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AIR PURIFIER PARTICLE FILTER LIFETIME EVALUATION ALGORITHM FIT FOR OUTDOOR PM2.5 LOW CONCENTRATIONS SITUATION

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Abstract: The paper aims to build an air purifier particle filter lifetime evaluation algorithm fit for outdoor PM2.5 low concentration. Current, GB/T 18801 standard gives the evaluation of particle filter lifetime base on outdoor PM2.5 concentrations based on CCM value of particle filter. But the formula that givens by GB/T 18801 only fit for outdoor PM2.5 concentrations that is higher than 58 ug/m^3. When outdoor PM2.5 concentrations is low than this value the result of filter lifetime will be negative value. However, in real case, outdoor PM2.5 concentration in most area is lower than 58 ug/m^3. Developing the particle filter lifetime evaluation algorithm fit for outdoor PM2.5 low concentrations situation is needed. The paper gives the new aspect of the calculation that considers low PM2.5 concentration outdoor to catch the real case of filter lifetime. And conduct the test to verify the results.
Keywords: Air purifier; Particle filter; Low pm 2.5 concentration; Filter lifetime

1 INTRODUCTION

Ambient air pollution remains a troublesome problem in many developing countries. PM2.5 is seriously exceeding the recommended thresholds in many regions [1-2]. PM2.5 refers to particulate matter that is less than 2.5 micrometers in diameter. These tiny particles can pose significant health risks due to their ability to penetrate deep into the lungs and even enter the bloodstream. Exposure to PM 2.5 will cause respiratory Issues: PM2.5 can cause or exacerbate respiratory diseases such as asthma, bronchitis, and chronic obstructive pulmonary disease (COPD). Controlling indoor air quality and mitigating the PM2.5 concentrations is beneficial to human health. Using air purifier is common and useful way to realize low PM2.5 concentrations inside the room. Particle filter is key component in air purifier to remove the PM2.5 in the air. Although, with the capture of particle on the filter, the lifetime of the particle filter is limited. GB/T 18801 give a method to test CCM (cumulated clean mass) of the filter and calculate the particle filter lifetime based on CCM data got from test [3-4]. But the formula given by GB/T 18801 is not fit the relative lower PM2.5 concentration situation. When outdoor PM2.5 concentrations is low than this value the result of filter lifetime will be negative value. Base on the World Air Quality report given by IQ AIR in 2023, only 2 cities out of 134 cities has average annual PM2.5 concentration outdoor higher than 58 ug/m^3 [5]. Hence, the calculation in GB/T 18801 cannot be used in most of area to give a relative reasonable filter lifetime. In this paper, the real outdoor PM2.5 concentration is considered to impact the indoor steady state PM2.5 concentration according to air purifier PCADR (particle cleaning air delivery rate) and served area. Based on this fact, the new calculation particle filter lifetime evaluation algorithm is more reasonable and will not give output of filter lifetime in any PM 2.5 concentrations outdoor. And test on used filter in low PM 2.5 concentration area also be conducted to verify the correction of the formula.

2 METHODS

2.1 Laboratory Experiments

Two different air purifiers (AP#1, AP#2) with particle filter were tested. The information of their corresponding test data is shown in Table 1.

Table 1 Air Purifier Information

	Raw material of particle filter	New filter PCADR(m^3/h)	CCM (mg)
AP#1	H13	226.2	7600
AP#2	H13	383.18	12000

2.1.1 Air cleaners: chamber CADR and CCM tests and lifetime calculations

The air cleaners were tested against cigarette smoke for several times for the CCM tests according to GB 18801-2022 [6-7]. In each challenge,30–100 cigarettes were lighted with a pressured cigarette lighter to guarantee the complete combustion and stability of dust generation in a 30 m3 stainless steel chamber. Furthermore, the smoke mass concentration was measured after lighting the cigarettes for 10 min to ensure an accurate estimation of the emitted smoke mass. The smoke (20 mg/m3 ~70 mg/m3) was loaded to the air purifier when the air cleaner ran at the maximum airflow, then its CADR of the total particulate matter (d > 0.3 μm) was measured after the loading process according to the standard [8]. CADR is defined as follows in laboratory tests:
CADR = V × (ke − kn) m3 / h
The CADR and CCM data tested also listed in the table 1. the CCM and PCADR is the key parameter to calculate filter lifetime. The served area based on GB 18801-2022 is listed in below formula (formula 1).

Severed area (m^2) = CADR * 0.07~0.12. (1)

In GB/T standard the formula that transform CADR and CCM to filter life is listed.
Particle filter lifetime calculation formula(formula 2)

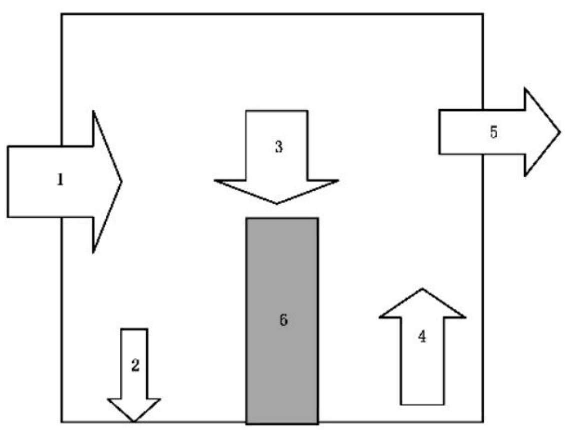
$$M_{AC} = [k_v \times P_p \times C_{out} - (k_0 + k_v) \times C_t] \times S \times h \times t \quad (2)$$

MAC is CCM value of the air purifier. In above formula. ‘t’ is the filter lifetime.
In the GB/T 18801-2022, the Ct is considered as 35 ug/m^3 (constant value). But the Ct is variant with CADR and served area as well as Cout. Hence, when Cout is lower than 58 ug/m^3. We will get negative value of filter lifetime in above formula.

2.2 Field Investigation

2 air purifiers were run in Stockholm (capital of Sweden) in 2022. The running time is for 1 year. Runing time for AP1#1 is 16 months. Running time for AP#2 is 12 months. According to AQI report from IQAIR. After running we check the remained PCADR of 2 air purifiers to check its lifetime.
The average PM2.5 concentration outdoor of Stockholm is 6.2 ug/m^3. Current GB/T 18801 standard consider balance concentration in the room is always 35 ug/m^3. Which is not suitable for this situation. We will get the filter lifetime as negative value. Hence, we need to consider the Ct as variant according to real situation.
Indoor particle pollutant transmits process model is shown in below Figure 1.

Figure 1 Indoor Particle Pollutant Transmits Process Model



1. The particle pollutant from outdoor to indoor due to ventilation
2. Natural decay of particle pollutant.
3. Particle concentration removed by air purifier
4. Particle concentration generated indoor.
5. The particle pollutant emission from indoor to outdoor.
6. Air purifier.

Particle pollutant mass conservation differential equation (3) <u>(E’ is 0 which means we are not consider point 4)</u>

$$\frac{dC}{dt} = P_p k_v C_{out} + \frac{E'}{S \times h} - (k_0 + k_v)C - \frac{Q}{S \times h} \times C \tag{3}$$

When **dC/dt= 0**, we can get Ct which is the **stable particle concentration** in the room after Air purifier running for long time in formula 4:

$$C_t = \frac{P_p k_v C_{out} + \frac{E'}{S \times h}}{k_0 + k_v + \frac{Q}{S \times h}} \tag{4}$$

Kv : Ventilation rate of building. 0.6
Pp : Penetrating coefficient.0.8
Cout: Particle concentration outdoor
K0: Natural decay rate of particle 0.2
Ct: Particle concentration @ time t
S: Area of room
h: Height of room
t : Running time of air purifier
E': Particle concentration generated indoor
Q: CADR of the air purifier

3 RESULT

We tested the remained PCADR after running certain time in Stockholm to check the real filter lifetime. Normally, when the PCADR drops to 50% of its initial status we consider the filter lifetime is gone. Table 2 is test result. We assume that filter CADR decay follows linear functions. The AP#1 particle filter lifetime should be 65 months. The AP#2 particle filter lifetime should be 60 months. And Table 3 and Table 4 show the calculation filter lifetime of AP#1 and AP#2, the results show AP#1 particle lifetime is 67.14 months and AP#2 particle lifetime is 61.59 months. The comparison of AP#1 and AP#2 lifetime between real case and calculation is listed in Tabel 5. The deviation is within 3.2% which is acceptable (Table 3-5).

Table 2 Filed Test Filter Running in Stockholm

	Run time in Stockholm (months)	New filter PCADR(m^3/h)	Remained CADR PCADR(m^3/h)	Remained CADR percentage	CCM (mg)
AP#1	16	226.2	198.4	87.67%	7600
AP#2	14	383.18	338.3	88.29%	12000

Table 3 Filter Lifetime Calculation with New Algorithm

AP#1	Value	Unit
Pp	0.8	
Kv	0.6	h-1
Cout	0.0062	mg/m^3
K0	0.2	h-1
Q	222.6	m^3/h
S	26.712	m^2
h	2.4	m
Ct	0.001	mg/m^3
t	24	h
CCM	7600	mg

Day	2042	day
Filter lifetime	5.60	Year
Filter lifetime	67.14	Month

Table 4 Filter Lifetime Calculation with New Algorithm

AP#2	Value	Unit
Pp	0.8	
Kv	0.6	h-1
Cout	0.0062	mg/m^3
K0	0.2	h-1
Q	383.18	m^3/h
S	45.9816	m^2
h	2.4	m
Ct	0.001	mg/m^3
t	24	h
CCM	12000	mg
Day	1873	day
Filter lifetime	5.13	Year
Filter lifetime	61.59	Month

Table 5 Filter Filed Test Lifetime Vs Calculation Lifetime

	Real lifetime (months)	Calculation lifetime (months)	Deviation
AP#1	65	67.14	3.19%
AP#2	60	61.59	2.58%

4 CONCLUSION

The paper gives a new filter lifetime calculation model that consider the real balance concentration of particle when air purifier running in a certain size of room. The result shows a good consistency with filed test filter result. But there are still some points missed like inner particle pollutant generation and air flow rate change during the air purifier running. But from engineering execution point of view, the result of the calculation gives enough accuracy of filter lifetime. It improves the defect of GB/T 18801-2022 standard that it can't calculate the low particle concentration outdoor.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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