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REPORT FOR AIRPURA INDUSTRIES INC.

PERFORMANCE OF AIRPURA I600-UV INDOOR AIR PURIFIER

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Purpose

This project aims to test the performance of the Airpura I600-UV air purifier in terms of its physical efficiency, i.e., its ability to remove particles of different sizes from the air. The evaluation involved determining the collection efficiency at different particle sizes and mass fractions as well as CADR (clean air delivery rate). Special attention was paid to the removal of particles, the size of which is relevant to the removal of viral-sized particles such as SARS-CoV-2, e.g., particles in the 20-250 nm range, which could be carrying individual viral particles and particles in the 0.25 – 2.5 µm range, which would correspond to particles carrying viral agglomerates and other particles. Measurements were also performed based on $PM_{2.5}$ and PM_{10} particles, i.e., the mass of particles smaller than 2.5 µm and 10 µm, respectively. PM_{10} fraction encompasses virus-carrying aerosols and also larger droplets.

Experimental Setup

Experiments were carried in a large test chamber (85 m^3 in size) at Rutgers University.

The testing was performed with NaCl particles aerosolized from a liquid suspension using a 6-jet Collison nebulizer (CH Technologies, Westwood, NJ). Aerosolization of NaCl solution typically yields aerosol particles with sizes ranging from 10 nm to approximately 10 µm. This size range represents individual viral particles, their fragments and agglomerates, and larger droplets carrying viral particles. The mass and size distribution of the produced aerosol were measured using these devices: DRX (Model 8534, TSI Inc., MN), which measures mass concentration of PM_1, $PM_{2.5}$, Respirable, and PM_{10} particles; P-Trak (Model 8525, TSI Inc.), which measures all particles larger than 20 nm; optical particle counter Grimm 1.109 (Grimm Inc.) which measures particles between 0.25 µm and 32 µm in 31 size channels. The combination of the latter two instruments allows measuring particle size distribution from 20 nm to 32 µm. In addition, by combining these instruments, we monitored the smallest particle size range of 20-250 nm, where individual viral particles would be found. The chamber's temperature and humidity were monitored using an IAQ meter (Model 7545, TSI Inc.). The instruments were positioned about halfway between the Airpura and the room's far wall (Fig. 1).

Procedure

The procedure was as follows:

(1) Before the start of testing, relative humidity was adjusted using a dehumidifier to about 50%, which is typical for the indoor environment; a low particle mass concentration baseline (e.g., less than 10 $\mu g/m^3$) was achieved by our own air cleaner. Airpura air purifier was positioned in the middle of the room and set to operate at a medium setting.

(2) Once the clean air baseline was reached and held steady, the baseline was measured for 30 min.

(3) As the next step, NaCl was aerosolized by a Collison nebulizer for about 7-10 min and continuously mixed using two fans in the opposing corners of the chamber (Fig. 1). The particle mass concentration in the chamber was measured by the devices mentioned above until it reached around 200 $\mu g/m^3$.

(4) Once the concentration was steady, the aerosolization was turned off, and aerosol particles in the chamber were mixed by allowing the fans to run for approximately 5 min.

(5) Then, the 1st measurement was carried out to estimate the natural particle concentration decay as a function of time and particle size for 90 min. The natural particle decay over time served as a reference point to calculate the AirPura air purifier's removal efficiency.

(6) As the next measurement step, all the preparations (Steps 1 to 4) were repeated, and then I600-UV was turned on for 60 min.

(7)

The mass and sizes of airborne particles in the chamber were measured every 1 minute until the concentration decayed to the baseline level. All devices in the chamber were operated remotely, and the chamber was not disturbed during the experiments.

The process above was repeated three times to take into account the experimental variability of particle concentration and I600-UV performance.

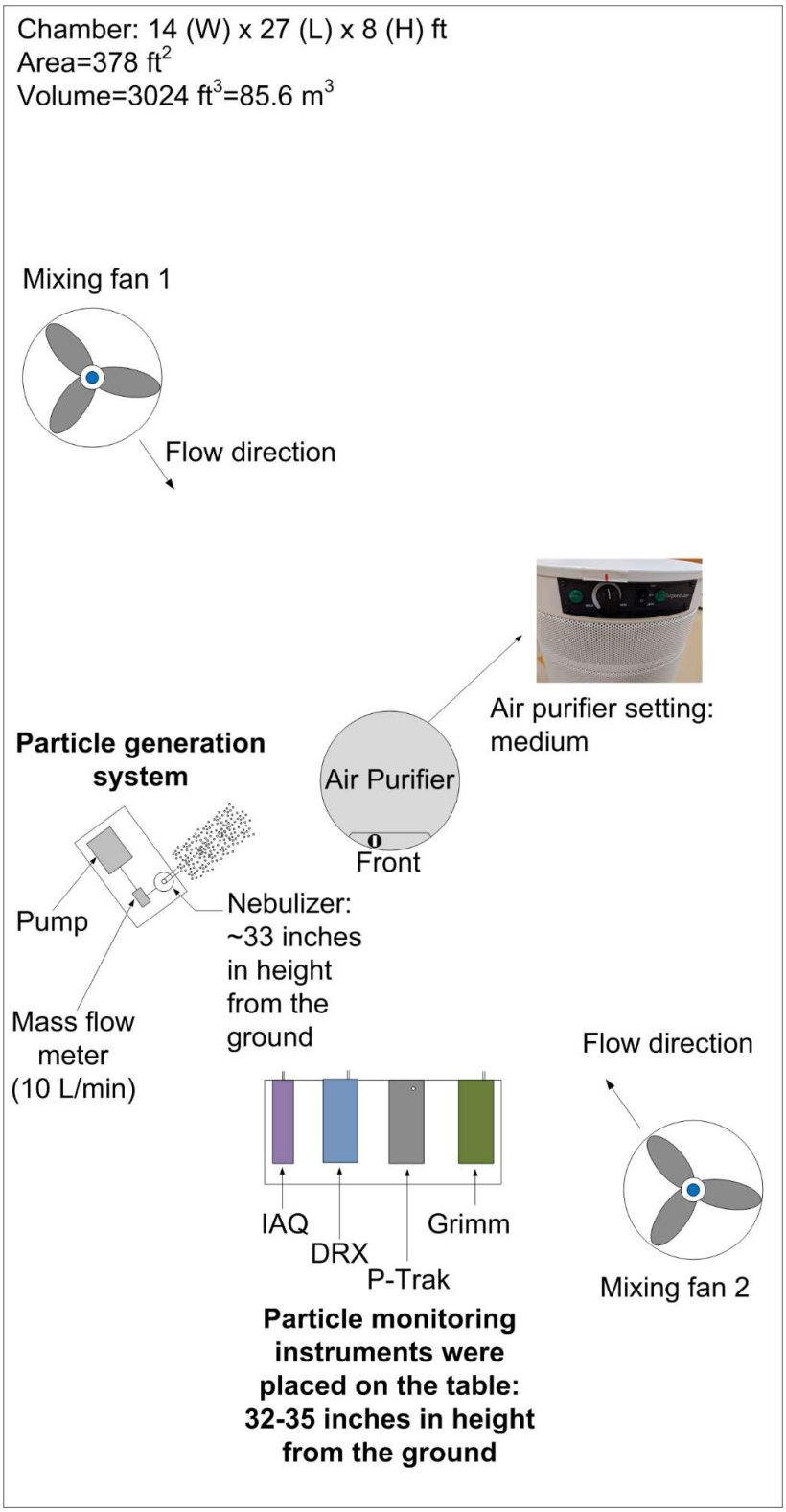


Figure 1. Schematic diagram of the experimental setup in the chamber.

Results

The removed particle fraction, η, was determined by comparing the NaCl particle concentrations during the natural particle settling due to gravity and the particle concentrations decay when the air purifier was operating during the same time points starting from the point when the aerosolization and mixing were turned off:

$$\eta = 1 - \frac{C_{Air\ purifier\ ON}}{C_{Reference}},$$

where $C_{Air\ purifier\ ON}$ is particle mass (or number) concentration at a time t_i when the air purifier was operating (step 6 above), and $C_{Reference}$ is mass (or number) concentration of test particles at the time t_i with the air purifier off (Step 5 above).

In addition to the removed particle fraction, the standard parameter to evaluate the performance of air cleaners, Clean Air Delivery Rate (CADR, cfm), was calculated using the following equations:

$$CADR = (k_A - k_N) \times V$$

$$k_i = \frac{\ln C_i(t) - \ln C_0(t = 0)}{t}$$

Where k_i is the particle decay rate: k_A for the air purifier in operation and k_N for natural settling; V is the volume of the test chamber (ft^3); C_i is particle mass or number concentration (e.g., $\mu g/m^3$ or $\#/cm^3$) for each respective case at time t; C_0 is particle mass or number concentration at t = 0 min; t is a period of operation during which the particle concentration change was measured. In our case, t = 60 min. CADR is an important air cleaner performance parameter because it is independent of the test chamber size and indicates the cleaner's performance. CADR is a product of the air cleaner's airflow and its collection efficiency, i.e., at a 100% particle capture efficiency, the CADR is equal to the cleaner airflow.

The summary of the results obtained with different instruments is presented below.

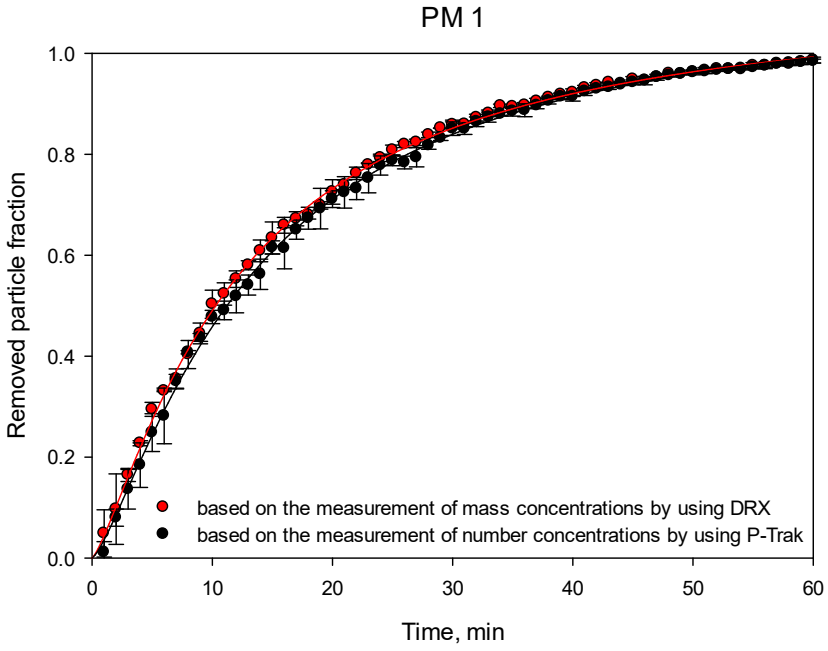


Figure 2. The removed fraction of PM1 particles (d < 1 μm) from the chamber as a function of time: 1) measured mass concentrations using DRX (mg/m^3) and 2) measured number concentration using P-Trak (#/cm^3). Each data point is an average of three repeats, and the error bars represent standard deviations.

The data were fitted with a 3 parameter sigmoid regression equation resulting in the following equation:

Based on mass concentrations: $\eta = \frac{1.125}{1+(\frac{t}{12.24})^{-1.271}}$ R^2=0.9991

Based on number concentrations: $\eta = \frac{1.129}{1+(\frac{t}{13.35})^{-1.316}}$ R^2=0.9988

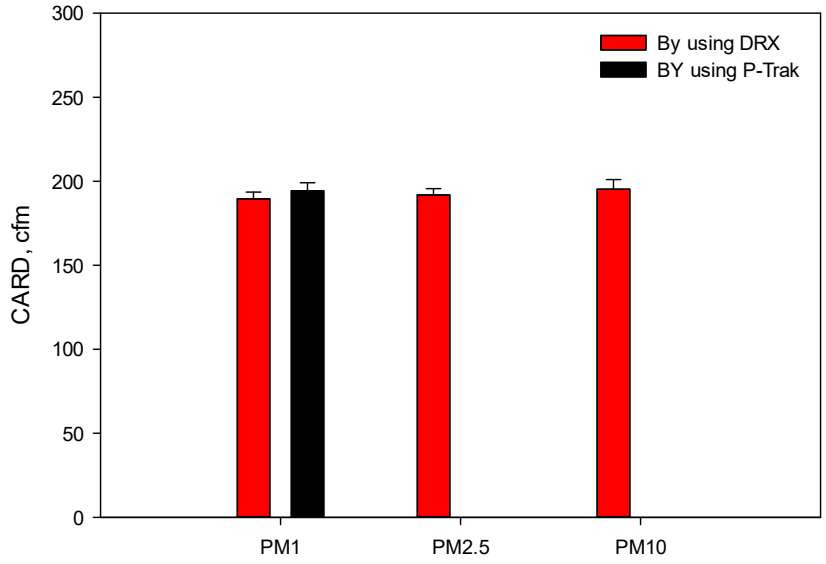
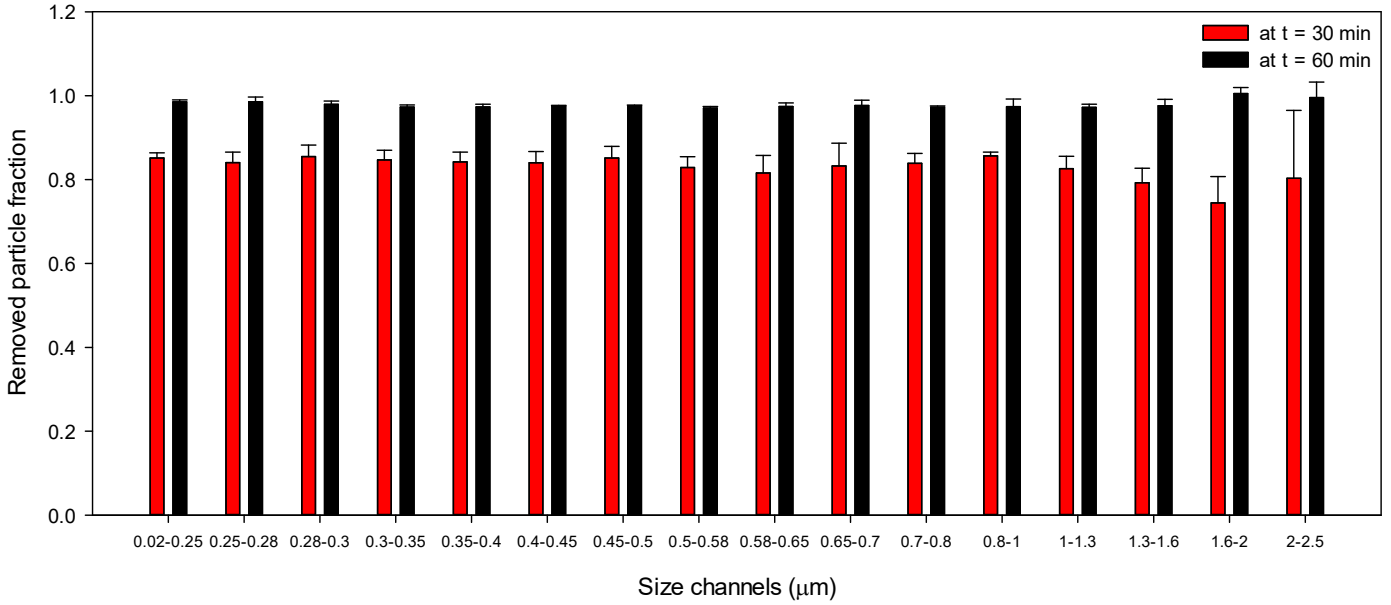


Figure 3. Clean air delivery rate (CADR, cfm) for different particle size fractions: 1) determined based on measured mass concentrations using DRX (mg/m^3) and 2) determined based on measured number concentrations using P-Trak ($\#/cm^3$). Each data point is an average of three repeats, and the error bars represent standard deviations.

Average clean air delivery rate (CADR) for PM1:

$CADR_{mass}=190 \pm 4$

$CADR_{number}=194 \pm 5$



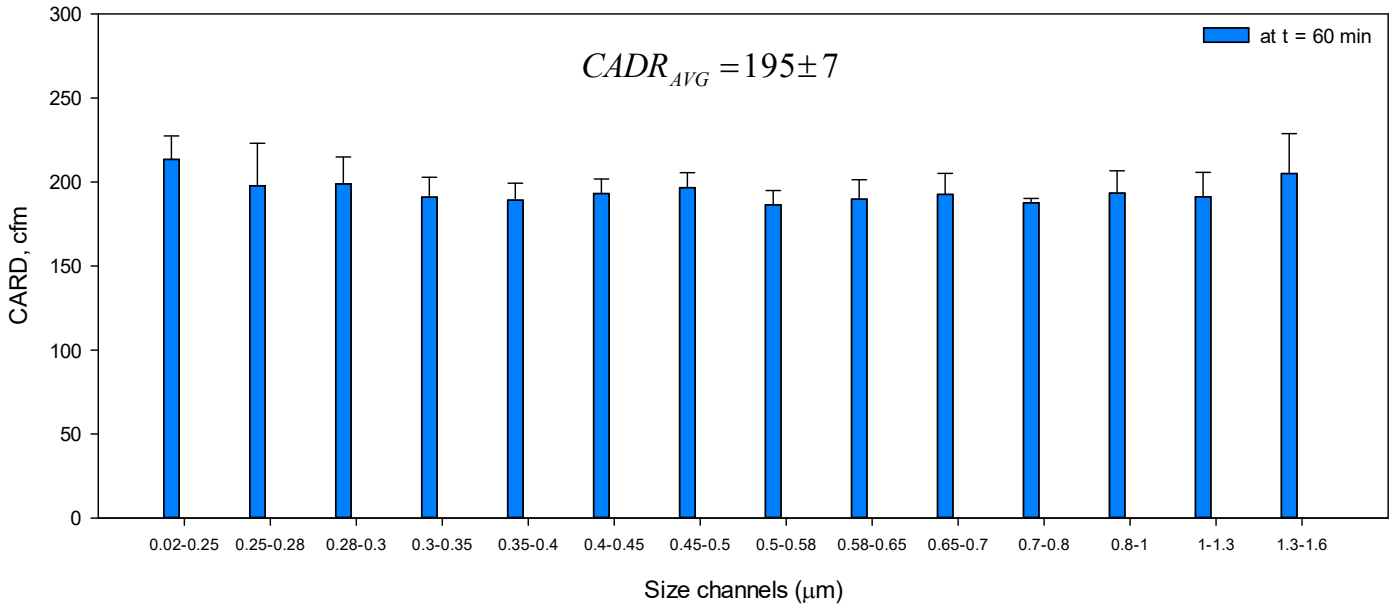


Figure 4. (a) Removed particle fraction for different particle size ranges: 1) removed particle fraction at t = 30 min and 2) at t = 60 min from the start of air cleaner operation. (b) CADR for different particle size ranges after t = 60 min. Each data point is an average of three repeats, and the error bars represent standard deviations.

Summary

The AirPura air purifier effectively removed particles across the investigated size range from 0.02 µm to 2.5 µm and even up to 10 µm when investigated at a medium operating setting. The CADR was uniform across the investigated size range and had an average value of 195 cfm. The size range at which this removal was achieved incorporates viral-sized particles such as SARS-CoV-2, e.g., particles in the 20-250 nm range, which could be carrying individual viral particles and particles in the 0.25 – 2.5 µm range, which would correspond to particles carrying viral agglomerates and other particles. PM_{10} fraction encompasses virus-carrying aerosols and also larger droplets up to 10 µm in size.

Using the measured CADR, one can quickly determine the number of air changes that will be obtained in a space with a particular volume.

The time needed to remove particles from space will depend on the volume of the particular space, e.g., room or office. In the performed experiments in the 85 m^3 chamber, more than 80% of particles smaller than 1 µm (e.g., including those that encompass individual viral particles) were removed in 30 min. In smaller spaces, the removal will be faster.

References

Noh, K. C., & Oh, M. D. (2015). Variation of clean air delivery rate and effective air cleaning ratio of room air cleaning devices. *Building and Environment*, *84*, 44-49.

ANSI, A. (2006). AHAM standard AC-1-2006, method for measuring performance of portable household electric room air cleaners. *Washington, DC: Association of Home Appliance Manufacturers*.