



EXPERIMENTAL CHARACTERIZATION OF PORTABLE ION GENERATORS

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ABSTRACT

A conservative assessment suggests that over 1% of homes in the U.S. use ionizing air cleaners. Ion generators use charged plates to remove oppositely-charged particles and often generate ozone as a byproduct of their operation. In the present paper, five commercially available ionizing air cleaners were evaluated and compared to a portable HEPA filter and dedicated ozone generator. Air flow rate, ozone emission rate, and size resolved (0.1 - 1 μm) clean air delivery rate (CADR) were measured in a stainless steel test chamber for each cleaner. The air flow rates ranged from less than 30 m^3/hr to 75 m^3/hr , about an order of magnitude lower than a portable HEPA filter. Ozone emission rates were 0.7 - 4.1 mg/hr , about an order of magnitude lower than a dedicated ozone generator. Although the ozone emission rates for ion generators were low, they still may represent a health concern. The ionizing air cleaners remove submicron particles with CADRs ranging from 8 - 82 (m^3/hr), considerably lower than the 200 - 250 m^3/hr range for the tested HEPA air filter. These results allow for a more complete analysis of the positive and negative indoor air quality impacts of portable ion generators.

INDEX TERMS

Ionizing air cleaner, Ozone emission, CADR, Particle removal, Measurements

INTRODUCTION

Portable air cleaners are a \$500 million per year business in the United States. Ion generators, one type of air cleaner, are heavily advertised and very popular. A scaling calculation suggests that over 1% of American homes have these devices. Ionizers work by charging incoming particles with a corona and removing them to oppositely charged electrodes. Most ion generators do not employ a fan to move air, and thus offer nearly silent operation. However, most ionizing air cleaners also generate ozone, a respiratory irritant and oxidizing agent that can react with other airborne contaminants to produce fine particles and other byproducts (Weschler and Shields 1999). The goal of our research is to characterize the particle removal and ozone emissions of five portable ion generators.

Despite their popularity, ion generators have received limited attention in the published literature. Liu *et al.* (2000) found that the wire surface temperature and geometric structure of a cleaner have a strong influence on ozone concentrations. Niu *et al.* (2001) measured ozone emission rates of 0.056 to 2.757 mg/hr for five portable ion generators. Tung *et al.* (2005) measured ozone emission rates of 0.234 to 2.144 mg/hr for three ionizers. Phillips *et al.* (1999) reported an ozone emission rate from a personal ionizing air purifier to be 0.102 - 0.114 mg/hr . Ion generators, and other air purifiers, are often characterized in terms of particle removal efficiency and clean air delivery rate (CADR), which is defined as the product of efficiency and air flow rate. Shaughnessy *et al.* (1994) tested two ion generators and found that one had no effect in removing 0.5 - 3.0 μm dust because of a very low air flow rate and the other, which had a fan, had an efficiency of only 5% and a CADR of 22.5 m^3/hr . Offermann *et al.* (1985) tested two ion generators with cigarette smoke: a residential unit had a CADR of 2 m^3/hr and a commercial device had a CADR of 52 m^3/hr . Niu *et al.* (2001) conducted a series of experiments with twenty seven ion generators, and measured that CADRs ranging from 4.6 to 234.8 m^3/hr for PM_{10} .

In this paper, we present a series of experiments on five portable ion generators. For each ionizer, we measured air flow rate, ozone emission rate, and particle size-resolved CADR for 0.1 - 1 μm particles. For comparison purposes, we also measured each of these parameters for a portable HEPA filter and a dedicated ozone generator. The goal of this research is to characterize this increasingly popular air purification technology and to obtain a greater understanding of the impact of ion generating air cleaners on indoor air quality.

RESEARCH METHODS

For each air cleaner, the air flow rate was measured by building an airtight capture hood that sealed tightly to the

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inlet of the air cleaner. An Energy Conservatory Duct Blaster calibrated fan was connected to the other end of the capture hood. The flow rate of the air cleaner is equal to that of the fan when the pressure difference between the outside and inside of the capture hood is zero. This methodology eliminates the impact of back pressure (Offermann *et al.*, 1985). Tests were done at each speed for all air cleaners.

Ozone emissions and particle-size resolved CADR were measured in 11 m³ and 14.5 m³ stainless steel chambers. In all testing, oscillating fans were used to ensure that the chamber air was well mixed. To measure the ozone emission rate, each ion generator was placed in a chamber that had an experimentally determined (by decay of CO₂) air exchange rate. Ozone monitors were placed both inside and outside of the chamber. With the ion generator switched on, the progressive increase of ozone concentration in the chamber was measured. Once a steady-state concentration was maintained for at least ten minutes, the ion generator was switched off and the ozone decay was recorded. A reactor model was applied to determine the emission rate, with the decay period used to assess the deposition loss to surfaces.

To measure the CADR, particles were generated by burning incense for 15 minutes. After extinguishing the incense, the natural decay due to deposition to chamber surfaces and air exchange was measured using a Particle Instruments Lasair-1002 optical particle counter for 0.1 - 1 µm particles and a TSI APS 3321 aerodynamic particle sizer for 0.5 - 20 µm particles. The incense was lit again for an additional 15 minutes, and the experiment was repeated with the air purifier activated at its highest setting. The CADR was calculated by applying a well-mixed reactor model and subtracting the background decay of particles. This procedure neglects particles that infiltrate into the chamber, a small assumption given that particle concentration outside the chamber was typically two orders of magnitude smaller than inside, for all reported particle sizes.

RESULTS AND DISCUSSION

Air flow and ozone emission rates for the seven tested devices are summarized in Table 1. The minimum air flow rate that can be measured using the testing method is 30 m³/hr. Flow rates for Ion Generators 3, 5, and the ozone generator fell below this minimum measurable level. Of the ionizers, Ion Generator 4 had the highest air flow rate of 75 m³/hr. All measured flow rates for the ion generators were an order of magnitude less than the HEPA filter, which had a maximum flow rate of 640 m³/hr. Results from repeated tests on Ion Generators 1, 2, and 4 were in close agreement with the values in Table 1.

Table 1. Air flow rates and ozone emission rates.

	Air Flow Rate* (m ³ /hr)	Ozone Emission Rate (mg/hr)
Ion Generator 1	50	2.7
Ion Generator 2	57	2.7
Ion Generator 3	<30 ^a	0.75
Ion Generator 4	75	4.1
Ion Generator 5	<<30 ^b	4.0
Ozone Generator	<<30 ^b	31
HEPA Filter	640	0

*Reported results are at highest air flow setting.

^a <30 indicates that the pressure difference between the outside and inside of the capture hood was less than 1 Pa at 30 m³/hr air flow rate, the lowest flow detectable with the Duct Blaster.

^b <<30 indicates that the pressure difference was greater than 1 Pa at 30 m³/hr air flow rate.

The ozone emission rates for the ion generators ranged from 0.74 - 4.2 mg/hr. This is comparable to the emission rates of 0.056 - 2.757mg/h found for five portable ion generators by Niu *et al.* (2001), and comparable to other ozone sources such as laser printers and photocopiers, with emissions of 1.2 and 5.2 mg/hr (Weschler 2000). The dedicated ozone generator emitted 31 mg/hr of ozone, which is one order of magnitude greater than that of the ion generators. As expected, the HEPA filter was not found to emit any ozone. Results from repeated tests on Ion Generators 3 and 5 were within 5% of the values in Table 1.

To put these ozone emission results in context, a recent epidemiological study of US communities found that a 10 ppb increase in the previous week's ambient ozone concentration was associated with a 0.52% increase in daily mortality (Bell *et al.* 2004). In order to compare the equivalent outdoor ozone concentration increase with the ozone emission from ion generators, the steady-state ozone concentration in a home with a portable ion generator in operation was compared to one without an ion generator. We used a one-box well mixed indoor model and assumed a value of 0.53 for ozone penetration, which is the mean value for an idealized fiberglass-insulated wall



(Liu and Nazaroff 2001), 377 m³ for indoor volume (American Housing Survey 2001) and varied the air exchange rate from 0.2 to 2 per hour. Figure 1 shows the equivalent increase in outdoor ozone concentration as a function of air exchange rate. For a typical residential air exchange rate of 0.5 per hour, the outdoor ozone concentration would need to increase by 4 to 20 ppb in order to achieve a steady-state indoor ozone concentration equivalent to that in the same home with an operating ion generator. This indicates the potential for an increase in health problems due to the increased ozone concentration. For comparison purposes, the dedicated ozone generator caused the same indoor concentration as an increase of 160 ppb in the outdoor concentration. The impact of the ozone emissions decreases as the building air exchange increases for all air cleaners, as does any beneficial effect related to particle removal.

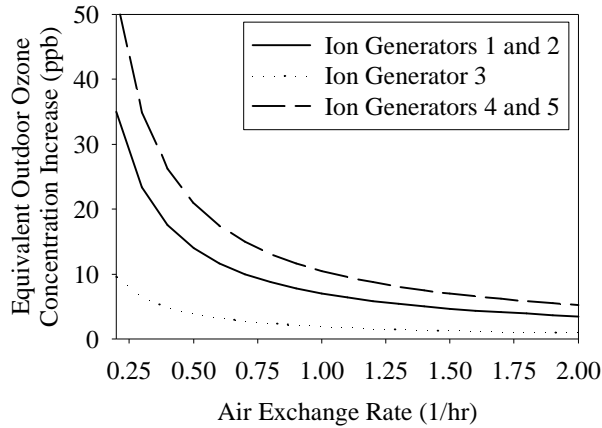


Figure 1. Change in outdoor ozone concentration necessary to achieve equivalent indoor concentration to home with an operating ion generator

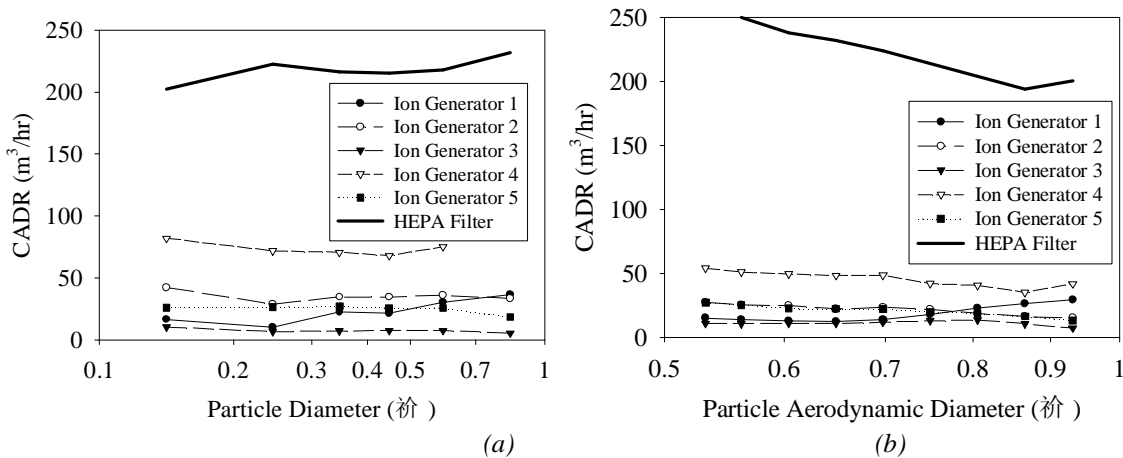


Figure 2. CADR as a function of particle diameter as measured with (a) Particle Instruments Lasair-1002 optical particle counter and (b) TSI Aerodynamic Particle Sizer

Figure 2 shows the particle size resolved CADR for the five ion generators and the HEPA filter. As expected, the ozone generator had a negligible CADR, as it is not designed to remove particulate contaminants. Figure 2a shows the results from the Lasair optical particle counter, and Figure 2b shows the results from the Aerodynamic Particle Sizer. Figure 2a shows that all of the ion generators have a much lower CADR than the HEPA filter, and that there is substantial variation in the CADR between ionizers. The lowest CADR, approximately 10 m³/hr for all particle sizes, was associated with Ion Generator 3. This unit also had a very low flow rate and a low ozone emission rate. The highest CADR, from 62 – 85 m³/hr, occurred for Ion Generator 4. Ion Generators 1, 2, and 5 all had comparable CADRs that ranged from 17 - 42 m³/hr. Ion Generator 2 had a UV lamp that is intended to have a germicidal effect. When the UV lamp was activated, the CADR dropped by a factor of 2 - 3 from the results displayed in Figure 2. Repeated testing on Ion Generator 3 produced results in agreement with Figure 2, falling within 10% of the reported CADR for all particle sizes. Two experimental repetitions on Ion Generator 1 showed much less agreement with a factor of two difference between the highest and lowest CADR from the three tests. The results reported here are the average CADR for Ion Generator 1. Monitoring the electrical power usage and examining the periodic nature of the air flow through this ion generator suggests that there might be a duty cycle associated with its operation and that the CADR may vary with time. Future testing will explore this

phenomenon in more detail.

Figure 2b shows similar results to Figure 2a and differences are likely due to differences in the particle sizing instruments. The Lasair optical particle counter used to obtain the results in Figure 2a measures the light scattering of particles. Its measurement of diameter is influenced by the index of refraction and the morphology of the particles. The Aerodynamic Particle Sizer used to obtain the data in Figure 2b measures the aerodynamic diameter and thus is influenced by particle density and shape.

The CADR results in Figures 2a and 2b generally agree with those presented in the literature (Offerman *et al.* 1985, Shaughnessy *et al.* 1994, Niu *et al.* 2001) and suggest that the average CADR for an ion generator is about an order of magnitude lower than for a portable HEPA air filter of comparable cost. However, there is a significant range of CADRs for the ion generators tested in our study. CADR was typically a weak function of particle size for all ionizers except for Ion Generator 1.

The single-pass efficiency, η , of an air cleaner is defined as $1 - C_{down}/C_{up}$, where C_{down} and C_{up} are the downstream and upstream concentrations of particles. The value of η is equal to the CADR divided by the air flow rate through the air cleaner. Figure 3 shows the efficiency as a function of particle size for the air cleaners that had measurable flow rates, using the CADR results in Figure 2 and the air flow rates in Table 1.

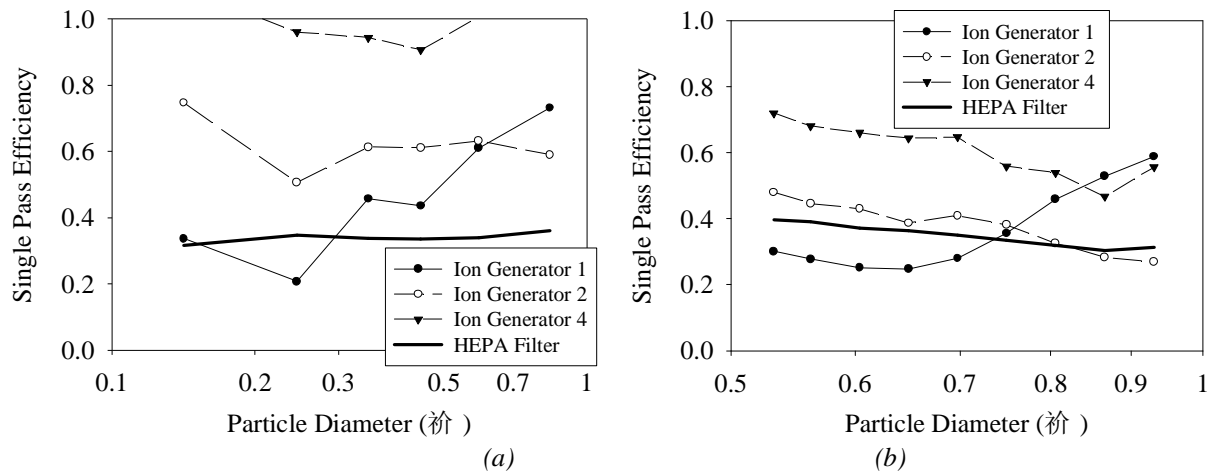


Figure 3. Efficiency as a function of particle diameter as measured with (a) Particle Instruments Lasair-1002 optical particle counter and (b) TSI Aerodynamic Particle Sizer

The efficiency curves in Figure 3 for each air cleaner have the same shape as in Figure 2, but the ranking of the air cleaners is different. Even though the HEPA filter media is nearly 100% efficient, the efficiency of this unit was considerably lower than most of the ion generators. The difference between the media efficiency and the overall device efficiency is a function of how much air goes through the media and how much bypasses the media. Ion Generator 4 had a very high efficiency, approximately 100% as measured by the Lasair (Figure 3a).

A central question about the operation of these devices is whether they reduce indoor particle levels. In order to determine this, it is important to compare the CADR to the deposition loss to surfaces and the ventilation flow rate. For a typical home with an air exchange rate of 0.5/hr, a volume of 377 m³, and typical deposition loss coefficients from Riley *et al.* (2002), the CADR from Ion Generator 3 is over an order of magnitude smaller than the losses due to other mechanisms, indicating that this device is unlikely to measurably affect indoor concentrations of particles from 0.1 – 1 μm. However, the ion generator with the highest CADR, Ion Generator 4, has a CADR that is considerably lower than, but more similar to, the loss rate associated with other mechanisms. Its use might diminish submicron indoor particle concentrations, but nowhere near as much as a portable HEPA filter. All air cleaning technologies will exhibit diminished performance for larger or leakier homes.

CONCLUSIONS

Portable ion generators are a popular air cleaning technology, but there are reasons for concern about their use. They generate considerably less ozone than dedicated ozone generators, but can still raise indoor ozone levels enough to cause concern about potential human exposure. Despite high single pass efficiencies, all of the tested devices had 0.1 - 1 μm CADRs that were 4 – 20 times lower than the tested portable HEPA filter, indicating an



impact on indoor particle concentrations that ranges from less than 10% reduction for the worst ion generator to a 10 - 20% reduction for the best ion generator. Future research will focus on testing portable ion generators with a larger test aerosol, measuring the potential for the emitted ozone to form fine particles, and examining the exposure implications of ionizing air cleaners.

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