Journal of Electrostatics 83 (2016) 35–41

Contents lists available at ScienceDirect

Journal of Electrostatics

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

Computational investigation toward selective collection of water particles containing odorous molecules by electrostatic spraying

Jin Muraoka [a], Kenichi Funamoto [b,*], Mariko Seno [a], Satoshi Arimoto [a], Ken Shimono [a], Satoshi Suzuki [c], Yoshio Mitsutake [c], Tetsuya Maekawa [d], Toshihiko Yoshioka [a], Toshiyuki Hayase [e]

[a] Advanced Research Division, Panasonic Corporation, 3-4 Hikaridai, Seika-cho, Soraku-gun, Kyoto 619-0237, Japan
[b] Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, 6-3 Aramaki aza Aoba, Aoba-ku, Sendai, Miyagi 980-8578, Japan
[c] Eco Solutions Company, Panasonic Corporation, 1048 Kadoma, Kadoma, Osaka 571-8686, Japan
[d] Appliances Company, Panasonic Corporation, 2-3-1-2, Noji-higashi, Kusatsu, Shiga 525-8555, Japan
[e] Institute of Fluid Science, Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai, Miyagi 980-8577, Japan

ARTICLE INFO

Article history:
Received 3 March 2016
Received in revised form
11 July 2016
Accepted 12 July 2016

Keywords:
Ionic wind
Atomizer
Odor separation
Multiphysics
Particle image velocimetry

ABSTRACT

The necessity of odor sensing has been increasing from environmental and health standpoints. Here, we propose the novel concept of a small device which can select odor molecules based on electrostatic spraying. For high selectivity of the target gas or odor, we conducted computational fluid dynamics coupled with an electrostatic field, as well as measurements by particle image velocimetry and anemometry. The computational model successfully reproduced characteristic features of ionic wind. Different trajectories of charged particles were computationally obtained owing to their electrical mobility. The results imply that different materials might be separated by the arrangement of the collecting electrode.

1. Introduction

In recent years, with an increase in the quality of life (QOL), awareness of the ill effects of malodor on the environment or general well-being has also increased [1–3]. This situation has resulted in a diversification of the sources of odors, which means that more various smells have been identified. Especially in public spaces where many people gather in a closed place, such as restaurants, hotels, dormitories, theaters, and public transportation, people may be more sensitive of the others' smells. The problem of smells greatly differs by individual, really depending on one's feeling. There is no absolute index for how bad or good a smell is. Therefore, it is very important to digitize not only the odor levels, but also the types of odor, referring to some standard to inform people of the odor level in an environment by means of simple equipment.

There are mainly two methods for measurement of the level of odor. One is by organoleptic examination, i.e., sniffing by humans or dogs, who are trained to detect a special odor [4–6]. However, the sensitivity and the selectivity of the method are influenced by physical conditions, and those trained for such detection easily tire. Hence, this method is costly and not commonly used. The other method is detection by equipment. Gas chromatography or mass spectrometry detects odorous small molecules very selectively and efficiently without fatigue [7–11]. However, these techniques are not easy to use for on-site detection because the necessary equipment is large and heavy. It is difficult to make handy-sized equipment with high selectivity of odor components.

Herein, we propose a novel concept for a small device capable of odor separation based on the principle of electrostatic spraying [12–14]. In this concept, by cooling the spray electrode in an electrostatic atomization device, atmospheric moisture condenses on the surface. Water particles are generated at the tip of the spray electrode due to electrostatic spraying, and an ionic wind is generated. A sample of the odor is then blown to the spray electrode. The odorous molecules are absorbed in the water particles by their polarity or charge. The charged water particles are carried for a long distance by the ionic wind and attracted by a collecting

* Corresponding author.
E-mail address: funamoto@fris.tohoku.ac.jp (K. Funamoto).

http://dx.doi.org/10.1016/j.elstat.2016.07.004

electrode at an appropriate location [15]. Odor components are moved onto the collecting electrode by charged particles, but some components cannot reach the collecting electrode owing to the electrical mobility of the charged particles. Consequently, an appropriate arrangement of electrode locations enables selection of the odor components.

In this study, a multiphysics coupling a flow field and an electric field was analyzed computationally. In addition, ionic wind was experimentally measured by particle image velocimetry (PIV) and hot-wire anemometry [16]. The computational modeling was then validated by comparing the computational results and experimental data. Finally, the effect of the location of the collecting electrode on the trajectories of charged particles was investigated by computational analysis.

2. Methods

The principle of odor separation using the electrostatic spraying method is first explained. Then, methods for measurement of the ionic wind by PIV and hot-wire anemometry and computational methods for analysis of multiphysics to investigate odor separation are explained.

2.1. Principles

In the mechanism of electrostatic spraying, liquid water firstly gathers on the tip of a spray electrode, which is a component of an electrostatic atomization device, by the capillarity effect or by cooling of the electrode. When high voltage, normally several kilovolts, is applied to the spray electrode, the electric potential exponentially decreases toward the counter electrode. If the electric potential in the vicinity of the spray electrode is sufficiently strong, the water forms a Taylor cone [12]. Charged particles, the charge of which varies with the polarity of the electrode, are formed and sprayed from the tip of the Taylor cone [17]. In the case of the addition of positive voltage to the spray electrode, the positive ions generated at the spray electrode travel toward the counter electrode, whereas the negative ions remain close to the spray electrode. In this phenomenon, the positive ions transfer momentum to the neutral molecules via collisions. Thus, the ionic wind, which is a charged current, appears [18]. The movement of a charged particle can be considered as a Stokes flow. The electrical mobility Z_p of a charged particle is derived from the balance between the particle velocity and electric field strength [17]:

$$Z_p = \frac{n_p e C_c}{3\pi\mu D_p}, \quad (1)$$

where n_p is the number of elemental charge, e is the elementary charge, μ is the gas viscosity, D_p is the mobility diameter of the nanosize particle, and C_c is the Cunningham slip correction factor. Equation (1) indicates that not only the diameters of nano-particles D_p but also the odor components with characteristic charges can be estimated based on their values of Z_p. If the value of D_p is constant, Z_p is determined by the value of n_p. On the other hand, if n_p is constant, Z_p is determined by D_p.

In the present concept, the value of Z_p is utilized for odor separation. The odor sample is blown to the spray electrode in the atomization device. The odorous molecules are absorbed in water particles, created at the tip of the spray electrode, by their polarity or charge. By controlling the diameter of the water particles uniformly, Z_p reflects the charge of the water particles containing odorous molecules. The charged particles are transported by ionic wind and collected on the collecting electrode.

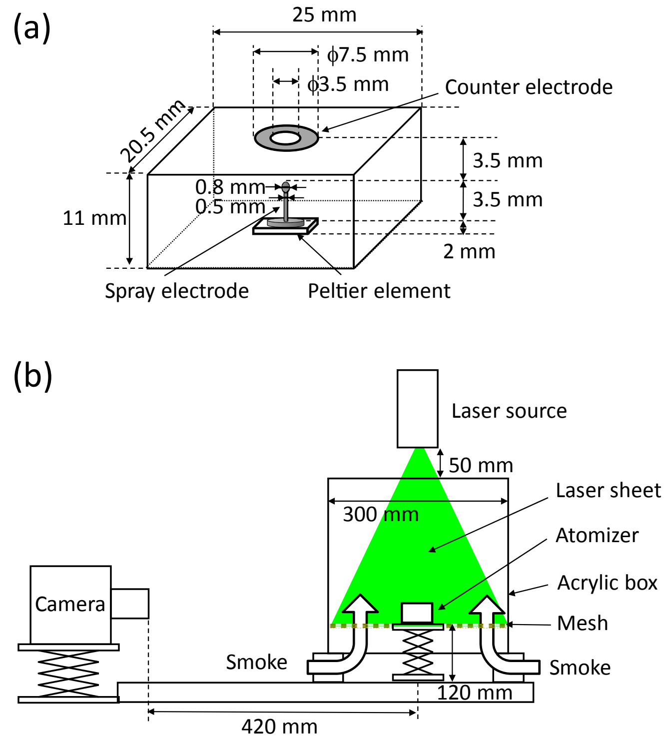

Fig. 1. Schematic diagrams of (a) electrostatic atomization device and (b) PIV system. The electrostatic atomization device was placed in the middle of an acrylic box filled with smoke, and a laser source produced a green laser sheet for visualizing the ionic wind. The ionic wind which appeared on the green laser sheet was captured with a high-speed camera. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

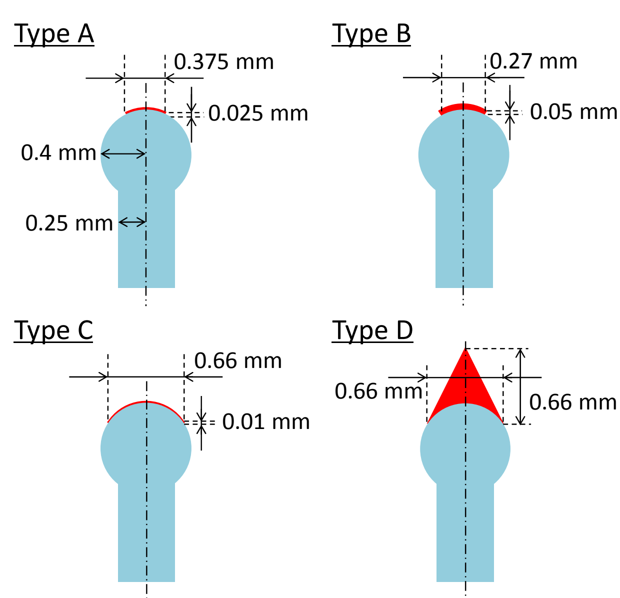

Fig. 2. Longitudinal cross-sectional view of the four different sample volumes, a body force being applied to simulate ionic wind on the tip of the spray electrode. Type A, the width of the body was 0.375 mm; Type B, the height was double that of type A; Type C, the arc length was double that of type A; and Type D, the shape was the Taylor cone shape.

2.2. Measurements

An electrostatic atomization device was employed to generate ionic wind. The device and the electronic control circuit were taken