Measurement and analysis of the air quality within a high-speed train carriage in a region of Southwest China

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Abstract: To investigate the air quality status and identify factors influencing air pollution, data on CO_2, formaldehyde, PM2.5, PM10, temperature, and humidity were measured in a high-speed train carriage of the Changsha-Zhuzhou intercity in southwest China. In the test section, CO_2, formaldehyde, relative humidity, and temperature exceeded the standard levels, and their compliance rates were 84%, 96%, 84%, and 76%, respectively. Then the influencing factors of pollutants were analyzed from three aspects: driving environment, the number of passengers, and relative humidity. Results show that the percentage of PM2.5 to PM10 in tunnel environments was higher; the increase in the number of passengers led to the elevation of CO_2 concentration in the carriage, while only in the ground environment, the number of passengers significantly correlated with particulate matter; the increase in relative humidity promotes the production and release of particulate matter and formaldehyde. Finally, fitting relationships between relative humidity and formaldehyde, as well as the number of passengers and CO_2 were established to predict the air quality status. It indicated that when the relative humidity of the carriage is less than 73%, the formaldehyde solubility was easy to exceed standards, and when the number of passengers was greater than 70, the CO_2 was easy to exceed standards.

1. Introduction

The need for residents to travel conveniently accelerates the development of rail transit trains, and trains and subways have become common choices for residents to work and travel[1, 2]. The relatively closed and limited ventilation of railroad carriages creates a unique microenvironment, and air quality within this environment is a growing concern[3, 4]

Researchers have conducted extensive research on the air quality of rail vehicles. Zhao[5] found that the temperature of the carriage was affected by the number of passengers, solar radiation, supply air temperature, and thermal current on the platform, and the temperature of the train decreased after entering the tunnel. Gong et al.[2] investigated the concentrations of volatile organic compounds (VOCs), formaldehyde, temperature and humidity, CO_2, and PM2.5 in the metro carriage. They analyzed the correlations between VOCs and formaldehyde, PM2.5 levels with both ground and underground driving conditions, as well as the relationship between PM2.5 levels and number of passengers. Cheng[6] found that PM2.5 and PM10 in the metro carriage were affected by a train running direction and outdoor ambient particle concentration. Wang et al.[7] and Huang et al.[8] analyzed the sources of PM2.5 in the subway system.

Zhang[9] investigated the concentration of particulate matter (PM) exposure in various modes of transportation, including high-speed trains and subways, during the Chinese New Year. Subsequently, Zhou et al.[10, 11] analyzed the relationship between PM10 levels and the driving environment within train carriages as well as the correlation between CO_2 concentrations and passengers' activities. Furthermore, Zhou examined variations in PM10, CO_2, and formaldehyde concentrations on high-speed trains during different trip durations and seasons.

Recently, there has been an increasing number of studies conducted on the air quality of subways and particulate matter within train carriages. However, limited attention has been given to investigating the air quality specifically inside high-speed trains. Furthermore, when examining factors influencing pollutants within carriages, researchers tend to primarily focus on correlations between pollutants and passengers rather than exploring their association with the thermal environment.

In June 2023, an integrated development plan was released by the two cities under study, which will facilitate population movement between the cities[12]. Consequently, intercity trains connecting these cities are expected to experience a surge in passenger traffic. Therefore, conducting a comprehensive analysis of pollutant quality characteristics and factors influencing air quality in this specific road section becomes crucial for effective air quality management and ensuring the well-being of passengers during their travel on similar

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intercity train routes. The focus of this study encompasses three key aspects: 1) providing statistical data on the current air quality status within the high-speed trains carriage of the designated study section; 2) conducting an analysis to identify patterns in air quality fluctuations, as well as exploring correlations between relative humidity and particulate matter/formaldehyde levels, passenger volume and particulate/CO_2 concentrations, and driving conditions and particulate matter; 3) proposing feasible recommendations for enhancing air quality within the specified study section.

2. Methodology

2.1.Subjects of survey

The air quality assessment was conducted in October 2023 on the carriages of the intercity high-speed trains section from Changsha to Zhuzhou South. The test high-speed train models, CJ6 and CRH6F, are designed in groups of four vehicles each. The designated testing position is the third carriage situated in the middle of the train. The train makes a total of 10 stops at various platforms (including the initial station), covering a journey distance of approximately 58 kilometers, with an average duration of around 64 minutes for a single trip. The railway route comprises two distinct sections: a ground segment and a tunnel section, wherein the tunnel portion spans 12.64 kilometers while the ground stretch extends over approximately 45.36 kilometers.

2.2.Sampling instruments

To minimize passenger travel disruption and reduce train passenger space occupancy, all sampling instruments are handheld. The PM2.5 and PM10 samples are collected using the laser particle counter developed by CEM company, which finds applications in CDCs, laboratories, aseptic workshops, and other environments with high cleanliness requirements. For formaldehyde sampling, the formaldehyde detector launched by PPM company is employed. This equipment has obtained national metrology certification in China and is extensively utilized by numerous professional testing centers worldwide in fields such as health and epidemic prevention, environmental protection, and occupational health. An air quality detector is used to sample CO_2 levels, temperature, and relative humidity. It incorporates a dual-wavelength NDIR (non-diffusive infrared) sensor for accurate CO_2 measurement with stability and low drift; temperature measurement relies on a thermistor while relative humidity is measured using a thin film capacitive sensor. The air quality detector meets various legal regulations' requirements. Table 1 presents the operating parameters of each instrument.

Table 1. Experimental instrument parameter.

Instrument	Model	Error	Sampling volume	Resolution ratio	Sampling time
Laser particle counter	DT-9881m	5%	2.83l/min	0.001mg/m^3	7s
Formaldehyde detector	htv-m	10%	10ml	0.01ppm	7s
Air quality detector	TSI 7545	3%or50 ppm	2.83l/min	1ppm	5s
		0.6℃	/	0.1℃	5s
		3%	/	0.1%	5s

2.3.Measurements and quality control

According to the requirements of TB/T1932-2014 Railway passenger train hygiene and testing technique provision, the field sampling locations are shown in Fig. 1 and Fig. 2. The sampling height is the height of the breathing belt when the human body is sitting still at 1.2 meters from the floor. To minimize contamination generated or carried by the human body from interfering with the instrument readings, the experimenter should keep 0.5m between the instruments and the human being during each sampling. To avoid affecting passengers and train operation during the peak period of traffic volume, this study sampling at only one measuring location, which is as close as possible to the middle of the carriage.

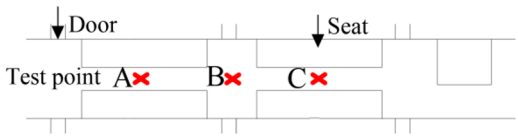

Fig. 1. CJ6 sampling distribution point.

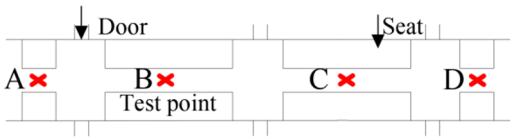

Fig. 2. CRH6F sampling distribution point.

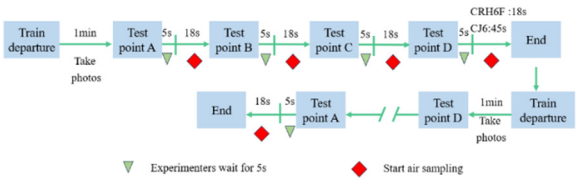

Fig. 3. Carriage air indicator sampling flow chart.

Fig. 3 shows the flow chart of air sampling. Air index sampling begins 1 minute after each train closes the door to reduce the impact of outdoor pollution on the pollution of the carriage. Before the test started, the experimenter took photos to record the number of passengers. Each sampling period takes about 2 minutes. When starting the next sampling period, the sampling direction is opposite to that of the previous sampling period, to avoid the researcher's walking back and forth affecting the passenger's ride experience. The data of each measuring point in the carriage was read once during each sampling cycle, with 3 to 4 test points being detected. When the experimenter arrives at the measuring point, wait 5s

before sampling, to avoid the rise or decrease of local pollutants caused by walking.

To accurately depict the air quality within the designated test section of high-speed trains, this study incorporated sampling periods during both morning (7:00-9:00) and evening peak hours (17:00-19:00), as well as off-peak hours (9:00-17:00), on weekdays and weekends.

The air quality of the carriage is evaluated regarding GB37488-2019 " Hygienic indicators and limits for public places ", and the PM2.5 concentration not specified in the standard is evaluated regarding GB/T18883-2022 "Indoor Air Quality Standard. As the test is in the transition season, the temperature and relative humidity in the carriage seating area are evaluated regarding GB/T33193.1-2016 "Air conditioning for main line rolling stock-Part 1: Comfort parameters". The evaluation indexes and their limits are shown in Table 2.

Table 2. Environment test index and test standard of carriage.

Environment category	Indicator	Unit	Standard Limit
Thermal environment	Temperature	℃	Comprehensive outdoor temperature determination
	Relative humidity	%	30%~65% (The temperature of the carriage is 20~26℃)
Air quality	CO_2	ppm	1500
	PM2.5	μg/m^3	50
	PM10	μg/m^3	150
	Formaldehyde	mg/m^3	0.1

3. Results

3.1.The test results of the thermal environment index of carriages

The trends of relative humidity and temperature with running time in some of the carriages detected in the direction of Zhuzhou are shown in Fig. 4 and Fig. 5. According to the different driving environments, the driving section is divided into a tunnel section and a ground section.

The control of relative humidity in the test train carriage is inadequate. During the test, a maximum relative humidity range of approximately 27.73% is observed in Train T3. In most test trips, the carriage's relative humidity increases upon entering the tunnel and decreases upon exiting it. The results from tests conducted in both directions indicate that the carriage's relative humidity rate is around 72%, while the compliance rate for ground sections is about 91%. Moreover, the tunnel section exhibits higher relative humidity levels and a greater likelihood of exceeding standards. Notably, there are no significant differences in relative humidity between the two vehicle models.

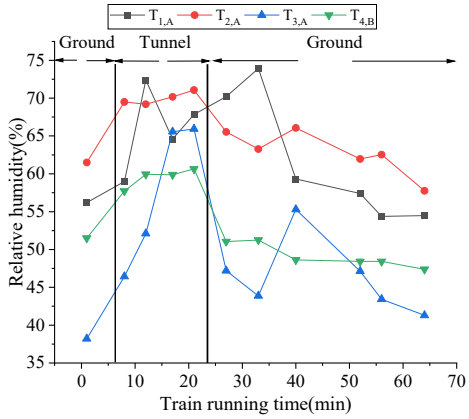

Fig. 4. The relative humidity of the carriage in the southbound direction in Zhuzhou exhibits temporal variations. (T1~T4 are different trains in the south direction of Zhuzhou defined according to the order of measurement; "A" and "B" stand for CJ6 and CRH6F respectively)

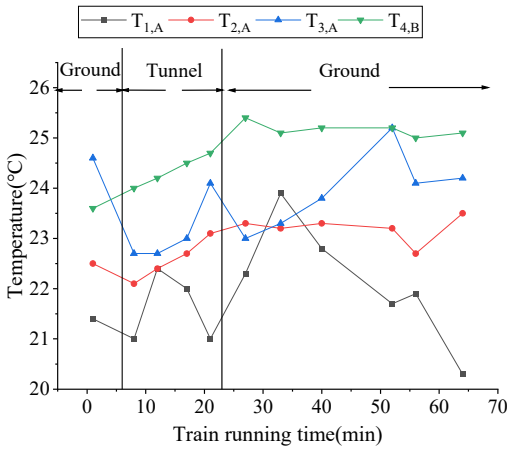

Fig. 5. The temperature of the carriage in the southbound direction of Zhuzhou exhibits temporal variations.

During the investigation period, the temperature variation of most test carriages at a height of 1.2m remained within 2℃, while trains $T_{1,A}$ exhibited larger temperature fluctuations, with a range of 2.9℃. Throughout the testing duration (6:00~18:00), the average carriage temperature in the ground section was approximately 23.7℃, whereas in the tunnel section, it averaged around 23℃. The average temperature outside the vehicle was determined by considering the average temperature of the starting station and the terminal station of the test section. The temperature compliance rate of the tested carriages is 76%, with CJ6 model carriages achieving a perfect compliance rate of 100% while CRH6F model carriages only achieved a meager 9%. Different trains employ distinct temperature control strategies, which is one of the main causes of temperature exceedance. Notably, the CJ6 model focuses on maintaining a controlled temperature range between 20 and 24 °C, while the CRH6F model exhibits higher temperatures within a concentrated range of 23 to 27 °C.

The temperature and humidity variation between the tunnel section and the ground section in this study is consistent with that observed by GONG Y[2] in the Shanghai metro car, where the tunnel temperature was

lower than that of the ground, while the tunnel humidity was higher compared to the ground conditions. This phenomenon may be attributed to the enclosed internal environment of tunnels.

3.2.Detection results of air quality index in train carriages

Table 3 shows the range, average value, and pass rate of each air quality detection index in the train carriages of Changsha to Zhuzhou South section. The operation section of the train carriages appeared CO_2, formaldehyde exceeded the standard phenomenon, in which the CO_2 pass rate was the lowest, 84%, and formaldehyde was the second, about 96%. PM2.5, and PM10 concentration mean value is lower than the standard limit (respectively, for the standard of 1/5, 1/7), the level of pollution was lower, it is less likely to exceed the standard.

The results presented in Table 3 illustrate the range, average values, and pass rates of each air quality detection index in the train carriage of the Changsha to Zhuzhou South section. It is observed that CO_2 and formaldehyde levels exceed the standard limits within the operational section of the train carriages, with a pass rate of only 84% for CO_2 and approximately 96% for formaldehyde. However, both PM2.5 and PM10 concentrations were found to be lower than their respective standard limits (1/5th and 1/7th of the standards), indicating a lower level of pollution and reduced likelihood of exceeding these limits.

Table 3. Air quality index range, mean, and pass rate.

Site	PM2.5(μg/m^3)			PM10(μg/m^3)			Formaldehyde(mg/m^3)			CO_2 (ppm)		
	Range	Mean	Pass rate(%)	Range	Mean	Pass rate(%)	Range	Mean	Pass rate(%)	Range	Mean	Pass rate(%)
Carriage	4~25	12	100	7~62	23	100	0~0.149	0.018	96	509~3871	1056	84

In this study, the pass rate for each test index in the carriage is comparable to Zhou et al.[10]on train operation; however, the formaldehyde concentration is only half of their summer study results (0.055 mg/m^3). Moreover, when compared to Zhang[9] who operated during the Chinese New Year period, our study observes PM2.5 levels that are half as low (0.0202 mg/m^3), while PM10 levels are similar (0.0234 mg/m^3). The reasons for the above phenomenon may be attributed to several factors. Firstly, in the summer test conducted by Zhou et al., the average concentration of formaldehyde in the old train (0.041 mg/m^3) was lower compared to that in the new on-line train (0.077 mg/m^3), which is closer to the current study. Additionally, all trains used in this study were taken for more than 3 years, and it is possible that the reduction of formaldehyde emission from the old train contributed to its lower level of formaldehyde in the carriage. Secondly, it should be noted that Zhang et al. conducted their study during the Chinese New Year, which represents a peak period for pollutants. And, their findings reported pollutant concentrations 2-4 times higher than those obtained by other researchers[13-17]. Therefore, considering this context, it can be inferred that our measured PM2.5 concentration is only 1/4 of what would be expected under more typical conditions.

4. Discussion

4.1.Factors affecting the air quality of carriage

After initial screening, the primary factors influencing carriage air quality include relative humidity, passenger volume, and driving conditions (ground section/tunnel section).

4.1.1.Relative humidity

The correlations between relative humidity and PM2.5, PM10, formaldehyde, and the number of passengers under different test conditions are presented in Table 4. The relative humidity was highly significant (Sig < 0.001) and the correlation was good (R > 0.4) with the particulate matter concentration and formaldehyde concentration under each test condition, indicating that the increase in relative humidity is likely to lead to higher levels of formaldehyde and particulate matter. The reason for this phenomenon may be related to the formation of particulate matter and the release mechanism of formaldehyde from the carriage materials.

Such a phenomenon may be attributed to the formation of particulate matter and the release mechanism of formaldehyde from carriage materials. Particulate matter with a size range of 0-10 μm is prone to coagulation within a relative humidity interval of 35% to 80%. Coagulation leads to an increase in the average size of fine particulate matter, with a more pronounced effect observed when the relative humidity exceeds 65% [18]. The hygroscopic growth of particulate matter is a rapid process, as demonstrated by Broday[19] who found that this process occurs within approximately 10 seconds. Therefore, there exists a stronger correlation between the performance of particulate matter and relative humidity. Additionally, due to the widespread use of adhesives in the floors and roof panels of high-speed trains, a large amount of formaldehyde is released[20]. Since formaldehyde is highly soluble in water, higher relative humidity promotes hydrolysis and subsequent release of formaldehyde from these adhesives[21], thus establishing a clear relationship between formaldehyde levels and relative humidity.

Variations in relative humidity may exhibit a correlation with passenger volume. As can be seen from

Table 4, the correlation between the number of passengers and relative humidity under each test condition is highly significant (Sig < 0.01) except for the tunnel section, which is consistent with the findings of Miyazawa Xiang et al.[22] and Liu Yijiang et al.[23] , who concluded that the source of humidity in the carriages mainly comes from the human body. The relative humidity and ridership in the tunnel section did not show significance may be due to its special underground environment. Unfortunately, the humidity inside the tunnel was not measured in this study. However, Fig. 4 in the previous section has shown that the average relative humidity in the carriages is higher in the tunnel environment. It is hypothesized that during the time the train is traveling through the tunnel, the main source of humidity inside the carriage is the tunnel environment, and the number of passengers is a secondary factor in the change of relative humidity in the carriages. That's the reason why the relative humidity in the tunnel section does not have a significant correlation with the number of passengers.

Table 4. Correlation of relative humidity with PM2.5, PM10 and formaldehyde under different test conditions

Factors	Direction of Zhuzhou South		Direction of Changsha		Ground		Tunnel	
	R	Sig	R	Sig	R	Sig	R	Sig
PM2.5	0.692**	<0.001	0.473**	<0.001	0.576**	0.001	0.562**	<0.001
PM10	0.625**	<0.001	0.554**	<0.001	0.592**	0.001	0.413**	<0.001
Formaldehyde	0.678**	<0.001	0.621**	<0.001	0.58**	0.001	0.744**	<0.001
Number of passengers	0.407	0.006	0.391**	0.008	0.488**	0.001	-0.157	0.389

4.1.2.Differences in the environment between the Ground environment and the tunnel environment

The variation of PM2.5/PM10 between the tunnel and ground periods for each vehicle during the test period is illustrated in Fig. 6. According to WHO recommendations, PM2.5 can serve as an appropriate indicator and guideline value for PM10 when the ratio of PM2.5/PM10 reaches 50%, which aligns with typical ratios observed in developing countries and falls within the range found in urban areas of developed countries (0.5 to 0.8) [24]. In this study, the ratio of PM2.5/PM10 in train carriages ranged from approximately 45% to 58% across nine test trips, indicating a more moderate ratio of PM2.5 to PM10 within these sections under examination. Except for trains T1, T4, and T5, most tunnel sections exhibited higher levels of PM2.5/PM10 compared to ground sections, suggesting that particulate matter with particle sizes smaller than 2.5 μm or a greater mass thereof is more prevalent within tunnel environments.

The average concentrations of PM2.5 and PM10 in both the ground and tunnel sections of the nine conducted trips are illustrated in Fig. 7. The average values of PM2.5 and PM10 ranged from 7 to 15 and 13 to 21, respectively, for the ground section, while for the tunnel section, they ranged from 14 to 29 and 24 to 43, respectively. Notably, the particulate matter concentration was found to be lower in the ground section compared to that in the tunnel section, with an increase by a factor of only 0.92 observed for average PM2.5 concentration within tunnels.

The variation of PM2.5 concentrations in the ground and tunnel sections of this study is consistent with that reported by Huang et al.[25] in Chengdu. However, Gong et al. [2] and Xu et al. [26] observed a higher concentration of PM2.5 in the carriages of the ground section compared to the tunnel section, which may be attributed to variations in atmospheric concentrations during the testing period.

Outdoor PM2.5 concentrations of 125 μg/m^3 and 133 μg/m^3 were observed by Gong et al. and Xu et al. respectively. In contrast, the present study recorded outdoor PM2.5 concentrations ranging from 41 to 54 μg/m^3, and Huang et al. reported a range of 10 to 57 μg/m^3. Notably, these values were significantly lower than the particulate concentrations observed in Gong et al. and Xu et al. KAM[27] demonstrated that the levels of particulate matter (PM) in the ground environmental carriages were significantly influenced by atmospheric conditions, and variations in outdoor air quality could potentially account for the observed decrease in particulate matter pollution within this investigation. The tunnel section, however, is prone to the accumulation of particulate matter due to its enclosed interior and low ventilation rate resulting from train operation. Conversely, the concentration of particulate matter in carriages is influenced by outdoor conditions, leading to a higher likelihood of particulate matter pollution occurring in the tunnel section.

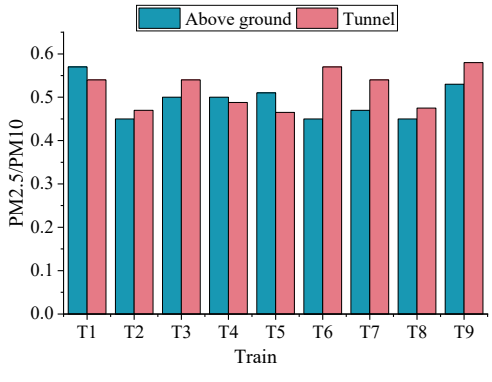

Fig. 6. Impact of ground and tunnel sections on PM2.5/PM10 levels in CJ6 carriage.
(T1~T9 are different trains in the south direction of Zhuzhou defined according to the order of measurement)

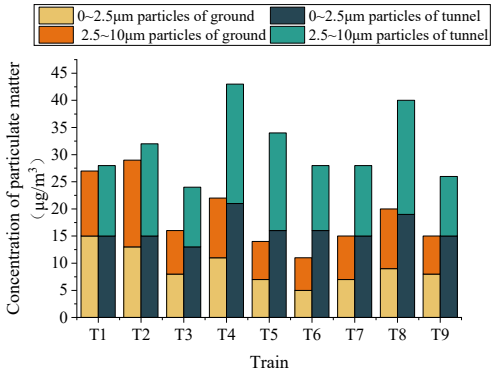

Fig. 7. Impact of ground and tunnel sections on the concentration of particulate matter.

4.1.3.Number of Passengers

Table 5 demonstrates the correlation between the number of passengers and PM2.5, PM10, and CO_2 under different test conditions. In the test along different train directions, only the PM10 in the direction of Changsha was significantly correlated with the number of passengers (Sig < 0.05), and the two were positively correlated (0.318), while the PM2.5 in the direction of Changsha and the particulate matter in the direction of South Zhuzhou were not statistically correlated with the number of passengers (Sig > 0.05). In the test along different sections of the train, PM2.5 and PM10 in the ground section were found to have a strong significant relationship with the number of passengers (Sig < 0.01, Sig < 0.001), and both were positively correlated with the number of passengers, with correlation coefficients of 0.348 and 0.482, respectively. The tunnel section did not exhibit a significant correlation between particulate matter and the number of passengers. This observation may be attributed to the fact that the increase in particulate matter within the carriage, caused by environmental factors specific to tunnels, surpasses that resulting from passenger activities. Consequently, any discernible change in particulate matter concentration within the tunnel section due to passenger numbers is negligible.

A similar conclusion was drawn in the research conducted by Gong et al.[2], indicating that an increase in the number of passenger leads to higher concentrations of particulate matter within the carriage. However, a contrasting phenomenon was observed in Huang's study[9] on the Chengdu subway line, where no significant correlation is found between passenger numbers and PM2.5 and PM10 concentrations in both ground and underground sections. This could be attributed to the utilization of masks by passengers during the COVID-19 pandemic, which effectively hindered the formation and proliferation of particles associated with exhaled droplets[28,29]. Moreover, it should be noted that different research methodologies may yield diverse outcomes when investigating the correlation between number of passengers and particulate matter concentration in subway cars. While Huang et al. covered a sample size ranging from 1 to 38 passengers, our investigation included a wider range of variation in the number of passengers (2 to 125), thereby exhibiting a more pronounced response profile.

Table 5. Correlation of number of passengers with PM2.5, PM10, and CO_2 under different detection conditions.

Factors	Direction of Zhuzhou South		Direction of Changsha		Ground		Tunnel	
	R	Sig	R	Sig	R	Sig	R	Sig
PM2.5	0.264	0.084	0.181	0.24	0.348	0.008**	-0.254	0.16
PM10	0.223	0.146	0.318	0.035*	0.482	<0.001**	-0.179	0.327
CO_2	0.746	<0.001**	0.875	<0.001**	0.82	<0.001**	0.926	<0.001**

After analyzing the correlation between the number of passengers and CO_2 concentration in Table 5, a highly significant correlation (Sig < 0.001) was observed under all test conditions, indicating that changes in the number of passengers play a crucial role in influencing CO_2 concentrations. The correlation coefficients between passenger numbers and CO_2 ranged from 0.746 to 0.926 across different test conditions, with the tunnel section exhibiting the strongest correlation coefficient with CO_2 concentration.

This phenomenon may be attributed to the ventilation rate of the train system. In the case of light rail models or trains traveling on elevated levels, continuous and efficient operation of the train ventilation system is facilitated by roof ventilators. However, when trains pass through tunnels, fresh air supply relies solely on mechanical ventilators[30]. Consequently, a reduced amount of fresh air is available in these instances, leading to inadequate dilution of indoor air and resulting in CO_2 accumulation. Therefore, a stronger correlation can be observed between CO_2 levels and the number of passengers in tunnel sections.

4.2.Correlation analysis of excessive pollutants

Based on the above analysis of carriages pollution and air quality influencing factors, we conducted fitting analyses for formaldehyde with relative humidity and CO_2 with the number of passengers separately, as shown in Eqs. (1) and (2). The analysis of the fitting relationship in Fig. 8 and Fig. 9 revealed that when the independent variables are close to a certain threshold, it is highly likely to exceed the problem with dependent variables formaldehyde and CO_2. Therefore, by exerting control over the independent variable in the functional relationship or implementing appropriate measures when the independent variable approaches its critical point, it is possible to effectively mitigate the risk of exceeding formaldehyde and CO_2 standards.

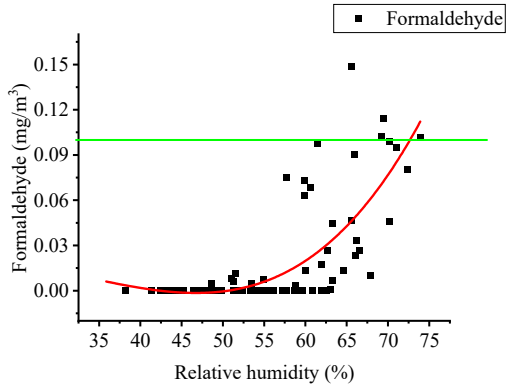

Fig. 8. Fitting analyses for formaldehyde with relative humidity.

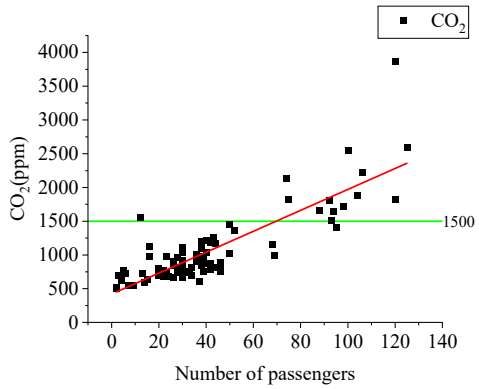

Fig. 9. Fitting analyses for CO_2 with the number of passengers.

$$Y_a = -0.046 + 0.0071x_1 - 2.41\cdot10^{-4}x_1^2 + 2.36\cdot10^{-6}x_1^3 \quad (1)$$

$$Y_b = 420.5 + 15.5x_2 \quad (2)$$

Where Y_a is concentration of formaldehyde(mg/m^3); x_1 is relative humidity(%); Y_b is concentration of CO_2(ppm); x_2 is number of passengers in the carriage.

The decidability coefficients of equations (1) and (2) are 0.55 and 0.7, respectively, indicating that the fitted curves account for 55% and 70% of the observed variations in values. Notably, equation (1) reaches its standard limit at a relative humidity of 73%, while equation (2) does so at a passenger count of 70. It is worth noting that exceeding these thresholds can lead to potential issues with formaldehyde and CO_2 levels. The relative humidity at 73% also exceeds the requirement of GB/T33193.1-2016 " Air conditioning for main line rolling stock-Part 1: Comfort parameters " which stipulates a maximum relative humidity of 65% in the passenger rest area. Therefore, it is necessary for the air-conditioning system of both intercity high-speed train models operating on this section to effectively control the relative humidity within the standard limit and increase fresh air circulation when passenger capacity exceeds 70, to mitigate potential risks associated with elevated levels of formaldehyde and CO_2.

5. Conclusions

(1) Current situation of vehicle pollution. The concentrations of formaldehyde, PM2.5, PM10, CO_2, temperature, and relative humidity were measured in the carriages of intercity trains traveling from Changsha to Zhuzhou South in this study. The results indicate that the levels of formaldehyde, CO_2, relative humidity, and temperature in the tested carriages exceeded the standard limits with compliance rates of 96%, 84%, 72%, and 76% respectively. During thermal environment testing, it was observed that relative humidity had the lowest pass rate in tunnel sections at approximately 72%. Additionally, CRH6F models exhibited higher temperatures resulting in a lower compliance rate of about 9%.

(2) Influencing factors of air quality in the carriage. During the test period, the PM2.5 concentration in the tunnel section exhibited a 0.92-fold increase compared to that in the ground section, accompanied by an elevation in the ratio of PM2.5 to PM10 within the tunnel section; meanwhile, across all train carriages, the proportion of PM2.5 to PM10 ranged from 45% to 58%. The ground section exhibited a significant correlation between the number of passengers and particulate matter, whereby an increase in passenger volume led to higher concentrations of PM2.5 and PM10. Furthermore, there existed a highly significant association between the number of passengers and CO_2 levels, with the linear relationship being even more pronounced within the train tunnel section. Relative humidity demonstrated strong correlations with concentrations of PM2.5, PM10, and formaldehyde.

(3) Fitting of exceedance pollutants to their influencing factors. The results of fitting formaldehyde to relative humidity and CO_2 to the number of passengers indicated that formaldehyde and CO_2 concentrations in the test carriages exceeded regulatory limits when the relative humidity surpassed 73% and the number of passengers exceeded 70 individuals, respectively.

Due to the limitations of test conditions, this study solely considered easily measurable factors that impact pollutants in the carriage. For instance, we did not account for the influence of different running cycles on formaldehyde concentration, which necessitates obtaining information through communication with train management personnel. Moreover, due to limited time for train stops at interchange stations and ensuring tester safety, synchronous air quality tests were not conducted on the train platform and its surrounding environment. Further research can enhance these aspects to obtain more accurate research conclusions.

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