RESEARCH ARTICLE OPEN ACCESS

Experimental Study on Resuspension of Particles in Ventilation Ducts

Huadong Yang, Zhen Li
Department of Mechanical Engineering, North China Electric Power University, Baoding, Hebei, 071003

ABSTRACT:
The resuspension of particles in the ventilation ducts and the human walking activity are important sources of indoor particles. The resuspension of particles will seriously affect people's health. Therefore, it is necessary to study the influencing factors of the resuspension of particles and then study its control strategy. In order to study the influencing factors of particulate matter resuspension in the indoor environment, this paper adopts the method of experimental research, through the design of the ventilation duct particulate matter suspension experimental platform, with aluminum oxide and silica particles as the research objects, and the flow rate, surface roughness and humiditywere discussed through experimental research. The experimental results show that the type of particulate matter has no obvious effect on the particulate matter suspension rate, and the reuspension rate is the largest at a flow rate of 2m/s. In addition, surface roughness has an important influence on the resuspension of particles.

Keywords: Humidity, surface roughness, ventilation duct, resuspension

---

Date of Submission: 10-07-2020 Date of Acceptance: 26-07-2020

I. INTRODUCTION

Common particulate matter in the indoor environment includes dust, fiber, tobacco smoke,volatile organic compounds and bioaerosols such as bacteria, fungi, dust mites, insect remains. The suspended particles in the air range from 0.01 microns to 100 microns, but studies have shown that typical indoor particles are 0.01-30 microns. Early research[1] revealed that inhalable particulate matter (such as dust particles, bioaerosols, and combustion products) can significantly increase lung cancer, heart and lung diseases, asthma, and other respiratory diseases. These particles are deposited on the wall and have strong adhesion. If the deposited toxic materials are suspended again into the air and inhaled by humans, it will seriously affect human health.

Resuspension refers to the phenomenon that particles that have been deposited on the surface are released under the drag force of the fluid or other external forces, detach from the wall, and then re-enter the airflow.The resuspension of particulate matter in ventilation ducts[2] is important source of indoor environmental particulate matter. The resuspension of indoor particulate sediments is due to the airflow in the ventilation ducts and human indoor activities[3-7] Therefore, it is important to study the mechanism of the resuspension of particles in the ventilation duct.

Current research demonstrated that particle size, particle material, flow rate, surface material, time, and wall vibration have important effects on the suspension of particles[8], and related researchers have conducted experiments on the impact of environmental humidity on particle suspension.However, the current experimental results are controversial[9]. The experimental results of Corn in 1961[10] and 1965[11] showed that when the humidity RH is greater than 30%, the adhesion of particles increases with the increase of humidity. Rosati's study[12] revealed that the suspension rate of particulate matter may increase or decrease with the increase of humidity, mainly depending on the surface material properties. The research results of Qian and Ferro in 2008[5] showed that 0.1~10μm ATD particles were resuspended in the wet condition due to human walking induced. The actual surface of ventilation ducts or indoor floors in indoor environments cannot be absolutely smooth, and even nano-scale surface roughness can affect adhesion[13].

Based on the above analysis, it can be seen that the influence of humidity and roughness on the resuspension of particles needs further experimental study. Therefore, from an experimental point of view, factors affecting the resuspension of particulate matter was discussed, and can provide a certain reference for theoretical research and further in-depth research.

II. EXPERIMENT PRINCIPLE

2.1 Experiment method

The study found that temperature, humidity, flow rate, wall surface roughness and other factors have a certain impact on the resuspension of particulate matter in the ventilation duct. In this experiment, controlled variable method is applied to study the effect of these factors on resuspension rate of particles in ventilation ducts. The resuspension rate of particles in the ventilation duct can be achieved by measuring and comparing the difference in particle concentration before and after gas flow. The specific principle is shown in Figure 1.

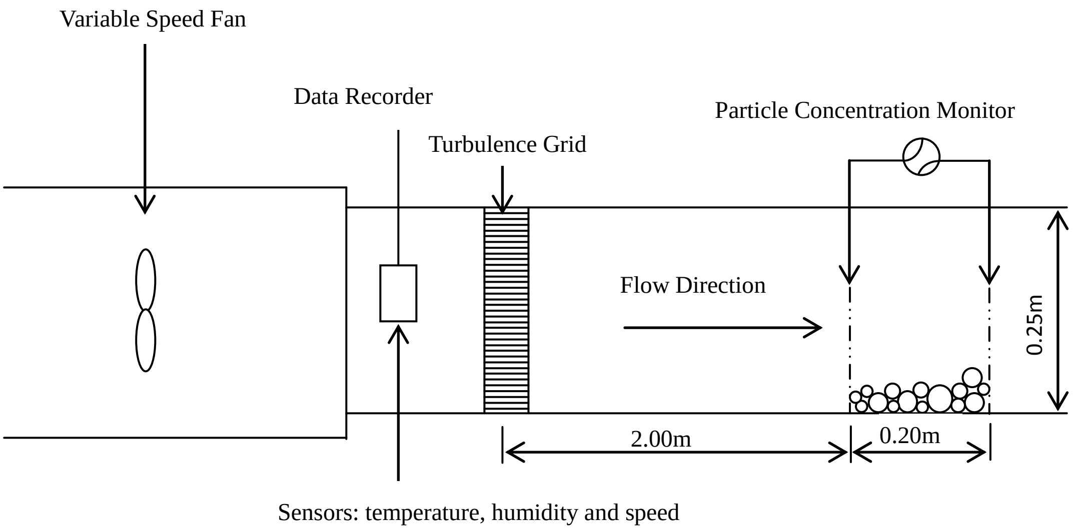

Figure 1. Test rig for particle resuspension in duct

As shown in Figure 1, the flow rate can be controlled by a variable speed fan, the wall roughness can be controlled by changing the substrate of the test section, and the humidity can be controlled by humidification. Due to the limitations of the experimental conditions, the temperature conditions are difficult to control. Therefore, the effect of temperature on resuspension rate of particles is not discussed in this experiment. The values of flow rate, temperature and humidity can be measured by corresponding sensors.

By modifying the above control conditions, the corresponding suspension rate (concentration difference) can be obtained. By comparing and analyzing the suspension rates under different control conditions, the influence of different control conditions on the secondary suspension of particles in the ventilation duct can be obtained.

2.2 The test rig configuration

The test rig is mainly composed of three parts: a generation module, a measurement module and an auxiliary module. The generation module includes an adjustable-speed fan, a ventilation duct, and a detachable experiment board. The measurement device includes a temperature and humidity sensor, a wind speed sensor, and a particle concentration sensor. And auxiliary module includes duct sealing device, grid, pipe bracket and adjustable height fan support frame.

The overall size of the ventilation duct is 25cm×25cm×240cm, and the stainless steel plate with a thickness of 1mm is selected as the material, which can not only ensure the strength of the entire ventilation duct, but also realize the simulation of the actual ventilation duct. In addition, the structural design at both ends of the pipeline can expand the adjustable flow rate range during the entire experiment, and provide convenience for exploring the influence of different flow rates on the resuspension. The adjustable-speed fan, with an outer diameter of 24cm, fits into the entire ventilation duct. It is the power source for the entire experiment, and can continuously provide a stable airflow during the experiment. In addition, the combination of its speed control device and flow sensor can basically adjust any flow rate, which provides a strong guarantee for the study of the effect of flow rate on the resuspension of particles in the experiment. The design of the detachable experiment board adopts the way of rubber nesting. The rubber ring with a thickness of 1mm has the following characteristics. The shape of the inner ring is seamlessly matched with the fixed glass plate, and the shape of the outer ring is aligned with the stainless steel cutout; the whole glass is recessed inside the rubber plate, but its upper surface is flush with the inner wall of the pipe. In addition, the glass glue is used to bond the outer ring of the glass plate and the stainless steel plate to ensure the tightness of the entire device. The transparent features on the upper surface and both sides of the pipe provide convenient conditions to observe the internal situation at any time, and also leave room for the subsequent installation of high-speed cameras to capture the movement of particles in the resuspension state. The lower surface is removable and replaceable. The device provides a strong feasibility for exploring the influence of the duct inner surface roughness on the resuspension in the experiment.

The temperature sensor, humidity sensor and wind speed sensor are installed at the same distance from the fan. The measurement method is embedded in the inner wall of the duct. The corresponding indicator can be displayed in time and accurately during the experiment. The feedback information can also help more accurately control the temperature, humidity and wind speed. Two particle concentration sensors are installed on the same side of the inner wall of the duct in sequence, located at the front and back of the detachable glass plate, so the concentration difference of sensors can be used to calculate the resuspension rate.

The sealing device adopts a complete coordination with the fan. This structure can effectively expand the adjustable wind speed range of the entire device, and also provides a strong guarantee for the entire experimental exploration process. The grid is composed of equally spaced gaps, and the size fits perfectly with the inner wall of the duct, which can ensure that the turbulent flow of the ventilation nozzle is converted into the laminar flow in the ventilation duct, so that it is consistent with the actual ventilation duct. The support is made of aluminum alloy, which can effectively support the ventilation duct. The height-adjustable fan support frame realizes the adjustability of the entire fan within a certain height range through the adjustability of the bolt height on the basis of ensuring that the fan can be fixed.

III. EXPERIMENT

3.1 Control and measurement of experimental variables

(1) Flow rate control and measurement

In order to study the effect of different flow rates on the resuspension of particulate matter, we use variable speed fans to control the flow rate. The flow rate ranges from 0 to 30m/scan be generated to meet the needs of the experiment. It can be easily achieved by rotating the governor knob. The flow rate can be continuously adjusted and controlled. The flow rate is measured by a speed sensor which can measure and display the flow rate in real time.

(2) Control and measurement of roughness

As mentioned above, the roughness of the wall is also an important factor affecting the resuspension of particles, and the control and measurement of the roughness variables are also crucial. Combining actual experimental conditions and experience, the surface roughness is equivalently replaced with sandpaper of different particle sizes. The roughness can be changed by changing different sandpaper particle sizes.

Finally 80, 240, 360 grit sandpapers were selected in this experiment to represent the wall surface roughness.

(3) Selection and concentration measurement of particulate matter

As mentioned above, the type of particulate matter, its size, and surface conditions are also an important factor affecting the resuspension of particulate matter. The following solutions are adopted for the measurement of the type and concentration of particulate matter:

Taking into account the influence of different types, particle sizes, and surface conditions of actual particles, two different particles can be selected in the experiment, namely small-diameter silica particles and large-diameter aluminum oxide particles. The particles are evenly smeared on the corresponding test board and placed in the test section to simulate the effect of different particles on resuspension.

In order to measure the concentration of particles before and after test section and calculate the resuspension rate, two particle concentration sensors are used. The value of the sensor can be returned to the computer through the serial port for direct reading.

3.2 The overall plan of the experiment

As mentioned above, this experiment mainly uses the controlled variable method to study the size of the resuspension rate of particulate matter in the ventilation duct under different particulate matter type, temperature, humidity, flow rate, and surface roughness. In the experiment, the effects of flow rate and humidity are studied in turn, and the effects of particle types and surface roughness are throughout the experiment. Specific steps are as follows:

(1) The effect of flow rate on resuspension of particulate matter

In order to study the impact of flow rate on resuspension of particulate matter, other variables must be completely consistent and unchanged. By modifying the flow rate, the concentration difference in the corresponding situation should be measured.In this experiment, 6 group tests with different particles and different surface roughness will be implemented.

(2) The influence of humidity on resuspension of particulate matter

When studying the influence of humidity on resuspension of particulate matter, it is necessary to ensure that other variables are completely consistent. It should be noted that flow rate in this group of experiments should be 2m /s in which is the maximum resuspension rate in the above experiments.Because the indoor humidity is difficult to recover in a short time after the humidity changes, so this group of experiments must pay attention to adjusting the humidity from small to large.Similarly, different particles and different surface roughness were used for humidity experiments, 6 group tests were implemented.

IV. EXPERIMENT RESULTS DISCUSSION

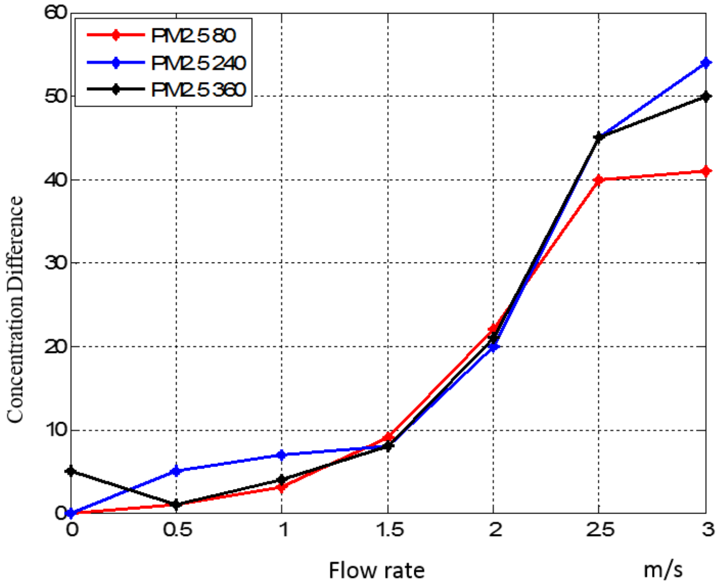

Figure 2. The relationship between the resuspension of aluminum oxide and the surface roughness, flow rate (PM2.5 measured value)

On the basis of the above-mentioned experimental device and experimental plan, relevant experiments were carried out, and the experimental data was recorded in detail.

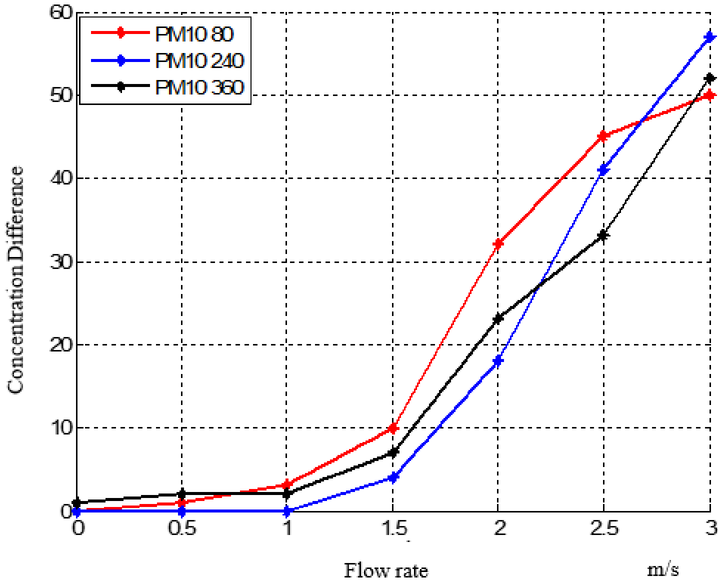

Figure 3. The relationship between the resuspension of aluminum oxide and the surface roughness, flow rate (PM10 measured value)

It can be found from Figure 2 and Figure 3 which are the concentration difference curve of the two concentration sensors before and after test section for the aluminum oxide at different flow rates when the surface roughness is different. From the experiment results, we can find that for flow rate 0-1m/s, the concentration difference before and after test section is in the range 0-8 which is basically unchanged or slightly changed. If flow rate is greater than 1m/s, the concentration difference increases.And when flow rate is 2m/s, the concentration difference increases sharply. However, when flow rate exceeds 2.5m/s, the concentration difference drops again. It shows that the resuspension of particle in the ventilation duct differs depending on flow rate, the effect of flow rate above 3m/s has a relatively stable effect on the resuspension of particlein the ventilation duct. And also, for flow rate 2m/s, it has the greatest impact on the resuspension of particles. From these figures, it can be found that the effect of surface roughness is little.

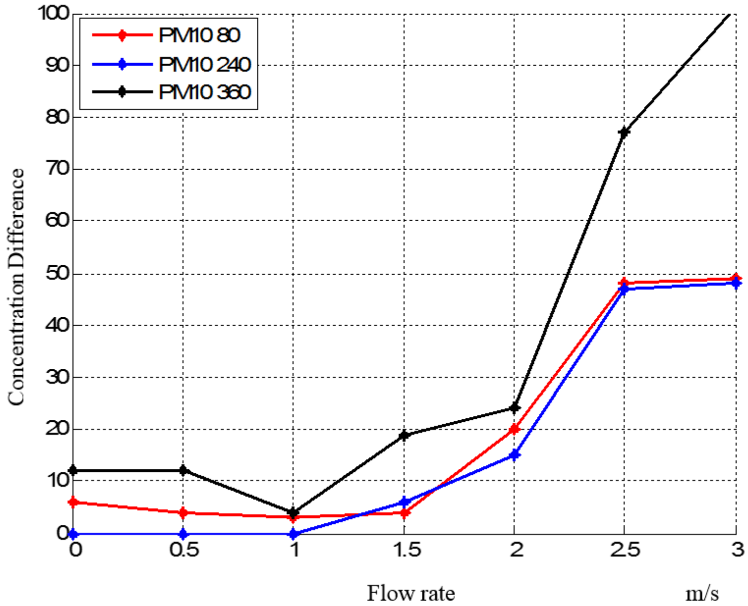

Figure 4.The relationship between the resuspension of silica and the surface roughness, flow rate(PM10 measured value)

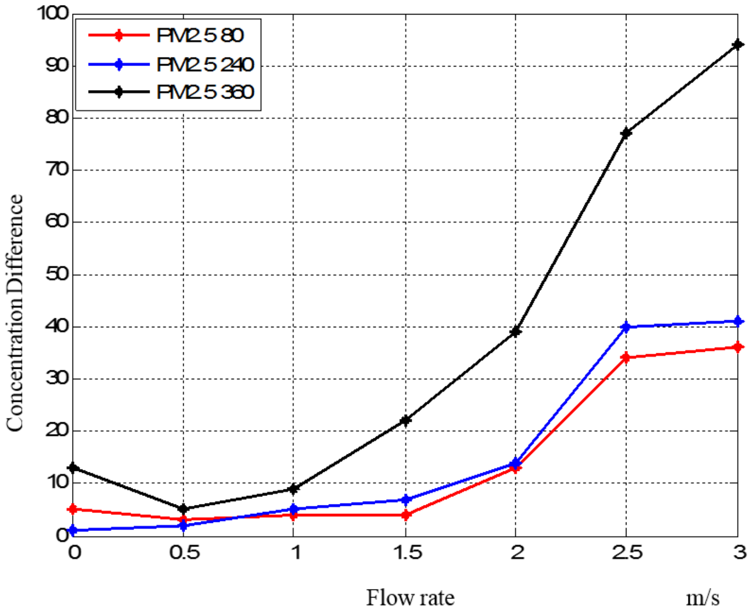

Figure 5.The relationship between the resuspension of silica and the surface roughness, flow rate (PM2.5 measured value)

It can be found from Figure4 and Figure 5 which are the concentration difference before and after test section for the silica under different flow rateswhen surface roughness is different. From the experiment results, we can find that forflow rate 0-1m/s,the concentration difference before and after test section is in the range 0-10 which is basically unchanged or slightly changed. If flow rate is greater than 1m/s, the concentration difference increases. When the wind speed is 2m/s, the concentration difference increases sharply. If flow rate exceeds 2.5m/s, the concentration difference decreases again. It shows that the resuspension is different under different flow rate. Similarly, when flow rate is greater than 3m/s, the effect of flow rateis relatively stable. It can be found that when the surface roughness is 80 and 240, there is little change for the concentration difference, while the roughness is 360 the concentration difference increase obviously.

By comparing Figure2-5, it can be seen that the flow rate affects the resuspension rate of particles for aluminum oxide and silica and the change trend is almost the same. It shows that the flow rate affects the resuspension of different particles in the ventilation duct. The change of roughness has different effects on aluminum oxide and silica, which shows that the roughness has different effects on the resuspension of different particles in the ventilation duct.

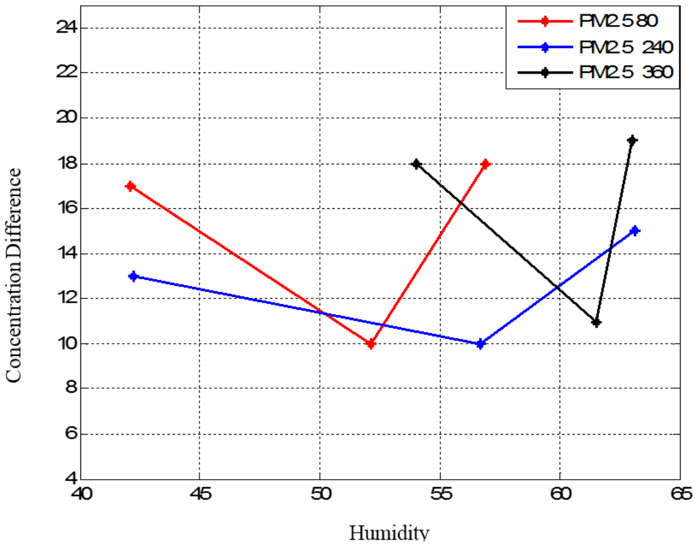

Figure 6. The relationship between the resuspension of aluminum oxide and the surface roughness, humidity (PM2.5 measured value)

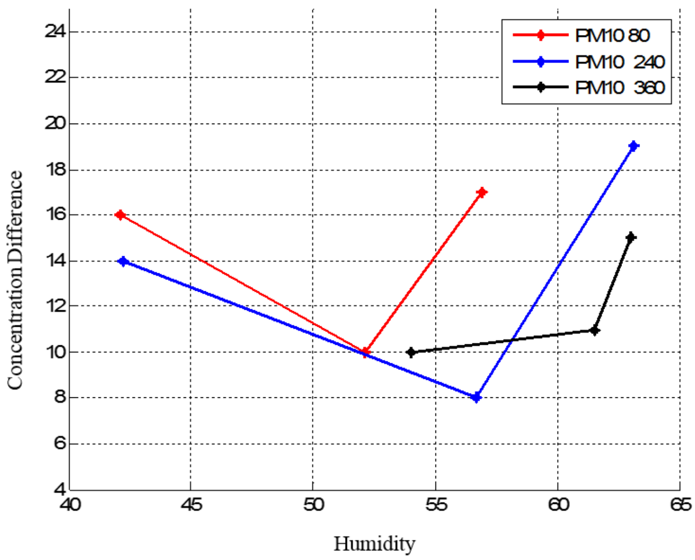

Figure 7. The relationship between the resuspension of aluminum oxide and the surface roughness, humidity (PM10 measured value)

It can be found from Figure6 and Figure 7 which arethe concentration difference of aluminum oxidebefore and after test section with different humidity when the flow rate is 2m/s and the surface roughness is different. It can be found that in the process of increasing humidity, the concentration difference firstly became larger and then smaller. The minimum value appeared in the humidity range of 55%-60%, and the minimum concentration difference ranged from 8-10, which indicated that the resuspension of particles in the ventilation ducts is different under different humidity. It can be found that the surface roughness affects the resuspension of particles to a certain extent, but no obvious regularity can be seen.

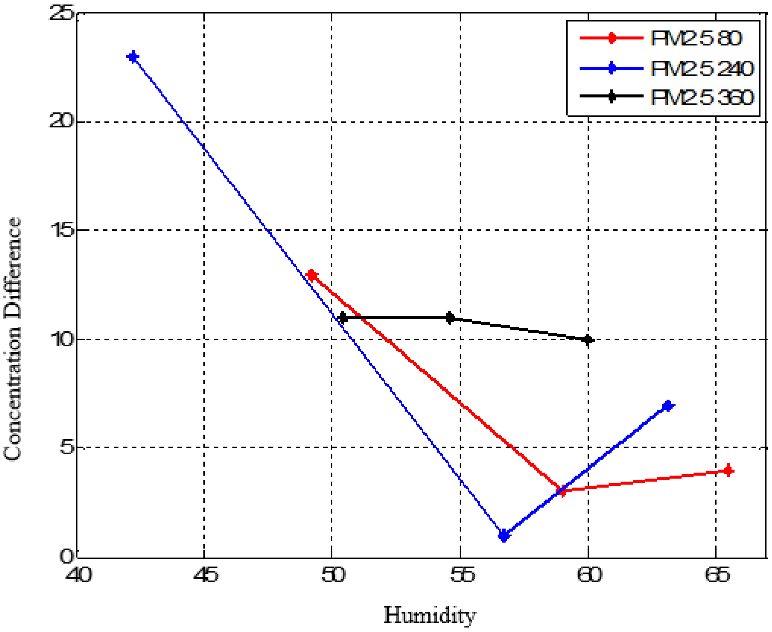

Figure 8. The relationship between the resuspension of silica and the surface roughness, humidity (PM2.5 measured value)

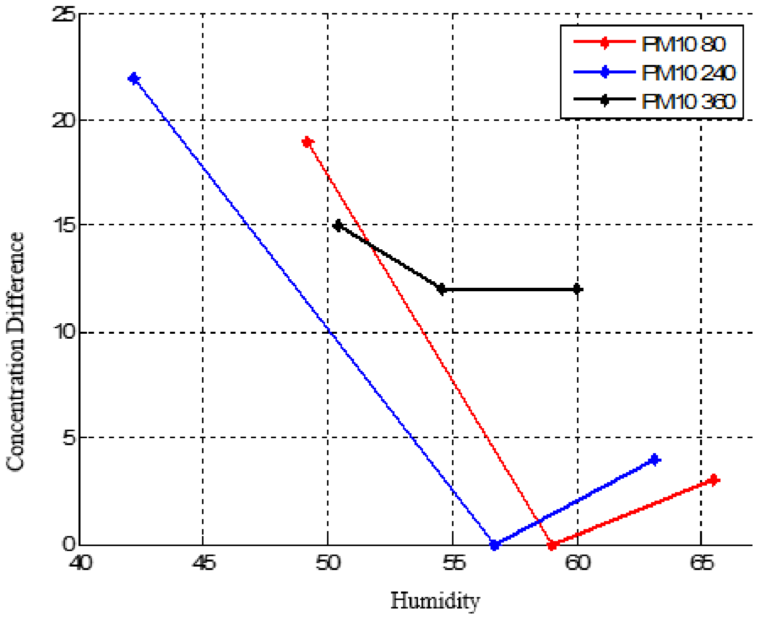

Figure 9. The relationship between the resuspension of silica and the surface roughness, humidity (PM10 measured value)

It can be found from Figure8 and Figure 9 which arethe concentration difference of silica before and after test section with different humidity when the flow rate is 2m/s and the surface roughness is different. It can be found that in the process of increasing humidity, the concentration difference firstly became larger and then smaller. The minimum value appeared in the humidity of 55%-60%. It indicates that the resuspension of particulate matter in the ventilation duct differs at different levels of humidity. And also, it is found that the roughness affects the suspension of particulate matter in the ventilation duct to a certain extent. When the roughness increases, the difference between the concentration differences will also increase.

By comparing Figures 6-9, we can get conclusions that the humidity affects resuspension rate ofboth aluminum oxide and silica and the change trend is almost the same.It shows that the humidity has a significant effect on the resuspension of different particles in the ventilation ducts and the change trend is the same, but the minimum value of the difference in concentration is different for the aluminum oxide and silicon dioxide values. It indicates that humidity has different effects on the resuspension of different particle types. The effect of surface roughness on resuspension of the aluminum oxide and silicon dioxide is different, which shows that the roughness has different effects on resuspension of different particles in the ventilation duct.

V. CONCLUSION

In order to study the influencing factors of particulate matter resuspension in the indoor environment, an experimental research method was used to design a ventilation duct particulate matter suspension experimental platform. Using aluminum oxide and silicon dioxide particles as the research objects, the effects of the resuspension of particles under different flow rates, roughness and humidity were investigated through experimental studies. The experimental results show that the type of particulate matter has little effect on the suspension rate of particulate matter. Of course, in addition to the other particles used in the experiment, further discussion is still needed. The experiment found that at a flow rate of 2m/s, the resuspension rate is the largest. In addition, roughness has an important influence on the resuspension of particulate matter. Therefore, in order to reflect the roughness of actual ventilation ducts, further research should be carried out by reverse engineering or discrete element simulation.

ACKNOWLEDGEMENT

This research was supported by the Fundamental Research Funds for the Central Universities (Grant No. 2017MS150)

REFERENCES

[1]. Krauter P , Biermann A . Reaerosolization of Fluidized Spores in Ventilation Systems[J]. Applied and Environmental Microbiology, 2007, 73(7):2165-2172.

[2]. Wang S , Zhao B , Zhou B , et al. An experimental study on short-time particle resuspension from inner surfaces of straight ventilation ducts[J]. Building & Environment, 2012, 53:119-127.

[3]. Thatcher T L , Layton D W . Deposition, resuspension, and penetration of particles within a residence[J]. Atmospheric Environment, 2014, 29(13):1487-1497.

[4]. Ferro A R , Kopperud R J , Hildemann L M . Source Strengths for Indoor Human Activities that Resuspend Particulate Matter[J]. Environmental Science & Technology, 2004, 38(6):1759-1764.

[5]. JingQian, Ferro A . Resuspension of Dust Particles in a Chamber and Associated Environmental Factors[J]. Aerosol Science and Technology, 2008, 42(7):566-578.

[6]. Tian Y , Sul K , Qian J , et al. A Comparative Study of Walking-induced Dust Resuspension using a Consistent Test Mechanism[J]. Indoor Air, 2014, 24(6):592-603.

[7]. Shaughnessy, R., and Vu, H. Particle Loadings and Resuspension Related to Floor Coverings in a Chamber and in Occupied School Environments [J]. Atmospheric Environment. 2012, 55:515–524.

[8]. Christophe Hery, Jean-Pierre Minier. Progress in Particle Resuspension fromRoughSurfaces by Turbulent Flows[J]. Progress in Energy and Combustion Science.2014,45:1-53.

[9]. Parichehr Salimifard, Donghyun Rim, Carlos Gomes, Paul Kremer, Paul Kremer,James D.Freihaut, Resuspension of biological particles from indoor surfaces: Effectsof humidity and air swirl [J]. Science of the Total Environment, 2017, 583:241-247.

[10]. Corn,M., The adhesion of solid particles to solid surfaces I. A review[J]. Journal of the Air Pollution Control Association, 1961, 11(11):523-528.

[11]. Corn,M., Re-entrainment of particles from a plane surface[J]. American Industrial Hygiene Association Journal, 1965,26(4):325-336.

[12]. Rosati, J.A., Thornburg, J., Rodes, C., Resuspension of particulate matter fromcarpet due to human activity [J]. Aerosol Science and Technology, 2008,42(6):472-482.

[13]. Rabinovich, Y.I., Adler, J.J., Ata, A., Singh, R.K., Moudgil, B.M.,. Adhesionbetween nanoscale rough surfaces I. role of asperity geometry[J]. Journal of Colloid and InterfaceScience. 2000,232:10–16.