Hindawi
Mathematical Problems in Engineering
Volume 2019, Article ID 9478659, 8 pages
https://doi.org/10.1155/2019/9478659

*Research Article*

# Numerical Simulation of Dust Deposition in the Filter Tube of Adsorption Air Purifier

**Zhongliang Lu,[1,2,3] Zhen Wei,[1] Qiang Li,[4] and Hongli Wang[4]**

[1] *School of Safety Science and Engineering, Henan Polytechnic University, Jiaozuo, Henan 454003, China*
[2] *Key Laboratory of Gas Geology and Gas Control, Jiaozuo, Henan 454003, China*
[3] *The Collaborative Innovation Center of Coal Safety Production of Henan Province, Jiaozuo, Henan 454003, China*
[4] *School of Mathematics and Information Science, Henan Polytechnic University, Henan, Jiaozuo 454003, China*

Correspondence should be addressed to Zhongliang Lu; lzl@hpu.edu.cn and Qiang Li; 350016391@qq.com

Received 18 August 2018; Revised 24 February 2019; Accepted 26 February 2019; Published 20 March 2019

Academic Editor: Bogdan Smolka



In recent years, indoor air quality that deeply affected people's health cannot be ignored. It is affected by many factors, and people have taken many measures to reduce the pollution level. In addition to diluting by controlling pollution sources and using natural ventilation, air purifiers have become one of the choices, but the results are not satisfactory. To improve the dust removal effect of the adsorption air purifier, we established the dynamic equation of $PM_{2.5}$ concentration under different ventilation modes based on the analysis of indoor $PM_{2.5}$ concentration change process, the integral and convergent operation of the equation were carried out, and the formula and main influencing factors of indoor $PM_{2.5}$ concentration in steady state under different ventilation modes were obtained. Meanwhile, the mathematical model of the internal pipeline of the purifier was established by using the Navier-Stokes equation; we selected the DPM model in the software FLUENT to simulate the deposition of particulate matter in the ventilation pipe. The results showed that the deposition of different diameter particles in the filter tube was different. The movement of the larger particle size (particle diameter >10 $\mu$m) was mainly affected by the influence of gravity and inertia, while the fine particles are easily deposited on the inner wall side of the elbow mainly by the turbulent diffusion. Therefore, the angle of the elbow should be adjusted to direct the airflow so that most of the particulate matter could deposit on the filter element, reducing the particulate matter from the exhaust port and the damage to the human body in the room, which will improve the dedusting effect of the purifier.

## 1. Introduction

In recent years, severe air pollution problems have caused many inconveniences, and continuous smog weather has made $PM_{2.5}$ (fine particles with aerodynamic equivalent diameter ≤2.5 $\mu$m) attracted more attention. Nowadays, people typically spend more than 70% of their time indoors, pollutant levels are typically several times to several hundred times higher indoors than outdoors. Brauer et al. [1] found that there was a high concentration of fine particles ($PM_{2.5}$) in South and East Asia (annual averages >50g/m$^3$). They were so small that they could get deep into the alveoli and cause a serious threat to the population health. However, $PM_{2.5}$ is not a chemical type of pollutant, but a collection of some pollutants. It is easy to enrich toxic heavy metals, acidic oxides, organic pollutants, bacteria, and viruses in the air [2].

The main component of indoor particles contained organic ingredients (PAEs, PBDEs, PAHs, PFCs, etc.) [3], inorganic components (quartz, asbestos, nitrate, etc.), heavy metals (mercury, cadmium, lead, chromium, etc.), and microorganisms (fungi, bacteria, mites, etc.) [4]. Outdoor fine particles can enter the room through different ways, such as ventilation pipes, filters, doors, and windows [5–7]. The indoor particle source and personnel activities [8] also lead to an increase in the concentration of indoor $PM_{2.5}$. These particles can enter the lungs with the breath, which have more harm to human body under the same concentration [9]. Studies showed that all-cause mortality, cardiovascular mortality, and lung-cancer mortality significantly increased with the annual average particle concentration [10]. With the further research of indoor particle concentration distribution characteristics and motion laws, scholars found that indoor

$PM_{2.5}$ concentration was affected by many factors, such as different forms of air supply, air exchange rate (ACH), and gravity deposition.

To fundamentally understand the characteristics of the concentration changes and the motion laws of indoor particulate matter, then we can propose the effective indoor dust removal measures. At present, experiments and CFD simulation methods are mainly adopted in this field [11–13]. Jurelionis et al. [13] experimentally tested the effects of air distribution methods on aerosol particle behaviour in a ventilated room, and the experiments were conducted in a full-scale test chamber with the source of contaminant (a nebulised solution of sodium chloride) positioned at the air supply and air exhaust sides. Computational fluid dynamics (CFD) predictions were performed to determine the spatial particle dispersion in the room and were compared to the results of the experiment. However, the application of each of the tested ventilation strategies should be carefully considered for the removal of particles, as well as additional factors affecting behaviour of aerosol contaminants in ventilated spaces.

However, with people's increasing comfort requirements for the indoor environment, the air purifiers with a variety of features on the market are undoubtedly the best choices for improving indoor air quality. Nowadays, the existing air purifiers on the market can be divided into 3 types according to the working principles: (1) physical type, the suspended particulate matter is removed by filtration; (2) chemical type, harmful gases are removed by neutralization, catalyzing, and decomposition; and (3) ionization type, which uses ionization, ozone deodorization, and sterilization. However, these products do not really achieve the effects as expected and there still exists many problems. For example, purification efficiency is not ideal under high air volume, we need to face optimization of structure and performance (miniaturization of purifier), cleaning problem of dust removal device [14] and control the ozone concentration of the purifier outlet. In other words, how to achieve bactericidal effect but not harm human health (no secondary pollution) is urgent problems to be solved.

Lee et al. [15] validated the steady state mass balance model based on the reasonably good agreement between the measured and modeled size-resolved effectiveness. They also found that effectiveness was highly size-dependent, and portable air purifiers (PAPs) was the dominant removal mechanism for submicrometer particles, whereas deposition could play a more important role in ultrafine particles removal. Sublett et al. [14] studied the effectiveness of recent filters alone or with integrated control measures in the treatment of allergic respiratory diseases and found that these filters work better when combined. However, the deposition law of particulate matter inside the purifier was not specified. Kolarik et al. [16] studied the use of photocatalytic air purifiers to improve indoor perceived air quality. They found that photocatalytic air purifiers can supplement ventilation when indoor air is contaminated by building-related sources, but it should not be used in the space where human biological sewage constitutes a source of pollution.

Although a large number of studies have been conducted on the diffusion and deposition characteristics of indoor particles, there is no good method to evaluate the removal effect of indoor particle under different ventilation modes. The main purpose of this paper is to analyze the diffusion and deposition characteristics of the particle in the air purifier tube, which is of great importance for the removal of indoor particle pollution.

The air purifier in this study mainly includes the chassis shell, filter section, air duct design, motor, power supply, and liquid crystal display. Among them, the filter section determines the purifying effect. This study mainly aimed at the problems that the purifier was difficult to clean and the purification effect was poor. By simulating the particles deposition law in the filter tube of the purifier, we found out the problems existing in the structure of the purifier then provided theoretical supports for improving the purification effect of the equipment. To this purpose, the experimental and theoretical analysis methods are used to carry out the research in this paper.

The rest of the study is organized as follows. The second section describes the experimental instruments, the theoretical basis for the change of indoor and outdoor particulate matter concentration, and the calculation model for the particulate matter concentration in the filter tube. In the third section, the deposition of particulate matters with different particle sizes in the filter tube was obtained by numerical simulation method, and the influence of the airflow field on the particle deposition was clarified. The main factors affecting the deposition of particulate matter were analyzed, and the measures to improve the effect of the air purifier were proposed based on the related results. The final section summarizes the paper and gives relevant conclusions.

## 2. Materials and Methods

*2.1. Introduction of the Test Equipment.* The PC-3A multifunction laser dust tester (abbreviated as dust meter) was used to detect the dust ($PM_{10}$, $PM_{2.5}$) concentrations in the tubes. It adopts the principle of light scattering to measure the light source with a semiconductor laser and performs highly sensitive noncontact measurement of dust in the air. Repeated errors in the determination of dust mass distribution and the amount of dust scattered distribution are, respectively, 10% and 8%. The single-chip microprocessor manages and controls the entire process of the test, using a high-resolution, large-screen, high-brightness liquid crystal display. The main control panel is as shown in Figure 1.

Its functional characteristics are shown in Table 1.

In this study, we used Pitot tubes and dust tester to measure the airflow speed in the pipe, the sketch of the experimental apparatus is shown in Figure 2.

We tested the indoor air quality (IAQ) indexes varying within 21 days in a certain building facility in Jiaozuo City, which is shown in Figure 3. It shows that the indoor air quality indexes measured by the experimental device are basically consistent with the changes of the outdoor air quality (OAQ) data monitored by the external station.

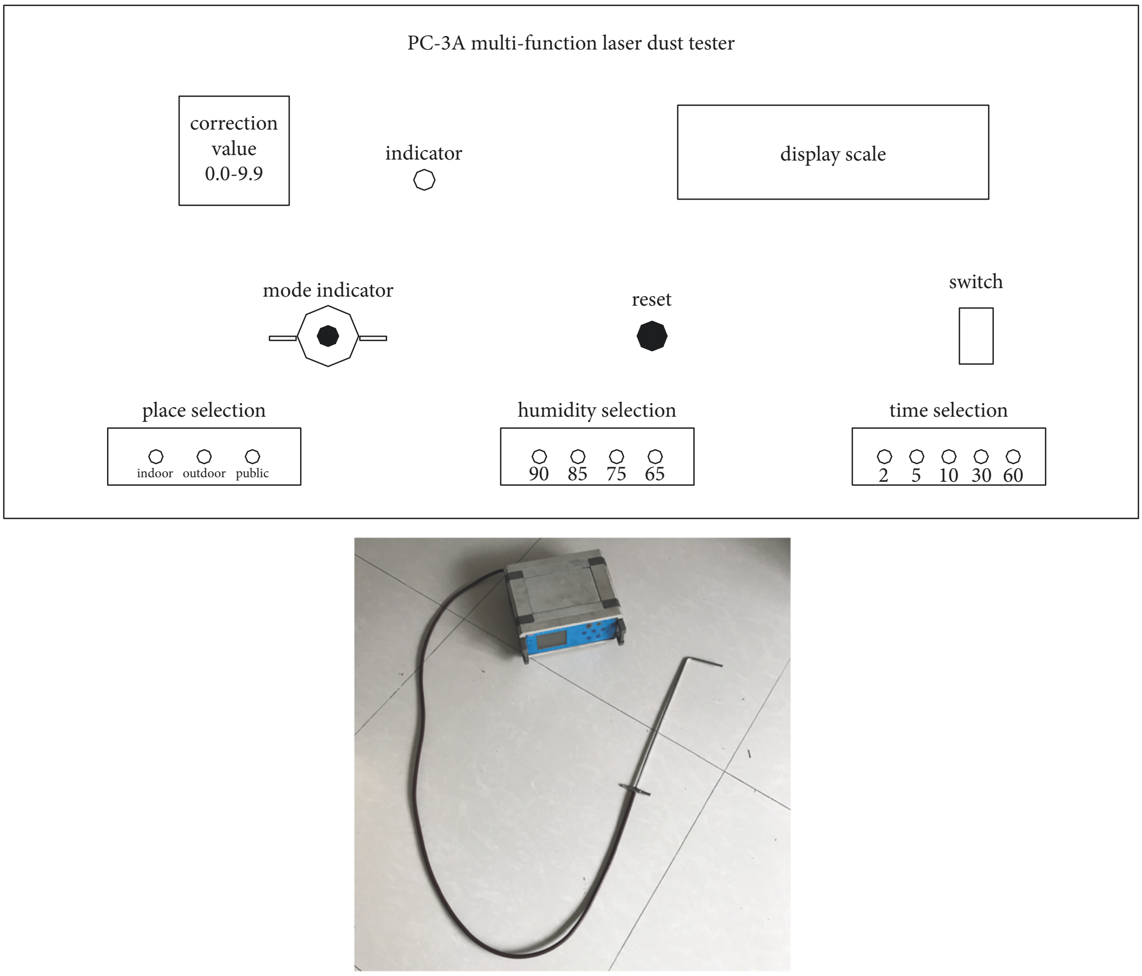


Figure 1: PC-3A multifunction laser dust tester.

Table 1: PC-3A dust meter's main technical parameter.

| | |
|---|---|
| The measuring range of the dust mass dispersion | $PM_{2.5}$, $PM_{10}$, TSP |
| The measuring range of dust amount dispersion | (0.3, 0.5, 0.7, 1.0, 2.5, 5.0, 10.0$\mu$m) which are displayed at the same time |
| Dust mass concentration measurement range | 0.001~10.0mg/$m^3$ |
| Detection sensitivity | 0.001mg/$m^3$ |
| Repeatability error | ≤±2% |
| Air sampling flow | 2.0L/min |
| Sampling time | 1min,2min. . ..30min |
| Working environment | Temperature (0-50°C), relative humidity (20%-80%) |

*2.2. The Theoretical Basis of Indoor $PM_{2.5}$ Concentration Changes.* As discussed earlier, the indoor $PM_{2.5}$ concentration is affected by many processes, mainly including (1) ventilation process, indoor and outdoor $PM_{2.5}$ exchange transmission through ventilation process; (2) conversion process, indoor $PM_{2.5}$ undergoes a series of physical and chemical reactions to increase; and (3) the resuspension process, the indoor personnel activities (such as fuel combustion or smoking) will cause the fine particles to be suspended again, thus increasing the value. According to the process of indoor $PM_{2.5}$ concentration change, assuming that the room volume is V, the amount of indoor $PM_{2.5}$ concentration change in d$t$ time is $\mathrm{d}C_i V/dt$.

*2.2.1. Analysis of Indoor $PM_{2.5}$ Concentration during Natural Ventilation.* For the natural ventilation mode, the amount of air permeating into the room through the building envelope is very small due to the tightness of the modern building, etc. Therefore, regardless of the amount of air permeating through the building envelope,

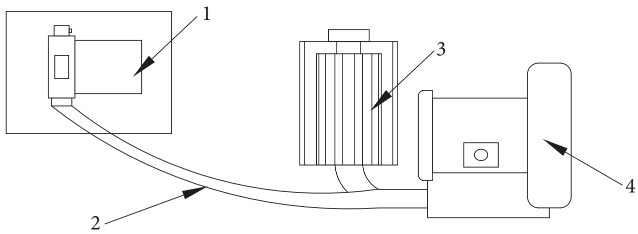


Figure 2: The sketch of the experimental apparatus. (1) Dust meter. (2) Connection hose. (3) Air purifier. (4) Hair dryer.

$$\frac{dC_iV}{dt} = Q_nC_w + S - Q_nC_i - K \quad (1)$$

where $C_i$ is the concentration of $PM_{2.5}$ in the room, $C_w$ is the concentration of outdoor $PM_{2.5}$, $Q_n$ is natural ventilation, $t$ is the time, and S means $PM_{2.5}$ dust production per unit time of conversion, resuspension, and indoor source.

Dividing both sides of the equation by V

$$\frac{Q_n}{V} = n \quad (2)$$

In the formula above, set $Q_n/V = n$, $n$ as the number of ventilations for natural ventilation to the room, $h^{-1}$.

$S/V = s$, the amount of $PM_{2.5}$ produced by transformation, resuspension, and indoor sources per unit volume per unit time, $\mu g/(h \cdot m^3)$.

$K/V = k$, the amount of indoor subsidence and other reductions per unit volume per unit time, $\mu g/(h \cdot m^3)$.

The above equation is simplified as

$$\frac{dC_i}{dt} = nC_w + s - nC_i - k \quad (3)$$

In the above formula, set $A = nC_w + s - k$, then

$$\frac{dC_i}{dt} = A - nC_i \quad (4)$$

$$\frac{dC_i}{A - nC_i} = dt \quad (5)$$

To integrate the two sides of (5):

$$C_t = \frac{A - (A - nC_0)e^{-nt}}{n} \quad (6)$$

From formula (6), we can see that when the time of natural ventilation is long enough and the indoor $PM_{2.5}$ concentration tends to a stable value, it means that

$$C_t = \frac{A}{n} = \frac{nC_w + s - k}{n} = C_w + \frac{S - K}{Q_n} \quad (7)$$

From the formula (7), the amount of dust and the amount of indoor subsidence per unit time are related to the amount of reduction. When no dust producing source in the room and ignoring the increase or decrease in $PM_{2.5}$ through the process of deposition and conversion, we can assume that after adopting the sufficient natural ventilation for a long time. The indoor $PM_{2.5}$ concentration would be approximately equal to the outdoor $PM_{2.5}$ concentration.

*2.2.2. Indoor Particle Concentration Calculation Model.* This paper mainly focuses on the purifiers installed in a certain office building that uses mechanical ventilation in Jiaozuo City. It is a major breakthrough for solving the indoor dust pollution problems through studying the settlement rules of fine particles in pipelines. Based on the mass balance principle, the indoor $PM_{2.5}$ concentration is analyzed as follows:

$$\frac{dC_iV}{dt} = Q_xC_w(1-\eta_x) + Q_hC_i(1-\eta_h) + S - (Q_h + Q_h)C_i - K \quad (8)$$

where $Q_x$ means fresh air volume, $m^3/h$; $Q_h$ is the amount of vitiated air, $m^3/h$; $\eta_x$ means the efficiency of fresh air filter; $\eta_h$ means the efficiency of vitiated air filter.

Dividing both sides of the equation by V:

$$\frac{dC_i}{dt} = \frac{Q_xC_w(1-\eta_x)}{V} + \frac{S}{V} - \frac{K}{V} - \frac{Q_x + Q_h\eta_h}{V}C_i \quad (9)$$

In the above equation, $Q_x/V = n_x$, which means the number of air changes for the fresh air volume to the room volume, $h^{-1}$. $Q_h/V = n_h$, which represents the amount of air return to the room volume, $h^{-1}$.

$$\frac{dC_i}{dt} = n_xC_w(1-\eta_x) + s - k - (n_x + n_h\eta_h)C_i \quad (10)$$

Set $B = n_xC_w(1-\eta_x) + s - k$

Integrate the above formula:

$$C_t = \frac{B - [B - (n_x + n_h\eta_h)C_0]e^{-(n_x+n_h\eta_h)t}}{n_x + n_h\eta_h} \quad (11)$$

When $t \longrightarrow \infty$

$$C_t = \frac{B}{n_x + n_h\eta_h} = \frac{n_xC_w(1-\eta_x) + s - k}{n_x + n_h\eta_h} \quad (12)$$

From (12), we can see that under the steady mechanical ventilation mode for a unit time, the concentration of indoor $PM_{2.5}$ is affected by the concentration of the outdoor $PM_{2.5}$, the efficiency of the new return filter and the new return air volume to the room volume. The amount of dust produced by $PM_{2.5}$ such as internal transformation, resuspension, and indoor sources is related to the amount of indoor sedimentation per unit time. However, the application of this model in predicting the settlement of particulate matter in the purifier ventilation duct has some limitations.

*2.3. Particle Concentration Calculation Model in Pipeline.* In fact, the particle size of the particles entering the purifier ventilation system is relatively large, and the moving airflow provides sufficient energy for the particles, so that particles with particle sizes of 10 $\mu$m and more can levitate in the air purifier.

In the gas-solid two-phase flow of ventilation ducts, the gas is treated as a continuous medium, and the particle phase is regarded as a discrete group that moves with


Figure 3

the gas along its own orbit. The mass, momentum, and energy of the particle group and the gas are measured. The interaction is regarded as the material source, momentum source, and energy source of a medium that is continuously distributed in the two-phase flow space. Due to the low particle concentration in the filter's equipment, the particle size is also small, and the particles have little effect on the gas, so the interaction between the particles and the effect of particle volume fraction on gas is not considered in the calculation, but the effect of gas on particle.

In this study, we used the FLUENT to simulate the discrete phases of particles and respectively define the boundary conditions for the gas flow and discrete phases; the mathematical model is described as follows [17–19].

*2.3.1. Gas Flow Boundary Conditions.* We defined the velocity-inlet at the inlet of the pipeline and selected the method that can accurately describe the turbulence intensity and hydraulic diameter. The turbulence intensity can be calculated via empirical formulas as follows:

$$I = \frac{u'}{u_{avg}} \cong 0.16\,(\mathrm{Re})^{-1/8} \tag{13}$$

$$Re = \frac{u_{avg} d \rho}{\eta} \tag{14}$$

where $I$ is the turbulence intensity, which is equal to the ratio of the RMS (root mean square) velocity fluctuations to the average speed; $u_{avg}$ is the average flow rate, m/s; $d$ is the hydraulic diameter of the circular pipe, which is equal to its diameter $m$; $\rho$ *is* the density, kg/m$^3$; $\eta$ *is* dielectric dynamic viscosity coefficient.

The continuity and momentum equations for the continuous phase are

$$\frac{\partial \rho_a}{\partial t} + \nabla \cdot \left(\rho_a u_a\right) = 0 \tag{15}$$

$$\frac{\partial \rho_a u_a}{\partial t} + \nabla \cdot \left(\rho_a u_a u_a\right) = -\nabla p + \nabla \cdot \mu \nabla u_a \tag{16}$$

Turbulence was modeled using the Large Eddy Simulation (LES) model with the Smagorinsky-Lilly subgrid scale model. Meanwhile, we selected the section of the pipeline export as the pressure-outlet and nonslip condition of solid wall was set for the wall boundary conditions.

*2.3.2. Discrete Phase Boundary Conditions.* In fact, inhalable particulate matter is mainly composed of fine particles. Particles larger than 10 $\mu$m account for a small proportion. Particles with a particle size of less than 7 $\mu$m account for more than 95%, particles with a particle size of less than 3.3 $\mu$m account for 80%–90%, and particles smaller than 1.1 $\mu$m in diameter account for more than 50%.

We chose the inertial particles to study. The trapping boundary conditions were selected that the particulate matter would be trapped on the wall surface. The volatile particles evaporated into the fluid medium here, and the nonvolatile particles were terminated at this point.

The discrete phase was modeled with Discrete Phase Model (DPM) using the Lagrangian approach. Particles were treated with unsteady particle tracking and were solved simultaneously with the transient fluid simulations.

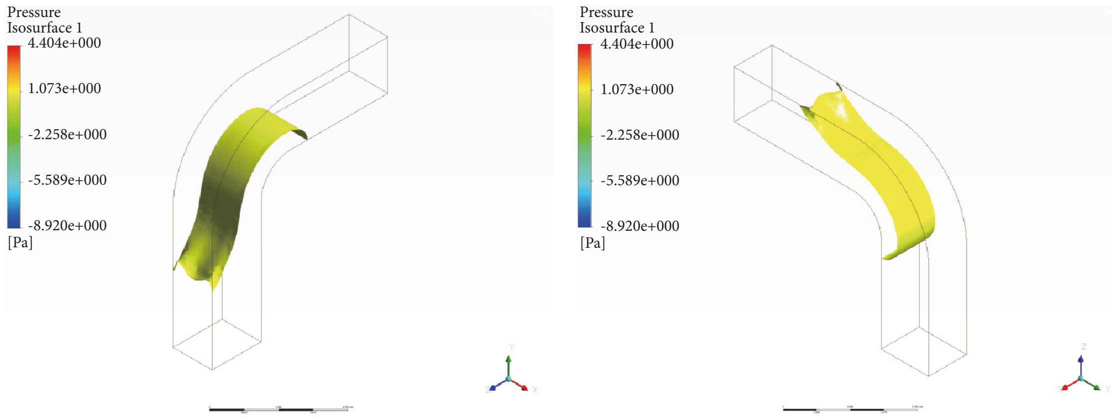


Figure 4

Particle trajectories were predicted by equating their inertia with forces acting on the particles:

$$\frac{du_p}{dt} = F_d\left(u_a - u_p\right) + \frac{g\left(\rho_p - \rho_a\right)}{\rho_p} + F_B \tag{17}$$

The Stokes-Cunningham drag law, appropriate for submicron particles, was employed ($C_C \approx 1$ for aerosols):

$$F_d = \frac{18\mu}{d_p^2 \rho_p C_C} \tag{18}$$

where $\mu$ means the dynamic viscosity, kg/(m·s); $f$ represents the continuous (air) phase; $p$ represents discrete (particle) phase; $t$ is the time, s; $u$ is the velocity, m/s; $C_C$ is the Cunningham correction factor. The connecting tube has a diameter of 180 mm and a length of 2000 mm with a 90° bend.

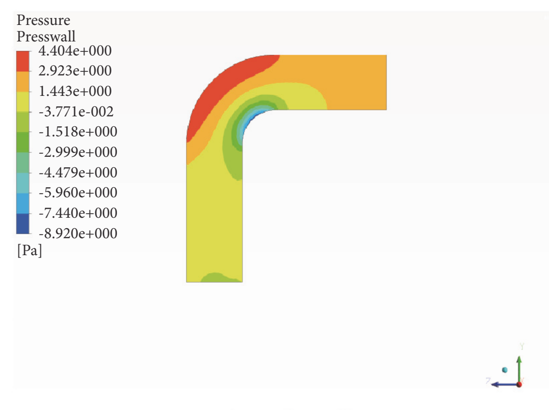


Figure 5

## 3. Result Analysis and Discussion

Assuming that it has no heat exchange with the outside world, the dusty air flow is in-compressible in its interior. We performed numerical simulations by using software FLUENT from a microscopic perspective to simulate the inner airflow fields and the results are shown as below.

Figures 4-5 reflect the pressure field distribution for each part of the elbow tube. The pressure values near the inside corner are negative and the peak values are distributed at the far corner, which are consistent with the flow velocity distribution of the gas flow in the pipe.

Figures 6-7 show the fluid velocity distribution vector in the filter tube, the fluid is mainly distributed in the internal flow path of the air purifier. In the direction of fluid flow, the fluid velocity exhibits a high velocity on the inner wall side and a low distribution on the far wall side. The filter tube is the core area of the air purifier through which fluid flows to form a vortex that separates the gas from the $PM_{2.5}$ particles.

In particular, as can be seen from Figure 6, on the inner wall side of the filter tube, the fluid flow rate first rises and then falls, forming a swirl inside it. As the flow rate at the inlet increases, the eddy currents formed inside the serration become more pronounced. It can be seen from the simulation results that the speed of the air purifier is mainly distributed inside the tube. In the main channel, the fluid flow rate can be increased to the maximum value at the inside corner, and then the fluid increases with the distance. The flow rate will have a certain degree of attenuation. The smaller the fluid flow rate at the inlet, the more pronounced the vortex formed at the corners, which is more conducive to improving the purification efficiency of the air purifier.

The larger the particle size, the more pronounced the increase in the sedimentation rate of the particles. It was secondly induced by a purifier, forming two vortices. As the eddy current moves to the filter material, particle contamination will become less and less. At the outlet of the connecting pipe, the velocity of the gas flow is greater than the velocity of the surrounding gas, and the purifier induces it so that more particles are removed by the filter element. When the flow path is discharged, the adsorption effect will be changed.

From the simulation results, it is easy to find that dust-laden airflow tends to generate eddy currents on the corners, and the pressure distribution on the wall of the pipeline is

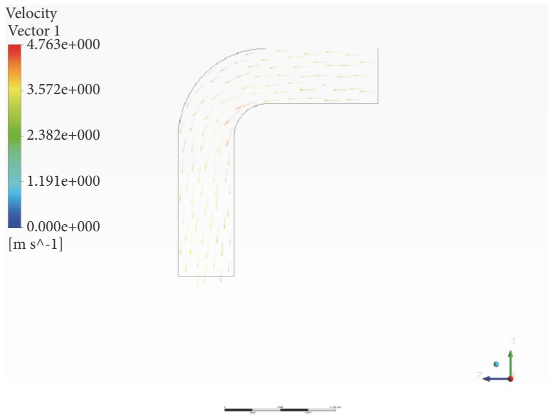


Figure 6

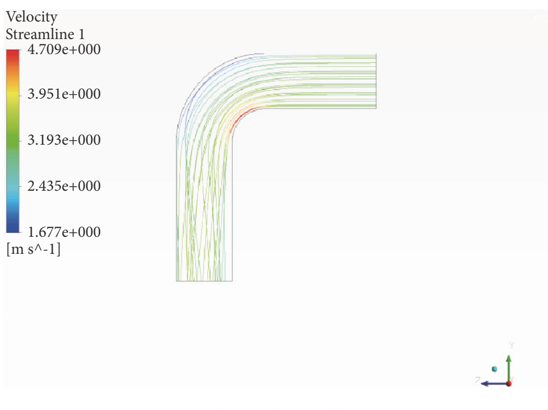


Figure 7

not uniform caused by the centrifugal force. The main flow region is first displaced toward the inner wall surface, and the outer wall surface is offset after flowing through the elbow. In addition, as the inlet flow rate increases, the velocity gradient in the z-axis direction becomes smaller and smaller, and the eddy current becomes increasingly difficult to notice. It is necessary to readjust its angle to induce airflow, slow down the velocity of particulate matter in the airflow, and make most of the particulate matter deposit on the filter element.

## 4. Conclusion

By studying the concentration distribution characteristics and movement law of indoor particulate matter, effectively improving the indoor air quality and reducing the secondary damage caused by the use of air purifier, we improved the calculation method of indoor and outdoor particulate matter concentration and obtained the particle calculation model in the filter tube. We used the Discrete Phase Model (DPM) in FLUENT software to simulate the deposition of particulate matter in the pipe, analyze the main factors affecting the particle deposition of different particle sizes, and proposed measures to improve the dust removal effect of the purifier. This study mainly draws the following conclusions.

(1) Considering the particle turbulent diffusion, the inlet conditions and boundary conditions have a great influence on the deposition rate of small particles in the elbow, while they have no obvious effect on the deposition rate of large particles (>10$\mu$m). This shows that when the particle size is large, its motion and deposition are still mainly affected by gravity and inertia, and the deposition of small particles in the elbow will be affected by the turbulent diffusion.

(2) Particles are more easily deposited on one side of the elbow and cannot be directly rinsed to achieve a good cleaning effect. The wind speed and the size of the pipe should be reasonably controlled to achieve the goal of efficient dust reduction.

(3) For the filter, it is necessary to improve its angle to induce airflow, slow down the velocity of particulate matter in the airflow, and make most of the particulate matter deposit on the filter element.

In summary, based on the analysis of the concentration distribution and motion law of particulate matter indoors and outdoors, the calculation model of particles deposition in the filter tube is obtained. Through the simulation results, we can provide the theoretical basis for enhancing the purifier's efficiency and improve the indoor air quality. Adjusting the structure of the filter tube can effectively improve the purifier's effect, while the harmful gas (ozone, etc.) formed during the use of the purifier should be further studied in future research.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## References

[1] M. Brauer, M. Amann, R. Burnett et al., "Exposure assessment for estimation of the global burden of disease attributable to outdoor air pollution," *Environmental Science & Technology*, vol. 46, no. 2, pp. 652–660, 2012.

[2] C. Tarhan, N. S. Ozcan, S. P. Ozkan et al., "The relationship between respiratory systems' cases and environmental urban factors," *Procedia - Social and Behavioral Sciences*, vol. 216, pp. 622–631, 2016.

[3] L. Wang, B. Zhao, C. Liu, H. Lin, X. Yang, and Y. Zhang, "Indoor SVOC pollution in China: a review," *Chinese Science Bulletin*, vol. 55, no. 15, pp. 1469–1478, 2010.

[4] H. Rintala, M. Pitkäranta, M. Täubel et al., "Microbial communities associated with house dust," *Advances in Applied Microbiology*, vol. 78, pp. 75–120, 2012.

[5] É. C. Pagel, N. Costa Reis, C. E. de Alvarez et al., "Characterization of the indoor particles and their sources in an Antarctic research station," *Environmental Modeling & Assessment*, vol. 188, no. 3, pp. 1–16, 2016.

[6] A. C. K. Lai, J. L. S. Fung, M. Li, and K. Y. Leung, "Penetration of fine particles through rough cracks," *Atmospheric Environment*, vol. 60, no. 4, pp. 436–443, 2012.

[7] E. Diapouli, A. Chaloulakou, and P. Koutrakis, "Estimating the concentration of indoor particles of outdoor origin: a review," *Journal of the Air & Waste Management Association*, vol. 63, no. 10, pp. 1113–1129, 2013.

[8] T. A. Myatt, M. S. Vincent, L. Kobzik, L. P. Naeher, D. L. MacIntosh, and H. Suh, "Markers of inflammation in alveolar cells exposed to fine particulate matter from prescribed fires and urban air," *Journal of Occupational and Environmental Medicine*, vol. 53, no. 10, pp. 1110–1114, 2011.

[9] W. Wei-Feng, Y. U. Jie, X. U. Dan-Dan et al., "Pollution characteristics of particles and its main components in ningbo urban atmosphere," *Environmental Monitoring in China*, vol. 29, no. 5, pp. 43–46, 2013.

[10] Y. Lv, H. Wang, S. Wei et al., "The transmission characteristics of indoor particles under two ventilation modes," *Energy and Buildings*, vol. 163, pp. 1–9, 2018.

[11] K. Zhong, X. Yang, Y. Kang et al., "Effects of ventilation strategies and source locations on indoor particle deposition," *Building and Environment*, vol. 45, no. 3, pp. 655–662, 2010.

[12] X. Cao, J. Liu, N. Jiang, and Q. Chen, "Particle image velocimetry measurement of indoor airflow field: a review of the technologies and applications," *Energy and Buildings*, vol. 69, pp. 367–380, 2014.

[13] A. Jurelionis and L. Gagyte, "The impact of the air distribution method in ventilated rooms on the aerosol particle dispersion and removal: the experimental approach," *Energy & Buildings*, vol. 86, pp. 305–313, 2015.

[14] J. L. Sublett, "Effectiveness of air filters and air cleaners in allergic respiratory diseases: a review of the recent literature," *Current Allergy and Asthma Reports*, vol. 11, no. 5, pp. 395–402, 2011.

[15] W.-C. Lee, P. J. Catalano, J. Y. Yoo, C. J. Park, and P. Koutrakis, "Validation and application of the mass balance model to determine the effectiveness of portable air purifiers in removing ultrafine and submicrometer particles in an apartment," *Environmental Science & Technology*, vol. 49, no. 16, pp. 9592–9599, 2015.

[16] J. Kolarik and P. Wargocki, "Can a photocatalytic air purifier be used to improve the perceived air quality indoors?" *Indoor Air*, vol. 20, no. 3, pp. 255–262, 2010.

[17] L. Zhong-liang, C. Wei-feng, X. Yahui et al., "Numerical simulation and parameter optimization of the inside intake and outside pressing particle collector," *Journal of Engineering Science and Technology Review*, vol. 8, no. 3, pp. 174–178, 2015.

[18] J. N. Hewett, "Transient simulation of accumulating particle deposition on a cylinder in cross-flow," in *Proceedings of the Eleventh International Conference on CFD in the Minerals and Process Industries*, Melbourne, Australia, 2015.

[19] Z. Can-Feng, *Particulate matter deposition regularity in air conditioning ventilation ducts [Doctoral dissertation]*, Anhui University of Science and Technology, 2013.