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Report UN2-201110-T5599900-318

Determination of the cleaning efficiency of an air cleaner in the particle size range of viruses and exhaled droplets

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1. Background

ProActiveAir GmbH contracted IUTA e.V. to investigate the filtration of aerosol particles in the size range of viruses and potentially virus-laden droplets by an air cleaner. For this purpose, the air cleaner was subsequently exposed to two different aerosols in a chamber of about 30 m³ according to GB/T 18801:2015. The exhaled droplets were simulated by paraffin, which is also used for testing respirators according to EN 149. The individual viruses were represented by solid potassium chloride (KCl) particles with a size of 0.12 µm (mean size of the SARS-CoV-2 virus according to Microsc. Res. Tech. 2020 1-16). The clean air delivery rate (CADR) for different particle size ranges was determined by comparing decay curves with and without the air cleaner operating.

2. Tested Air Cleaner

The tested air cleaner was delivered by ProActiveAir GmbH without any noticeable damage and was tested for correct function. The air cleaner did not contain any replaceable filters that had to be inserted or conditioned in advance. The unit was operated at the highest continuous fan level (level 3). The air cleaner, which has rollers, is designed as a floor unit and was therefore positioned on the floor in the center of the test chamber for testing.

3. Measurements

3.1 Test Chamber

All measurements were performed in the test chamber schematically shown in Figure 1 according to GB/T 18801-2015. The internal dimensions of the chamber are 3.45 m × 3.40 m × 2.50 m, corresponding to a volume of 29.3 m³. The walls of the test chamber were lined with an antistatic foil to minimize electrostatic particle losses. The test chamber has an active ventilation system to remove any particles present prior to the start of measurements and an air conditioning system to set the required temperature. The relative humidity was adjusted with a portable humidifier. During the actual CADR measurements, the ventilation, air conditioning and humidifier were turned off. Only a fan on the floor of the chamber was running as required by various test standards for air cleaners to homogenize the test aerosol. Sampling was performed by extracting a small volume flow from the chamber, which was fed to the respective measuring devices. The sampling point was located 0.50 m from the wall and 1.20 m above the floor, following GB/T 18801:2015.

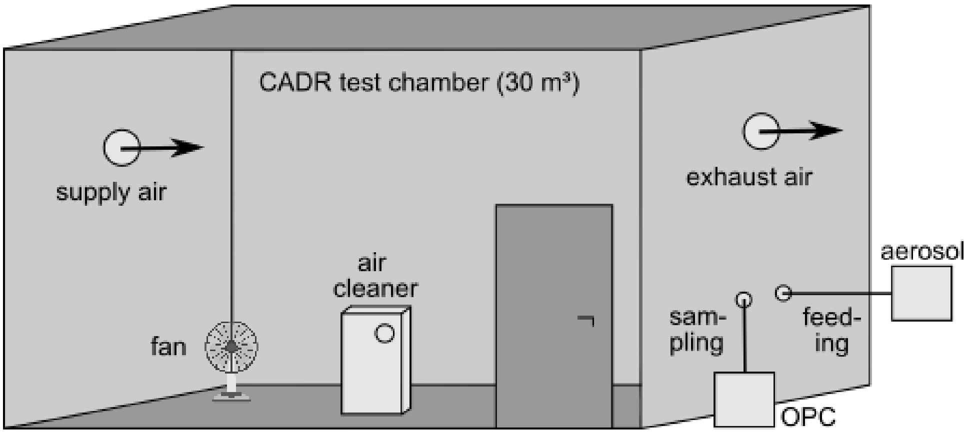

Figure 1 Schematic structure of the CADR test chamber according to GB/T 18801-2015.

3.2 Test and Measurement Equipment

The following test and measurement equipment was used for the measurements:

- KCl particles were generated by means of an atomizer (model Palas AGK 2000) from an aqueous KCl solution (100 g KCl per liter of de-ionized water) at a working pressure of 2 bar and dried by dilution with dry compressed air. The particles were then passed through an antistatic hose into the test chamber. No specific neutralization of the particles was carried out, since it is to be expected that the particles will reach a bipolar equilibrium state during the residence time in the test chamber by interaction with the ions naturally present.
- Monodisperse particles with a size of 0.12 µm were classified from the polydisperse test aerosol using a differential mobility analyzer (DMA, model TSI 3080/3081) and then counted using a butanol-based condensation particle counter (CPC, model TSI 3776). The CPC was operated at a flow rate of 1.5 l/min and the sheath flow of the DMA was set to 15 l/min to achieve sharp classification.
- The size range from 0.2 to 10 µm was measured with an optical aerosol spectrometer (OPC, model Palas welas digital 2000, sensor 2070).
- The size range from 0.5 to 20 µm was measured with an aerodynamic particle size spectrometer (APS, model TSI 3321).

3.3 Test Procedure

First, the test chamber was cleaned, the temperature was set to (25 ± 2) °C and relative humidity to (50 ± 10) %rh. Subsequently, KCl particles were dispersed into the test chamber for 2 min. After a waiting period of 5 min to achieve homogeneous mixing, the natural decay curve was measured for 30 min without operating the air cleaner as a reference. Subsequently, the air cleaner was switched on and operated at the highest level for 30 min to record the decay curve with air cleaner.

After completion of the measurement with KCl, the room was cleaned again, the initial values for temperature and relative humidity were readjusted and the same procedure was repeated with paraffin. The only difference was that 3 min were selected as the addition time in order to achieve a suitable starting concentration for this case.

4. Calculation of the Clean Air Delivery Rate (CADR)

The Clean Air Delivery Rate (CADR) described in GB/T 18801-2015, ANSI/AHAM AC-1 and other standards was used as a measure of purification performance. It describes the flow rate of cleaned air provided by the air cleaner. Under ideal conditions, the CADR is equal to the product of the air cleaner's filtration efficiency and its flow rate.

The change in particle concentration C_t over time t follows the exponential function

$$C_t = C_0 e^{-kt}$$

with the initial particle concentration C_0. By linear regression of the natural logarithm of the particle concentration $\ln C_{t_i}$, the decay rate k can be determined as

$$k = -\frac{\left(\sum_{i=1}^{n} t_i \ln C_{t_i}\right) - \frac{1}{n}\left(\sum_{i=1}^{n} t_i\right)\left(\sum_{i=1}^{n} \ln C_{t_i}\right)}{\left(\sum_{i=1}^{n} t_i^2\right) - \frac{1}{n}\left(\sum_{i=1}^{n} t_i\right)^2}$$

where the time t_i corresponds to the ith data point and n to the number of data points. The natural decay rate k_{nat} and the total decay rate k_{tot} can be obtained from decay curves with and without operation of the air cleaner.

The correlation coefficient R^2 is a measure of the degree of linear relationship between the independent variable x_i and the dependent variable y_i. It is calculated according to

$$R^2 = \frac{\left[\sum_{i=1}^{n}\left(x_i - \frac{1}{n}\sum_{i=1}^{n} x_i\right)\left(y_i - \frac{1}{n}\sum_{i=1}^{n} y_i\right)\right]^2}{\sum_{i=1}^{n}\left(x_i - \frac{1}{n}\sum_{i=1}^{n} x_i\right)^2 \left(y_i - \frac{1}{n}\sum_{i=1}^{n} y_i\right)^2}$$

In this case, we have $x_i = t_i$ and und $y_i = \ln C_{t_i}$. Following GB/T 18801-2015, a correlation coefficient >0.98 was assumed as the minimum criterion for a usable measurement. From the natural and total decay rate, the CADR is calculated to

$$\text{CADR} = (k_{tot} - k_{nat}) \cdot V$$

with the effective volume V of the test chamber. It can be specified for individual particle size classes or summarized size ranges.

5. Results

Figure 2 shows a summary of the decay curves for the three size ranges 0.12 µm (DMA+CPC), 0.2 - 0.5 µm (OPC) and 0.5 - 1 µm (APS). Contrary to the original planning, the APS data were evaluated for KCl instead of paraffin, as this allowed a further size range to be covered. In the overlapping size range from 0.5 to 1 µm, however, there was good agreement with the measured values for paraffin. The decay curves are shown in linear form on the left-hand side and in logarithmic form on the right-hand side. The air cleaner was switched on after 30 min in each case. Black lines show the exponential fits used to determine the decay rates.

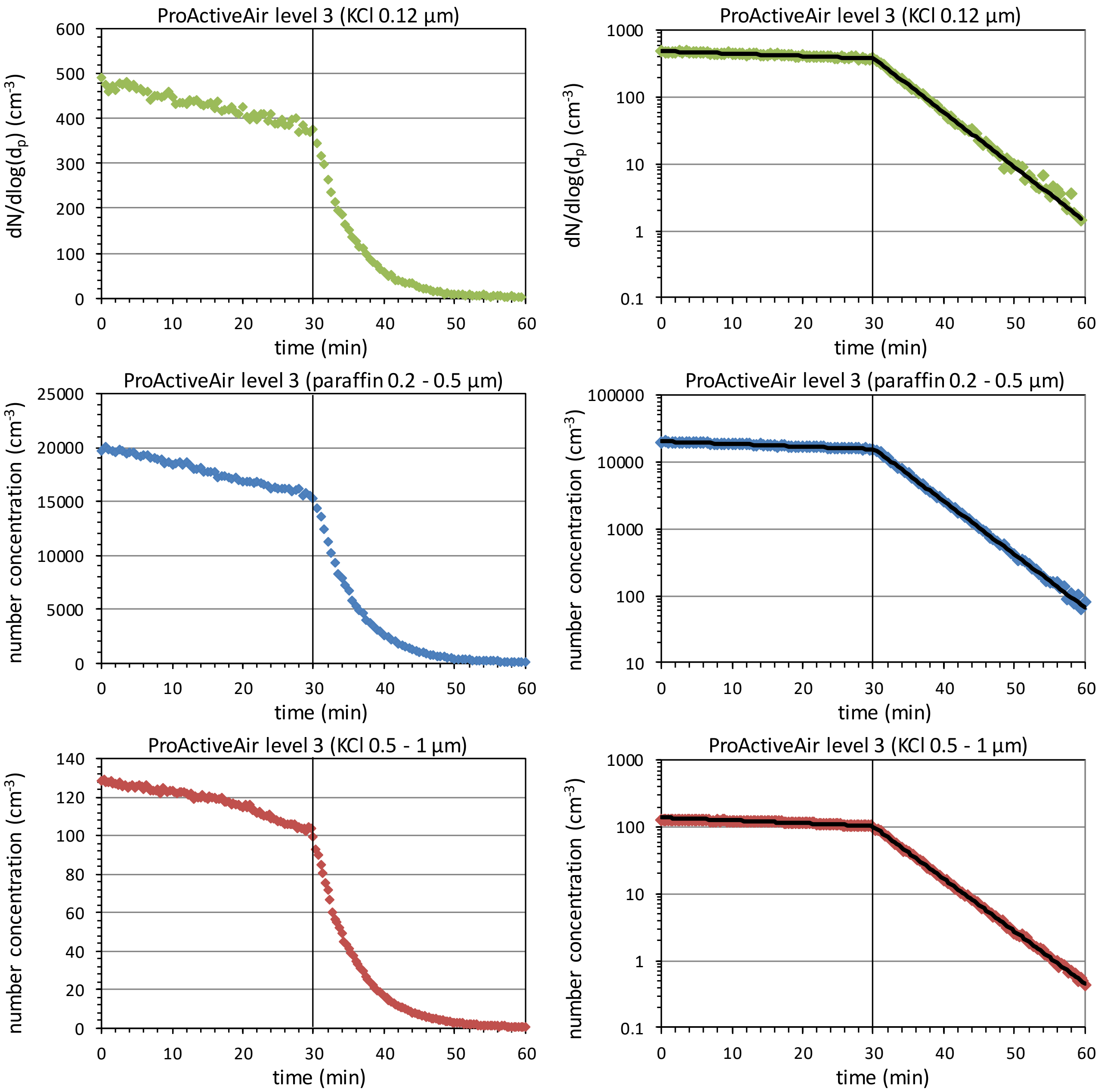

Figure 2 Decay curves for three different particle size ranges (30 min without and 30 min with air cleaner on) in linear and logarithmic representation. The black lines are exponential fits to the data points.

Table 1 summarizes the integrated CADR values for the three size ranges. In addition, the respective test aerosol, the measurement technique used, the natural and total decay rates as well as the correlation coefficient for the measurement with the air cleaner switched on are given.

Table 1 Size-integrated CADR for different size ranges.

Test aerosol	Particle size	Meas. technique	k_{nat} (min^{-1})	k_{tot} (min^{-1})	R^2_{tot} ( )	CADR (m^3h^{-1})
KCl	0.12 µm	DMA+CPC	0.0084	0.1879	0.9949	**315**
Paraffin	0.2 – 0.5 µm	OPC	0.0090	0.1833	0.9994	**306**
KCl	0.5 – 1 µm	APS	0.0099	0.1804	0.9996	**300**

The size-dependent CADR determined from the decay curves of the individual size classes (summarized to 16 classes per decade in each case) over the entire size range considered from about 0.12 to 3 µm is shown in Figure 3. As already evident from the data previously averaged over the size ranges, there was no pronounced size dependence, suggesting a relatively efficient filtration by the air cleaner.

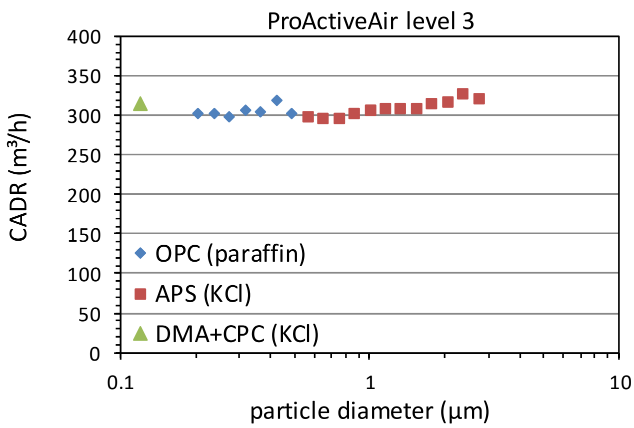

Figure 3 Size-resolved CADR of the air cleaner when operating at level 3.

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