

DEPOSITION MECHANISM AND INFLUENCING FACTORS OF PARTICULATE MATTER PENETRATION IN BUILDING ENVELOPE

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ABSTRACT

Particulate matter is a complex mixture of extremely small particles and liquid droplets. It is a diverse pollutant class whose excessive presence in indoor air contributes to an array of adverse health and material-damage effects. The size of particles is directly linked to their potential for causing health problems. Particles are classified according to their diameter into three size modes: ultrafine (less than 0.1 μm), accumulation (0.1-2 μm), and coarse (larger than 2 μm).

The following deposition mechanisms of particulate matter through crack should be considered: gravity deposition (caused by the gravity of particles), Brown diffusion deposition (caused by the diffusion of particles) and inertia impaction. Some studies point out that inertia is not an important mechanism as particle with enough inertia to be lost by impaction was also likely to be lost by settling, but in L or Z or more bend cracks, if the crack is not long enough for particle to settling by gravity, inertia can not be ignored. It has been found that the air exchange rate plays an important role in the rate of transmission of outdoor air contaminants into the indoor environment, particle size and crack height were another two main factors that governed fractional particle penetration. Besides the crack material is another important factor that influence the particle deposition in the crack of all size distribution. By analyzing the above items, the over all penetration of particle penetration through the building envelops can obtain.

KEYWORDS

Deposition Mechanism, Influence Factors, Penetration, Particulate Matter

INTRODUCTION

Particulate matter (PM) is a complex mixture of extremely small particles and liquid droplets, which is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. As people spend most of their time indoors and the elevated concentrations of particle can cause adverse health effects, therefore, more attention should be paid to the indoor air quality. As a large fraction of indoor aerosol particles originate from outdoor air, it is essential to study the transportation of aerosol particles from outdoor to indoor. During the transportation process, particles may deposit in the crack, and its concentration in the indoor air decreases, and consequently reduces human exposure to aerosol particles.

Since people spend most of their time indoors, in out another study, we found that people in Changsha city of China spend 85% of there time indoors and setting indoors accounts to half. Therefore, most exposure to particles of outdoor origin occurs indoors. However, the concentrations of particles are not

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the same indoors as outdoors, as it may be lost or transformed as air penetration building envelopes, especially through building cracks.

There are four approaches to study the penetration of particle through small cracks or gaps in the building envelop (Nazaroff 2004): observational studies of indoor-outdoor particle relationships; manipulation experiments in buildings; laboratory measurements of penetration through simulated leakage paths; and mathematical modeling of penetration through idealized leakage paths. By analyzing the deposition mechanism and influence factors, the mathematical modeling can interpret the inherently reality of characteristics for penetration through a thin air-leakage crack. Some researchers (Liu and Nazaroff 2001, Christopher et al. 2003) have studied the particle penetration in building envelopes.

Many studies (Chao and Tung,2001; Vette et al. 2001; Thatcher et al. 2003; Liao et al. 2004) have focused on the indoor/outdoor ratio (I/O ratio) of different types of buildings, and pointed that the outdoor particle penetration coefficient, the air exchange rate and the indoor deposition were the three essential parameters in the evaluation of the indoor /outdoor ratio. As infiltration-dominated air exchange is common in residences, especially when air conditioning or heating is required to maintain thermal comfort, the penetration of particle through building envelop becomes critical, which determines the amount of particle brought into indoors. Penetration factor (P) is a parameter to describe the particle penetration degree, which defined to quantify the ability of building fabrics, door gap and window louver in reducing the amount of outdoor particulate matter brought into the building by infiltration.

Previous experiments on penetration factors have found a large variation in values. In some cases, it appears these variations are due to the variability found in houses and in experimental conditions. In other cases, the results are confounded by the inability to separate deposition and penetration effectively and to account for time dependencies in the underlying measured values. Thatcher and Layton (1995) measured particles as a function of size and found penetration factors near 1. Tung (1999) investigated that the dust penetration coefficient varied from 0.69 to 0.86. Mosley (2001) measured the penetration of different size of particles under different pressure different and crack height, and the P value range was vary large.

Most of the obtained concentrations of particulate matters came from local monitoring station, and the indoor concentrations can not gain. In this study, we first attempt to understand the deposition mechanisms of particles through building envelop, and then establish the mathematical model to simulate the penetration of particle in building cracks, and finally, prediction the amount of particle originally outdoors

METHOD

When ventilation air enters buildings through small cracks or gaps in the building envelope, particles suspended in this air may partly deposited onto adjacent surfaces, The parameter P (penetration) denotes the fractional penetration of particles from outdoors to indoors associated with infiltrating airflow.

The fraction of particles that pass through the building envelope into indoors depends on many factors including the characteristics of the airflow across the building envelope (mainly caused by pressure differential), the size and shape of the penetration cracks, and the size of the particles.

The characteristics of airflow

Particle deposition in the building leakage cracks is an important factor that affects the concentrations

of indoor particles. We assume that the crack geometry is uniform throughout the crack, and the inner surface is smooth, and that airflow through the crack is steady and linear. The configurations of cracks are divided into three kinds: horizontal cracks, vertical cracks, and inclined cracks.

The dimensions of the crack is known as crack height (denoted z), crack depth (denoted L), and the third dimension crack width (denoted W), which is much larger than crack height, and then airflow can be reasonably modeled as two dimensional. The ΔP is expressed by the following equation (Baker et al. 1987):

$$\Delta P = \frac{12\mu L}{Wz^3} Q + \frac{(1.5+n)\rho}{2W^2 z^2} Q^2 \quad (1)$$

Where,

ΔP is the pressure difference (Pa)

μ is the viscosity of air (kPa·s)

n is the number of right-angle bends of crack

ρ is the density of air (mg/m^3)

Q is the airflow rate (m^3/s)

L is the crack depth (m)

z is the crack height (m)

w is the crack width (m)

Then the mean airflow velocity u in the crack is

$$u = \frac{Q}{Wz} \quad (2)$$

Penetration of PM in building leakage cracks

The driving force of airflow through a crack is the pressure difference between the two side of the crack, which may be induced by wind, indoor/outdoor temperature difference, or unbalanced fan-driven flow. When assumes that the particle concentration at the inlet is equal to that of the incoming airflow. The penetration factor due to gravitational settling (P_g) equals to:

For cracks which is $z/v_s > L/u$:

$$P_g = 1 - d_g = 1 - \frac{L/u}{z/v_s} = 1 - \frac{L \cdot v_s}{z \cdot u} \quad (3)$$

Here, v_s is the is the settling velocity

$$v_s = \frac{d^2(\rho_p - \rho)g}{18\mu} \quad (4)$$

When the crack is a inclined crack, then,

$$P_g = 1 - \frac{L \cdot v_s \cdot \cos \theta}{z \cdot (u - v_s \cdot \sin \theta)} \quad (5)$$

θ is the angle from horizontal to the crack surface(for horizontal crack $\theta=0$).

For small particles, the deposition mechanism to the surfaces is due to the diffuse to the inner surfaces of the crack and adhere by means of van der Waals forces. The penetration factor is considering Brownian diffusion alone (P_d), which is,

$$P_d = \exp\left(-\frac{1.967DL}{h^2u}\right) \quad (6)$$

Where, D is the particle diffusion coefficient, which is given by the S-E (Stokes-Einstein) equation:

$$D = \frac{KTC_c}{3\pi\mu d} \quad (7)$$

Here, K is Boltzmann's constant

T is the absolute temperature

C_c is Cunningham slip correction factor

D is the diameter of the particle

Particle deposition caused by impaction is a function of the Stokes number (St), which is the ratio of the

Particle stopping distance to the characteristic dimension associated with flow acceleration (Hinds 1982). The greater the Stokes number the higher the likelihood of particle impaction at crack bends. The penetration factor associated with impaction, P_i , was taken as one minus the fractional loss caused by inertia.

Shapes of cracks

The types of idealized cracks are shown in figure 1, n-bends cracks is the combination of L-shaped cracks.

For cracks which is $z/v_s \leq L/u$, there is enough time for particle to gravitational settling, $P_g=0$ and $P=P_d$. otherwise, consuming the gravitational settling P_g and Brownian diffusion (P_d) are independent of each other, and assumed it to be independent of time, then:

$$P = P_g \cdot P_d \quad (8)$$

For horizontal and inclined cracks, the P_i is ignored, as particle with enough inertia to be lost by impaction was also likely to be lost by settling.

For bend cracks, if there is enough time for particle to gravitational settling, the P_i can not be ignored, otherwise, it can not be ignored.

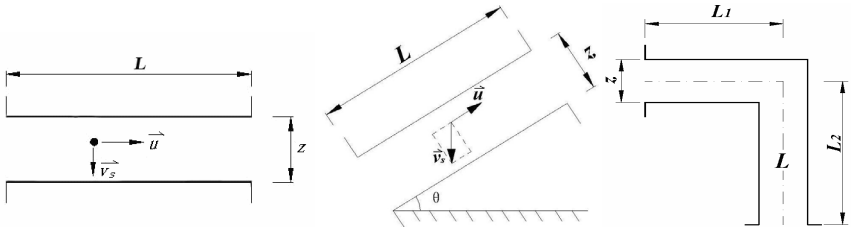


Figure 1. Types of idealized cracks through building envelopes

And then the overall penetration concentration (per unit time, s^{-1}) of particles into indoors can be calculated by the equation (9)

$$\Delta C = (C_o \cdot P - C_{ii}) \frac{Q}{V} \quad (9)$$

Here, C_o is the ambient concentration of particle, C_{ij} is the indoor initial concentration of particle, V is the volume of room.

Crack materials

For theoretic analysis of the particle deposition on crack surface, the surface is smooth, and once the particle reaches the surface, it deposits. Actually, particle deposition onto real crack surfaces should be treated different according to the particle size and the crack height.

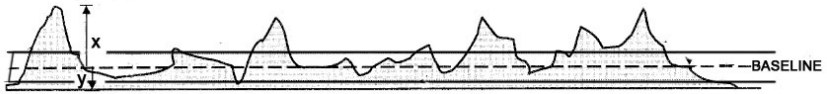


Figure 2. Schematic illustration of material surface roughness

For large particle, the deposition mechanism to the surfaces is due to the gravity, once a particle is below the tip of the roughness elements, it settles, and then the effective height (z') of crack is shorter than the crack height. For small particles, the deposition mechanism to the surfaces is due to the diffuse to the inner surfaces of the crack, once a particle is below the roughness tips (within the grains), it still diffuses, that is to say the effective height (z') of crack is larger than the crack height. For large particles, the roughness of crack surface will strengthen the deposition, for small particles, the roughness of crack surface will weaken the deposition. The concentration boundary layers are different for different particle size, and the effective height of crack is also different for different size particles.

But following the increase of crack wide, the effect of roughness is inconspicuous, Liu (2003) had experimentally studied the particle penetration factors for six crack materials at crack heights of 0.25mm and 1mm, and compared with model predictions, and got a conclusion that moderately good agreement of the model predictions with measurements for most materials. But for 1mm crack height, this is correct, for 0.25mm crack height, model prediction penetration is higher than measurement for larger particles (diameter $>0.1\mu\text{m}$) and lower for ultrafine (diameter $<0.1\mu\text{m}$) particles.

CONCLUSIONS

In this study, the particle deposition mechanism and influencing factors through building envelope are discussed. By analyzing the deposition mechanism of particle in different types of idealized cracks, we found that,

The deposition mechanisms are different for different particle size and different types of idealized.

For different value of z/v_s and L/u , the expression is different.

For different crack materials, the influencing of roughness is different for different particle size. The roughness strengthens the deposition of larger size particles and weakens the deposition of smaller size particles

Through the deposition mechanism and influencing factors provide important clues, it is not yet sufficient to reliably predict pollutant penetration into real buildings from models. Further studies should be based on the experiment, and the practice in real buildings, such as windows and doors, to minimize human exposure to pollutants of outdoor origin

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