Journal of Electrostatics 71 (2013) 963–969

Contents lists available at ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

Ionic wind generator derived from a liquid filled capillary pin. Application to particle capture

Elio Quinton [a], Jean-Luc Achard [b], Jean-Maxime Roux [a,*]

[a] CEA-LETI, MINATEC Campus, 17 rue des Martyrs, F-38054 Grenoble Cedex 9, France
[b] Laboratoire des Ecoulements Géophysiques et Industriels, F-38041 Grenoble Cedex 9, France

ARTICLE INFO

Article history:
Received 15 April 2013
Received in revised form
24 June 2013
Accepted 7 August 2013
Available online 28 August 2013

Keywords:
Ionic wind generator
Electrospray
Electrostatic precipitator
Airborne particle collection
Electrohydrodynamic

ABSTRACT

A new fluid pin-based ionic wind generator applied to airborne pathogen collection combines the processes of air flow generation by ionic wind, electrospray and electrostatic particle collection. This new concept brings a breakthrough in integration as it combines these three phenomena with a single driving force in order to perform the four functions of an airborne pathogen sampler, namely air flow production, particle capture, sample phase transfer and collecting electrode decontamination. The characterizations presented in this article led to a proof of concept and demonstrated the device's performance for a compact and portable airborne pathogen collection system.

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1. Introduction

The development of electrostatic capture devices is being driven by changes in legislation regulating the emission of pollutants into the atmosphere and concern over the toxicity of fine and ultrafine particles. The literature contains numerous examples of studies concerning electrostatic precipitators (see review in this issue by Jaworek and Krupa [1]). Studies of such devices for collecting airborne biological agents are also tending to develop [2–13] owing to their considerable efficiency in collecting submicron-sized particles and their compatibility with conventional analysis techniques such as culture [3–5,8–11]. The fundamental difference between electrostatic precipitators intended for purifying the air or collecting airborne particles is that in the second case it is necessary to recover the sample, which is generally captured on the surface of an electrode. Different strategies may be adopted, such as depositing a culture medium on the surface of the collecting electrode [2–5] or rinsing its surface [8–13]. It should be noted that two of the functions performed by samplers do not involve high voltage: air flow production, which is usually done by a blower, and transfer from the sample to the culture medium or an aqueous medium, which is usually done by a pump. For obvious reasons of simplicity, it would be better to construct an air sampler in which air flow production and air/water transfer would also be based on electrostatic mechanisms. Now there are processes for producing air flow and wetting an electrode that use the Coulomb force as their driving force. These are respectively ionic wind generators and electrospray nozzles.

This article presents the proof of concept of a complete, compact airborne particle collection system that uses electric force as its only driving force. More specifically, it demonstrates that it is possible to produce an air flow, capture particles, spray the collecting electrode to transfer the sample and then decontaminate the collecting electrode by using physical phenomena induced by high voltage: air flow production by ionic wind, electrostatic capture and electrospray. Using this approach, it is possible to simplify the device and hence significantly improve the compactness of the system; all actuators collapsing into a single one.

It should be pointed out first of all that, in its simplest form, an ionic wind air flow generator is a system comprising two electrodes, one that is highly curved – usually a pin or wire – and the other that is only slightly curved, between which a high voltage is applied. A corona discharge appears in the vicinity of the highly-curved electrode when the electric field reaches a threshold referred to as the Peek field. An unipolar ionic wind which depends of the spatial distribution of electric field develops from the pin towards the counter-electrode under the effect of the Coulomb force [14]. Air flow production takes place as a result of momentum

* Corresponding author.
E-mail address: jean-maxime.roux@cea.fr (J.-M. Roux).

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http://dx.doi.org/10.1016/j.elstat.2013.08.002

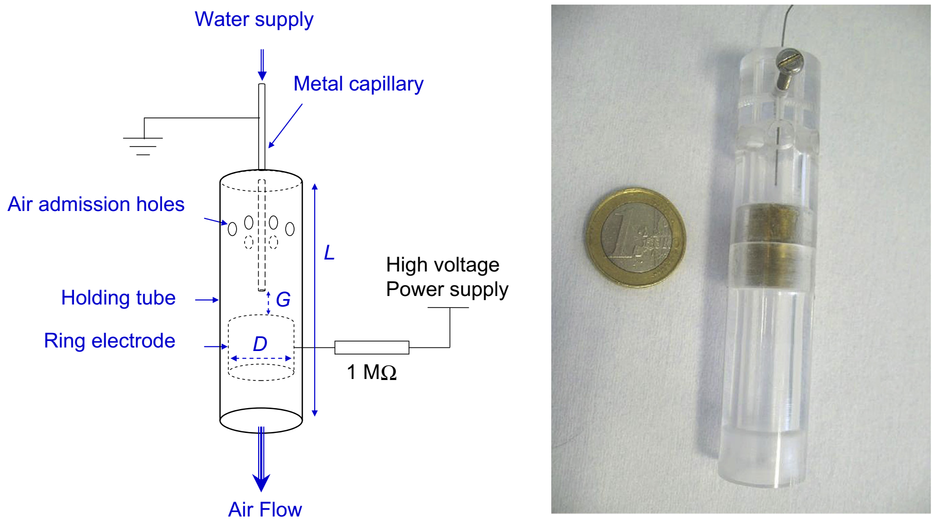

Fig. 1. Diagram and photograph of electrostatic actuator and sampling device.

transfer between these charged particles and the neutral particles and molecules in the air. To obtain a strong electric field and high charge injection, the surface of the discharging electrode must have a high curvature. On the other hand the geometry of the counter-electrode is less critical provided that it does not produce an electrical discharge as well. If it is also necessary to entrain air in a tube, it must also present minimum resistance to the air flow and therefore in the vast majority of cases has the form of a screen with a sufficiently large mesh [15] or ring following the inside wall of the carrying tube [15–18]. Other less conventional geometries may also be considered [19]. Propulsion [20,21] or cooling by convection [22] is used with conventional geometries of the pin–plate type [23,24] or variants [25,26]. In terms of performance, it may be noted that electroaerodynamic pumping produces velocities of the order of a few metres per second.

The electrospray process, the second electrical phenomenon to be integrated, is also well known. This pulverises a liquid into fine droplets the diameter of which is linked to the physical properties of the fluid and to the operating conditions: the liquid flow rate, the applied voltage, the diameter of the capillary used and the geometry. The conventional configuration used for an electrospray involves two electrodes: a metal capillary that is used to polarise the liquid and a counter-electrode, which is usually flat. The liquid sent through the capillary is thus pulverised on the counter-electrode. Zeleny [27] carried out pioneering experimental work that revealed the conical deformation of the meniscus of a liquid under the effect of an intense electric field and the production of a liquid jet at its tip. Almost fifty years later, Taylor resumed this work and showed that capillary forces and the electrostatic force can balance one another on a conical interface, for which he calculated the tip angle [28]. This fundamental work led to this meniscus geometry being called the Taylor cone. Numerous experimental, theoretical and numerical studies have been carried out on the electrospray phenomenon (see review in this issue by de la Mora [29]). Various spray functioning modes exist and have been classified according to their characteristics and conditions of existence (see review in this issue by Cloupeau [30]). One of the difficulties is to produce and control a monodisperse spray, that is to say one in which all the droplets are of the same size.

The use of electrospray in collection devices has already been considered and studied; it improves the capture capability of electrostatic precipitators. Recently, Tepper and Fenn [31] also used this process to develop a personal polar or polarizable gas species sampler. However, all these devices require the use of pumps and/or blowers, thus increasing their energy consumption.

2. Experimental setup

The set-up used for this study is based on the configurations commonly used for cylindrical electrostatic samplers, pin-to-cylinder ionic wind generators and capillary-to-plate electrosprays. The ring counter-electrode configuration was chosen in order to address simultaneously the constraints imposed by the three phenomena involved. On the one hand, the metal capillary carries the liquid to be pulverised and polarises it at the same time [30–37] while having a very small radius of curvature. On the other hand, the ring counter-electrode presents minimum resistance to air flow and a large area for capturing airborne particles. This geometry for the counter-electrode has already been used and validated for air flow production [15–17] and for electrostatic capture [1,6] but to our knowledge has never been used for an electrospray process. The challenge here is to spray the inside of the tube using this process in order to rinse the sample out and then decontaminate it.

Fig. 1 shows a diagram and a photograph of the study set-up. It consists of a cylindrical polycarbonate tube with an inner diameter D of 10 mm and length L of 10 cm. The ring electrode also has an inner diameter of 10 mm to avoid any discontinuity in diameter along the path taken by the air flow. The tube is open at one end to allow the air flow to escape and closed at the other to hold the capillary. The position of the capillary can be adjusted. Consequently, the distance G between the electrodes can also be adjusted. The high voltage generator used in the experiments can create DC voltages ranging from 0 to 10 kV. A mass flowmeter (TSI, model 4043) is placed at the outlet from the support tube to measure the air flow produced by the device, as shown in Fig. 2. A video camera fitted with a macro lens is used to take pictures of the end of the capillary through the transparent tube. The camera produces grayscale films at the maximum rate of 24 frames/s. The applied voltage and the current circulating in the circuit are also measured. A salt water nebulizer is used to generate airborne particles. A custom-built isokinetic sampling pipe associated with a particle counter (GRIMM, model 1.109) containing several channels for

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