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Spatial Distribution of Negative Air Ions Produced by an Ultrasonic Mist Maker

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The density of negative air ions produced from an ultrasonic mist maker was measured to be 1.5 $\times$ 10^4 ions/cm^3, which is much higher than the value for ambient air, 1.1 $\times$ 10^3 ions/cm^3 and it is the result of the Lenard effect of water shear of spray electrification due to ultrasonic vibration. The negative air ion density was high compared with that of ambient air at a long distance near the ground floor. No ozone or nitrogen oxides were generated as by-products, but the density of charged air ions decreased rapidly with increasing of height from the floor. Within a distance of 10 m, we could produce a high density of negative air ions, which could be absorbed into our body through skin contact and aspiration.

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I. INTRODUCTION

In recent years, indoor air quality has attracted much scientific concern. Especially in well-developed countries, indoor air environments are very important in relation with human health because mental and physical stresses are affected by indoor air conditions. Many people spend more than 90% of their time in indoor areas. Sick building syndrome (SBS) is a typical phenomenon of buildings with modern construction materials. SBS is mainly due to volatile organic compounds (VOCs) and formaldehydes that evaporate from the construction materials. In addition to the VOCs and formaldehyde, indoor air is more polluted with micro dust and microbes than outdoor air [1–3]. Therefore, many home owners buy air purifiers that can filter micro dust, kill microbes and dissolve odors.

Recently, ionizers have been widely used to control the spread of airborne infection. The bactericidal action of air ions has been reported in many scientific papers [3–7], but the reports are controversial [8]. The physical and the biological mechanisms of the bactericidal action remain unclear because electrical ionizers produce ozone and a strong electric field is applied around the electric pole. Fletcher *et al.* clarified this issue by determining the physical mechanism associated with microbial cell death [7]. Their results suggested that the bactericidal action attributed to negative ions by previous researchers might have been overestimated by neglecting the bactericidal actions of the positive ions, ozone and electric field. Most of the research results for air ions are qualitative, so a simple, clear, quantitative investigation is needed.

One of the mechanisms of purifying air is ionizing the indoor air. Negatively charged air ions are generally known to be good for human health, and positively charged air ions bad for health [4,9–18]. Negative air ions are also known to activate cell functions, stabilize the emotional state and promote the recovery from fatigue by preventing acidification of blood [16–19] and improving aerobic metabolism [17]. Most of the air purifiers on the market have an ionizing function based on a corona discharge [1,20,21]. Ionizers with a corona discharge generate ozone as a by-product in addition to negative air ions, but ozone is harmful to human health through aspiration and skin contact. The Lenard effect is one of the natural ionization process observed at waterfalls [22–24]. Charged air ions are produced due to spray electrification of water. Small water drops carry extra electrons weakly attached to the drops, and relatively big water drops and bulk water are charged positively, losing some electrons to the small water drops. There is no production of ozone in spray electrification of water [25]. The Lenard effect is a safe mechanism for air ionization. An ultrasonic mist maker is a good apparatus for spray electrification of water.

The lifetime of negative air ions is known to be less than 30 seconds. In calm ambient air the natural diffusion length is very short. Most researchers are concerned about the positive health effects of negative air ions. The health effects come from the direct interaction with our body, *i.e.*, skin contact and aspiration. For systematic

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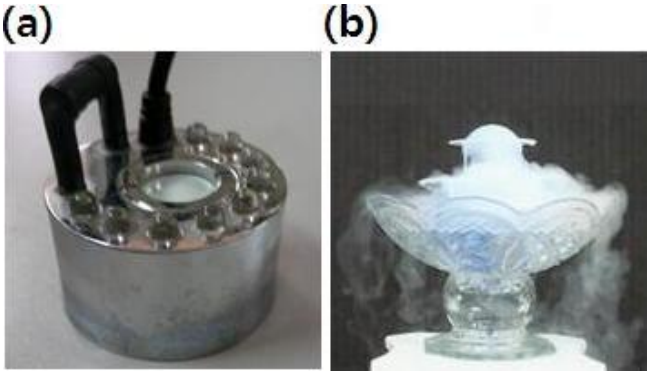


Fig. 1. (Color online) (a) Ultrasonic mist maker. (b) Ultrasonic humidifying air purifier Fognee (model DH-014T manufactured by NIT Corp. in Korea).

research of negative air ions, which affect biological objects, we have to know the spatial distribution of the negative air ions and check the possibility of contact between air ions and our body. We measured the spatial distribution of the negative air ions generated by the ultrasonic humidifying air purifier Fognee (model DH-014T) manufactured by NIT Corp. in Korea.

II. EXPERIMENT

Negative air ions can be generated by a humidifying air purifier that produces negatively and positively charged micrometer-sized water droplets by the Lenard effect through water shear. Most of the relatively smaller size water droplets are charged negatively, and relatively bigger size water droplets are charged positively [22, 23]. Each of these negatively charged water droplets can carry tens of thousand extra electrons attached electronically and can collide with air molecules and dust in the air [23]. Most of the collisions occur with nitrogen molecules, oxygen molecules and some positively charged air ions. Oxygen molecules are much stronger than nitrogen molecules in electron affinity. Therefore, oxygen molecules are charged negatively easily with attached extra electrons. Nitrogen molecules collide with negatively charged water droplets about 4 times more than with oxygen molecules in the air, but they become negative ions rarely because their electron affinity is much weaker than that of oxygen molecules. Therefore, most of the negative ions in air are oxygen molecule ions. Positively charged, relatively bigger water droplets also collide with air molecules and charged dust in air. They also produce many positive air ions, but the number of positive air ions produced through water shear by an ultrasonic humidifier is smaller than the number of negative air ions produced through water shear by an ultrasonic humidifier.

We did the experiment in a closed room (2.90 × 3.35 × 2.25 m^3). We used an ultrasonic vibrator with a 2-cm-diameter piezoelectric ceramic disc working at 1.74 MHz. We measured the air ion density for both polarities by using an air ion counter (Alpha Lab Inc, USA). The Fognee DH-014T humidifying air purifier is an open-structured ultrasonic humidifier, as shown in Fig. 1.

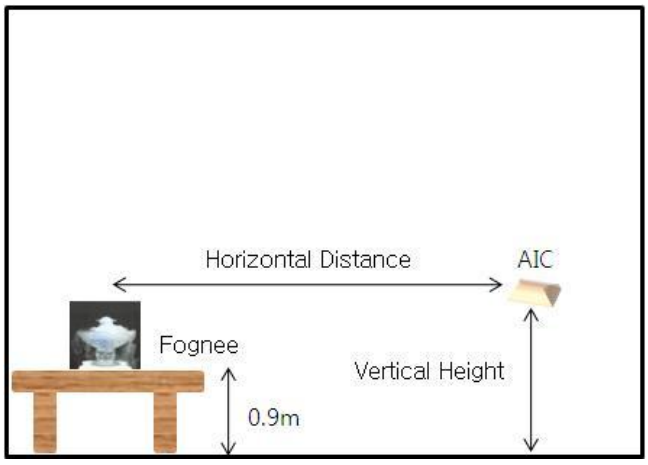


Fig. 2. (Color online) Schematic diagram of the experiment.

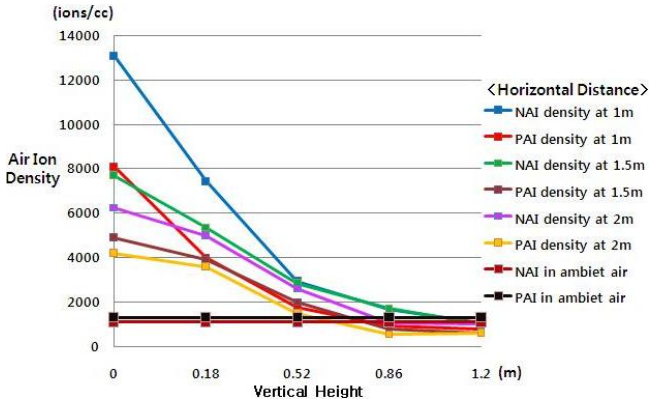


Fig. 3. (Color online) Spatial distribution of both polarity air ions.

The water droplets flow out of the glass bowl by natural diffusion. Due to gravity, water droplets fall and diffuse out along the flat ground. During the flight, the droplets evaporate and become smaller and smaller. Micrometer-sized water droplets evaporate completely within about 10 minutes, depending upon the humidity and the temperature of the ambient air. The charged water droplets behave like charge carriers. Thus, air ions produced from collisions with water droplets can be measured at a distance of 10 m from the humidifier in a calm room.

A schematic diagram of the experiment is shown in Fig. 2. We measured the negative air ion density and the positive air ion density along the height from floor at horizontal distances of 1 m, 1.5 m, and 2 m. The air ion density decreases with increasing height from the floor. The vertical distributions of charged air ions of both po-

Table 1. Performance test of Fognee (DH-014T model) for ozone production.

Measurement Distance (mm)	Measurement Period (hr)	Measured Value (ppm)
50	24	0.000

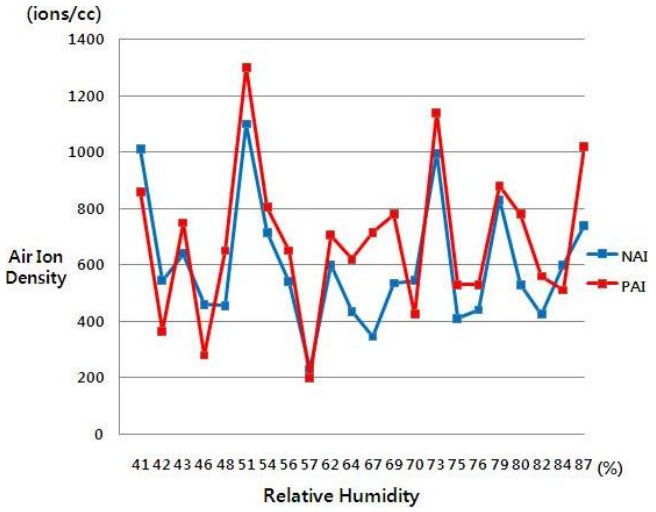


Fig. 4. (Color online) Air ion density versus humidity in different weather conditions.

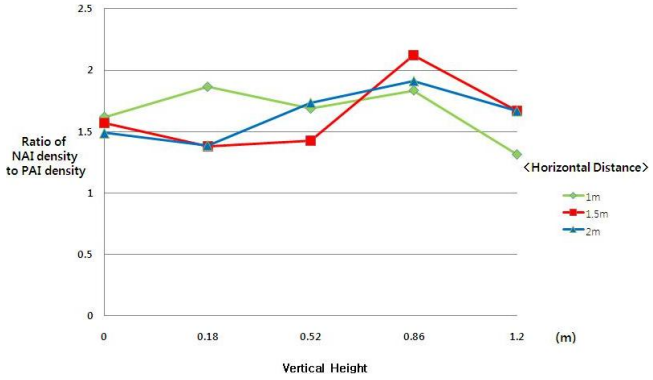


Fig. 5. (Color online) Ratio of the negative air ion (NAI) density to the positive air ion (PAI) density produced by using the ultrasonic humidifying air purifier Fognee (model DH-014T).

larities decrease with increasing height from the floor and become almost the same level as that of ambient air at a height of 1.2 m. The density of air ions near the floor is measured to be 1.5×10^4 ions/cm^3, and it decreases rapidly to the value of ambient air, 1.1×10^3 ions/cm^3. Fig. 3 shows the spatial distributions of both polarities of air ions. This result says that researchers have to be very careful about the spatial distribution of air ions. Even though in the same room, the air ion density can be much different from position to position.

One might worry that the density of charged air ions might depend upon humidity. We measured the negative air ion density versus humidity. The result is shown in Fig. 4. There is no proper correlation between the air ion density and humidity. The fluctuation occurs due to other weather conditions, such as before raining and after raining.

In ambient indoor air, the positive air ion density is generally known to be higher than the negative air ion density. We see the same result in Fig. 5. When the ultrasonic humidifying air purifier Fognee is operated, the ratio of the negative air ion density to the positive air ion density is in the range of 1.4 - 2.1, *i.e.*, about 40% - 110% more negative air ions are produced by the Lenard effect.

An electrical negative air ion generator has the disadvantage of producing ozone and nitrogen oxides as by-products. We also attempted to measure the ozone at a distance of 50 mm from the Fognee DH-014T unit for 24 hours continuously, but no ozone was measured. We confirmed that the Lenard effect does not produce ozone and produces charged air ions only. This result is shown in Table 1 [25].

III. DISCUSSION AND RESULTS

The spatial distributions of the air ion density produced by the Lenard effect of an ultrasonic humidifying air purifier are highly dependent upon the height from the floor. The lifetime of air ions is known to be less than 30 seconds. In calm ambient air, the diffusion length of air ion is short. The number of collisions of air molecules in a second is about 10×10^{13} . The air ions can be neutralized with exchange of charges through collisions with oppositely charged air ions. The air ions produced by collisions with charged water droplets show higher density at the floor than at higher heights above the floor. The air ion density decreases very rapidly with increasing height due to the short diffusion length. This result seems to indicate that small water droplets flow out and generate many negative air ions around their path through collisions with air molecules, and these negative air ions with short lifetimes diffuse out and become neutral through collisions with oppositely charged particles. Therefore, we have to take into consideration the spatial distribution of air ions when investigating the effects of air ions on human health, bactericidal action and ionic air purification.

There is no production of ozone during the generation of air ions by the Lenard effect. The Lenard effect is a safe mechanism for producing air ions. The ratio of

negative air ions to positive air ions produced by an ultrasonic humidifying air purifier is in the range of 1.4 - 2.1. In ambient indoor air, the density of air ions shows no specific correlation with humidity, the high fluctuation depends upon other weather conditions.

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