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System for generation of fogs with controlled impurities

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In this article a system for generation of fogs is presented, which can be used for testing fog sensors under laboratory conditions. Our prototype is able to generate fogs with various chemical composition (up to 6 kinds of fluids), amount, diameters and size distribution of droplets with spraying driven by pulses of different duration (0.2 to 5.5 seconds). Thus, sensors for use in different areas can be tested, for example: control of attacks with CBRN (Chemical, Biological, Radiological, and Nuclear) agents, measurements of industrial pollutants, dust pollution, detection of poisonous gases, etc. The main goal of the system development is to eliminate the human error and to improve the results of producing artificial fog with predictable parameters. An important advantage of this system is that it allows the amount of impurities in fog to be precisely controlled.

Keywords: Artificial fog, Spraying techniques, Droplet size distribution, Air pollution

INTRODUCTION

Fog is a natural phenomenon which is a subject of observation and scientific research. This phenomenon is usually harmless to living organisms, but, when polluted, it could also be dangerous and harmful. In 1952 a dense fog covered London for five days and caused death of 12000 people and thousands of animals in the region due to chemical processes leading to a deadly mix of fog and pollution (sulfur dioxide (SO_2), dust and others) [1,2]. The same events nowadays often occur in China and other locations. According to a recent study [3], environmental pollution was the reason for one of every six premature deaths in the world in 2015 and is killing more people every year than all wars and violence in the world. There are different sources emitting chemicals to the atmosphere and ambient fog could also contain a number of potentially toxic substances [4-6]. Often fog interacts with pollutants physically, chemically or biologically, thus increasing their toxic effect. Water droplets in fog may concentrate soluble toxic air pollutants and, when inhaled, or fall on the skin, droplets deliver very high doses of toxicants. Effects of exposure to chemical pollutants under foggy conditions are of great interest since fog droplets penetrate easily into the lower respiratory tract, especially droplets of less than 10 μm in diameter [7].

Fog is widely used as a cleaning agent for contaminated areas in a number of applications: industrial processes, defense, aerospace, automotive, (e.g. corrosion test chambers and salt fog cabinets), power generation, telecommunications, for medical purposes (e.g. nebulizers), etc. [8]. These applications require precise control of the amount and properties of the used fog. That is why further research in this field is needed in order to gain the required insight into fog formation and dynamics, as well as to develop fog-sensing elements for detection and identification of harmful biological and chemical aerosols in natural fogs being of special interest. Fog studies more often are performed by using theoretical simulations of fog formation through a number of models [9], resulting in slightly overestimated droplet numbers [10]. Theoretical simulations have been also used to predict the chemical behavior of polluted fog [11, 12].

Fog generation technology is currently widely available [13-16] and experimental simulators (test chambers/cabinets) of polluted fog are used in industry for corrosion tests investigation in atmosphere of salt or acidic impurities. However, there is still lack of laboratory simulators of chemically polluted fog.

For development of gas sensors based on the SPCE (surface photo-charge effect) [17, 18] we needed a laboratory fog simulator for their laboratory testing and calibration. Since the size distribution and the number density of droplets are the most important parameters of fog, they play a crucial role in the investigation and the development of fog sensors. That is why we need a flexible system, which produces fogs with controllable/predictable amount and size distribution of droplets, being also able to produce

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fog with variable and controllable chemical composition. The system should easily switch between different solutions with varying chemical composition, in order to study interactions between fog and different kinds of impurities. During our literature and market survey, we could not find any existing system satisfying all of our experimental requirements. We have already reported the first version of an experimental laboratory system for generation of fog with predictable droplet amount and parameters, working with tap water elsewhere [19]. Here, the second version of the system is presented, which generates fogs with different impurities and varying parameters.

EXPERIMENTAL SETUP OF THE AUTOMATED SYSTEM FOR FOG GENERATION

Figure 1 shows the automated system for fog generation: the pulverizing unit having the ability of simultaneous water and impurity spraying and the pulse control unit, respectively.

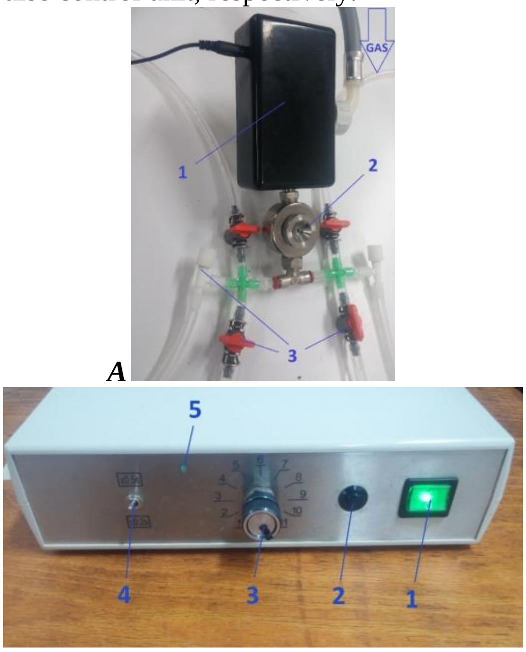


Fig. 1. A. Fog spraying unit: (1) electromagnetic valve; (2) fog generating nozzle (orifice diameter of 0.4 mm); (3) valves; **B.** Control unit: (1) power button; (2) pulse initiation button; (3) knob for setting the timer (seconds); (4) switch for selection of time multiplier; (5) LED indicator for operation

The control unit developed by us was described elsewhere [18]. It generates uniform pulses with duration of 0.2 or 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 part of the system intended for generation of fogs with varying chemical composition. Working liquid is atomized by means of a pneumatic atomizing nozzle [19] which works on a siphon principle. The system operates in the following way: pressurized gas (nitrogen) is fed from the tank (5) to the atomizing nozzle (4), which draws water from one of the containers (7) and fogs the working area with the operating liquid. The supply of pressurized gas to the atomizer is regulated by an electromagnetic valve (3). The supply of operating liquid to be fogged (tap or distilled water and contaminating medium) is regulated by corresponding valves (6). Depending on the impurity, which is to be included in the generated fog, the corresponding container is used. The prototype has six branches with six valves, so that switching between different containers can be done easily and quickly. The electromagnetic valve (3) between the source of pressurized gas and atomizing nozzle is controlled by a specially developed pulse generator (2) (shown in Fig. 2) and supplies pressurized gas to the atomizing nozzle in response to an output signal coming from the pulse generator (controller). Different settings can be used, in order to achieve desired durations of fog spraying.

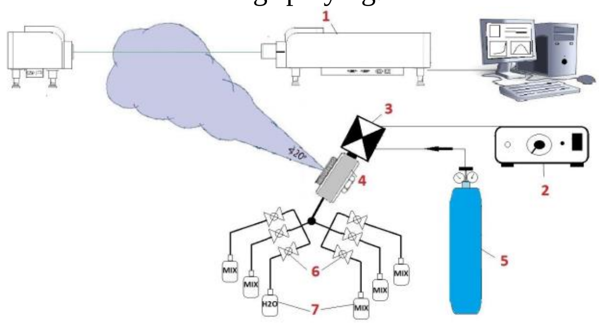


Fig. 2. Block diagram of the automated system for generation of fog with impurities – (1) laser particle size analyzer; (2) spray duration control unit; (3) electromagnetic valve; (4) nozzle; (5) pressurized gas tank; (6) valves; (7) fluid containers

To analyze the distribution and microphysical characteristics of droplets and clarify how the feeding gas pressure influences the parameters of fog, a laser particle size analyzer *(JNWINNER, model 319A)* was used. The nozzle (4) is positioned at a certain distance from the measuring equipment (1). The control unit (2) generates pulses with durations varying from 0.2 to 5.5 seconds, and passes them to the electromagnetic valve (3), so that uniform and identical sprayings can be achieved. As mentioned above, with the aid of the pressurized gas from tank (5) and thanks to the special construction of the nozzle, only the fluid from the chosen container (7) is used. It should be noted that for investigating specific chemical solutions additional valves (6) are used, which allow convenient sprayings with different duration for each kind of fluid.

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

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

Investigation on fog parameters at different gas pressures

Research on droplets generated by the automated pulverizing system which uses a gas-liquid (nitrogen and distilled water) mixing nozzle, was performed at four different feeding gas pressures of 1, 2, 3, and 4 bar, with nozzle orifice diameter of 0.4 mm. One hundred measurements were taken for each of the four gas pressures. The spraying distance was kept constant for all experiments – 65 cm. The purpose of the study was to find out how the number density and the diameter of the droplets vary with the gas pressure.

Fig. 4 compares the average results for the amount and the diameter distribution of droplets for each gas pressure. The graphs represent the distribution of the diameter of the measured particles – on the X-axis the different sizes are given, so, according to the height of a certain blue bar, the volumetric percentage for the respective size can be detected on the right Y-axis. The red curve, on the other hand, gives information about the percentage of particles, with smaller than each size marked on the X-axis, and its values can be detected on the left Y-axis. The variation of general fog characteristics with atomizing gas pressure can be easily seen in the figure.

Table 1 shows the summarized results from measurements of microphysical characteristics and distribution of droplets generated by the automated system: modality of the distribution (i.e. the number of peaks – monomodal, when there is only one peak in the spectrum; bimodal, when there are two peaks; and multimodal, when there are more than two peaks); the values of the local peaks of the distribution; average diameters, calculated by surface area and by volume; surface area-to-volume ratio; fit error.

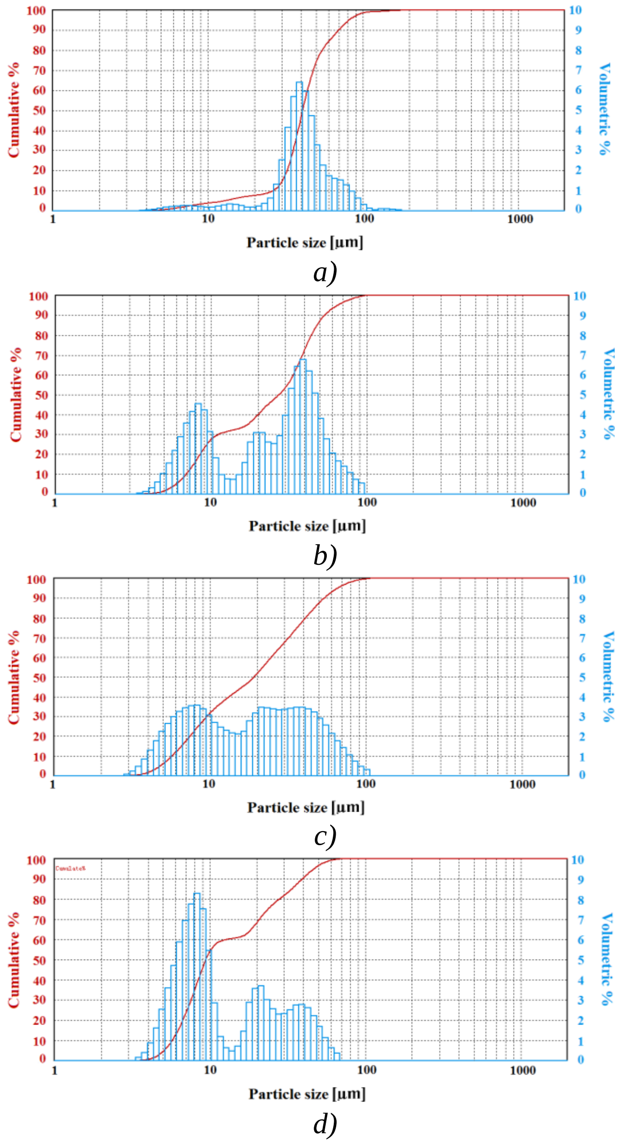


Fig. 3. Diameter distribution and amount of droplets, generated at different gas pressures: a) 1 bar; b) 2 bar; c) 3 bar; d) 4 bar

The summarized results of testing the automated system for fog generation are represented graphically in Fig. 5.

The observed overall tendency is that the values of the average diameters calculated by surface area and by volume decrease with increasing gas pressure. At the highest gas pressure of 4 bar, these values are the lowest. Also, the difference between the maximum and the minimum diameter is the smallest in that case – 65 µm, which means that the width of this diameter distribution is the narrowest one.

The widest size distribution spectrum, on the other hand, is observed at gas pressure of 1 bar, where the difference between the maximum and the minimum diameter is about 170 µm, and the values of the average diameters are highest.

Table 1. Summarized results from measurements of droplets, produced by the automated spraying system at varying gas pressures

Gas pressure [bar]	1	2	3	4
Modality of the distribution	Multimodal	Multimodal	Multimodal	Multimodal
Peak(s) [µm]	7 15 40	8 20 40	8 20 38	8 20 40
Averaged diameter by surface area [µm]	32.867	15.643	12.65	10.103
Averaged diameter by volume [µm]	44.061	28.587	24.806	16.875
Surface area-to-volume ratio [cm^2/cm^3]	1825.552	3835.695	4742.945	5938.751
Fit error ×100 [%]	0.009	0.008	0.010	0.008
Min. diameter [µm]	3.979	3.65	3.071	3.65
Max. diameter [µm]	177.477	96.993	105.737	68.675

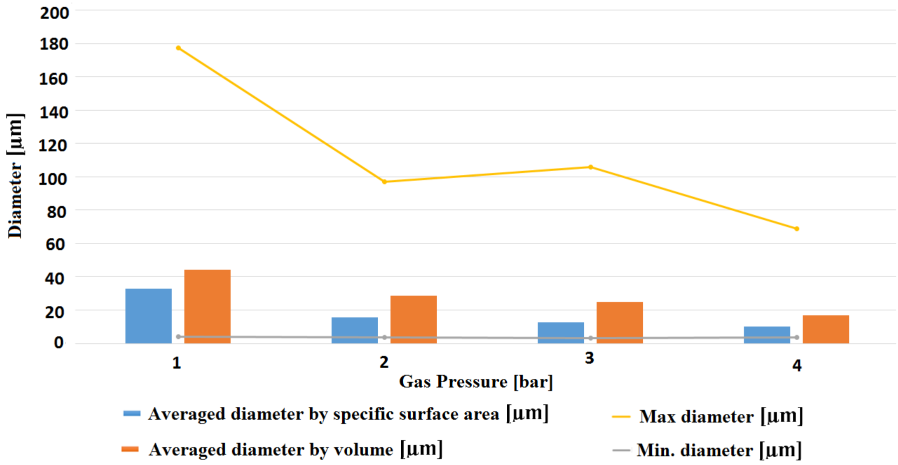


Fig. 4. Summarized results for the minimum and the maximum diameters detected, averaged diameters by specific surface area and by volume, for different gas pressures (1-4 bar), for the automated system for fog generation, at a spraying distance of 65 cm

At gas pressure of 4 bar the automated system produces the smallest droplets and they have similar sizes, while at 1 bar the generated droplets are relatively big, but a small amount of tiny ones is also present. At gas pressures of 2 and 3 bar the size ranges are almost identical, but while at 3 bar the diameter distribution is relatively smooth and the amounts of droplets of different sizes are similar, at pressure of 2 bar only 10% of all droplets have sizes between 10 and 20 µm.

The experimental results for the automated system for fog generation show that the parameters of the produced fog can be precisely controlled, as well as the way they change when varying the gas pressure, fed to the nozzle.

Investigation on fog parameters with added impurities

We have performed tests which show how impurities influence the parameters of fog. Figure 9 compares the change in the number and the diameter distribution of droplets of pure distilled water, when 5% of KH_2PO_4 are added. The droplets were produced by the automated system at gas pressure of 2 bars for both cases and the measurements were taken at 65 cm distance from the nozzle.

There is a notable change in the fog parameters when 5% of KH_2PO_4 are added to distilled water. The percentage of small droplets between 3 and 10 µm increases significantly, while larger droplets (above 80 µm) disappear.

Figure 6 shows the deviation of the sensor's spraying of seven solutions with varying concentrations of tetracycline. One capsule of tetracycline was dissolved in different amounts of distilled water – 400, 200, 100, 80, 60, 40 and 20 ml.

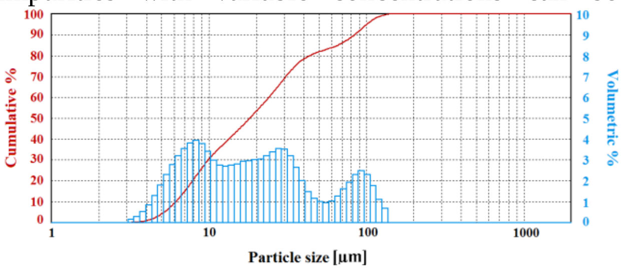
It can be seen from the graph that the increase in the content of tetracycline leads to higher deviations of the signal from our sensor.

CONCLUSIONS

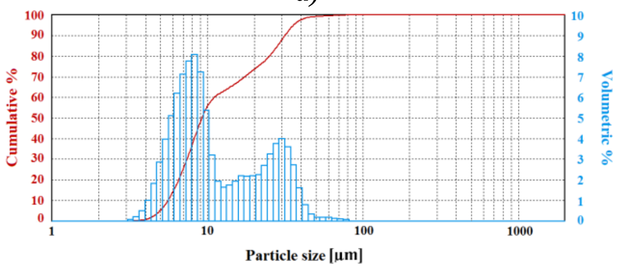
A simple, innovative laboratory simulator of chemically polluted fog is designed and studied. It allows improved control of water spraying, control of droplet amount and size distribution, stable parameters of the fog and introducing different kind of pollutants in it. The fog density and droplet size are in the range of the real fog ones. The system makes possible the production of fogs with great predictability and repeatability. At the same time, impurities with variable concentrations can be signal from its initial indication after included to the generated fog easily and quickly, thus allowing convenient study of the interactions between fog and different kinds of impurities.

The conducted experiments show that the system functions properly and satisfies all requirements for successful development of fog sensors. Tests in a controlled environment allow precise calibration of sensors, adjustment of their working characteristics and evaluation of their work with different pollutants.

Although the system was developed for testing SPCE-based gas sensors, it can be included in research projects for studying atmospheric chemistry, different aerosol sources, industrial pollutants, chemical and biological weapons and their disposal. The system could also find application in other testing equipments and experiments which require control of the number density, size distribution of aerosol particles and pollutant concentrations.



a)



b)

Fig.5. Diameter distribution and amount of droplets of: a) pure distilled water; b) distilled water + 5% KH_2PO_4.

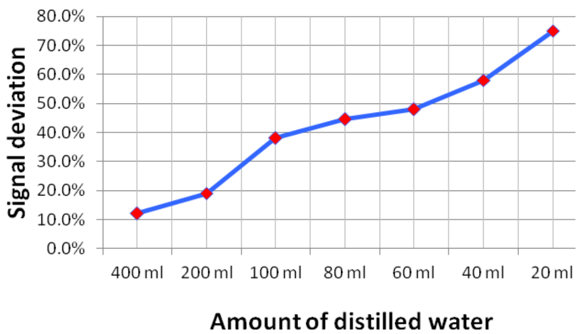


Fig.6. Sensor's signal deviation in response to spraying by fog of distilled water and varying amounts of Tetracycline.

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СИСТЕМА ЗА ГЕНЕРИРАНЕ НА МЪГЛА С КОНТРОЛИРАНИ ПРИМЕСИ

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(Резюме)

В статията е представена система за генериране на мъгла, която може да се използва за тестване в лабораторни условия на датчици за мъгла. Нашият прототип може да генерира мъгли с различен химичен състав (до 6 вида флуиди), количество, диаметър и разпределение по размери на капчиците при различна продължителност на импулсите на пулверизиране. С помощта на тази система могат да се тестват сензори за различни цели, като например за проверка при атака с химични, биологични, радиологични или ядрени агенти, за измерване на промишлени замърсявания, замърсяване с прах, детектиране на отровни газове и др. Основна цел на системата е елиминирането на човешката грешка и подобряване на резултатите при получаване на изкуствена мъгла с предварително зададени параметри. Важно предимство на тази система е, че тя позволява прецизен контрол върху количеството примеси, добавяни към мъглата.