Influence of the purification system of machining factories on indoor air quality

Yukun Wang*, Zhengwei* Long[*]*, Xiong* Shen

Tianjin Key Laboratory of Indoor Air Environmental Quality Control, School of Environmental Science and Engineering, Tianjin University, Tianjin 300072, China

Abstract. High-concentration oil mists from machining plant equipment can cause serious health problems for workers. The concentration of oil mist is generally reduced by ventilation and purification systems. However, the coupling relationship and interaction between purification and ventilation systems are not well understood. This study is based on an actual machining factory. First, the CFD simulation method was validated by the experimental data. Secondly, the influence of purifier exhaust air and exhaust air direction on oil mist distribution was studied. The results show that the influence of purifier exhaust air cannot be ignored in the prediction of oil mist concentration distribution. The difference in oil mist concentration and oil mist removal efficiency was 24% and 20%, respectively, with and without the purifier exhaust. Compared with the vertical exhaust direction of the purifier, the purifier with horizontal exhaust has fewer areas with higher oil mist concentrations. However, for the oil mist concentration at 1.5 m above the floor, the vertical exhaust air of the purifier is 0.1 mg/m^3 lower than the horizontal exhaust air, and the removal efficiency is increased by 6.9%

1 Introduction

Metalworking fluids (MWFs) are used frequently to cool and lubricate workpieces in turning, cutting, or other metal machining processes. During machining, MWFs generate oil mist because of impaction, centrifugation and evaporation/condensation [1-3]. The OSHA (U.S. Occupational Safety and Health Administration) Metalworking Fluids Standards Advisory Committee recommended an eight-hour time-weighted average permissible exposure limit (PEL) of 0.4 mg/m^3 thoracic particulate (0.5 mg/m^3 total particulate) [4]. And long-term exposure to the high concentration of oil mist may cause asthma, laryngeal cancer, bronchial hyper-responsiveness, and lung cancer or other diseases [5-8]. Therefore, it is necessary to study the oil mist concentration distribution in machining factories.

To reduce the concentration of contaminants in factories, two types of ventilation systems are commonly used in the factory: mixing ventilation and displacement ventilation [9]. For factories with high-intensity contaminant emission sources, local exhaust and local purification are also used [10-11]. Previous studies found that electrostatic methods capture of oil mist is very efficient [12-14]. Therefore, electrostatic precipitators are widely used to control oil mist concentration in machining plants. For electrostatic precipitators used in machining plants, the maximum air volume is more than 3000 m^3/h. And many purifiers are usually placed close to the equipment to reduce the emission intensity of pollution sources. So, the purification of air exhaust should not be ignored and it may also have a great impact on the distribution of oil mist concentration distribution and thermal comfort in the machining plant.

Therefore, this paper researched the influence of the purification system on the oil mist concentration distribution in machining plants. And the results can provide a reference for the design of ventilation and purification system in factories.

2 Case description

This study was based on an actual machining factory. Fig. 1 is the schematic of the machining plant with dimensions of 206 m long, 90 m wide, and 8 m high. The factory had three types of ventilation systems shown in Fig. 2: roof exhausts system, displacement ventilation system and air recirculation system. And it contained several production lines. The manufacturing processes in this factory involved cutting, grinding and quenching, which produced a different concentration of oil mist.

The oil mist purifier is used to reduce the concentration of oil mist in the machining plant. And the purifier is directly connected to the equipment. After investigation, it was found that two kinds of air outlet forms of purifier were frequently-used. It was shown in Fig. 3, that the air exhaust orientation is vertical and horizontal respectively. Therefore, the influence of two kinds of air outlets on oil mist concentration distribution

---

[*] Corresponding author: longzw@tju.edu.cn

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).

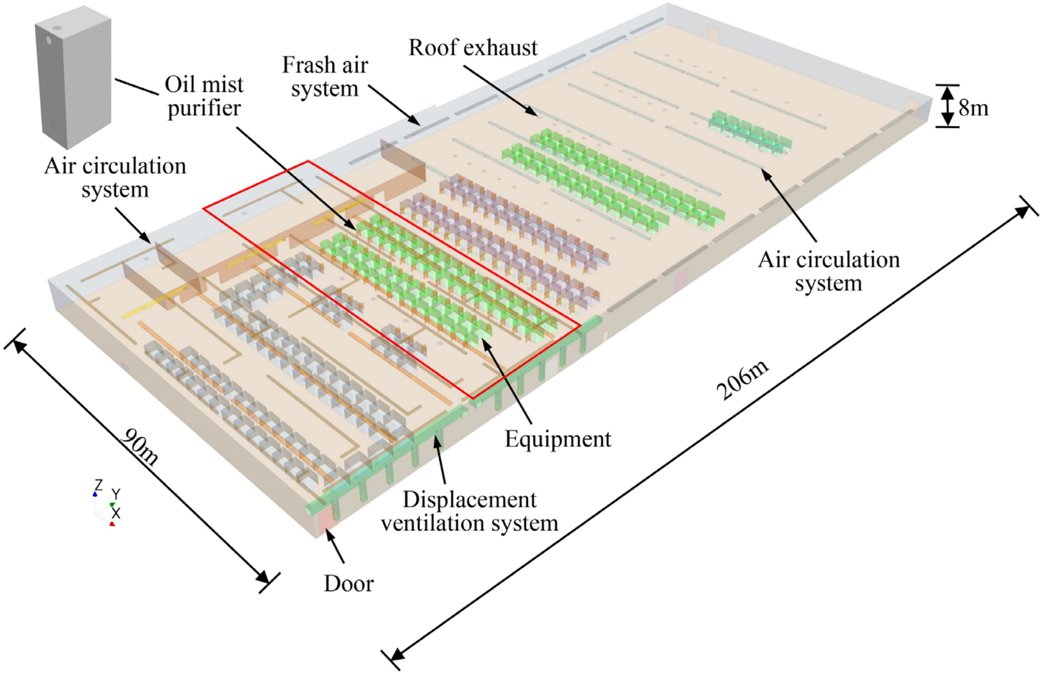


Fig. 1. Sketch of the machining factory, where red lines indicate the region investigated in this study

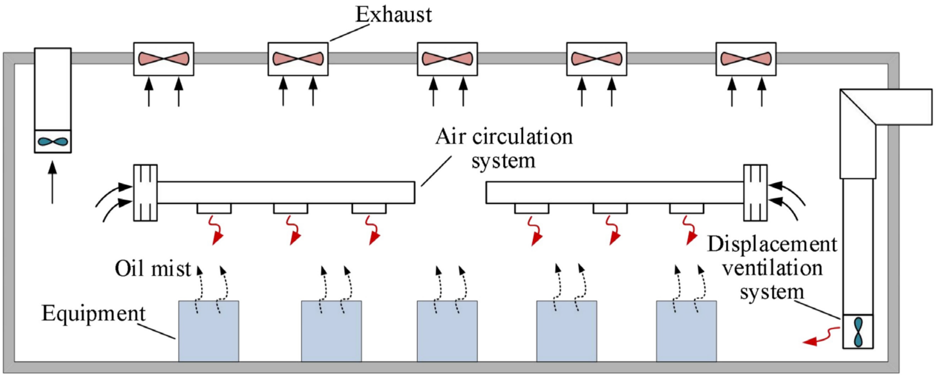
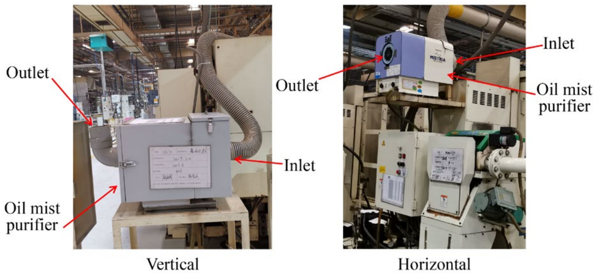


Fig. 2. Sketch of the main ventilation system in the factory.

was researched. And the purification air volume was set to 1000 m^3/h. the electrostatic precipitators have high purification efficiency, so the oil mist concentration of the exhaust air from the oil mist purifier was set to 0.

Previous research had found that the combination of roof exhaust and displacement ventilation systems can greatly improve air quality and maintain thermal comfort at acceptable levels in this factory [15]. And the research in this paper was also carried out under this condition.



Vertical

Horizontal

Fig. 3. Typical air outlet form of purifier in machining plant

3 Methods

CFD method has been used in a great number of studies of indoor environments in factories and the results show that this method can predict indoor environments quickly and inexpensively. However, the CFD method needs to be verified by experimental data.

3.1 CFD models

To simulate and predict the turbulent airflow in the factory, this investigation used CFD methods based on the Reynolds-average Navier Stokes equations whit the Realizable k-ε two-layer turbulence model. This model can be applied accurately to wall-function type meshes of y$^+$ greater than 30. And the general form of the governing equations can be written as:

$$\frac{\partial}{\partial t}(\rho\phi)+div(\rho u\phi)=div\left(\Gamma_\phi grad\phi\right)+S_\phi \qquad (1)$$

where ρ is the fluid density; u_i is the velocity of the fluid in all directions; ϕ is a specific variable, which can be velocity, temperature, concentration, etc.; Γ_ϕ is the diffusion coefficient; and S_ϕ is the source term of the general equation.

For oil mist transport in machining plants, the influence of the oil mist on turbulent flow is negligible because of the low concentration of oil mist. Previous studies have shown that both the Eulerian and Lagrangian methods predict the oil mist concentration with reasonable accuracy [16]. And the Eulerian method was used in this study because of the lower computing cost.

The Eulerian method can be written as:

$$\frac{\partial C_p}{\partial t} + \nabla\left(C_p\vec{u}_m\right) = -\nabla\left(C_p\vec{v}_{dr,p}\right) \tag{2}$$

where C_p is particle concentration, $\vec{u}_m$ is the mass-averaged velocity, $\vec{v}_{dr,p}$ is the drift velocity for the particle phase, and the $\vec{u}_m$ is defined as:

$$\vec{u}_m = \alpha_p\rho_p\vec{u}_p + \alpha_a\rho_a\vec{u}_a/\rho_m \tag{3}$$

Where α_p is the volume fraction of particles, α_a is the volume fraction of air, ρ_p is particle density, ρ_a is the air density, ρ_m is mixture density, $\vec{u}_p$ is particle velocity, $\vec{u}_a$ is air velocity. And $\vec{v}_{dr,p}$ is defined as:

$$\vec{v}_{dr,p} = \vec{u}_p - \vec{u}_m \tag{4}$$

To evaluate the performance of the ventilation and purification coupling system, the contaminant removal effectiveness η was used, which is defined as:

$$\eta = \frac{C_e - C_s}{C - C_s} \tag{5}$$

Where C_e is the contaminant concentration in the exhaust, C is the mean contaminant concentration at 1.5 m above the floor, C_s is the contaminant concentration in the supply air.

3.2 Validation of the CFD model

To validate the CFD model, this study performed CFD simulations with the measured thermo-fluid boundary conditions. And the simulated air velocity, temperature and oil mist concentration were compared with the measured data at several locations in a machining plant. The measured thermos-fluid boundary condition and the locations selected for measuring the velocity, temperature and oil mist concentration were shown in previous studies [15].

Fig. 4 compares the simulated air velocity, air temperature and oil mist concentration. The results demonstrate that the model can predict the indoor environment with high accuracy. And the Realizable k-ε two-layer turbulence model can be used in the indoor environment prediction of machining plants.

4 Results and discussion

4.1 The influence of purifier air exhaust on the oil mist concentration

Fig. 5 depicts the oil mist concentration distribution at 1.5 m above the floor. Compared Fig. 5 (a) with (b), the oil mist concentration in the breathing zone considering the purifier exhaust was lower than the oil mist concentration without considering the purifier exhaust. The mean oil mist concentration was 0.78 mg/m^3 and 1.03 mg/m^3. And removal effectiveness of the two conditions was 66.2% and 53.0%. As shown in fig. 6, the purifier air exhaust significantly reduced the concentration of oil mist in the working area and spread more oil mist near the roof. Therefore, the purifier exhaust could not be ignored in the calculation of oil mist concentration distribution.

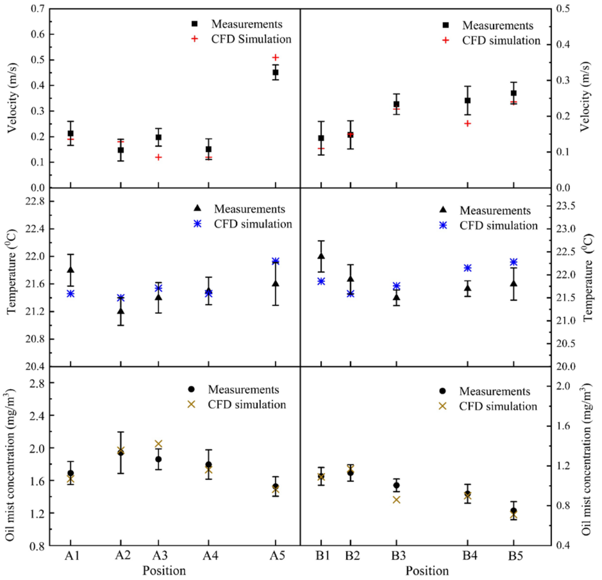
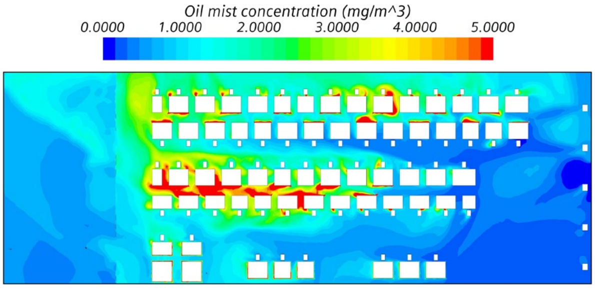
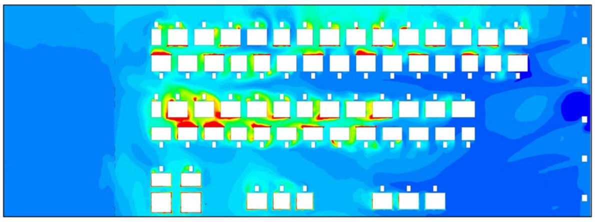


Fig 4 Comparison of the simulated air velocity, temperature and oil mist concentration with the experimental data

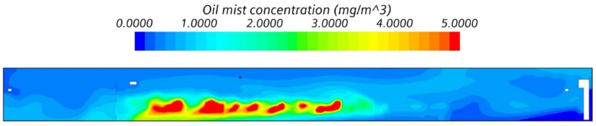


(a) Without purifier air exhaust

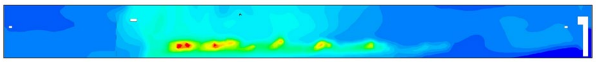


(b) With purifier air exhaust

Fig. 5. Oil mist concentration at 1.5 m above the floor



(a) Without purifier air exhaust



(b) With purifier air exhaust

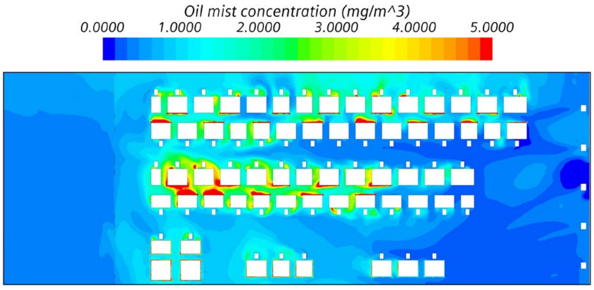
Fig. 6. Oil mist concentration on the middle vertical plane in the working region.

4.2 Purifier exhaust direction of vertical and horizontal

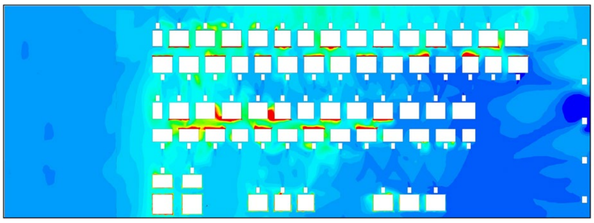
Compared to Fig. 7 (a) with (b), the area of “red” concentration in the breathing zone with horizontal purifier air exhaust was smaller. This was mainly because the horizontal exhaust of the purifier promoted the diffusion of oil mist in the horizontal direction. But the mean oil mist concentration of vertical exhaust and horizontal exhaust was 0.78 mg/m^3 and 0.88 mg/m^3. The removal effectiveness was 66.2% and 59.3%.

As Fig. 8 shows, the oil mist concentration near the roof with vertical exhaust was higher than that with horizontal exhaust. The ventilation system in this study was: a combination of roof exhaust and displacement ventilation systems. Therefore, higher oil mist concentration near the roof represented more efficient pollutant removal.

In conclusion, horizontal exhaust only reduced the areas with high oil mist concentration, and the removal effect was lower than that of vertical exhaust.

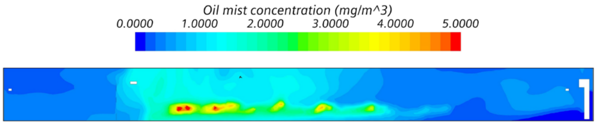


(a) Vertical purifier air exhaust

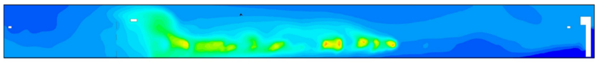


(b) Horizontal purifier air exhaust

Fig. 7. Oil mist concentration distribution at 1.5 m above the floor



(a) Vertical purifier air exhaust



(b) Horizontal purifier air exhaust

Fig. 8. Oil mist concentration on the middle vertical plane in the working region.

5 Conclusion

This investigation is based on an actual machining factory. Firstly, the CFD simulation method was verified by experimental data based. Secondly, the influence of purifier air exhaust and the exhaust direction on the distribution of oil mist was studied. The following conclusion can be drawn:

(1) The purifier exhaust could not be ignored in the calculation of oil mist concentration distribution. The difference in oil mist concentration and removal effectiveness is 24% and 20%, respectively, with and without purifier air exhaust.

(2) Compared with the vertical exhaust direction of the purifier, the purifier with horizontal exhaust has fewer areas with higher oil mist concentrations. However, for the oil mist concentration at 1.5 m above the floor, the vertical exhaust air of the purifier is 0.1 mg/m3 lower than the horizontal exhaust air, and the removal efficiency is increased by 6.9%

Acknowledgment

This work was supported by National Natural Science Foundation of China (Grant No.51878442)

References

1. Y. Yue, J. W. Sutherland, W. W. Olson, Proc. of the Symp. on Design for Manufacturing and Assembly. **89**, 37-46 (1996)
2. J. Thornburg, D. Leith, Appl. Occup. Environ. Hyg., **15(8)**, 618-628 (2000)
3. J. Thornburg, D. Leith, M. J. Tribol., **122(3)**, 544-549 (2000)
4. OSHA, Metalworking fluids: safety and health best practices manual, 1999
5. J.K. Wendt, E. Symanski, T.H. Stock, W. Chan, and X.L. Du, Environ. Res. **131**, 50–58 (2014)
6. G. Buonanno, L. Morawska, L. Stabile, J. Aerosol Sci. **42**: 295–304. (2011)
7. Y. Yang, Z. Ruan, X. Wang, Y. Yang, T.G. Mason, H. Lin, L. Tian, Environ. Pollut. **247**, 874–882 (2019)
8. R. Tong, M. Cheng, X. Yang, Y. Yang, M. Shi, Process Saf. Environ. Prot. **128**, 184–192 (2019).
9. G. Cao, H. Awbi, R. Yao, Y. Fan, K. Siren, R. Kosonen, J.J. Zhang, Build. Environ. **73**, 171–186 (2014)
10. R. Mead-Hunter, A.J. King, B.J. Mullins, Separ. Purif. Technol. **133**, 484–506 (2014)
11. J. Goldfield, Heating/Piping/Air Cond. **57 (2)**, 47–51 (1985)
12. Z. Feng, W. Pan, H. Zhang, X. Cheng, Z. Long, J. Mo, Powder Technol. **327**, 201-214 (2018)
13. S. Li, S. Zhang, W. Pan, Z. Long, T. Yu, Powder Technol. **356**, 1-10 (2019)
14. Z. Long, Q. Yao, Powder Technol. **215**, 26-37 (2012)
15. J. Zhang, Z. Long, W. Liu, Q. Chen,. Aerosol Air Qual. Res. **16(2)**, 442-452 (2016)
16. G. Wei, B. Chen, D. Lai, Q. Chen, Atmos. Environ. **228**, 117419 (2020).