DEPOSITION RATE AND PURIFICATION EFFECT OF ATMOSPHERIC PARTICLE BY DIFFERENT PIPELINE CONNECTION FORMS

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The connection form of pipelines has an important impact on the comprehensive performance evaluation of fresh air systems. The most used PVC fresh air pipeline material in the market was selected for experimental research in this paper, and the deposition rates of particles of different pipeline connection form of 45°, 90° bend, and straight tee were all tested and compared. The purification effect of the pipeline connection form of the highest deposition rate is tested and studied. The results showed that the particle deposition rates were the highest in the connection form of straight tee, with deposition rates of 47.61, 18.06, and 8.13% for PM_{10}, $PM_{2.5}$, and $PM_{1.0}$, respectively. As the particle size increases, the deposition rate of particles also gradually increases. The larger the inlet velocity, the greater the deposition rate. The particle concentration on the outlet of the pipeline in the connection forms of straight tee was significantly decreased after adding the purification equipment, and the deposition rates of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ decreased by 45.01, 68.89, and 77.48%. Therefore, the use of pipeline elbows should be reduced, and purification equipment should be installed in the process of using, which will reduce the deposition of particles in the fresh air systems.

Keywords: *Pipeline structure; PVC; particles; deposition rate; Purification effect*

1. Introduction

With the normalization of epidemic prevention and control, people are paying more attention to the health of indoor environments [1-3]. People might spend as much as 80% to 90% of time indoor [4], and the architecture is one of the environments that have the closest contact with people. Therefore, good indoor air quality and fresh air content are the most important part for indoor environments [5].

Fresh air system is currently one of the effective ways to solve indoor environmental hygiene in buildings, and has been widely popularized and widely applied [6]. However, domestic and foreign scholars have focused on the study of the filtration efficiency of fresh air systems [7-9], fan energy consumption [10,11], and noise [12-14]. In addition, parts of the existing research on the connection forms of pipelines mainly focuses on the explosion characteristics of gas pipelines [15], seismic links [16], and dust layers in connecting pipelines [17]. Although some certain achievements had been made, there was relatively rare research on the connection forms of pipelines in fresh air systems. The researches on the deposition rate of particles in pipelines under different connection form into fresh air systems were deeply not enough [18]. The main reasons were that fresh air systems had only been widely used in recent years, and the using of fresh air pipelines was relatively less compared to traditional rectangular galvanized iron sheet ducts for air conditioning. There were differences in sizes, materials, and cross-section [19], which made them deeply difficult to calculate, such as the fresh air pipelines of flat pipe PVC materials and corrugated pipe PE materials [19]. On the other hand, many researchers from different countries mainly focused on the research and development of the filtration performances of fresh air systems for particles [20], with a focus on the selection of air filters [21], and the default was that the deposition rates in the fresh air pipelines were very small, which could be ignored. In addition, some research had also summarized and experimental study on the energy-saving applications of heat pipeline heat exchangers and pulsating heat pipeline heat exchangers in air conditioning [22,23]. In a word, the research on particle deposition in fresh air systems under different connection forms is still insufficient. As a result, it has led to the existing designers often only relying solely on experience to determine the selection of fresh air pipelines [24].

In addition, construction workers often modify the actual pipeline connection form of the building based of their years of engineering experience or aesthetic perspective due to the practical structure of the building and the actual installation difficulty on site when during the actual engineering installation and use process. Maybe even modified the original design and installation plans. Based on the above actual situation, there is currently a slight lack of researches on the deposition rate of particles in different connection forms into pipelines structures of practical application of fresh air systems. There is still a lack of relevant experimental research on whether adding the purification equipment can reduce the deposition rate of particles in the fresh air pipelines.

In this paper, the commonly used fresh air system PVC pipes in the market were selected to conduct experimental research on the deposition of atmospheric particles in response to the above practical issues, and conducts in-depth analysis of particle deposition in pipelines under different pipeline connection forms. It provides reference value for the reasonable layout and installation of fresh air pipelines systems in practical engineering.

2. Methods

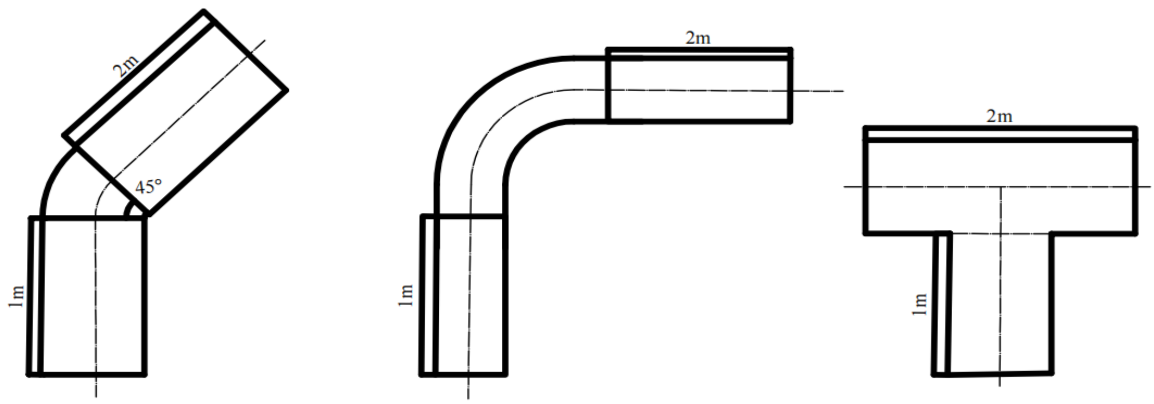
2.1. Pipeline related parameters

The physical picture of PVC pipeline material was shown in Fig. 1. The sizes are 130 mm * 30 mm, with length of 3.0 m. The friction coefficient of the pipeline is 0.03, and the material of PVC was product by the company of 51BLUESKY, China. The velocity ranges of indoor fresh air pipelines were 2.0~4.0 m/s [19,25]. The pipeline connection form without a purification equipment was selected for testing and research in order to compare the deposition rates of particles of different pipeline connection form. The testing time was from January 18th to 23rd, 2019.

Fig. 1. Physical picture of PVC pipeline material

2.2. Experimental instruments

HD37AB1347 indoor air quality monitor was used to measure the velocity. The measuring accuracy range was ± 3%. GRIMM1.109 aerosol particle size spectrometer was used to measure the mass and counting concentration of particles before and after the fresh air pipelines. Measuring range was 0.1~100.000 μg/m^3. Counting range was 2000000 P/L, and 31 particle size channels were divided between 0.25~32 μm. The repeatability was 5%. TESTO480 climate measuring instrument was used to measure the temperature and humidity. Measuring range was -100~+400 °C. Measurement accuracy was ± (0.3 °C~0.1 % measured value). The humidity measuring range was 0~100 %RH. Measurement accuracy was ± (1.4 %RH~0.7 % measured value). One end of the pipeline was connected with a fan of the same model during the experiment, which was used as the air outlet [19,25]. While the other end was used as the air inlet. The measuring point was the central position of the pipeline to ensure the accuracy of the data. Each group of testing was 10 minutes, and the average concentration of 5 minutes before and after was recorded. The data were analyzed by mean value to reduce the experimental error. The calculated value of PVC pipe was the average value of two outlets [19,25]. The different pipeline connection forms of 45°, 90° bend, and straight tee were shown in Fig. 2.



(a)45°bend (b)90°bend (c)Straight tee

Fig. 2. Different pipeline connection forms

3. Results and discussion

The outdoor atmospheric dust was directly used as the experimental dust source [26], and the particle size distribution of the testing period was shown in Tab. 1.

Table 1. Concentration distribution of atmospheric particles

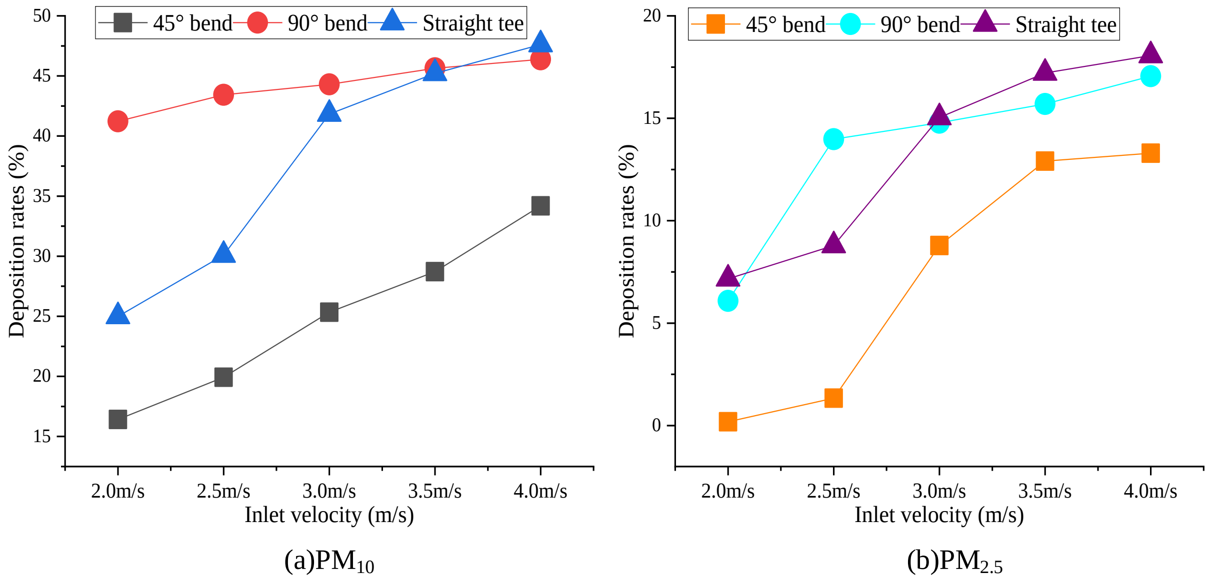
The range of particle sizes (μm)	The average of particle sizes (μm)	Quantity proportion (%)
0~0.5	0.25	95.62
0.5~1.0	0.75	4.10
1.0~2.5	1.75	0.21
2.5~5.0	3.75	0.06
5.0~10	7.5	0.01
10~30	20	0.001

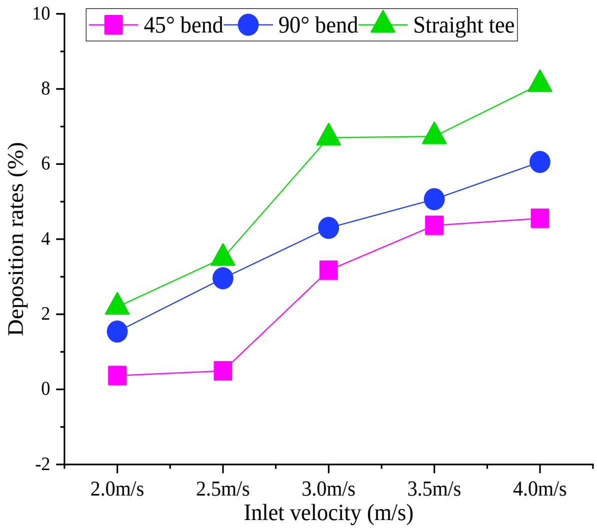
(the average temperature was -3 ℃~10 ℃, and the average humidity was 17.8%~56.7%)

From the Table 1, it could be seen the particle sizes of 0~2.5 μm accounted for the majority of the atmosphere during the testing, about 99.93%. The particle sizes of 0~1.0 μm accounted for 99.72%, which is consistent with the results given in reference [27]. It can be seen that the particles of atmosphere in Xi'an were mainly composed of small-sized particles, and those particles were highly prone to causing health problems for people [28,29]. Therefore, the purification effect of fine particles should be improved to achieve the goal of creating a good indoor environment and hygiene [25].

3.1. Deposition rates of PM of different pipeline connection form

The deposition rates of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ of different pipeline connection form were shown in Fig. 3.





(c)$PM_{1.0}$

Fig. 3. Deposition rates of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ of different pipeline connection forms

As shown in Fig. 3, the deposition rates of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ all showed a gradually increasing trend with the continuous increased of the inlet velocity. The pipeline connection form was 45° bend, and the variation range of PM_{10} was 16.41 to 34.19%, with the variation range of 17.78%. The variation range of $PM_{2.5}$ was 1.33 to 13.29%, with the variation range of 11.96%. The variation range of $PM_{1.0}$ was 0.49 to 4.55%, with the variation range of 4.06%. While the pipeline connection form was 90° bend, and the variation range of PM_{10} was 41.22 to 46.38%, with the variation range of 5.16%. The variation range of $PM_{2.5}$ was 6.09 to 17.05%, with the variation range of 10.96%. The variation range of $PM_{1.0}$ was 1.54 to 6.06%, with the variation range of 4.52%.

The pipeline connection form was straight tee, and the variation range of PM_{10} was 24.99 to 47.61%, with the variation range of 22.62%. The variation range of $PM_{2.5}$ was 7.17 to 18.06%, with the variation range of 10.89%. The variation range of $PM_{1.0}$ was 2.20 to 8.13%, with the variation range of 5.93%. The larger the inlet velocity, the greater the deposition rate. It can be seen the change of $PM_{1.0}$ was the smallest, while the change of PM_{10} was the largest. When the inlet velocity was 4.0 m/s, the deposition rates of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ were reached their maximums. The main reasons were that with the inlet velocity increased, the diffusion effect decreased and the inertial effect of the particles increased, and the turbulent deposition rate of particles increased sharply. The results were consistent with the conclusions of the literature [30]. Figure 4 showed the changes in deposition rates of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ at the inlet velocity of 4.0 m/s.

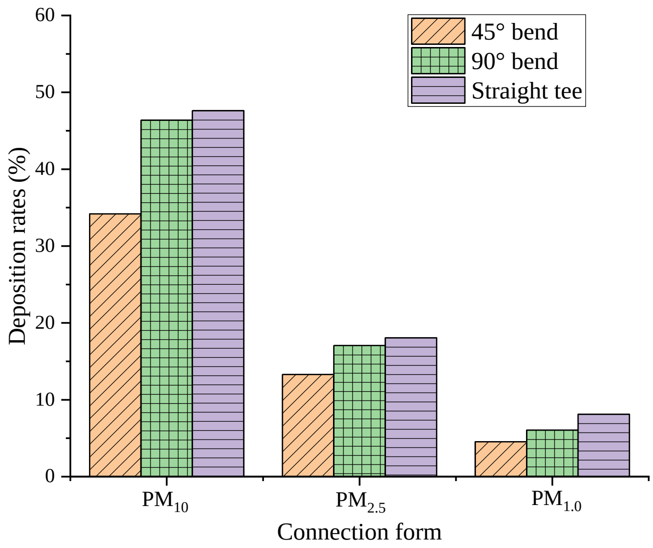


Fig. 4. Comparison of PM deposition rate of different pipeline connection form

It can be seen from the figure the deposition rates of PM_{10}, $PM_{2.5}$, $PM_{1.0}$ reached the maximum when the inlet velocity was 4.0 m/s. The particle deposition rates were the highest in the connection form of straight tee. The deposition rate showed PM_{10}>$PM_{2.5}$>$PM_{1.0}$. The deposition rates of PM_{10}, $PM_{2.5}$, $PM_{1.0}$ were 47.61, 18.06, 8.13%, respectively. The deposition rate of PM_{10} in connection forms into straight tee was 1.39 times and 1.03 times higher than that in connection form of 45° and 90° bend. While the deposition rate of $PM_{2.5}$ in connection forms into straight tee was 1.36 times and 1.06 times higher than that in connection form of 45° and 90° bend under the same conditions. The deposition rate of $PM_{1.0}$ in connection forms into straight tee was 1.78 times and 1.34 times higher than that in connection form of 45° and 90° bend under the same conditions. Therefore, it could be seen that different pipeline connection forms had significant differences in the deposition rate of particles, and the use of pipeline elbows and local components should be reduced in the fresh air system pipelines [30].

3.2. Deposition rates of different particle size of different pipeline connection form

The deposition rates of particles with different particle sizes of different pipeline connection form were shown in Fig. 5.

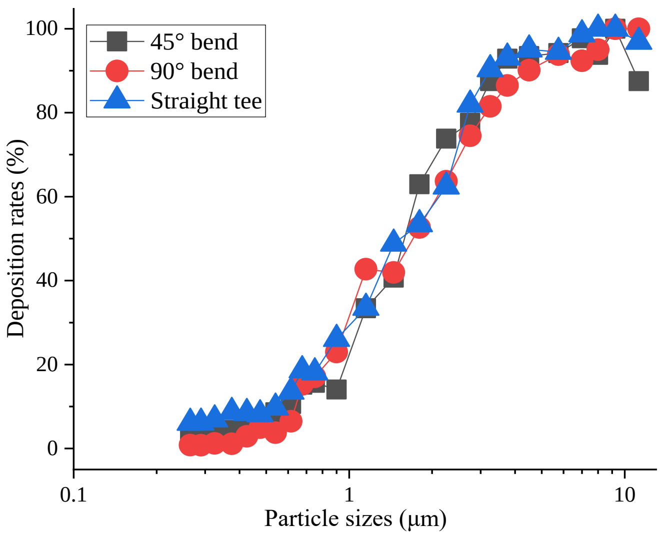


Fig. 5. Deposition rates of different particle sizes of different pipeline connection forms

From Fig. 5, it could be seen with the particle size increases, the deposition rate of particles of different pipeline connection forms showed a gradual increasing trend. The deposition rates of different particle sizes were greater in the connection form of straight tee. For particle sizes less than 1.0 μm, and the deposition rates were small. At this point, the particles were at the junction of the diffusion area and the diffusion collision area, and the diffusion effect played a decisive role in the deposition process of particles [19,31]. With the particle size increased, the diffusion effect was weakened. The particles were located at the junction of the inertia-relaxation area and the diffusion collision zone when the particle sizes were about 3.0 μm, where both the inertia effect and diffusion effect played a role in the deposition process of particles [19,31].

With the particle sizes continued to increase, the inertial effect played a decisive role, which increased the deposition rates of particles. The previous relevant experiments had been verified the correctness of this paper [19,31]. In addition, there were certain fluctuations in the experiments of different particle sizes, because it was also related to the composition type and the concentration distribution of aerosol in the test area [32]. The particle sizes concentrations distributions of large particles were relatively unstable. On the other hand, it was related to the performance of pipeline materials themselves [19,33]. However, the pipeline connection form of straight tee often had a high utilization rate of the actual engineering installation and use process due to the difference in soft connection and pipeline direction in the practical structure of the building and the actual installation difficulty on site. It is more valuable to conduct in-depth researches on the purification effect of particles in the connection form of straight tee of fresh air systems.

3.3. Concentrations of PM of straight tee before and after adding purification equipment

Air purification equipment is often added to the fresh air systems in practical use, which can purify the fresh air at the inlet and make the air entering the pipeline cleaner and more hygienic, thus achieving the goal of purifying indoor air quality [34]. Air purification equipment generally chooses a combination of coarse filters and Sub-HePa filters [34]. The concentrations of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ at the inlet and outlet before and after purification equipment were shown in Fig. 6.

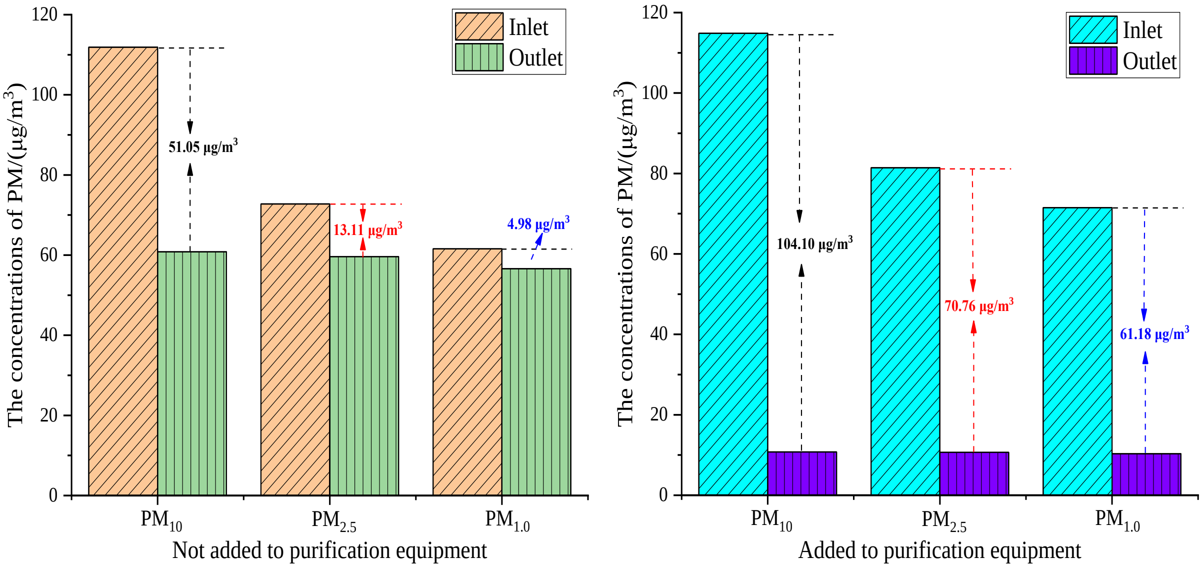


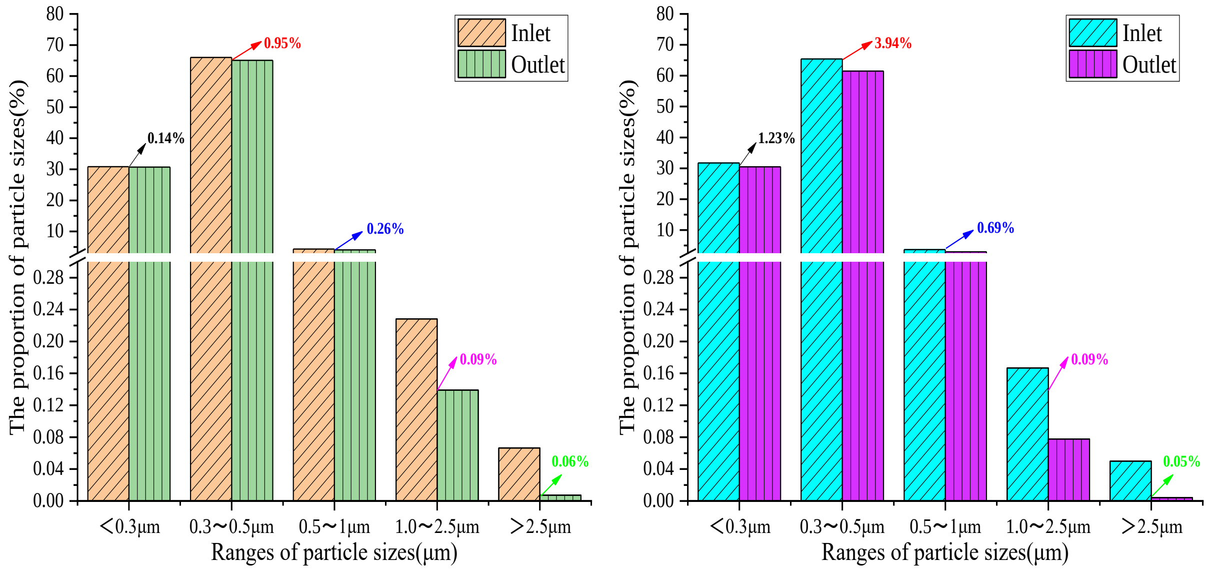
Fig. 6. Concentrations of PM at the inlet and outlet before and after purification equipment

Figure 6 showed the mass concentration of PM_{10} at the inlet was about 105.5 to 116.7 μg/m^3 before not added to purification equipment at the inlet velocity of 4.0m/s, and the mass concentration of PM_{10} at the outlet was about 60.5 to 61.4 μg/m^3. The mass concentration of $PM_{2.5}$ at the inlet was about 71.5 to 73.9 μg/m^3 before not added to purification equipment, while the mass concentration of PM_{10} at the outlet was about 59.1 to 60.1 μg/m^3. The mass concentration of $PM_{1.0}$ at the inlet was about 60.8 to 62.3 μg/m^3 before not added to purification equipment, while the mass concentration of PM_{10} at the outlet was about 56.1 to 57.1 μg/m^3. Overall, the average decreased in concentrations of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ was 51.05 μg/m^3、13.11 μg/m^3, and 4.98 μg/m^3. From the Figure 6, it could be seen that the concentration ranges of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ at the outlet were not significantly different, but the concentration ranges of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ at the inlet were significantly different. It might be because the concentrations of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ in the outdoor were greatly affected by the outdoor weather, such as wind velocity, temperature, and humidity. Therefore, there were significant differences in the inlet and outlet concentration of PM_{10} without purification equipment.

After added to the purification treatment, the mass concentration of PM_{10} at the inlet was about 109.5 to 120.2 μg/m^3, and the mass concentration of PM_{10} at the outlet was about 6.2 to 13.6 μg/m^3. The mass concentration of $PM_{2.5}$ at the inlet was about 78.3 to 85.7 μg/m^3 before not added to purification equipment, while the mass concentration of PM_{10} at the outlet was about 6.2 to 13.3 μg/m^3. The mass concentration of $PM_{1.0}$ at the inlet was about 68.9 to 75.7 μg/m^3 before not added to purification equipment, while the mass concentration of PM_{10} at the outlet was about 6.0 to 13.1 μg/m^3. Overall, the average decreased in concentrations of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ was 104.10 μg/m^3、70.76 μg/m^3, and 61.18 μg/m^3. It could be seen the deposition rates of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ in the pipeline decreased by 45.01, 68.89, and 77.48% after added to the purification treatment. This was because the purification treatment had good filtration efficiency for particles, which can reduce the concentrations of particles at the outlet [35], and also reduce the deposition rates of particles in the pipeline. As a result, it is conducive to the creation of indoor environment by added to the purification treatment of using.

3.4. Counting concentrations of straight tee before and after adding purification equipment

The counting concentration of particles at the inlet and outlet before and after purification equipment were shown in Fig. 7.



(a)Not added to purification equipment (b)Added to purification equipment

Fig. 7. Counting concentrations of particles at the inlet and outlet before and after purification equipment

Figure 7 showed there was small difference in the counting concentrations of particles with small particle sizes at the inlet and outlet before not added to purification equipment. The particle sizes between 0.3 and 0.5 μm were only reached the maximum difference, with 0.95%. While there was a certain difference in the counting concentrations of particles with small particle sizes at the inlet and outlet after added to purification equipment. For particle sizes less than 0.3 μm, and the difference was 1.23%. The particle sizes between 0.3 and 0.5 μm were reached the maximum difference, with 3.94%. The concentration differences after added to purification equipment were much higher than the concentrations difference before not added to purification equipment. Therefore, it has a good filtration effect [36]. However, fine dust particles would also condense in the actual ventilation pipelines [37], which was beneficial to the purification equipment to capture particles. Therefore, adding a purification equipment can effectively reduce the deposition rate of particles in the pipelines. With the development of the mining environment, the connection of pipelines and the deposition of particles in deep mining operations [38,39]or flotation processes [40,41]is a new challenge and research hotspot.

4. Conclusion

This paper conducted experimental research on the deposition rates of particles in residential fresh air systems through different connection forms of pipelines. The deposition rates of particles of different pipeline connection form of 45°, 90° bend, and straight tee were all tested and compared, as well as the purification effect before and after added to purification equipment. The following conclusions were as followed. The particle deposition rates were the highest in the connection form of straight tee, with deposition rates of 47.61, 18.06, and 8.13% for PM_{10}, $PM_{2.5}$, and $PM_{1.0}$, respectively. As the particle size increases, the deposition rate of particles of different pipeline connection forms also gradually increases. The larger the inlet velocity, the greater the deposition rate. The particle concentration on the outlet of the pipeline in the connection forms of straight tee was significantly decreased after adding the purification equipment, and the deposition rates of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ decreased by 45.01, 68.89, and 77.48%.

Therefore, the use of pipeline elbows should be reduced, and purification equipment should be installed in the process of using, which will reduce the deposition of particles in the fresh air systems.

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