Study on particle filtration performance of high volume air purifier: Experimental results

Yingying Fan [1], *Junjie* Liu [1*], and *Hanyu* Li [1]

[1] School of Environmental Science and Engineering, Tianjin University, Tianjin, China 300072.

Abstract. With the spread of SARS-CoV-2 virus all over the world, the indoor air quality of commercial buildings has received intense attention. The evaluation of high-volume air purifiers (HAP, CADR≥800m^3/h) is of unprecedented importance. According to the national standard GB/T 18801-2015, the purification performance of HAP and its three different replacement elements was tested by the environmental chamber method. The results show that the particulate matter purification of single effect filter is better than that of composite filter. The presence of particulate matter generated by activated carbon layer and bypass air flow leads to a difference of about 10% between the clean air delivery rate (CADR) value for the count and weight of composite filter. In the durability test, the CADR value decreases greatly when the smoke volume is 1000 pieces due to the increase of resistance and the electrostatic elimination effect of incense smoke. The CADR test standards of air purifiers in 5 countries were compared. Only Korea mentioned that when the air volume of the air purifier is greater than 960m^3/h, 50m^3 test chamber is used. However, due to the different sources of experimental dust and sampling methods, this standard does not conform to China's national conditions. The analysis results will provide reference for the formulation of relevant test methods and standards

1 Page layout

IAQ has been shown to play a significant role in both the effects of viral spread and fatal symptoms. We should include PM as one of the contaminants with the worst effects on human health [1].Suspended particulate matter has a porous structure, and its surface can be attached to heavy metals, organic pollutants, acid oxides and other substances, and it is often the main carrier of pathogenic microorganisms such as viruses and bacteria. Inhalable particulate, PM_{10} can enter the respiratory system, and $PM_{2.5}$ can even enter the blood circulation system through the alveoli [2,3], hence causing harm to the lungs and other organs and leading to various respiratory diseases.

Current air purification technologies include filtration, electrostatic, negative ions, adsorption, etc. Some researchers have evaluated the purifying effect of different types of air purifiers on $PM_{2.5}$ produced by cigarettes, cooking and oil fume, and the results show that the performance of filter air purifiers is less affected by humidity changes, and its comprehensive performance is the most stable [4].As the core filtration unit, HEPA is the key to measure the level of filtration technology and provides the most basic and reliable means for air purification [5]."Sandwich" filters (HEPA layer, activated carbon layer and support layer via adhesive) are currently popular in air purifiers.

The research on air purifiers began in the 1970s and 1980s, when people realized that there was no unified standard test method in the process of using air purifiers. Whitby [6] et al developed a method for dynamic measurement of smog and hydrocarbon gas removal and odor emission rates. Then the ANSI/AHAM standard first introduced the use of "clean air volume (CADR)" to measure the efficiency of air purifiers. Shaughnessy [7] studied the matching relationship between different room areas and the air cleanliness of the purifier. Li Mu [8] et al. compared China's existing relevant standards with foreign standards in various aspects and proposed shortcomings and improvement methods, laying a foundation for the formulation of the 2015 edition of national standards, The standard test of CADR of air purifiers is realized in the environment chamber, and the value obtained in most experiments is lower than the manufacturer's nominal value [9].And the CADR experimental value decreases with the increase of the environmental chamber size. Effective air purification ratio EACR (the ratio of actual CADR to nominal CADR) was proposed to evaluate the real performance of air purifier, and the EACR value was in the range of 0.70~0.83 [10]. By using numerical simulation analysis, the concentration distribution of pollutants in public space and bedroom was studied, and it was found that different locations of air purifiers would significantly affect their purification effect [11,12]. Zhang Xin [13] and Hu Xinrui [14] optimized the air distribution form of air purifier, put forward the evaluation index of air distribution efficiency, and put forward suggestions for the revision of national standard.

The current standard system in China, HAP performance can not be evaluated effectively and accurately. There are few researches on the purification performance and durability of large-capacity air

* Corresponding author: jjliu@tju.edu.cn

purifiers. In this study, CADR and CCM for HAP of three different types replacement elements were tested. The analysis results will provide reference for the formulation of relevant test methods and standards.

2 Materials and methods

2.1 Research on air purifier standard

The CADR performance test methods of air purifiers in five countries that are generally used are investigated and analyzed, and there are differences in the experimental test chamber, dust source selection and sampling methods, etc. Only Korea mentions the test standard of air volume greater than 960m3/h, as shown in Table 1. Among the standards investigated so far, only China has proposed CCM, which reflects the life span of purifiers, and the corresponding durability index in the Japanese standard. For both standards, acceleration experiments were carried out in smaller tanks, during which CADR values were tested by moving back to larger tanks several times. There are some limitations in the performance test of HAP(CADR>800m^3/h) by using the existing standards at home and abroad..

2.2 Research object

The model of this study is AS488BWB, with a size of 590×320×1840mm. The maximum air volume is 1200m^3/h, as shown in Figure 1. In order to compare the effects of different built-in filters on the performance of HAP. In addition to its own filter element (single effect filter element), two "sandwich" composite filters are selected on the market.

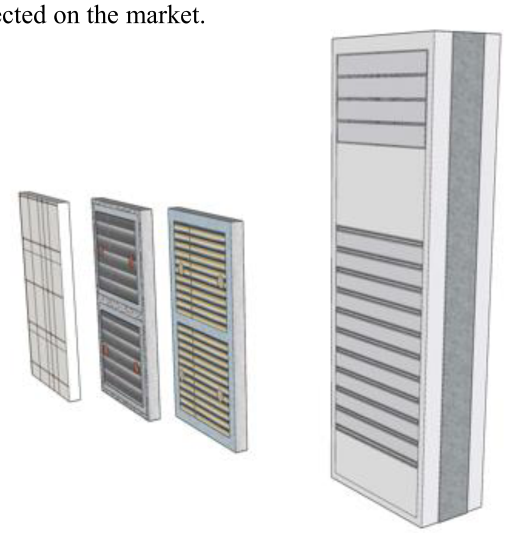


Fig. 1. Schematic diagram of HAP and its filter.

2.3 Experimental procedure

The environment chamber used in this experiment is specially built for the performance test of air purifiers according to national standards and is made of stainless steel as a whole, as shown in Figure 2, with a size of 3.5m×3.4m×2.5m and a total volume of 29.75m3. The air tightness of the experimental cabin shall meet the requirements of ≤ 0.05h^{-1}, and the temperature and humidity can be adjuste. In the course of the experiment, the number of different particle sizes was recorded by aerodynamic particle size spectrometer (TSI 3321 APS) and its corresponding diluter (TSI 3302A, Dilution ratio:100:1). Use Dusttrak8530 to record the weight of $PM_{2.5}$.

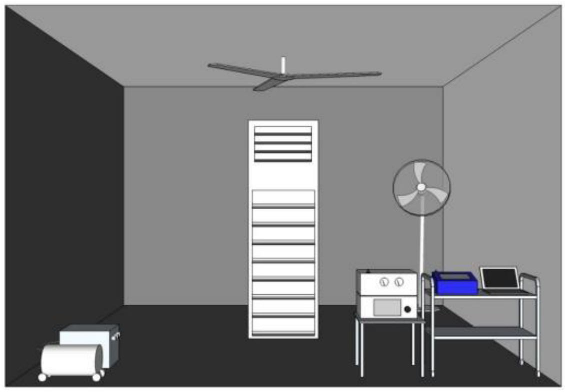


Fig. 2. Visual field of view from observation window of laboratory module

According to GB 18801-2015 test method, CADR and CCM experiments were carried out on this HAP. The experimental dust source was incense dust.

CADR test steps: The test is divided into two stages: natural decay and total decay. Before the experiment, the temperature was 25±2℃, the humidity was between 40% and 60%, the background particle concentration was less than 1000 P/L, and the circulating fan and stirring fan were started at the same time. The cigarette is lit in the smoke generator, and the counting concentration of particulate matter with a particle size above 0.3μm is detected to rise to 2×10^6~2×10^7P/L. At this time, the stirring fan still needs to stir for another 10 min to fully mix the smoke particulate matter. The natural decay experiment started after the stirring fan was turned off, and the initial concentration C_0 as the first point. The total decay begins at the end of the natural attenuation process. At this time, ensure that the particle count concentration is still within the range of 2×10^6~2×10^7P/L. Turn on the air purifier, and the steps are consistent with the natural attenuation. The calculation formula is shown in Formula (1) and (2) in Table 1.

CCM test steps: The purifier used in this experiment is too large to be carried out in a 3m³ environmental chamber, so a 30m^3 chamber is chosen instead. When the concentration of particulate matter was lower than 0.035mg/m^3, the purifier was turned off and left for more than 30min. It was found that the attenuation of CADR in this state was less than 5% of the initial value. Therefore, the number of cigarettes lit can be adjusted until the volume of each cigarette is 300, and the CADR drop range of 5-10% stipulated in the national standard can be achieved, as shown in Figure 3. Repeat the above steps until the end of the experiment when CADR 50% initial value. The cumulative amount of particulate matter removed at the initial value of 50% CADR was calculated as the CCM of the large air purifier.

 https://doi.org/10.1051/e3sconf/202339601113

Table1. Comparison of CADR performance test methods for air purifiers

Country	**China**		**US**			**Canada**		**Japan**	**Korea**		
Standard	**GB/T 18801-2015**		**ANSI/AHAM AC-1-2006 IEC/PAS 62587-2008**			**NRCC-54013-2011**		**JEM 1467-2013**	**SPS-KACA002-132:2018**		
CADR	$C_t = C_0 e^{-kt}$ (1) $Q = 60 \times (k_e - k_n) \times V$ (2)							$P = -\frac{V}{(N)t} \times [\ln(\frac{C_2}{C_{02}}) - \ln(\frac{C_1}{C_{01}})]$			
Air volume (m^3/h)	10~30	30~80	17~756	17~672	42~756	--		--	6~96	96~960	>960
Test chamber size (m^3)	3	30	28.5			55		20~32	8.0±0.5	29.5±1	50.0±1
Temperature (℃)	25±2		21±3			21±2		20±15	23±5		
RH(%)	50±10		40±5			40±5		65±20	55±15		
Dust source	Incense smoke (hongtashan)		Incense smoke	Dust	Pollen	KCL/ NaCL Ultrafine	KCL/ NaCL Fine & coarse	Incense smoke (MildSeven)	KCL		
Initial concentration	≥ 0.3μm: 2000~2000 P/mL		24000~35000 P/mL	200~40P/mL	4~9 P/mL	10000 P/mL	200 P/mL	5 cigarettes (≥ 0.3μm):1~5mg/m^3	100~300 P/mL		
Sampling interval(min)	2		1			3		Initial sampling once, run 30 minutes sampling once; Until 1/3 of the initial concentration	Initial sampling once, run 30 minutes sampling once； Until 1/10 of the initial concentration		
Sampling time(min)	20		20			30					

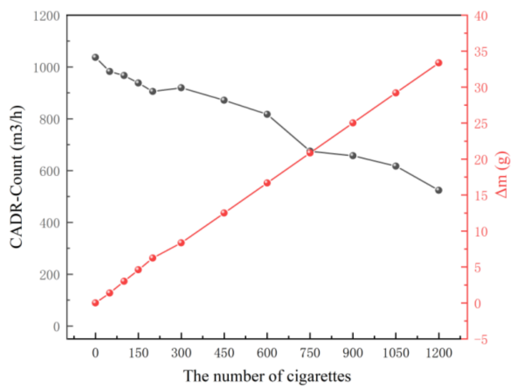
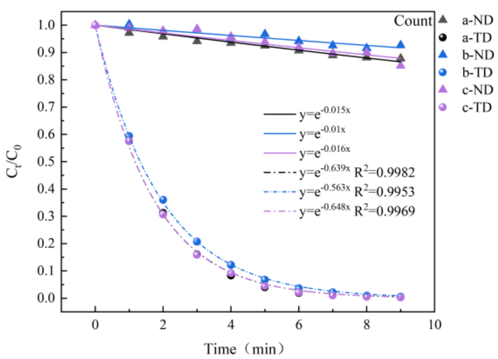


Fig. 3. CADR changes during CCM test

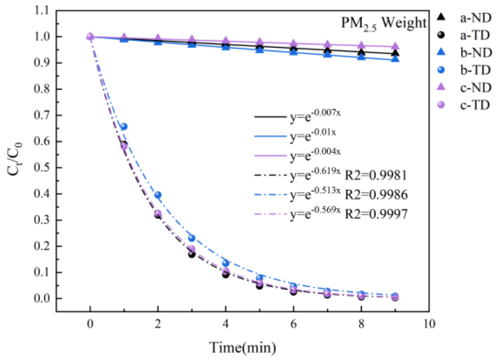
3 Results

3.1 The purification performance of HAP under different filter elements was tested

In order to have at least 9 effective sampling points, one sampling point was taken every 1 min during the experiment. The results of natural decay (ND) and total decay (TD) after concentration normalization are shown in Figure 4. The calculation results of root CADR are shown in Table 2, the counting purification effect of 0.3μm particulate matter is as follows: c > a > b, a and c are about the same; $PM_{2.5}$ weight purification effect: a > c > b. The original filter element a is a single effect filter, which has only the support layer and HEPA layer. Compared with the other two filter elements, it has more folds and a larger filtration area, showing a better purification effect. Under the same working condition, the increase of resistance of composite filter element leads to the decrease of air supply volume, so the CADR value of composite filter element b is less than c. In addition, the count of single effect filter element a is basically consistent with the weight CADR, while the difference between compound filter element b and c is about 100m^3/h (10%).



a)≥ 0.3μm



b)PM2.5

Fig. 4. Particle concentration attenuation of HAP based on three filter elements

Table 2. CADR-Results

Type of filters	a	b	c
CADR-Count (m^3/h)	1121	995	1139
CADR-PM2.5 Weight(m^3/h)	1101	905	1017

3.2 Persistence testing for HAP

Figure 5 shows the change trend of CADR during CCM test when the large purifier is equipped with built-in original filter element a. It can be seen that the ability of air purifier to purify particles gradually decreases with the process of dust absorptio. CCM with three built-in filters is shown in Figure 6, b > c > a, the CADR of the three filters began to decrease significantly when about 1000 cigarettes were emitted. At this time, there are two reasons for the decrease of CADR. On the one hand, the filter resistance increases, which leads to the decrease of air volume. On the other hand, due to the antistatic effect of incense dust, the electrostatic on the surface of PP material gradually disappears, leading to the reduction of the single pass efficiency of the filter itself.

The CCM test results of the three filters were used to calculate the use status of the HAP under moderate pollution according to Formula 3. The outdoor $PM_{2.5}$ concentration of moderate pollution was 150μg/m^3, and the use days of the HAP in the 158m^2 building were 266, 344, and 338 days, respectively. The results are summarized in Table 3.

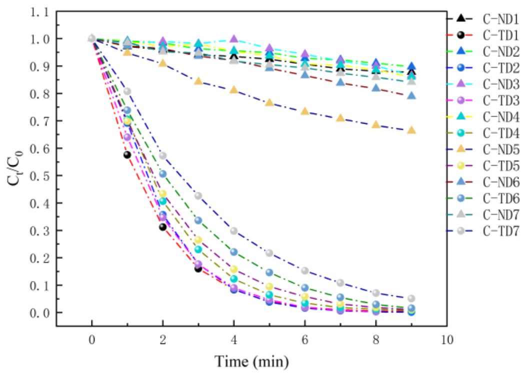
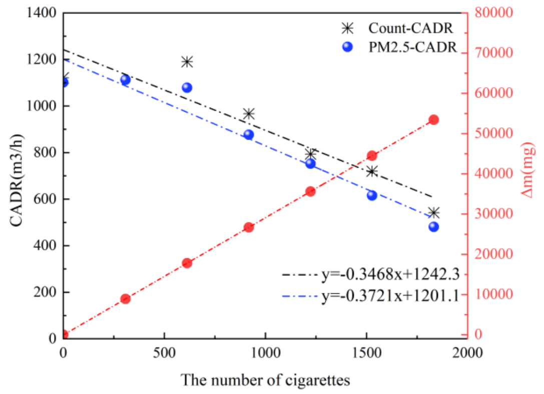
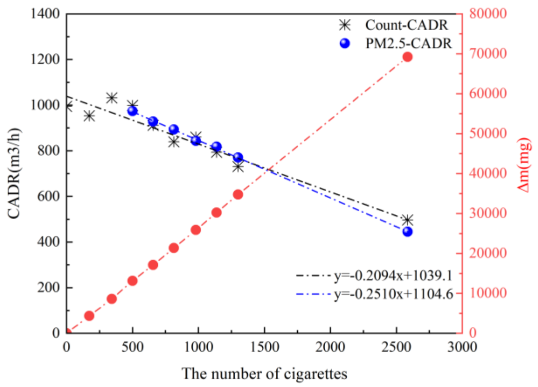


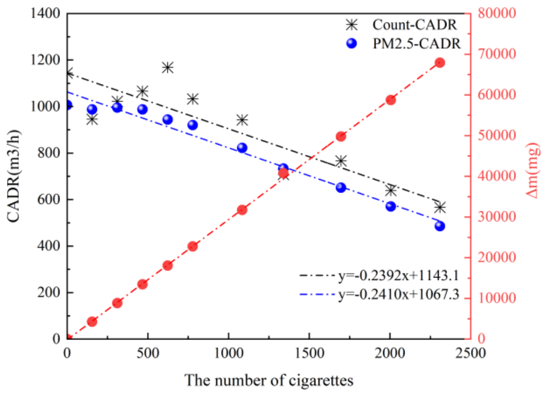
Fig.5. Count-CADR results during CCM test



a) Filter a



b) Filter b



c) Filter c

Fig.6. CCM of air purifier with different filters

$$\tau \le \frac{CCM}{[k_v P_p c_{out} - 35(k_0 + k_v)] \times S \times h \times t} \quad (3)$$

Table 3. CCM results

Type of filters	a	b	c
CCM (Mparticle/mg)	53414	68980	67817
The number of cigarettes	1833	2585	2310
Service life τ(d)	266	344	338

4 Discussion

The CADR test of HAP in this study is based on the national standard, and it is proposed to revise the air purifier test in the range of 800m^3/h~1200m^3/h CADR. Formula 4 is obtained from formula 1 and 2.

$$C_0 = \frac{C_t \times M}{e^{-(\frac{CADR}{60 \times V} + k_n) \times t}} \quad (4)$$

where, based on the lowest measured concentration of the experimental apparatus, we get C_t =50 P/L, CADR is taken as 1200m^3 /h, V is taken as 30m^3, kn is taken as 0.013 min^{-1} from the experimental average results, M is the dilution ratio 100 and M is taken as 107 due to the maximum loss of 7% from TSI3302A.

Based on the above analysis, modification suggestions are proposed:

1) This study proves that it is feasible to ensure the collection of effective data points by changing the sampling time. In this test method, multiple pre-experiments are required to determine the sampling interval.

2)Increase the size of the environment chamber and keep the smoke concentration and sampling time unchanged. When the lowest concentration is 2×10^6 P/L, it is calculated that the volume of the environment chamber needs at least 63m^3.

3)Increase the smoke concentration and keep the size of the environment chamber and sampling time unchanged. It can be concluded from the above equation that the initial smoke concentration should be at least 1.1×10^9 P/L, so as to ensure that there are no less than 9 effective points when a value is taken every 2 min according to the standard.

In this study, the CCM experiment takes a long time. In order to reduce the sedimentation and escape of particles and shorten the experiment time, it is recommended to use 10m^3 environment chamber. When the CCM level of HAP was evaluated by the current national standard, the results were much higher than P4. Therefore, the effect of HAP cannot be correctly evaluated, and the grading of CCM in the criteria needs to be further adjusted to include the increasing prevalence of HAP

During the epidemic prevention and control period, high volume air purifiers are essential in hospitals, classrooms, cinemas, gyms and other commercial places where people stay for a long time.The analysis results can provide data reference for the formulation of performance test standard of high volume air purifier.

5 Conclusion

This study summarized the test standards of air purifiers, measured the CADR and CCM values of HAP using the current national standard environmental chamber test method, and analyzed the limitations of the test method and evaluation scheme. Provide reasonable opinions for the evaluation of HAP through real experimental results, which is conducive to the promotion and market regulation of commercial purifier. The main conclusions are as follows:

1)The CADR of the original filter element A is the largest. Particulate matter released from the activated carbon layer of the composite filter and the existence of bypass air flow will affect the weight CADR, resulting in the difference between the count and $PM_{2.5}$-weight CADR of the composite filter about 10%. During the CADR test of HAP, the concentration of particulate matter can approach 0 mg/m^3 within 10min. On the premise of keeping one data point every 2min in the standard, it is recommended to increase the size of the environmental chamber to 63m^2, or increase the initial smoke concentration to 1.1×10^9P/L.

2)During the test of CCM, due to the increase of resistance and the antistatic effect of cigarette dust, the CADR drops significantly when the smoke is 1000 cigarettes. In order to reduce the sedimentation and escape of particulate matter and shorten the experiment time, the CCM experiment of HPA can be considered to be carried out in a 10m^3 environmental chamber.

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