Bulgarian Chemical Communications, Volume 50, Issue 1, (pp. 89 –93) 2018

Laboratory system for artificial fog generation with controlled number and size distribution of droplets

O. D. Ivanov[1*], Y. I. Ralev[1], P. V. Todorov[1], I. P. Popov[1], K. N. Angelov[1], J. L. Pérez-Díaz [2], M. K. Kuneva[1]

[1] *Georgi Nadjakov Institute of Solid State Physics, Bulgarian Academy of Sciences, 72 Tzarigradsko Chaussee blvd., 1784 Sofia, Bulgaria*

[2] *Universidad de Alcalá, EPS, Campus externo N-II km 33,600, Alcalá de Henares 28805, Spain*

Received September 26, 2017; Accepted October 31, 2017

In this article a system for generation of fogs is presented, which can be used in testing equipment and experiments that require control of the amount and size distribution of aerosol particles. The main goal of the system development is to eliminate the human error and to improve the results on producing artificial fog with predictable parameters.

Key words: artificial fog, spraying techniques, droplet size distribution, aerosols

INTRODUCTION

Fog is an aggregation of microscopic water droplets, spread in the air. The average size of natural fog droplets is of about 10-15 μm, but can vary between 1 and 100 μm. According to the droplet size distribution, fogs could be divided in two main groups: composed of relatively small droplets – few microns in diameter (typical for radiation fogs) and composed of bigger droplets – above 45 μm in many cases (typical for advection fog). Fog is widely used as a cleaning agent for contaminated areas in a number of applications: industrial processing, defense, aerospace, automotive, (e.g. corrosion test chambers and salt fog cabinets), power generation, telecommunications, for medical purposes (e.g. nebulizers), etc. These applications require precise control on the amount and properties of the used fog. Further research for gaining the required insight into fog formation and dynamics is needed in order to develop different devices such as fog sensing elements (sensors), etc.

For the development, testing and calibration of fog sensors based on the SPCE (surface photo-charge effect) [1] a specialized installation for producing artificial fog under laboratory conditions is needed. The process of natural fog formation involves a number of physical processes (thermo-dynamic and microphysical ones) which cannot be completely reproduced in a laboratory environment. The main problem in the case of artificial fog generation is to produce droplets of desired amount and size distribution to simulate fogs with parameters close to those of the natural ones. Such setups have been developed in the industry, in cases when different features of spray nozzles had to be investigated [2]. For example, numerous scientific papers exist, in which the variation in the size distribution of droplets was experimentally determined [3-5]. In these studies, the fluid pressure of nozzles and the proportion of fluids were varied [4, 5]. Various methods for fog generation have been reported - vibro-acoustic and acoustic generators for aerosols [6], vortex sprayers [7], pneumatic nozzles [8], electro-sprayers [9], and others. In a number of studies the relationship between the geometrical features of nozzles and the amount and size of the droplets they produce, is analyzed [9-11]. Since the size distribution and the droplets number density are the most important parameters of fog, they play a crucial role in the investigation and the development of fog sensors. Therefore, for the purpose of fog sensors development, a flexible system is needed, which allows to precisely control the number density and the size distribution of the droplets, as well as to be capable of generating droplets with predefined parameters. During our literature and market survey, we could not find any existing system satisfying all our experimental requirements. The main requirements to fog simulator for our sensor tests include: (i) producing fogs with controllable number density and size distribution of droplets and (ii) producing fogs with variable and controllable chemical composition. The second one will be a subject of a separate paper.

* To whom all correspondence should be sent.
E-mail: ogi124@yahoo.com

EXPERIMENTAL SETUP OF THE AUTOMATED SYSTEM FOR FOG GENERATION

Since controlling the number density and the diameter distribution of the droplets is the main requirement to a system for producing artificial fog, the first part of the setup designed by us and described here is intended to provide control on these parameters. The main parts of our setup are the fog generation unit (Fig. 1A) and the control unit (Fig.1B).

A

B

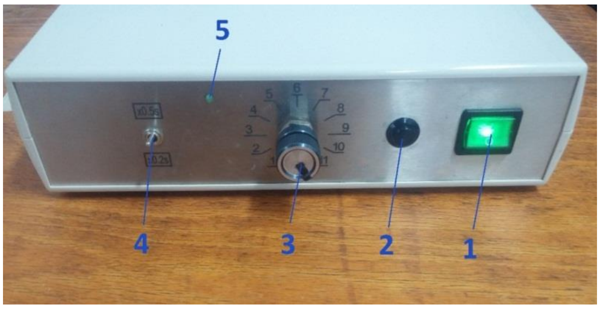

Fig. 1. Main parts of the system for fog generation: **A.** System unit for fog generation working with tap water: (1) hose fluid inlet; (2) bleeding valve; (3) inlet shut-off valve; (4) electromagnetic valve; (5) outlet shut-off valve; (6) nozzle; **B.** Control unit: (1) power button; (2) pulse initiation button; (3) knob for setting the timer (seconds); (4) switch for selection of time multiplier; (5) LED indicator for operation

Fig. 1A shows the water dispensing system of the fog generation unit. The system is fed with tap water through hose (1) and is bled *via* valve (2) when filling. After fixation of the device, taps (3) and (5) are successively opened. The fog generation is accomplished by the valve (6) and by passing a pulse with a specific duration, which comes from the control unit to the electromagnetic valve (4).

The fog generating unit is put in action by the control unit through an electromagnetic valve. The control unit generates uniform pulses with duration varying from 0.2 to 0.5 seconds, selected by the switch (4) and multiplied by the multiplier (3). When the desired values for the pulse duration are set, button (2) is used to initiate fog generation.

Fig. 2 depicts the block diagram of the experimental setup for measuring the diameters of droplets produced by the system. It is set to the desired position, so that the generated fog falls in the working area of the measuring equipment - a laser particle size analyzer (1). The system uses the pressure from the water dispensing system (5) and - *via* the nozzle (3) - fog with desired characteristics is produced. The control unit (2) sends regular pulses to the electromagnetic valve (4), so that the same amount of water is fed each time.

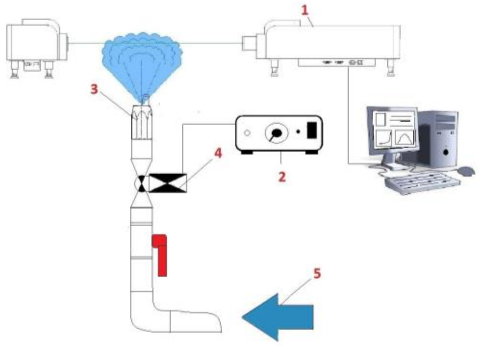

Fig. 2. Block diagram of the experimental setup for measuring the size of droplets generated by the system working with tap water: (1) laser particle size analyzer; (2) control unit; (3) nozzle; (4) electromagnetic valve; (5) source of water at a pressure of 6 bar.

A laser particle size analyzer *(JNWINNER, model 319A)* was used to analyze the droplet distribution and their microphysical characteristics in order to clarify how the nozzle orifice diameter influences the parameters of fog. The nozzle (4) is positioned at a certain distance from the measuring equipment (1).

A manometer and valves were mounted on the pressurized gas tank, which allow to control precisely the feeding pressure of nitrogen, so that fogs with variable characteristics, such as number density and size distribution of the generated fog droplets, to be produced.

EXPERIMENTAL RESULTS ON THE OPERATION OF THE AUTOMATED SYSTEM FOR FOG GENERATION

Since fog depends on the mass flow of pulverized water which is determined by the type of nozzle used, we conducted experiments to examine the effect of nozzles with different orifice diameters on fog formation at a constant gas pressure of 6 bar and by using tap water. The device has a set of eight nozzles [12] and each of them creates fog with specific parameters (number of droplets, diameter distribution, etc.), so that it is possible different types of fog to be investigated. Three of these nozzles (Fig. 3) were chosen to be studied in this experiment: PJ6 with orifice diameter of 0.152 mm (1); PJ10 with orifice diameter of 0.254 mm (2), and P54 with orifice diameter of 1.37 mm (3). One hundred measurements were taken for each nozzle. The spraying distance was kept constant for all experiments – 65 cm. Fig. 4 represents the amount and diameter distribution of droplets sprayed by nozzles PJ6, PJ10 and P54.

The summarized results from the measurements of the droplets produced by the three nozzles of the system operating with tap water are shown in Table 1 and graphically represented in Fig. 5.

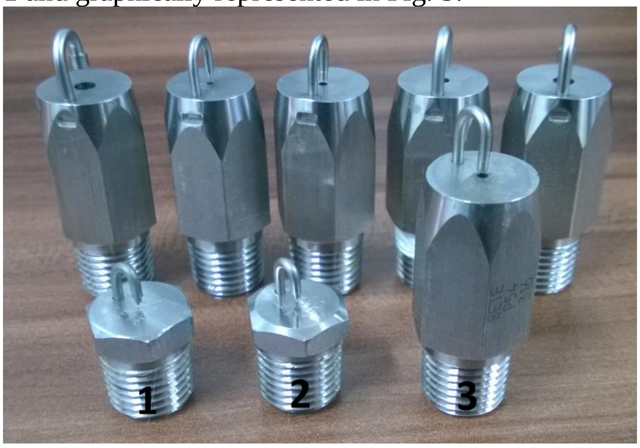

Fig. 3. Three of the tested BETE nozzles (http://www.bete.com/pdfs/BETE_PJ.pdf): PJ6 with orifice diameter of 0.152 mm (1); PJ10 with orifice diameter of 0.254 mm (2), P54 with orifice diameter of 1.37 mm (3).

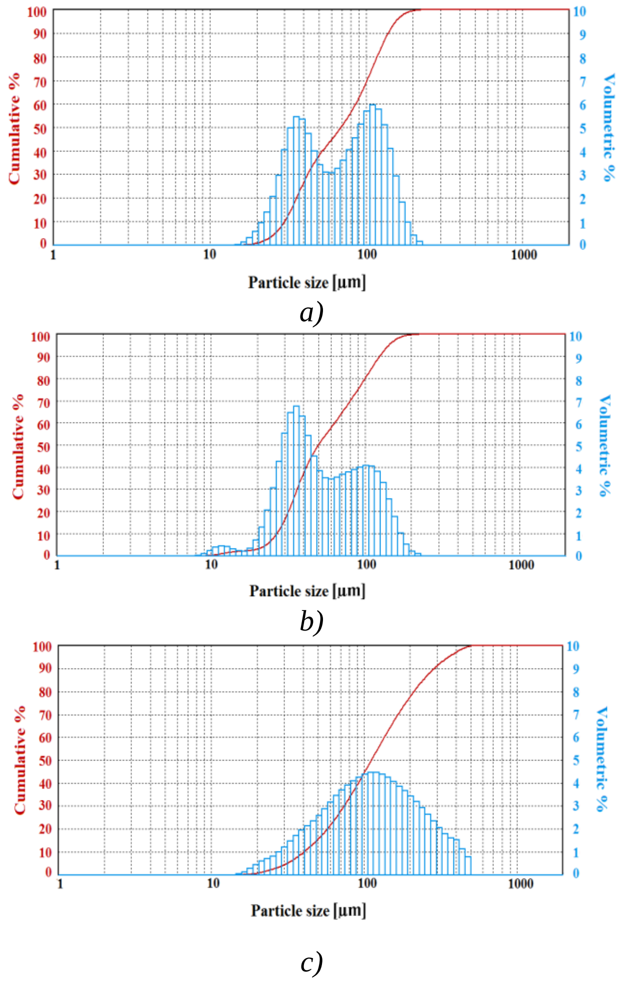

Fig.4. Diameter distribution and amount of droplets produced by a nozzle: a) PJ6; b) PJ10; c) P54

Table 1. Summarized results from measurements of droplets produced by the automated spraying system, and nozzles with varying orifice diameters.

Nozzle	PJ6	PJ10	P54
Modality of the distribution	Bimodal	Multimodal	Monomodal
Peak(s) [µm]	36 110	12 36 100	120
Averaged diameter by surface area [µm]	55.164	44.899	83.298
Averaged diameter by volume [µm]	77.179	64.434	139.791
Surface area-to-volume ratio [cm^2/cm^3]	1087.674	1336.332	720.305
Fit error × 100 [%]	0.006	0.005	0.028
Min. diameter [µm]	16	9	16
Max. diameter [µm]	230	230	500

The experimental results show that the investigated nozzles generate droplets with different size distributions and within different size ranges. 55% of the droplets, produced by nozzle PJ6, have diameters between 60 and 230 µm, and 45% of them are in the range 16-230 µm. Nozzle PJ10 generates droplets, which are predominantly within the same size interval as those produced by PJ6, but also a small amount of tiny droplets between 9 and 20 µm are present.

The other difference is that about 55% of the droplets from nozzle PJ10 are between 20 and 60 µm, and only 42% of all generated droplets have diameters between 60 and 230 µm. Nozzle P54, on the other hand, produces significantly larger droplets than the other two nozzles – 55% of them are in the range 100-500 µm, and only 45% are between 16 and 100 µm.

The other difference is that about 55% of the droplets from nozzle PJ10 are between 20 and 60 µm, and only 42% of all generated droplets have diameters between 60 and 230 µm. Nozzle P54, on the other hand, produces significantly larger droplets than the other two nozzles – 55% of them are in the range 100-500 µm, and only 45% are between 16 and 100 µm.

These results show that the system working with tap water has the capability of generating different kinds of fogs with specific predefined parameters.

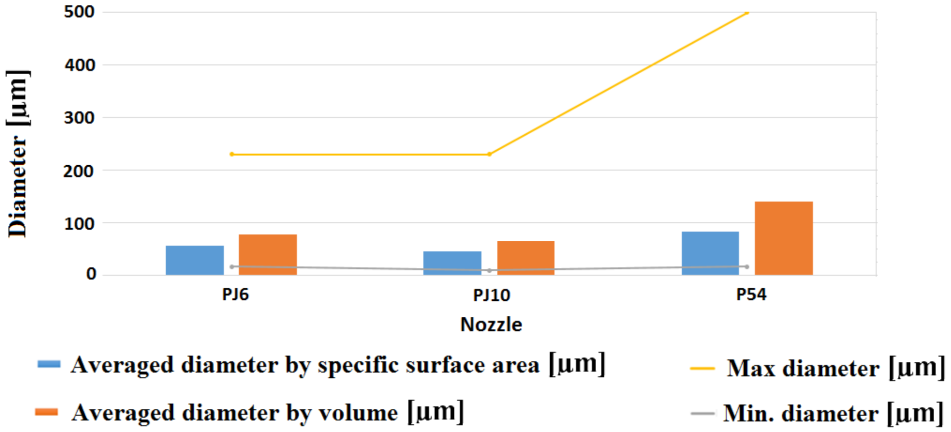

Fig. 5. Summarized results for the diameter distribution and the amount of droplets, generated by the system working with tap water and nozzles PJ6, PJ10 and P54

CONCLUSIONS

A simple, innovative laboratory system for producing artificial fog is designed and described. It allows improved control of water spraying, control of droplet amount and size distribution, stable parameters of the fog. The droplet diameters vary in the range of the real fog ones.

The system was developed for the purpose of eliminating the human factor, when conducting experiments, and also to increase the efficiency of our investigations by achieving high functionality. Our system is able to generate fog with predefined parameters, and it also gives the freedom to precisely control these parameters (amount and diameter distribution of droplets), thus producing fogs with great predictability and repeatability. The established setup can be used in research projects to study different aerosol generators and could also find application in other testing equipments and experiments which require control of the number, density and size distribution of aerosol particles.

Acknowledgements: *The European Commission is acknowledged for supporting the work described in this paper by EU FP7 Security program under Contract 312804.*

REFERENCES

1. N. Vankova, O. Ivanov O, I. Yordanova, *Spectroscopy Letters*, **30** (2), 257 (1997).
2. W. Schäfer, S. Rosenkranz, F. Brinckmann, C. Tropea, *Particuology*, **29** (12), 80 (2016).
3. J. Majewski, *Przegląd Elektrotechniczny*, **89** (3), 300 (2013).
4. M. Ochowiak, *Chemical Engineering and Processing*, **109** (11), 32 (2016).
5. X. Liu, R. Xue, Y. Ruan, L. Chen, X. Zhan, Y. Hou, *Cryogenics*, **83** (4), 59, (2017).
6. W. Yuen, S. Fu, C. Chao, *Journal of Aerosol Science*, **104** (2), 79 (2017).
7. K. Park, S. Heister, *International Journal of Multiphase Flow*, **36** (1), 1 (2010).
8. P. Andreussi, L. Tognotti, M. Graziadio, G. De Michele, *Aerosol Science and Technology*, **13** (1), 35 (1990).
9. O. Lastow, W. Balachandran, *Journal of Electrostatics*, **65** (8), 490 (2007).
10. M. Ochowiak, L. Broniarz-Press, S. Rozanska S, M. Matuszak, S. Wlodarczak, *Chemical Engineering and Processing: Process Intensification*, **98** (12), 52 (2015).
11. M. Altimira, A. Rivas, G. Larraona, R. Anton, J. Ramos, *International Journal of Heat and Fluid Flow*, **30** (2), 339 (2009).
12. http://www.bete.com/pdfs/BETE_PJ.pdf/

ЛАБОРАТОРНА СИСТЕМА ЗА ГЕНЕРИРАНЕ НА ИЗКУСТВЕНА МЪГЛА С КОНТРОЛИРАНИ БРОЙ И ДИАМЕТЪР НА КАПКИТЕ

О. Д. Иванов[1*], Я. И. Ралев[1], П. В. Тодоров[1], Й. П. Попов[1], К. Н. Ангелов[1], Х.Л. Перес-Диас [2], М. К. Кънева[1]

[1] Институт по физика на твърдото тяло „Акад. Г. Наджаков", Българска академия на науките, бул. „Цариградско шосе" 72, 1784 София, България
[2]Университет на Алкала, Алкала де Енарес, Мадрид, Испания

Постъпила на 26 септември, 2017 г.; приета на 31 октомври, 2017 г.

(Резюме)

Представена е система за генериране на мъгла в лабораторни условия, която може да се използва при експерименти, изискващи контрол върху количеството и разпределението по големина на аерозолни частици. Основната цел на системата е елиминирането на възможна човешка грешка и подобряване на резултатите при получаване на изкуствена мъгла с предварително зададени параметри.