EFFECT OF PIPES MATERIALS ON PARTICULATE MATTERS DEPOSITION IN FRESH AIR FILTRATION SYSTEMS
A Case Study

by

Xin ZHANG [a,b*], ***Jingyao MA*** [a], ***Yijie MA*** [a], ***Xingxin NIE*** [a*], ***Hao SUN*** [a], ***Weixi AI*** [a], **and *Zhe WANG*** [a]

[a] School of Resources Engineering, Xi'an University of Architecture and Technology, Xi'an, Shaanxi, China
[b] School of Environmental and Municipal Engineering, Xi'an University of Architecture and Technology, Xi'an, Shaanxi, China

Original scientific paper
https://doi.org/10.2298/TSCI220708183Z

With the widespread popularity of fresh air filtration systems, the pipes materials have become one of the important parameters that affect the overall performances of the fresh air systems. In this paper, an experimental study on the deposition of particulate matters on two commonly used pipes materials (PVC and PE) in the market was tested, and conducted an in-depth analysis of its influencing factors. The results showed that the deposition rates of particulate matters in the PVC pipe increased with the increased of the inlet velocity, and the deposition rate reached the maximum at the velocity was 4.0 m/s. While the deposition rates of particulate matters in the PE pipe were increased first and then decreased with the increased of the inlet velocity, and the deposition rates reached the maximum at the velocity was 3.5 m/s. The PM values deposition rates showed the pipe systems of PE were higher than that of PVC. With the increased of the particle sizes, the tends of deposition rates increased gradually. There were big differences in the deposition rates of particle sizes of less than 1.0 μm, and the largest difference was 0.615 μm, with 8.44%. Therefore, reasonable pipe-line materials should be selected comprehensively according to actual need in the process of pipe-line installation and use. It would provide a useful reference value for the selection of pipe-line materials in the fresh air filtration systems in the post-epidemic era.

Key words: *pipe materials, fresh air systems, particulate matters, deposition*

Introduction

With the increasing of air pollution and the improvement of building air-tightness levels in recent years, indoor air pollution problems have become increasingly prominent [1, 2]. It was not only seriously affected people's normal life, such as bad living conditions and unsatisfactory living feelings [3, 4], but also brought many diseases to people's physical and mental health [5, 6]. Relevant literature had shown that particles of different sizes would enter different parts of the human body and they could cause varying degrees of damage [7], as showed in fig. 1. With the large-scale outbreak of COVID-19 (Corona Virus Disease 2019) in the world [8, 9], the indoor environment has been attracted more attention than ever. Organisms such as bacteria and viruses may be attached to the surfaces of particulate matters, causing more

* Corresponding authors, e-mail: 2601084634@qq.com, niexingxin@126.com

serious harm. Relevant literature showed that people would spend as much as 80% to 90% of time indoor [10]. Therefore, how to build a good, healthy and comfortable indoor environment is extremely more urgent. Among them, good air supply quality in the fresh air systems is even the most important things of all [11].

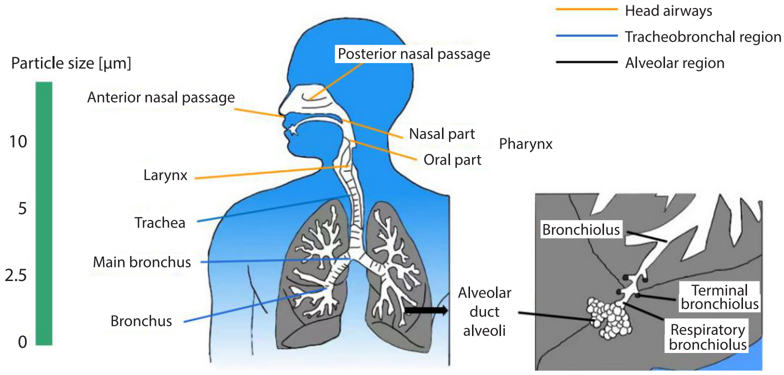

Figure. 1 Particles of different size deposited in the respiratory tract [7]

Fresh air filtration system could be solved the current situation of indoor air pollution effectively, and it has been widely promoted and applied in a large number now [12]. Such as energy conservation technologies for fresh air supply [13], combined application with renewable energy systems [14], novel integrated system with heat recovery combining [15], and the waste heated recovery systems (WHRS) [16]. In addition, many researchers from different countries had also carried out a lot of researches on the connection methods and application of the pipes for the fresh air filtration systems, which were on the pipe-line structure [17, 18], secondary pollution [19], deposition mechanism [20, 21], and the dust loading and microorganisms of HVAC duct systems [22]. However, connection methods of the fresh air pipe were often changed due to the spatial lay-out of the place of using and the actual idea of the users, which had great requirements for the performances of the pipes materials. It must not only meet the requirements of air quality and air volume, but also meet the requirements of construction difficulty and strength. It also can achieve the purpose of simple operation, convenient installation and beautiful appearance [23]. Although some certain achievements had been already obtained. There were few studies on the deposition of particles of pipes of different materials in the current fresh air filtration systems [23]. The main reasons were that the pipes of fresh air filtration systems are relatively less used compared to the traditional air conditioning rectangular galvanized iron pipe-lines, and there are differences in sizes, materials composition, and cross-sections [23], which are difficult to calculate in using.

On the other hand, fresh air filtration systems were popularized in a large area only in recent years. Many researchers worked on improving the filtration performances of filters [24-27], energy consumption of fans [28] and the new air filter materials [29-31]. The default for fresh air pipe-lines deposition was small, which could be ignored. That would lead to the fresh air pipe-lines were selected only relying on experience of the existing designers now, and even change the original design scheme. At present, mainstream fresh air pipes materials on the market are mainly flat pipe PVC materials and corrugated pipe PE materials. However, there are many manufacturers of pipes on the market in China, and the parameters and quality of PVC pipes and PE pipes produced are also uneven. There were also some advantages and disadvantages of the two pipes in actual application. The pipe systems of PVC are mostly in series, and their main advantages are flexible installation, simple operation, and relatively low prices. While the disadvantages are that the air volume is small and uneven, it is easy to produce noise, and may be causing secondary pollution. The pipe systems of PE are mostly parallel structure, their main advantages are large air volume and controllable, and also can be diversified. They can repeatedly clean the inside of the pipes. While the disadvantages are that the construction operation is complicated,and relatively high prices [23]. All of those aforementioned factors have combined to lead to a research on the deposition of particulate matters in pipes of fresh air filtration systems were deeply not enough. With the outbreak of COVID-19 in the World [8, 9], researches on the fresh pipes deposition in fresh air filtration systems will return to hot topics again.

In this paper, two mainstreams used fresh air pipe materials (PVC and PE) in the market were tested for experimental research on the deposition of atmospheric particulates, and conduct an in-depth analysis of relevant factors that affect pipe-line deposition.

Methods

Two existing mainstream fresh air system piping materials (PVC and PE) was selected for experimental research according to the results of the previous market survey [23], as showed in fig. 2. Both of the materials of PVC and PE were all product by the company of 51BLUESKY, China. The velocity ranges from indoor fresh air pipes were 2.0-4.0 m/s. Sizes of PVC flat pipe were 130 mm × 30 mm. Sizes of PE round pipe were 75 mm. The length of them was all 3 m. The pipe connection form without a purifier was selected for testing and research in order to visually compare the influence of pipe material on the deposition of particulate matter. The testing time was from January 18th to 20th, 2019.

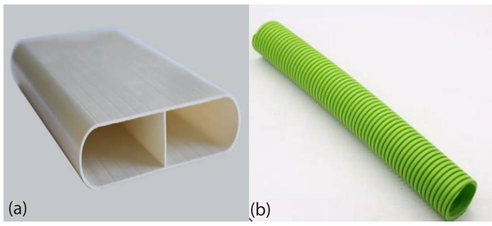

Figure. 2 Pipe materials of the fresh air systems; (a) PVC and (b) PE

The TESTO480 climate measuring instrument was used to measure the temperature and humidity. Measuring range was –100 to +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). The HD37AB1347 indoor air quality monitor was used to measure the velocity. The measuring accuracy range was ± 3%. The GRIMM1.109 portable aerosol particle size spectrometer was used to measure the mass and counting concentration of particles before and after the fresh air pipe-lines. 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%. One end of the pipe was connected with a fan of the same model during the experiment, which was used as the air outlet. While the other end was used as the air inlet. The measuring point was the central position of the pipe-line 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 2 outlets.

Results and discussion

The outdoor atmospheric dust was used as the test dust source to make the experimental data had an engineering significant [32]. The change of outdoor parameters during the test period was shown in tab. 1. The data in this part were from the related network, such as http://www.tianqihoubao.com/aqi/xian.html, http://www.tianqi.com/air/xian.html. The distribution of atmospheric particle sizes of the testing period was showed in fig. 3.

Table 1. The values of various meteorological parameters

Date	Average of AQI	Average of $PM_{2.5}$ [μgm^{-3}]	Average of PM_{10} [μgm^{-3}]	Weather	Wind (grade)	Temperature [ºC]	Humidity [%]
2019/1/18	146	111	161	Cloud	1-2	0-4	39-56%
2019/1/19	114	81	133	Haze	1-2	0-3	32-54%
2019/1/20	84	57	106	Cloud	1-2	3-6	20-29%

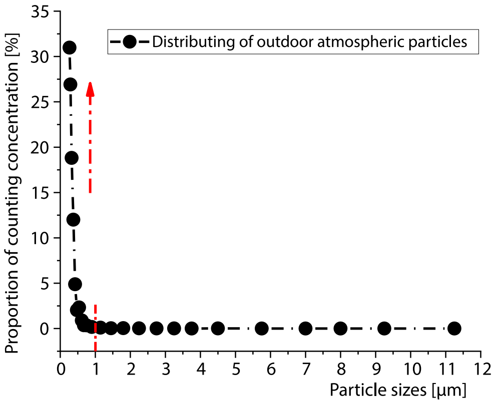

Figure 3. Proportion of counting concentration of outdoor atmospheric particles

The different proportional values of different particle sizes ranges were showed in fig. 3. Such as, 0-0.3 μm accounted for 76.7%, 0.3-0.5 μm accounted for 21.2%, 0.5-1.0 μm accounted for 1.8%, 1.0-2.5 μm accounted for 0.21%, 2.5-5.0 μm accounted for 0.05%, 5.0-10 μm accounted for almost zero.

The particle sizes of 0-2.5 μm accounted for most of the particles below 10 μm in the atmosphere during the tested, which was accounted for 99.9%. The particle sizes of 0-1.0 μm accounted for more than 99.7%. Particles in the atmosphere in Xi'an were mainly small in size, which was easy to enter the human respiratory tract and lungs, it is consistent with the conclusion of the literature [4, 33]. Therefore, it is very necessary to effectively filter and purify the particulate matter in the fresh air system. It is also more important to study the deposition of the fresh air pipe-line, which is beneficial to avoid secondary pollution.

Deposition rate of particulate matters in PVC pipes

The deposition rates of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ were all showed a gradual increasing trend with the continuous increased of the inlet velocity in fig. 4(a). The variation range of PM_{10} was 12.6-18.6%, and the variation range was 6.0%. The variation range of $PM_{2.5}$ was 2.79-10.1%, and the variation range was 7.31%. The variation range of $PM_{1.0}$ was 1.13-4.49%, and the variation range was 3.36%. 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. There were 18.6%, 10.1%, and 4.49%, respectively. This was because the inlet velocity increased, and the effect of turbulence in the tube increased, which would increase the probability of particles by collision with the wall surfaces [23]. As a result of the deposition rates were all increased. The larger the particle size, the more obvious the effect of the change in inlet velocity. The length of the pipe-line would also cause certain errors to the experimental results [34]. The diameter of the pipes was fixed, and the deposition rates of particulates were increased from the pipe length, which verified the correctness of this paper [34].

Figure 4(b) showed the particle sizes increased, the deposition rates of particles at different inlet velocities showed a gradual increase. But some still had a tendency first decrease and then increased, which were mainly among small particles. The higher the inlet velocity, the greater the deposition rates of particle matters at different particle sizes. The deposition rates

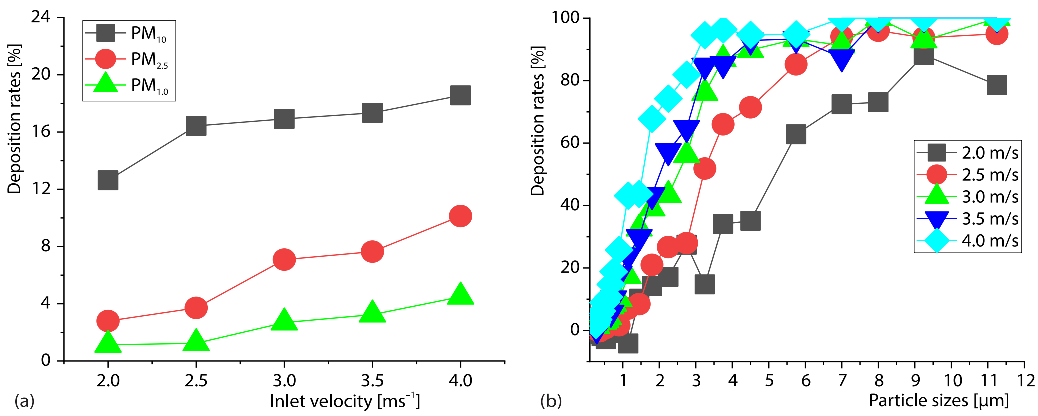

Figure 4. Changes in particulate matter deposition in PVC pipes; (a) deposition rates vary with inlet velocity and (b) deposition rates vary with particle sizes

were small for the particle sizes, which were less than 1.0 μm. At this time, the particles were at the boundary of the diffusion area and the diffusion-collision area, and the diffusion effect played a decisive role in the deposition process of the particle matters [35]. It also affected by the small vortex in the flow field, small-size particles could follow the fluid to move in the direction of the flow well, as a result of the deposition rates were relatively small. With the particle sizes increased, the diffusion effect gradually weakened. The particle matters were at the junction of the inertia-relaxation area and the diffusion-collision area when the particle size was about 3.0 μm. The inertia effect and the diffusion effect were all played a role in the deposition process of the particles at the same time [35]. As the particle sizes continued to increase, the inertial effect played a decisive role, and it led to a gradual increase in the deposition rates of particulate matters.

Deposition rate of particulate matters in PE pipes

The deposition rates of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ all showed a trend of first increased and then decreased with the continuous increased of the inlet velocity in fig. 5(a). The variation range of PM_{10} was 22.0-44.5%, and the variation range was 22.5%. The variation range of $PM_{2.5}$ was 6.80% to 21.2%, and the variation range was 14.4%. The variation range of $PM_{1.0}$ was 4.5% to

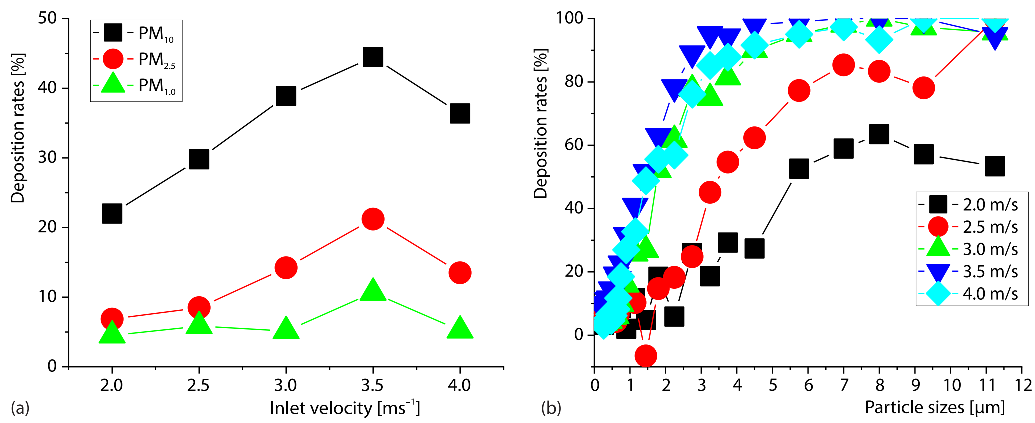

Figure 5. Changes in particulate matter deposition in PE pipes; (a) deposition rates vary with inlet velocity and (b) deposition rates vary with particle sizes

10.6%, and the variation range was 6.1%. The change of $PM_{1.0}$ was the smallest, while the change of PM_{10} was the largest. When the inlet velocity was 3.5 m/s, the deposition rates of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ were reached their maximums. There were 44.5%, 21.2%, and 10.6%, respectively. It could be found that the error obtained with regard to the deposition rates of PM_{10} was relatively large. The reason was that the distribution of aerosol particles in the PE pipe was very randomness, and the spiral structure of the PE pipes itself increased the contact area between the particles and the pipe walls [36]. In addition, it was also related to the local aerosol composition type and the concentration distribution [37]. The particle sizes concentration distribution of particles above 3 μm was relatively unstable, and the combined effect of the previously mentioned factors led to a large particle deposition rates in the PE pipe-lines [35].

With the particle sizes increased, the deposition rates of particles at different inlet velocities in fig. 5(b) had the same trend with fig. 4(b). The overall deposition rates of particulate matters showed a gradually increasing trend. But some still had a tendency first decrease and then increased, which were mainly among small particles. The higher the inlet velocity, the greater the deposition rates of particle matters at different particle sizes. Deposition rates of particle matter under different particle sizes reached the maximum when the inlet velocity was 3.5 m/s. However, the relative deposition rates of particle matters with a particle size of less than 1 μm were much higher. The main reasons were that the particles were between at the diffusion area and the diffusion-collision area at that time. The diffusion effect played a decisive role [35]. But PE pipes were mostly corrugated, and it could enlarge the Brownian motion space of particles. As a result, the deposition rates under Brownian motion were slightly increased, but it was still relatively small. With the particle sizes increased, the diffusion effect was weakened. The particulate matters were between the inertia-relaxation area and the diffusion-collision area. The inertia effect and the diffusion effect were all played a role at the same time, and the deposition rates gradually increased. Particle sizes continued to increase, and the inertial effect played a decisive role. The results were the same with that of PVC.

Deposition rates of PM under different pipe materials

The differences in the deposition rates of particulate matters between these two fresh air pipes materials were selected for a study, and the maximum deposition rates were taken into compared, which the inlet velocity was used 4.0 m/s in PVC pipe and 3.5 m/s in PE pipe, and the results were shown in fig. 6.

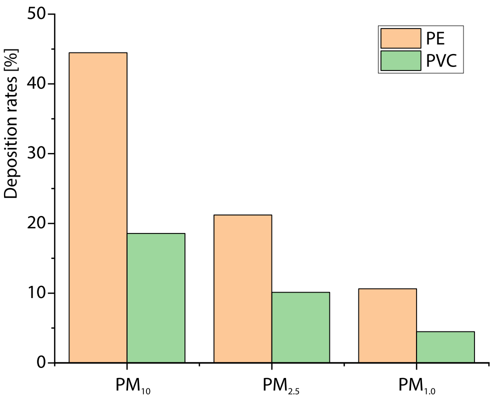

Figure 6. Comparison of PM deposition rate of different pipes materials

The deposition rates of different PM value of the two fresh air pipe materials were quite different in fig. 6. The deposition rate showed $PM_{10} > PM_{2.5} > PM_{1.0}$. The deposition rates of PM_{10}, $PM_{2.5}$, $PM_{1.0}$ in PE pipes were higher than that of in PVC pipes, and there was 25.9%, 11.1%, 6.1%, respectively. The largest change of the deposition rate was PM_{10}, while the smallest change of the deposition rate was $PM_{1.0}$. The main reasons were that PE pipes were mostly corrugated, with a certain recessed structure inside, which would make the particle matters easy to deposit in it. In addition, it was also related to the material properties of PE pipes [36]. From the figure that the deposition rates of pipes particles were large that was because the size of the fresh air pipes was small. Under the same inlet velocity conditions, the relative area in contact with the air-flow were larger, which would increase the contact between the pipes particles and the probability of wall, as a result it in turn produced a greater deposition rate of pipes materials. However, fine dust particles would also condense in the actual ventilation pipes [38]. It might result in a substantial increase in the amount of deposition in the ventilation pipes.

Deposition rates of different particle size under different pipe materials.

Similarly, the inlet velocity was used 4.0 m/s in PVC pipe and 3.5 m/s in PE pipe to comparative analysis, and the results were shown in fig. 7.

With the particle size increases, the deposition rates of the two types of pipes both showed a gradually increasing trend in fig. 7. The deposition rates of PE pipes were higher than that of PVC pipes. For particles less than 1.0 μm, the two types of pipe-lines were quite different. The deposition rates ranges of PE pipe-lines were from 7.7-31.6%, while the deposition rates ranges of PVC pipe-lines were from 1.8% to 25.8%. The deposition rates ranges of PE pipe-lines were 3.04-8.44% higher than that of PVC pipes. The differences in the deposition rates of the two types of pipes materials reached the maximum at the particle size was 0.615 μm, which was 8.44%. This was because the PE pipes were mostly corrugated, which increased the Brownian motion space of particles and also increased the deposition rated of particles. With the particle size increased, the deposition rates of PE pipes were not much different from that of PVC pipes. This was because the particle size increased, the diffusion effect decreased and the inertial effect of the particles increased, which would lead to the deposition rates of particles gradually increases. It was consistent with the conclusion of the literature [35].

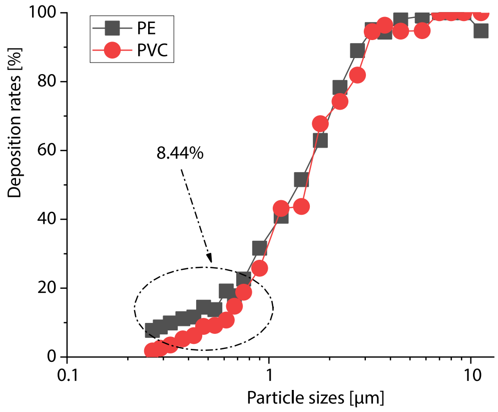

Figure 7. Deposition rates of different pipes with different particle sizes

However, the different connection lengths, soft connection, use of pipe elbows and the direction of the pipe-line, they would all have varied degrees of impact on the pipe-line deposition in the actual installation and use of the pipe-line [23]. But this was slightly different from the results of the author to test the deposition rates of small particles of longer PVC pipe-lines [23]. The main reasons were that the length of the pipe-line would affect the capture of small particles [34], as a result, there were certain differences with that. In addition, the particle deposition rates of the pipe-lines were also related to the type of aerosol composition and concentration distribution in the test area [37, 38]. Therefore, the selection of the material of the fresh air pipes was based on comprehensive factors in using. Air filters fibers were added to the front of the fresh air filtration systems, which could effectively block the deposition of particles in the pipe-lines, and it reduced the frequency of pipe-line cleaning and the quality of air supply [39-41].

Conclusion

The depositions of particulate matters on two pipes materials (PVC and PE) in the fresh air filtration systems were given in this paper. The deposition rates of particulate matters in the PVC pipe increased with the increase of the inlet velocity. The deposition rates of PM_{10},

$PM_{2.5}$, and $PM_{1.0}$ were reached maximums at the inlet velocity was 4.0 m/s. While the deposition rates of particulate matters in the PE pipe first increased and then decreased with the increase of the inlet velocity. The deposition rates of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ were reached maximums at the inlet velocity was 3.5 m/s. The higher the inlet velocity, the greater the deposition rates of particle matters at different particle sizes. The deposition rates of PE pipes were higher than that of PVC pipes under the same conditions. For particles less than 1.0 μm, the two types of pipe-lines were quite different, and the largest difference was 0.615 μm, with 8.44%.

However, the different connection lengths, soft connection, use of pipe elbows and the direction of the pipe-line, they would all have varied degrees of impact on the pipe-line deposition in the actual installation and use of the pipe-line. Therefore, reasonable pipe-line materials should be selected comprehensively according to actual need in the process of pipe-line installation and use. It would provide a useful reference value for the selection of pipe-line materials in the fresh air filtration systems.

Acknowledgment

The work was supported by the National Key R and D Program of China (No. 2016YFC0700503) and the Special Research Project of Educational Commission of Shaanxi Province of China (No. 17JK0467).

References

[1] Pozzer, A., *et al*., Long-Term Concentrations of Fine Particulate Matter and Impact on Human Health in Verona, Italy, *Atmospheric Pollution Research*, *10* (2019), 3, pp. 731-738
[2] Cakmak, S., *et al*., Metal Composition of Fine Particulate Air Pollution and Acute Changes in Cardiorespiratory Physiology, *Environmental Pollution*, *189* (2014), June, pp. 208-214
[3] Fan, X. X., *et al.*, More Obvious Air Pollution Impacts on Variations in Bacteria Than Fungi and Their co-Occurrences with Ammonia-Oxidizing Microorganisms in PM2.5, *Environmental Pollution*, *251* (2019), Aug., pp. 668-680
[4] Zhang, X., *et al*., Vertical Distribution Characteristics of Outdoor Particles Concentrations in High-Rise Buildings, *Polish Journal of Environmental Studies*, *30* (2021), 2, pp. 1913-1922
[5] Filonchyk, M., *et al*., Temporal and Spatial Variation of Particulate Matter and Its Correlation with Other Criteria of Air Pollutants in Lanzhou, China, in Spring-Summer Periods, *Atmospheric Pollution Research*, *9* (2018), 6, pp. 1100-1110
[6] Chen, Q., *et al.*, Seasonally Varied Cytotoxicity of Organic Components in PM2.5 from Urban and Industrial Areas of a Chinese megacity, *Chemosphere*, *230* (2019), Sept., pp. 424-431
[7] Hu, Y. J., Environmental Behavior and Human Inhalation Exposure of Particles and Typical Organic Contaminants in Indoor and Outdoor Air (in Chinese), Ph. D. thesis, University of Chinese Academy of Sciences, Guangzhou, China, 2018
[8] Shereen, M. A., *et al*., The COVID-19 Infection: Emergence, Transmission, and Characteristics of Human coronaviruses, *Journal of Advanced Research*, *24* (2020), July, pp. 91-98
[9] Xu, C. W., *et al*., The 2019-nCoV Epidemic Control Strategies and Future Challenges of Building Healthy Smart Cities, *Indoor and Built Environment*, *29* (2020), 5, pp. 639-644
[10] Deng, L. J., Deng, Q. H., The Basic Roles of Indoor Plants in Human Health and Comfort, *Environmental Science and Pollution Research*, *25* (2018), Nov., pp. 36087-36101
[11] Zhang, X., *et al*., Research on Outdoor Design PM2.5 Concentration for Fresh Air Filtration Systems Based on Mathematical Inductions, *Journal of Building Engineering*, *34* (2021), 101883
[12] Zacharias, N., *et al*., Air Filtration as a Tool for the Reduction of Viral Aerosols, *Science of The Total Environment*, *772* (2021), 10, 144956
[13] Zhong, B., *et al*., Review of Energy Conservation Technologies for Fresh Air Supply in Zero Energy Buildings, *Applied Thermal Engineering*, *148* (2019), Feb., pp. 544-556
[14] Greco, A., *et al*., A Review on Geothermal Renewable Energy Systems for Eco-Friendly Air-Conditioning, *Energies*, *15* (2022), 5519
[15] Liu, S. L., *et al*., Experimental Study of Ventilation System with Heat Recovery Integrated by Pump-Driven Loop Heat Pipe and Heat Pump, *Journal of Building Engineering*, *52* (2022), 104404

[16] Abdelkareem, M. A., *et al.*, Heat Pipe-Based Waste Heat Recovery Systems: Background and Applications, *Thermal Science and Engineering Progress*, *29* (2022), 101221
[17] Wang, S., *et al.*, An Experimental Study on Short-time Particle Resuspension from Inner Surfaces of Straight Ventilation Ducts, *Building and Environment*, *53* (2012), July, pp. 119-127
[18] Lu, H., *et al.*, Numerical Study of Monodispersed Particle Deposition Rates in Variable-Section Ducts with Different Expanding or Contracting Ratios, *Applied Thermal Engineering*, *110* (2017), 5, pp. 150-161
[19] Zhao, B., Wu, J., Modelling Particle Deposition from Fully Developed Turbulent Flow in Ventilation Duct, *Atmospheric Environment*, *40* (2006), 3, pp. 457-466
[20] Zhu, Y. Y., *et al.*, A Particle Resuspension Model in Ventilation Ducts, *Aerosol Science and Technology*, *46* (2012), 2, pp. 222-235
[21] Majlesara, M., *et al.*, A Model for Particles Deposition in Turbulent Inclined Channels, *Journal of Aerosol Science*, *64* (2013), Oct., pp. 37-47
[22] Liu, Z. J., *et al.*, Investigation of Dust Loading and Culturable Microorganisms of HVAC Systems in 24 Office Buildings in Beijing, *Applied Thermal Energy and Buildings*, *103* (2015), Sept., pp. 166-174
[23] Zhang, X., *et al.*, Experimental Study on Particle Deposition in Pipe-Lines in a Fresh Air System, *Thermal Science*, *25* (2021), 3B, pp. 2319-2325
[24] Tang, M., *et al.*, Filtration Efficiency and Loading Characteristics of PM2.5 through Commercial Electret Filter Media, *Separation and Purification Technology*, *195* (2018), Apr., pp. 101-109
[25] Zhu, S., *et al.*, Triboelectric Effect of Polytetrafluoroethylene Fibers to Improve the Filtration Performance of Air-Purified Materials, *Journal of Engineered Fibers and Fabrics*, *13* (2018), 1, pp. 60-71
[26] Zhang, X., *et al.*, Influence of Fiber Diameter on Filtration Performance of Polyester Fibers, *Thermal Science*, *23* (2019), 4, pp. 2291-2296
[27] Wu, Z. T.,. *et al.*, Attributable Risk and Economic Cost of Hospital Admissions for Mental Disorders Due to PM2.5 in Beijing, *Science of The Total Environment*, *718* (2020), 137274
[28] Zhong, X. Y., *et al.*, Assessing the Energy and Indoor-PM2.5-Exposure Impacts of Control Strategies for Residential Energy Recovery Ventilators, *Journal of Building Engineering*, *29* (2020), 101137
[29] Singh, V. K., *et al.*, Transparent Nanofibrous Mesh Self-Assembled from Molecular LEGO for High Efficiency Air Filtration with New Functionalities, *Small*, *13* (2017), 6, 1601924
[30] Yang, S., *et al.*, Carbon Nanotubes/Activated Carbon Fiber Based Air Filter Media for Simultaneous Removal of Particulate Matter and Ozone, *Building and Environment*, *125* (2017), Nov., pp. 60-66
[31] Tang, X. L., *et al.*, Introduction of Amino and rGO into PP Non-Woven Surface for Removal of Gaseous Aromatic Pollutants and Particulate Matter from Air, *Applied Surface Science*, *511* (2020), 145631
[32] Tang, X. L., *et al.*, Introduction of Amino and rGO into PP Non-Woven Surface for Removal of Gaseous Aromatic Pollutants and Particulate Matter from Air, *Applied Surface Science*, *511* (2020), 145631
[33] Gu, X. Y., *et al.*, Effects of PM2.5 Exposure on the Notch Signaling Pathway and Immune Imbalance in Chronic Obstructive Pulmonary Disease, Environmental Pollution, *226* (2017), July, pp. 163-173
[34] Zhu, L Y., *et al.*, Study on Sedimentation Movement of Fine Particles in Pipe-Lines of Different Sizes, (in Chinese), *Nuclear Science and Engineering*, *39* (2019), 5, pp. 695-700
[35] Li, W., Turbulent Deposition Rule of Fine Dust in Ventilation Ducts, (in Chinese), *China Powder Science and Technology*, *20* (2014), 2, pp. 56-60
[36] Luo, M., *et al.*, Effect of Temperature on Tensile Properties of Reinforced Thermoplastic Pipes, *Composite Structures*, *241* (2020), 112119
[37] Galindo, N., *et al.*, The PM Events and Changes in the Chemical Composition of Urban Aerosols: A Case Study in the Western Mediterranean, *Chemosphere*, *244* (2020), 125520
[38] Xu, J. C., *et al.*, Heterogeneous Condensation for Electric Arc Furnaces Fine Particles Removal, *Powder Technology*, *374* (2020), Sept., pp. 323-329
[39] Tian, E. Z., *et al.*, Electrostatic Air Filtration by Multifunctional Dielectric Heterocaking Filters with Ultralow Pressure Drop, *ACS Applied Materials and Interfaces*, *12* (2020), 26, pp. 29383-29392
[40] Bian, Y., *et al.*, Influence of Fiber Diameter, Filter Thickness, and Packing Density on PM2.5 Removal Efficiency of Electrospun Nanofiber Air Filters for Indoor Applications, *Building and Environment*, *170* (2020), 106628
[41] Zhang, X., *et al.*, Experimental Study on the Structure and Properties of Modified Non-Woven Filter Fibers by Impregnation with Carbon Black, *Journal of Engineered Fibers and Fabrics*, *15* (2020), 1, pp. 1-7

Paper submitted: July 8, 2022
Paper revised: November 4, 2022
Paper accepted: November 14, 2022