the drops (Fig. 2).

Fig. 2 *Device for measuring the number and diameter of fog drops (Fog Detector 6).*

The idea is to compare the signals it measures at the various points with the results of a laser particle analyzer. In this way, we can calibrate it by the number of drops so that at each point we have a signal proportional to that number. It should be taken into account that in each point there will be an admixture from the number of drops in the following points. To neutralize this additive, we must subtract from the signal at a given point the signal at the next point. Thus, we will obtain an electrical signal that is proportional only to the number of drops that have settled to that point.

For example, through point 1 all the drops from the following points will pass. We will measure a common signal V_{1n}. To obtain a signal V_2 that is proportional only to the number of drops that have settled between points 1 and 2, we must subtract the signal from drops that have passed through point 2 from V_{1n}. In other words, $V_2 = V_{1n} – V_{2n}$. In this way, we obtain information about the number of drops with diameters between d_1 and d_2. The same is repeated for all subsequent intervals. The diameter distribution will appear simultaneously on the display.

4. Experimental setup

To realize the idea, we performed a series of experiments. We used an automated fog generation system and measured the number and diameter of droplets at various distances from its nozzle, with a laser particle size analyzer. Thus, we established the presence of gravitational separation of the drops after the jet has travelled a certain distance from the nozzle in the direction in which it is fired, i.e. when the flow changes from turbulent to laminar. The laminar flow zone is actually also our working zone where we can evaluate droplet separation. We then selected five specific distances from the nozzle at which we made measurements with a laser particle analyzer to determine the actual parameters of the generated fog and thus to be able to calibrate our device Fog Detector 6.

The block diagram of the experimental setup for carrying out the measurements is given in Fig. 3. From a water source (1) water with a pressure of 6 bar is supplied to a nozzle (4), and the fog generation is carried out on pulses set by a control module (3). , which controls a solenoid valve (2). The produced jet passes through several Fog Detector 6 devices, consisting of an emitter (5) and a receiver (6), located along the jet. The measured signals from the electromagnetic echo effect at these several points are passed through a preamplifier (7) and transmitted to a measuring module EMEE Meter 1 developed by us. It forwards the detected values of signal amplitudes to a VLC-1 amplifier (9), after which they reach a processing and visualization module (10).

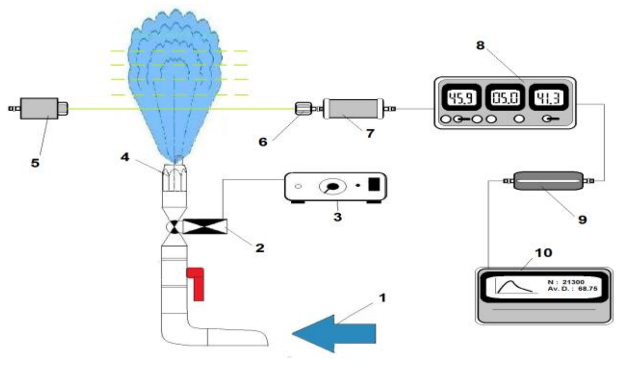

Fig. 3 Block diagram of the fog generation system, measurement and visualization of its parameters: 1. water source (6 bar); 2. electromagnetic valve; 3. device for setting the duration of fog generation; 4. atomizing nozzle; 5. laser module; 6. sensor; 7. preamplifier; 8. measuring module (EMEE Meter 1); 9. amplifier (VLC-1); 10. signal processing and visualization module.

5. Experimental results

We conducted measurements with several nozzles from the company BETE Fog Nozzle, Inc. (http://www.bete.com). Here we present the results of the P40 nozzle (with an orifice diameter of 1.07 mm). We experimentally found that the working area for the mist generation system starts at 120 cm from the nozzle, i.e. at this distance the droplet flow becomes laminar. We selected five points at 140, 160, 180, 200, and 220 cm from the nozzle, respectively, and measured the average droplet size with a laser particle analyzer. For each distance, 100 measurements were taken within 100 seconds, which were then averaged. The results of these measurements are given in Fig. 4. The average droplet diameters for these distances are 69.415, 67.283, 61.156, 60.780 and 53.509 μm, respectively.

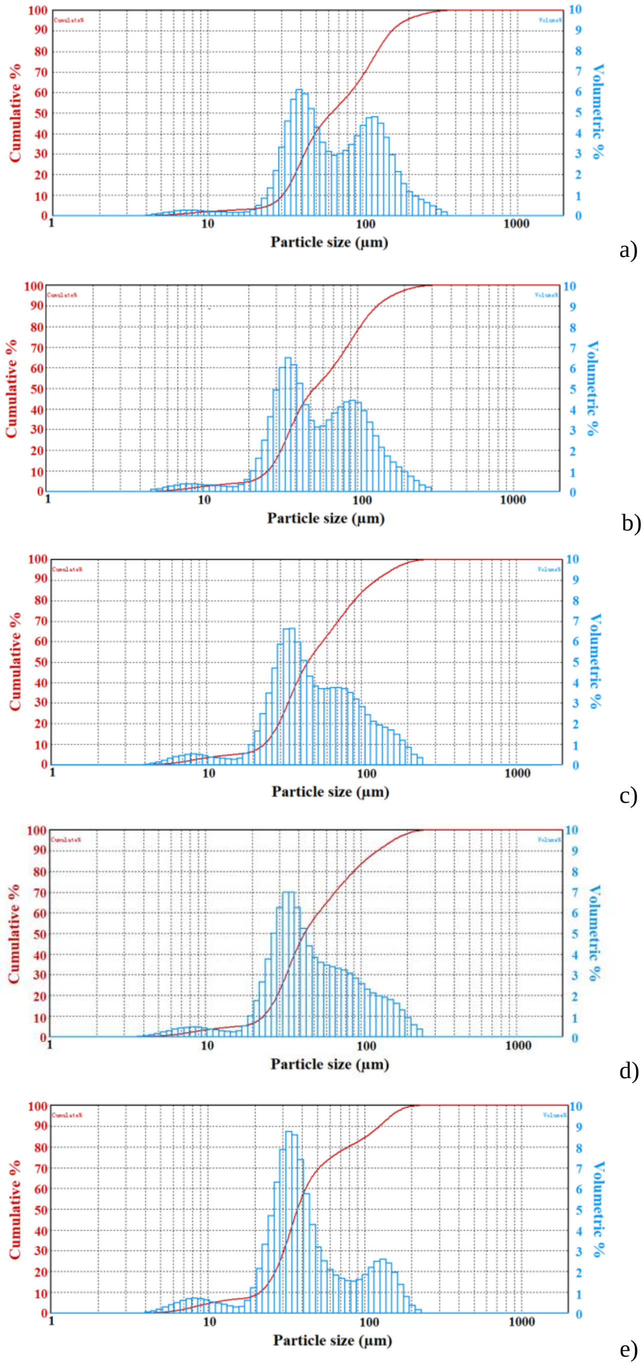

Fig. 4 Droplet diameter distributions produced by nozzle P40 at distances: a) 140 cm; b) 160 cm; c) 180 cm; d) 200 cm; e) 220 cm.

A decrease in mean as well as maximum measured droplet diameter was observed as the distance from the nozzle increased. For the aforementioned distances, it is 354.020, 297.890, 250.660, 229.932 and 193.476 μm, respectively (Fig. 5).

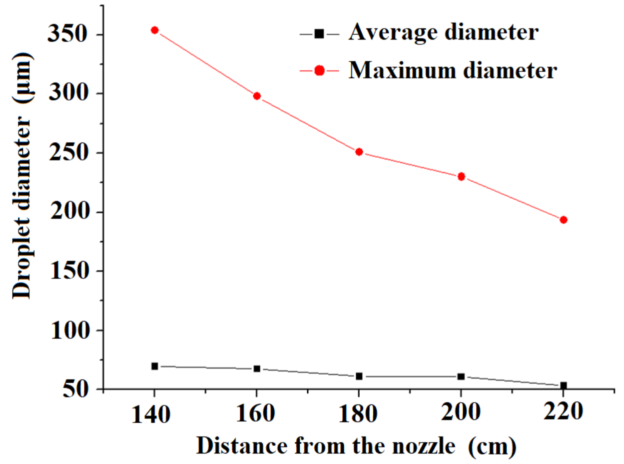

Fig. 5 *Average and maximum diameter of fog drops as a function of distance from the nozzle.*

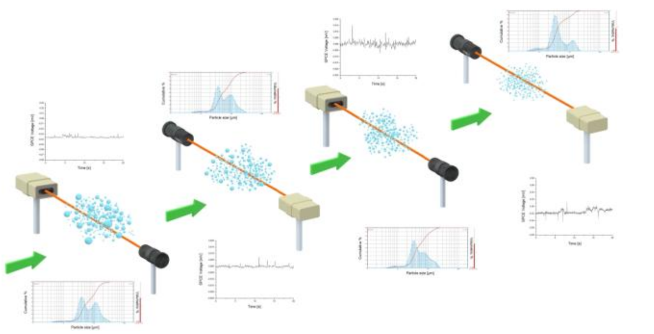

Fig. 6 *Visualization of the method for non-contact measurement of fog parameters by matching EMEE signals with laser particle size analyzer results.*

6. Conclusion

The results confirm the presence of drop size separation at distances greater than 120 cm from the nozzle. It can be concluded that it is quite possible to calibrate our Fog Detector 6 device in each of the five points using the results of the laser analyzer. In fact, a real implementation of non-contact drop measurement involves several such devices located at each point (Fig. 6). As the fog cloud moves from one point to the next, the drops begin to fall under their own weight. Naturally, at first the largest fall, at the next point the next largest, and thus a division by size is obtained. The second point, for example, will be missing the drops that fell between the first and second points. Accordingly, the signal must change. This change gives us the number of drops of that diameter. The difference in the processed signals between the individual points corresponds to the changes in the size distribution.

The advantages of the method include high accuracy, quick access to results and the possibility of real-time measurements, without the need for complex equipment. Research on this development continues to improve the devices and optimize their operation.

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References

[1] I. G. Droppo, Filtration in Particle Size Analysis, In book: *Encyclopedia of Analytical Chemistry: Applications, Theory and Instrumentation*, R. A. Meyers and R. B. Flippen (Eds.), (2006) doi:10.1002/9780470027318.a1506

[2] S. Andrews, D. Nover, G. Schladow, Using laser diffraction data to obtain accurate particle size distributions: the role of particle composition, *Limnology and Oceanography Methods*, **8**(10), 507-526 (2010) doi:10.4319/lom.2010.8.507

[3] H. Chen, H. Tang, Y. Liu, H. Wang, G. Liu, Measurement of particle size based on digital imaging technique, *Journal of Hydrodynamics*, **25**(2), 242-248 (2013) doi:10.1016/S1001-6058(13)60359-5

[4] O. Ivanov, P. Todorov, J. L. Pérez-Díaz, Non-contact determination of the number and diameter of fog drops, by means of gravitational separation and measurement of electrical signals, patent No. 67164 B1, Patent Office of Republic of Bulgaria (issued on 10.12.2020)