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Study on Influence factors of Deposition Efficiency of Particles in Airflow Channel of Wall Absorbing Haze Automatically

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Abstract. The effect of velocity, channel's width, particle size and concentration on particles' deposition efficiency were simulated and analyzed by Fluent. The results show those particles' deposition efficiency increases with the increase of air velocity. When the air velocity is greater than zero point five meters per second, the deposition efficiency begins to decrease slightly. The deposition efficiency of the particles increases with the increase of the airflow channel width when the airflow channel size is reasonable. The particles' deposition efficiency increases with the increase of the concentration. When the particle's concentration reaches 250μg/m³, the deposition efficiency no longer changes.

1. Introduction

In recent years, most parts of our country have suffered from severe fog and haze. At the same time, the indoor air's quality is not optimistic [1]. A large number of inhalable particles enter the room and directly endanger the respiratory system of the human body. Can indoor particles be effectively and timely removed has become an important problem affecting people's health. Due to the complexity and long-term nature of China's economic restructuring, the haze weather in China is difficult to cure from the source in the short term. So making the building posse the function absorbing haze has become more and more urgent [2].

At present, the purification of indoor air is mostly using air conditioning air supply system or placing haze removal equipment in the building indoor. It is rare to use building envelope to absorb haze. Different traditional airtight wall, there are airflow channels in wall absorbing haze automatically on the premise of ensuring the basic load-bearing function. And the adsorption material plates are arranged on both sides of airflow channels. In this paper, a new type of wall based on industrialized building is presented. The function absorbing haze is integrated into the wall, and it utilizes the way of absorbing to remove inhalable particles with the help of the characteristic that the contact area between the wall and indoor air is large. The wall does not occupy the effective usable area of the building, and its adsorption area is large, so the absorbing haze efficiency can be greatly improved. Its diagrammatic sketch is shown in the Fig.1-1 [3].

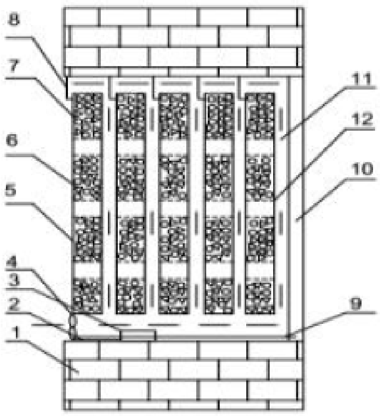

Figure.1-1. Diagrammatic sketch of structure of wall absorbing haze automatically
1—Wall, 2—Wire, 3—Battery, 4—Fan, 5—Metal mesh, 6—Adsorption material, 7—Phase Change material, 8—Bracket, 9—Wire, 10—Solar panel, 11—Airflow channel, 12—Hardware cloth.

Part of the particles [4] mixed in the airflow is absorbed by the absorption material in the metal mesh, and the part deposited in the channel after the airflow entered the wall. Therefore, the indoor air is purified. The deposition amount of particles in the airflow channel is mainly determined by gravity and inertial impact [5]. Gravity is derived from the mass size of particles, so the gravity of large particles is larger than that of small particles. However, most of the particles in the indoor air are PM2.5, and the effect of particle size on the deposition efficiency is negligible.

In general, the greater the air velocity is, the easier the particles collide and attach to the internal face of the airflow channel. At the same time, the collisions between particles and particles are also more frequent [6], and then the amount of particles deposited in the airflow channel is increasing. In addition, the airflow channel width and particles concentration also have a great influence on the deposition efficiency. In this paper, the influence factors of the deposition efficiency of particles in the channel are discussed based on the airflow structure and air purification performance of the wall absorbing haze automatically.

2. Relevant Theories and Wall Model

There are two kinds of collisions when particles move in the airflow channels, collisions between particles and collisions between particles and inner wall of the channels. Usually when the density of particles is sparse, there are almost no collisions between particles and particles. By comparing the magnitude of residual kinetic energy of particles and the attractive force of the internal wall surface, we can determine whether the particles will deposit in the channel after the particles collide with the surface of the channel. If the residual kinetic energy of the particles is greater than the attractive force given by the wall, the particles fly away from the wall. If not, the particles will deposit in the channel.

If the particles size is small and the continuum assumption is no longer applicable to the air flow near the particles, it is necessary to modify the drag force based on the continuous medium condition, as indicated in equation (1).

$$\Phi o=\Phi/X. \quad (1)$$

In the above equation, Φois the modified drag coefficient, and X is slip correction factor.

According to RANS theory, the velocity of air flow can be expressed as a sum of time average velocity and a pulsating component. The eddy viscosity model of RNG k- epsilon turbulence is expressed as turbulent flow energy k and turbulent flow energy dissipation rate e, and they are solved with momentum equations. We assume that the turbulence of the airflow is in the same.

The deposition efficiency of particles in the airflow channel represents the ratio of the number of particles deposited in the channel and the total number of particles passed through the channels; it can be calculated by the following equation (2).

$$E=N/No. \quad (2)$$

N represents the number of particles deposited in the airflow channel, and No represents the total number of particles passed through the channel.

A three-dimensional wall model [7] is established by using Fluent, and the calculation area is meshed in the form of Hex-Map. The wall model is shown in Fig. 2-1.

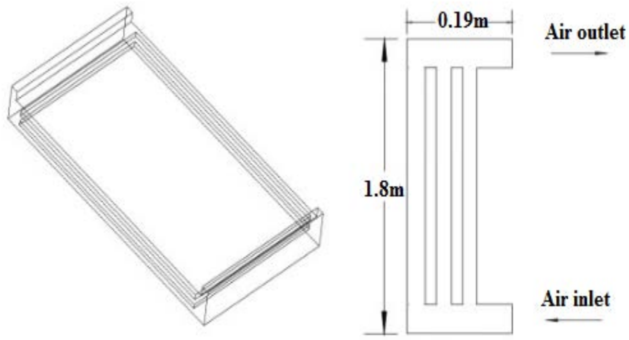

Figure.2-1. Diagrammatic sketch of the model of wall absorbing haze automatically

A particle trajectory analysis model based on Lagrange method is established, we comprehensively consider the effect of Drag force, and Gravity, Brown diffusion force, Thermophoretic force and Saffman lift on particles [8]. Hard sphere model is applied to collision process between particles and wall, and RNG k-ε turbulence eddy viscosity model is adopted for air flow. Momentum and turbulence equations are dispersed by the two order upwind scheme, and pressure and velocity are solved by SIMPLE coupling algorithm [9].

Firstly, the physical quantities involved in the model are iterated, and the number of iterations is 100. There are three types of boundary conditions in the wall model, velocity inlet, outflow and wall. These three kinds of boundary conditions involve velocity, pressure and density in XYZ directions. After the iteration, the residual curve is relatively stable. It shows that the numerical convergence result is reasonable and can carry out following simulation [10].

3. Influence factors of Deposition Efficiency

3.1. Air velocity's effect

By analyzing the velocity change diagram of air in wall absorbing haze automatically, we can found that the deposition amount of particles in the airflow channel has a direct impact on the change of air velocity. This effect is mutual, so the air velocity also affects the deposition efficiency of particles [11].

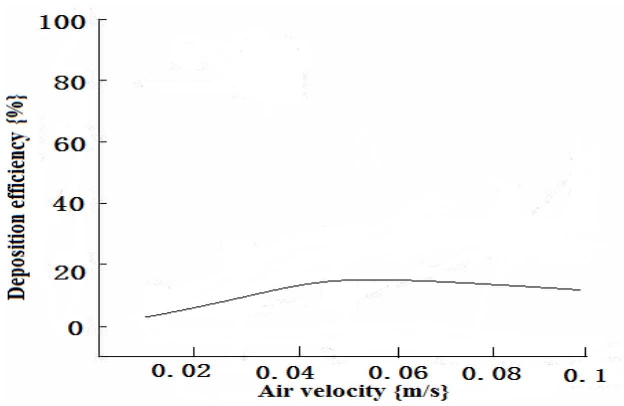

Figure.3-1. Variation of deposition efficiency of PM2.5 with the air velocity

It can be seen from Fig.3-1 that the deposition efficiency of particles (PM2.5) increases with the increase of air velocity. When the air velocity is greater than 0.5m/s, the deposition efficiency begins to decrease slightly. The reason for this change is that the larger the particle velocity is, the easier it is to collide with the internal face of the channel. When the particle velocity is less than 0.05m/s, the initial kinetic energy is not large. The residual kinetic energy of the particles is less than the attractive force given by the wall after the particles collide with the surface of the channel, so the particles deposit in the channels and the amount of deposition is mainly affected by inertial impact. When the air velocity is greater than 0.05m/s, the probability of collision between the particles and the internal face of the channel increases, but the initial kinetic energy of the particles also increases. The residual kinetic energy of the particles is greater than the attractive force given by the wall, so the particles fly away from the surface of the channel, and the amount of deposition is mainly affected by gravity.

3.2. The effects of the airflow channel width and particle size

The velocity of airflow at the entrance is set as 0.05m/s, and the particle density is set as 200μg/m³ [12] and the range of the particle size is 0.1μm~15μm. To simulate the deposition efficiency of the particles in the channel with width 20mm, 30mm, 40mm, 50mm and 60mm.

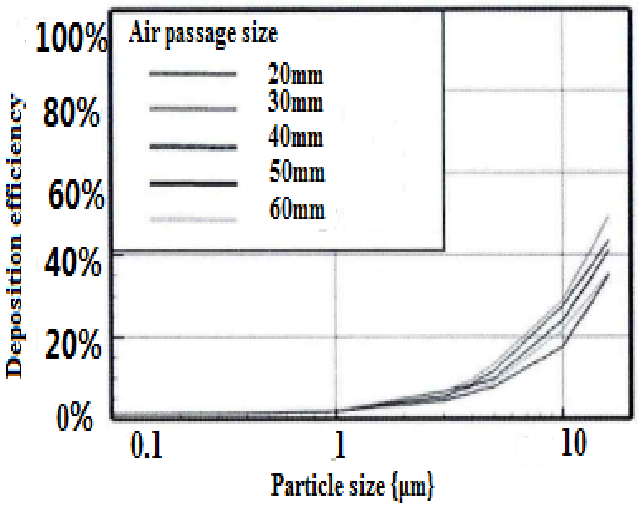

Figure.3-2. Deposition efficiency of particles with different size in airflow channel with different width

It can be seen from Fig.3-2 that the deposition efficiency of the particles that the size is less than 1μm is almost zero. This is because the mass of the particles is too small, and the effects of gravity and inertial impact are extremely limited. These particles almost do not deposit in the airflow channel. The deposition efficiency of the particles that the size ranges from 1μm to 5μm in the airflow channel with different widths is hardly different. The particles in indoor air are mainly composed of PM2.5, so the effect of particle size on deposition efficiency can be neglected. In this paper, the size of the wall model is based on the size of the wall of ordinary residential buildings, and its airflow channels' layout must ensure the basic load-bearing function of the wall. The six set of channel size parameters set in the simulation are in reasonable range. To analysis Fig. 4, we can found that the deposition efficiency of the particles increases with the increase of the airflow channel width when the airflow channel size is reasonable. This change is because the particles' Drag force and Brown diffusion force are relatively large in the wider airflow channel. To a certain extent, it effectively hinders the continuous movement of particles, so particles are easy to deposit.

3.3. The effect of the particles concentration

Setting air velocity as 0.05m/s, then we simulate the deposition efficiency of PM2.5 that its concentration ranges from 100μg/m³ to 300μg/m³ in the airflow channel of 60mm width.

It can be seen from Fig.3-3 that the deposition efficiency of particles (PM2.5) increases with the increase of the concentration. When the particles concentration reaches 250μg/m³, the change of particles' deposition efficiency tends to be stable, and it is no longer affected by concentration. When the particle concentration is large, collisions are easy to occur between particles. Collision causes an increase in particles' internal energy, and then Thermophoretic force gets larger. Therefore, the effect of gravity on particle deposition is greatly weakened by Thermophoretic force. In this state, the particles are mainly attached to the airflow channel surface with the help of inertial impact.

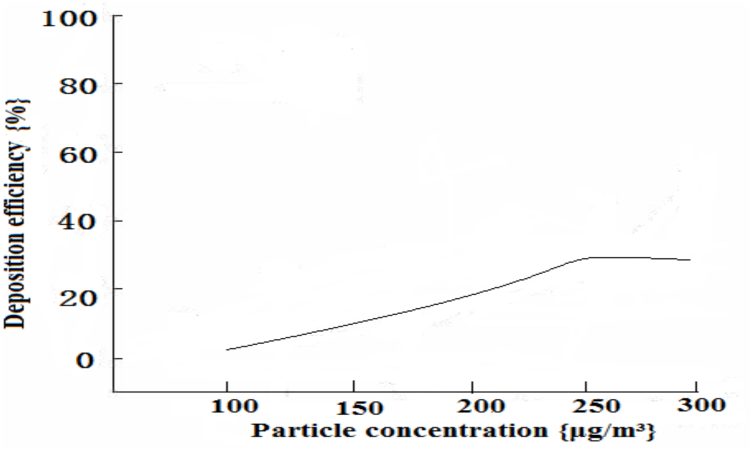

Figure.3-3. The change of PM2.5 deposition efficiency with its concentration

4. Conclusions

Different from traditional method removing haze, using building envelope to remove haze has the characteristics of energy saving, environmental protection and good economy. As a new type of absorbing haze, wall absorbing haze automatically is of great significance for improving the quality of building indoor air. Particles deposit in the airflow channels of wall absorbing haze automatically, which is part of the air purification process. Therefore, several factors affecting the particles' deposition efficiency were simulated and analyzed by Fluent. The results are as follows:

(1) The deposition efficiency of particles increases with the increase of air velocity. When the air velocity is greater than 0.5m/s, the deposition efficiency begins to decrease slightly.

(2) The deposition efficiency of the particles that the size is less than 1μm is almost zero. For indoor air, the effect of particle size on the deposition efficiency can be neglected.

(3) The deposition efficiency of the particles increases with the increase of the airflow channel width when the airflow channel size is reasonable.

(4) The deposition efficiency of particles increases with the increase of the concentration. When the particles concentration reaches 250μg/m³, the change of particles' deposition efficiency tends to be stable, and it is no longer affected by concentration.

5. Acknowledgment

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6. References

[1] ZHANG Yinping, DENG Qihong and QIAN Hua, "Progress report on indoor environment and health in China 2012," China Building Industry Press, 2012.

[2] YAO Li and XU Kuan, "The Pollution Situation and Countermeasures of Building Indoor Environment Under Haze-weather Condition," Journal of Green Science and Technology. vol. 8, 2016, pp49-51.

[3] ZHANG Zhen, "Airflow organization's simulation analysis of wall absorbing haze automatically," unpublished.

[4] LIU Zhirong, "Classification and nomenclature of atmospheric particulates," China Terminology. vol. 2, 2013, pp31-34.

[5] ZHANG Jie, “Characteristics study of aerosol particles settling in an air conditioning system,” unpublished.
[6] FANG Tianyu, “Modeling of Airborne Particle Filtration in a Breathing Wal,” unpublished.
[7] WANG Chengyue and FANG Tianyu, “Study on Trombe’s air filtration performance,” Science and Technology Innovation Herald. vol. 7, 2015, pp1-1.
[8] QIAO Chunzhen, ZHANG Zhen, YUAN Xiang and LI Zhiyong,“ Airflow organization’ simulation study of wall absorbing haze automatically based on industrial Architecture,” Symposiu of Chinese society of environmental science’s annual conference on science and technology in 2017,Xiamen, in press.
[9] Gao R and Li A, “Modeling deposition of particles in vertical square ventilation duct flows,” Building and Environment. vol. 1, 2012, pp245-252.
[10] Hinds W, “Aerosol technology: properties, behavior and measurement of airborne particles,” John Wiley & Sons, 2013.
[11] SUN Lei, “Study on Seismic Performance of the Self-insulation Structural Wall with Inner Frame,” unpublished.
[12] WU Qian, “Study on the relationship between indoor air flow rate and human comfort and physiological stress,” unpublished.