Experimental test research on the release characteristics of particulate contaminants in cigarettes

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Abstract. Indoor air quality is particularly important not only in schools, hospitals, nursing homes and other environments that accommodate sensitive people, but also in production places with high cleanliness requirements. At present, most researches are aimed at testing the mass concentration of contaminants and there are few characterizations of the release characteristics (that is, the release rate) of contaminants. Air pollutants are generally include particulate contaminants and gaseous contaminants. This paper takes cigarettes as typical representatives of particulate contaminants and takes the solid particulate matters PM2.5 produced by cigarettes as the research object. In the 30m³ air purification test chamber, the PM2.5 release rate produced by smoldering cigarette and the smoke generator, the diffusion rate and mass concentration of PM2.5 in the air purification test chamber were tested. According to linear regression, the fitting curve of PM2.5 mass concentration of cigarette smoldering and smoke generator was obtained and the release rate law and the static diffusion and dynamic diffusion law of PM2.5 in the test chamber were obtained. The research results can provide basic data when there are PM2.5 particulate matters pollution sources in the indoor environment and provide scientific and reasonable important basis for subsequent research on airflow organization, ventilation frequency, indoor cleanliness, etc.

1 Introduction

With the development of society and economy, people pay more and more attention to health. The quality of indoor air is not only particularly important in schools, hospitals, nursing homes and other facilities that accommodate sensitive people, but also has extremely strict control indicators in production sites with high cleanliness requirements[1]. The harm of particulate matter itself is well known and what has a greater impact on human health is the adhesion of bacteria, fungi and viruses to particulate matter[2]. PM2.5 will adsorb bacteria, fungi and viruses so that cause toxic effects[3]. Experiments have shown that there is a linear positive correlation between the number of colonies and the concentration of particles with a particle size less than 10μm and the correlation coefficient is 0.7005~0.9997[4]. The virus is more likely to attach to the equivalent particle size. Since the concentration of particulate matter is proportional to the concentration of microbial contaminants, so removal of carrier particulate matter can achieve better control of microbial contamination. Therefore, fine particulate matter has a profound impact on indoor environmental quality. When studying indoor environmental quality, fine particulate matter can be used as a control index.

Most of the current research is aimed at testing the mass concentration of pollutants. The release characteristics of pollutants, that is, the release rate, are poorly characterized, which greatly limits the relevant research on indoor pollutant control. This paper takes cigarettes as typical representatives of particulate contaminants and takes the solid particulate matters PM2.5 produced by cigarettes as the research object. In the 30m³ air purification test chamber, the PM2.5 release rate produced by smoldering cigarette and the smoke generator, the diffusion rate and mass concentration of PM2.5 in the air purification test chamber were tested. According to linear regression, the fitting curve of PM2.5 mass concentration of cigarette smoldering and smoke generator was obtained and the release rate law and the static diffusion and dynamic diffusion law of PM2.5 in the test chamber were obtained. The research results can provide basic data when there are PM2.5 particulate matters pollution sources in the indoor environment and provide scientific and reasonable important basis for subsequent research on airflow organization, ventilation frequency, indoor cleanliness, etc.

2 Experimental test

2.1 Experimental environment and experimental instruments

The experiment was carried out in a 30m³ purification test chamber, which was 3.5m long, 3.4m wide and 2.5m high. The detailed drawing of the 30m³ purification test

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chamber is shown in Figure 1. The origin $O$ is located at the lower left corner of the floor of the test chamber. According to the right-hand rule, the $x$-axis is the length direction of the test chamber, the $y$-axis is the width direction of the test chamber, and the $z$-axis is the height direction of the test chamber and upward is positive. The air flow organization in the $30m^3$ purification test chamber is of the upper and lower return type, which can realize self-purification (complete self-circulation to achieve the effect of purifying the background), ventilation (to realize external circulation, full delivery and full exhaust), experiment (the cabin is completely closed) three states. The number of air changes in this $30m^3$ test chamber is not more than 0.05h$^{-1}$ and the mixing degree is 87.73%, which meets the requirements of air tightness and mixing degree [5].

![Fig. 1. Detail of $30m^3$ test chamber.](image)

**Table 1.** The relevant parameters of the experimental instrument

| Laboratory apparatus   | Measuring range | Measurement accuracy |
|------------------------|-----------------|---------------------|
| Temperature sensor     | -40-80°C        | ±0.5°C              |
| Humidity sensor        | 0-100%RH        | ±0.5RH              |
| PM2.5 sensor           | 0-2999μg/m$^3$  | -                   |
| Hot wire anemometer    | 0.4-30m/s       | 0.1 m/s             |

**2.2 Experimental test plan**

A large amount of particulate matter of 0.3–2.5μm can be produced when cigarettes are burned [5]. So cigarette smoke is selected as the source of PM2.5. Cigarette smoke is generated from smoldering cigarettes and automatic smoke generators.

The layout plan of the measuring points is shown in Figure 2. According to the sampling point layout principle [6], 3 measuring points are evenly arranged at 1 m from the ground and 1 m from the wall, measuring point 1 (0.9m, 1m, 1m), measuring point 2 (1.8m, 1m, 1m) and measuring point 3 (2.7m, 1m, 1m). No.1 pollution source is the location where the automatic smoke generator releases PM2.5, the coordinate is (1.375m, 0.05m, 1m). No.2 pollution source is smoldering cigarettes, the coordinate is (1.8m, 2m, 1m).

![Fig. 2. Layout plan of measuring points in $30m^3$ test chamber](image)

**3 Experimental results and analysis**

**3.1 Static and dynamic diffusion of PM2.5**

The ventilation system is not turned on in the $30m^3$ purification test cabin and the cabin is in a closed state. When the stirring fan is not turned on, it can be considered that the gas in the cabin does not flow, and the diffusion of PM2.5 is in a static diffusion state. After the stirring fan is turned on, the gas in the cabin flows, the diffusion of PM2.5 is in a dynamic diffusion state. The static and dynamic diffusion of PM2.5 in the test chamber are shown in Figure 3. It can be seen from Figure 3 that the mass concentration fluctuates greatly during the static diffusion of PM2.5. After the stirring fan is turned on, the mass concentration of PM2.5 in the cabin is in a stable growth state compared with when the
stirring fan is not turned on, which also proves that the gas mixing degree in the cabin is better after the stirring fan is turned on. The static diffusion of PM2.5 is higher than the dynamic diffusion mass concentration. But after a period of diffusion, the mass concentration of PM2.5 under static diffusion will be close to the mass concentration of PM2.5 under dynamic diffusion, which reflects the PM2.5 mass concentration follow ability of airflow.

According to the single-chamber mass balance equation \[7-8\], the release rate of PM2.5 from cigarette smoldering and smoke generators is obtained. The single-chamber mass balance equation is shown in equation (1): 

\[
\frac{dC_{\text{in}}}{dt} = \frac{E_{\text{in}}}{V} - k_{\text{obs}} \times C_{\text{in}} + k_{\text{AER}} \times C_{\text{out}} \tag{1}
\]

\(C_{\text{in}}\) is the mass concentration of particulate matter in the cabin, \(\mu g/m^3\). \(C_{\text{out}}\) is the mass concentration of outdoor particulate matter, \(\mu g/m^3\). Because the 30m³ test cabin is equipped with high-efficiency and medium-efficiency filters, so \(C_{\text{out}}=0\). \(t\) is the time, \(s\). \(E_{\text{in}}\) is the release rate of particulate matter, \(\mu g/m^3\). \(V\) is the volume of the clean room, \(m^3\). \(k_{\text{obs}}\) is the removal rate, \(times/s\). \(k_{\text{AER}}\) is the number of air changes, \(times/s\). Since the ventilation system was not turned on in this experiment, the test chamber is kept airtight. So \(k_{\text{AER}}=0\).

Assuming that the release rate of particulate matter is constant and the initial mass concentration of particulate matter in the test chamber is very low relative to the concentration of particulate matter released by cigarettes, it can be considered that the initial mass concentration is approximately 0 and can be obtained from formula (1):

\[
C_{0} = \frac{E_{\text{in}}}{k_{\text{obs}}} (1 - e^{-\frac{t}{k_{\text{obs}}}}) \tag{2}
\]

In order to ensure that the mass concentration of particulate matter in the test chamber is uniform, in the actual measurement of the release rate of PM2.5, the stirring fan is turned on and the average value of the three measurement points is taken as the mass concentration of PM2.5 in the test chamber. According to the single-chamber mass balance equation, the release rate of PM2.5 was obtained by curve fitting of the mass concentration of PM2.5 in the test chamber.

### 3.2.1 Smoldering cigarette

After the cigarette smolders, the mass concentration change and fitting curve of PM2.5 during cigarette smoldering are shown in Figure 4. The red dotted line represents the smoldering time of the cigarette, and the burning time is 256s. It can be seen from Figure 4 that during the smoldering process of cigarettes, the mass concentration of PM2.5 increases rapidly in the first period of combustion and the mass concentration of PM2.5 is in a stable state after 150s. After burning the incense, the mass concentration of PM2.5 in the test chamber was in a stable state. By curve fitting the change in the mass concentration of PM2.5 during cigarette smoldering (where the correlation is 0.83632). According to the single-chamber mass balance equation, the mass concentration change of cigarettes can be obtained. When the incense burning time is 256s, the PM2.5 release rate is 45.338\(\mu g/s\). The release rate of PM2.5 was obtained by curve fitting of the mass concentration of PM2.5 in the test chamber.

### 3.2.2 Smoke generator

When the smoke generator acts, it is divided into three working conditions, namely low-speed emission, medium-speed emission and high-speed emission. Place a cigarette every time the smoke generator is turned on. After the smoke generator acts, the change of the mass concentration of PM2.5 in the test chamber with time is shown in Figure 5. Among them, the burning time of incense at low speed is 221s, the burning time of incense at medium speed is 149s, and the burning time of incense at high speed is 75s. It can be seen from Figure 5 that after burning the incense, the mass concentration of PM2.5 in the test chamber is still increasing. The faster the emission rate, the shorter the burning time and the earlier the mass concentration of PM2.5 in the test chamber reaches its peak value. At low-speed emission, the peak mass concentration of PM2.5 in the test chamber is significantly lower than that of medium-speed emission and high-speed emission. Compared
with the PM2.5 mass concentration peak value of 120 μg/m³ in the smoldering state of cigarettes, the cigarette can be obtained. The slower the burning speed, the lower the peak value of PM2.5 mass concentration in the test chamber. When the emission speed of the smoke generator is at the medium speed and above, the peak value of the mass concentration of PM2.5 in the test chamber tends to be consistent. By curve fitting the changes in the mass concentration of PM2.5 during the combustion of cigarettes in the smoke generator (the correlation coefficient of low-speed emission is 0.98436, the correlation coefficient of medium-speed emission is 0.98605 and the correlation coefficient of high-speed emission is 0.95719). The mass balance equation of the chamber is used to obtain the release rate of PM2.5 in the smoke generator. The release rate of PM2.5 under each working condition is shown in Table 2.

![Fig. 5. The mass concentration change of PM2.5 with time](image)

| Test conditions                              | Incense burning time/s | Release rate/(μg·s⁻¹) |
|----------------------------------------------|-------------------------|-----------------------|
| Smoldering cigarette                         | 256                     | 45.34                 |
| Smoke generator emits at low speed           | 221                     | 61.14                 |
| Smoke generator emits at medium speed        | 149                     | 63.32                 |
| Smoke generator emits at high speed          | 75                      | 160.99                |

### 4 Conclusion

1. During the static diffusion process of PM2.5 in the 30m³ purification test chamber, the mass concentration fluctuates greatly, which is higher than that of dynamic diffusion. As the diffusion time increases, the mass concentration of PM2.5 under static diffusion will be close to the mass concentration of PM2.5 under dynamic diffusion.
2. Take the average value of the three measuring points as the mass concentration of PM2.5 in the test chamber, according to the single-chamber mass balance equation and through the curve fitting of the mass concentration of PM2.5 in the test chamber, we can get. When the smoldering time of the cigarette is 256s, the release rate of PM2.5 is 45.34μg/s. When the smoke generator emits incense at low speed for 221s, the release rate of PM2.5 is 61.14μg/s. When the smoke generator emits incense at medium speed for 149s, the release rate of PM2.5 is 63.32μg/s. When the smoke generator emits incense at high speed for 75s, the release rate of PM2.5 is 160.99μg/s.

3. After burning the incense, the mass concentration of PM2.5 in the test chamber is still increasing. The faster the emission rate and the shorter the burning time, the earlier the mass concentration of PM2.5 in the test chamber reaches its peak value. The slower the burning speed of the cigarette, the lower the peak of the mass concentration of PM2.5 in the test chamber.

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