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AN INVESTIGATION ON EXPOSURE TO PARTICULATE MATTER IN SUBWAY STATION

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ABSTRACT

In recent years, the subway system has experienced rapid development all over the world. However, the air quality in the station has attracted more public attention. This paper concentrates on the variation of the $PM_{2.5}$ and PM_{10} concentrations on platforms in the entire operation periods of the train. The train frequency and piston wind are considered to investigate the influence of passing trains number, the train arrival and departure on the $PM_{2.5}$ and PM_{10} concentrations on the platforms. The results show that the diurnal average concentrations of $PM_{2.5}$ and PM_{10} on platforms are 81 and 147 μg/m^3, respectively. The maximum concentrations of $PM_{2.5}$ and PM_{10} (104 and 173 μg/m^3, respectively) occur in the morning rush hours, when the number of passing trains is the largest. The piston wind can push the polluted air in the tunnel into the platform and increase the PM concentrations on platforms. Moreover, passengers walking can also cause the suddenly sharp increase of $PM_{2.5}$ and PM_{10} concentrations when the train stops at the station. It can be deduced that reasonable ventilation strategy and efficient air filtration system are necessary to be studied in the further research for the improvement of air quality and energy saving of the ventilation and air-conditioning system in subway stations.

Keywords: subway station; air quality; particulate concentration; ventilation and air-conditioning system

1. INTRODUCTION

Subway system has been considered as the most popular mode of transportation due to its high capacity, reduced traffic congestion and distinct security in many metropolises around the world. Based on the latest report from China Association of Metros, 33 cities in China have opened the subway system with the operation length of 4354.3 km by the end of 2018, which accounts for 75.6 % of the total operation length in the urban rail transit [1]. As most subway lines are built underground, subway system is characterized by many advantages, such as saving ground space, saving energy and efficient transit.

Despite the significant advantages, however, subway system suffers from the air quality problems, particularly in underground subway stations. In particular, the exposure to particulate matter (PM) has seriously threatened the human health because of the enclosure space and restricted ventilation. Numerous studies have reported the increasing PM levels in underground subway systems. Kwon et al. conducted a long-term monitoring of the PM_{10} concentration in six subway transfer stations for two years in Seoul, and concluded that the average PM_{10} concentrations on platforms were two or three times higher than outdoor concentration [2]. Bao et al. obtained similar conclusions in Shanghai, indicating that the average $PM_{2.5}$ and PM_{10} concentrations (352 and 457 μg/m^3 respectively) on platforms were 3 times higher than those monitored at the outdoor level [3]. Some studies have observed that the high exposure levels of PM are strongly associated with respiratory diseases and even increased the risk of lung cancer. Li et al. conducted an intranasal sensitization model and demonstrated that long-term exposure to PM could easily lead to pulmonary injury [4]. Epidemiological studies pointed out that inhalable particles could seriously damage human lung function and significantly increased the risk of lung cancer [5]. However, current researches mainly focus on the influence of external environment factors on indoor PM concentrations in underground subway stations [6-7]. Studies on the influence of train operation and piston effect on platform PM concentrations in underground subway stations are still limited.

In this paper, field measurements of $PM_{2.5}$ and PM_{10} concentrations on platforms are conducted in the winter of 2018, for the purpose of investigating the variation of $PM_{2.5}$ and PM_{10} concentrations on platforms. Train frequency is taken into account to analyze the hourly variations of $PM_{2.5}$ and PM_{10} concentrations on platforms during train operations. The transient variations of $PM_{2.5}$ and PM_{10} concentrations on platforms during the train arrival and departure are discussed. This study can provide the basic data for the improvement of air quality in subway stations.

2. MEASUREMENT CAMPAIGN

2.1 The selected subway station

The monitoring of PM concentrations is carried out in one underground subway station in Tianjin with the characteristics of side platforms. This station has been in operation since 2006. The depths of concourse and platform below the ground surface are 3 m and 9 m, respectively. Half-high platform bailout doors (HPBDs) are stalled at both sides of the tunnel which allow piston wind to enter the separated platforms. The photo of the HPBDs is shown in Fig. 1.

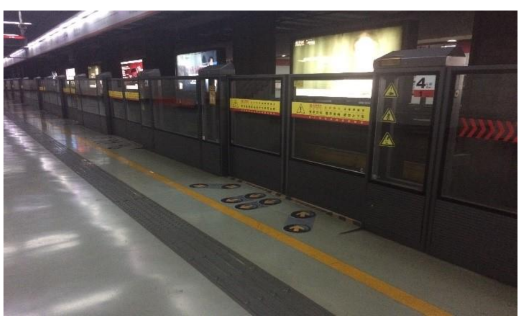

Fig 1 The photo of HPBDs

2.2 Monitoring method

The $PM_{2.5}$ and PM_{10} concentrations on platforms are continuously monitored from 6:00 am to 23:00 pm using the portable DUSTTRAK II aerosol monitor (Model 8532, TSI, USA). This instrument is a handheld battery-powered light scattering photometer, which can provide users with a large number of real-time PM concentrations. The monitoring periods can be divided into three parts: morning rush hours (7:00 am-9:00 am), normal-operation hours (6:00 am-7:00 am, 9:00 am-17:00 pm, 19:00 pm-23:00 pm), and evening rush hours (17:00 pm-19:00 pm). The detailed setting parameters of this instrument are listed in Table 1. Three sampling points are evenly distributed on either platform at a height of 1.5 m to monitor the PM concentration in human breathing area. The calculated average concentrations in three sampling points are prepared for the following discussion. The monitoring instrument is calibrated before conducting the measurement. The photos of the field measurement are presented in Fig. 2.

(a) (b)

Fig 2 The photos of the field measurements

Table 1 Technical parameters of the monitoring instrument

Monitoring items	$PM_{2.5}$, PM_{10}
Concentration range	0.001-150 mg/m^3
Resolution	1 μg/m^3
Sampling flow rate	3 L/min
Data logging interval	1 s

3. RESULTS AND DISCUSSIONS

3.1 Variation of the PM concentrations on platforms with the train frequency

In order to investigate the effect of train frequency on PM concentrations on platforms, $PM_{2.5}$ and PM_{10} concentrations are monitored and the number of passing trains in one direction is recorded simultaneously. From the measurement results, the average $PM_{2.5}$ and PM_{10} concentrations on platform range from 65-104 μg/m^3 and 120-173 μg/m^3, respectively. The hourly variation of PM concentrations on platforms with train frequency is shown in Fig. 3. As depicted in Fig. 3, the $PM_{2.5}$ and PM_{10}

concentrations demonstrate the same variation trend, whereas the concentration of PM_{10} is generally higher than that of $PM_{2.5}$ during the measurement period. Moreover, the PM concentration on platforms display a strong correlation with train frequency, which is also observed in previous studies[8, 9].

As the first train runs in the morning, the PM concentrations on platforms start to increase. In the morning rush hours, the PM concentrations increase rapidly and reach the peak value when the train frequency is the highest. The largest $PM_{2.5}$ and PM_{10} concentrations are 104 and 173 μg/m^3, respectively. The sharp increase of PM concentrations can be attributed to the resuspension of PM on platforms and the introduction of airborne particulate matter generated by the friction between the wheels and the rail track in the tunnel. After the morning rush hours, the PM concentrations drop fast and maintain a relatively stable value. The PM concentrations on platforms obtain the peak again in the evening rush hours.

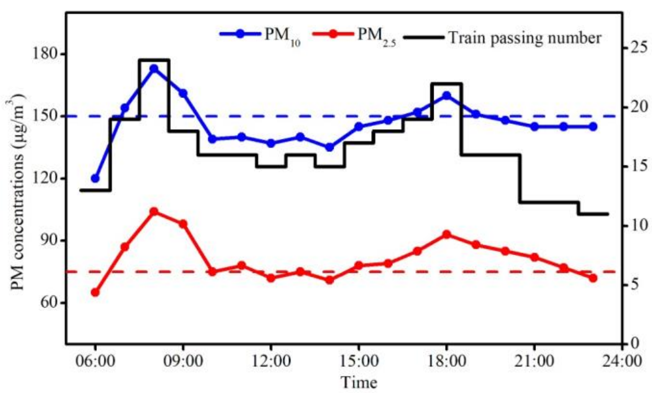

Fig 3 Variation of the PM concentrations on platforms with the train frequency

According to Ambient Air Quality Standard (GB3095-2012) and Indoor Air Quality Standard (GB/T 18883-2002) in China, the limited concentrations of $PM_{2.5}$ and PM_{10} are 75 and 150 μg/m^3, respectively, as shown by the red and blue dotted lines in Fig. 3. The measurement results indicate that passengers and the station staff are suffering from high PM concentrations, especially the $PM_{2.5}$.

3.2 Influence of piston effect on platform PM concentrations

The variation of PM concentrations on platforms with the piston effect which is influenced by the train arrival and departure is shown in Fig. 4. From the results, it is concluded that the concentrations of $PM_{2.5}$ and PM_{10} both increase when the train enters the station. The highest $PM_{2.5}$ and PM_{10} concentrations in the train arrival are 21% and 16% respectively higher than the average concentrations in the selected periods. As the train approaches the station, the polluted air in the tunnel is pushed into the platform by the piston wind and deteriorate the air quality on platforms. When the train departs the station, the PM concentrations decrease due to the inverse piston effect which removes the polluted air and renews the air on platforms. In the platform area close to the doors of the train, there is a strong air turbulence induced by passengers' walking, which can explain the sharp increase of PM concentrations during the train stops at the station. In general, the piston wind increases the PM concentrations on platforms, and more efficient air filters should be developed in order to improve the air quality in the subway station.

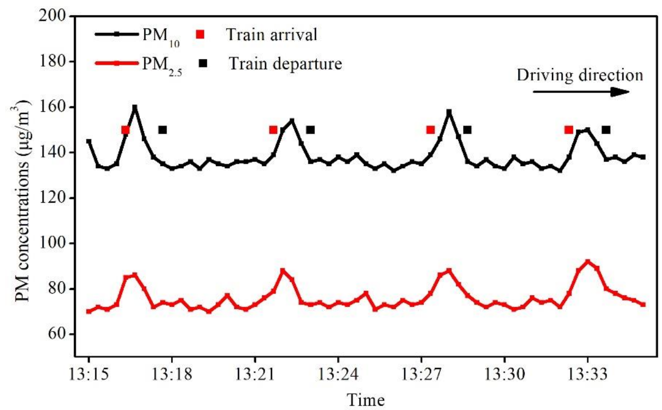

Fig 4 Variation of PM concentrations on platforms in the train arrival and departure

3.3 Further discussion on ventilation strategies and air filtration

Based on the analysis above, reasonable ventilation strategies and higher quality of air supply are essential to improve the air quality and save energy use in the ventilation and air-conditioning system. Under the premise of meeting passengers comfort requirements, automatic ventilation control strategy based on the current air quality on platforms should be studied in the further research to maintain a healthy air quality on platforms and avoid excessive ventilation energy consumption, especially in the rush hours. In addition, more efficient air filtration system should be investigated in order to improve the supply air quality and efficiency of the air conditioning system.

4. CONCLUSION

This paper investigates the influence of the train frequency and piston effect on $PM_{2.5}$ and PM_{10} concentrations on platforms. Through the field test, the diurnal variation of PM concentrations on platforms can be obtained. The number of passing trains, the time of the train arrival and departure are recorded simultaneously. The main conclusions are listed as follows:

(1) The high train frequency greatly increases the PM concentrations on platforms. The average $PM_{2.5}$ and PM_{10} concentrations on platform range from 65-104 $\mu g/m^3$ and 120-173 $\mu g/m^3$, respectively. The highest $PM_{2.5}$ and PM_{10} concentrations on platforms in morning rush hours are 23 and 27 $\mu g/m^3$ higher than those average concentrations during the whole monitoring periods.

(2) The $PM_{2.5}$ and PM_{10} concentrations on platforms rise significantly as the train enters the station because of the piston wind pushing the polluted air in the tunnel into the platform.

(3) More efficient air filtration system and reasonable ventilation strategies are expected to be investigated in further research to improve the air quality on platforms and save energy use in the ventilation and air-conditioning system.

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