Journal of Environmental Sciences Vol. 11, No. 3, pp. 355—360, 1999

ISSN 1001—0742
CN 11—2629/X

Traffic emission and its impact on air quality in Guangzhou area*

Zhang Yuan-hang, Xie Shao-dong, Zeng Li-min, Wang Hui-xiang

Laboratory of Atmospheric Environmental Simulation, ESPC, Center of Environmental Sciences, Peking University, Beijing 100871, China

Yu Kai-heng, Zhu Chang-jian, Pan Nan-ming, Wang Bo-guang

Guangzhou Research Institute of Environmental Protection, Guangdong 510620, China

Abstract—A comprehensive field measurement was set up in Guangzhou City of China and the key was placed on NO_x and O_3 pollution. The results indicated that the average driving speed of vehicle was only 14 km/h in downtown with high frequency of idle and acceleration. Upward fluxes of CO and NO were observed in Dongfeng Street. NO_x annual mean concentration in urban area increased year by year, and NO_x was identified as the most important pollutant since 1995. Photochemical smog pollution was serious in general, spatial and seasonal distribution of O_3 was observed. O_3 concentration was kept in a high level in autumn, and its formation was restrained in summer due to frequent thunderstorm and high humidity. The numerical simulation showed the average concentration and maximum concentration of O_3 would increase 60%—100% if vehicular emission increased 100% in Guangzhou.

Keywords: ozone, photochemical smog, traffic pollution.

1 Introduction

In the process of rapid urbanization, total amount of vehicle in China increased dramatically and reached more than 20 million in 1995 with an average increase rate of 15%. Because of poor quality of vehicle, bad road condition, low driving speed, and no catalytic converter, the emission of pollutants from vehicular exhaust is much higher than that in Europe and the United States. As a consequence of high emission, the air quality in some big cities is getting worse, photochemical smog is observed, and O_3 and its precursor NO_x concentration are kept at a high level, over national air quality standard NAQS. Air pollution is in transition from coal burning caused problem to vehicle exhaust related pollution, and showed the characteristics of pollution combined them (Zhang, 1997; 1998).

Guangzhou is one of the cities which suffer from serious NO_x pollution. Its NO_x concentration was highest to be 0.129 mg/m^3 in China in 1995 (Editorial Board of China Environmental Yearbook). As an initial calculation, vehicular emission contributed about 42.3% of total NO_x and 84.8% of total CO in atmosphere in 1994. Vehicular emission was identified as a main source for air pollution in urban area. Based on the analysis for current situation of traffic pollution in Guangzhou, a comprehensive field measurement was set up in Guangzhou area and the key was placed on NO_x and O_3 pollution. The purpose of this paper is to present the traffic characteristics, to study its impact on air quality in street and downtown, and to assess secondary pollution level in Guangzhou area.

2 Experimental

Guangzhou is located in the south coastal area of China. Its terrain is relatively flat with some small hills in northwest of Pearl River Delta. The weather is general mild, annual mean temperature is 22℃, humidity 79% and radiation 1898 hours. The meteorological conditions in

---

* Supported by the Trans-Century Training Program Foundation for the Talents by the State Education Ministry of China

this area are characterized by southerly wind in summer months and northerly wind in winter months.

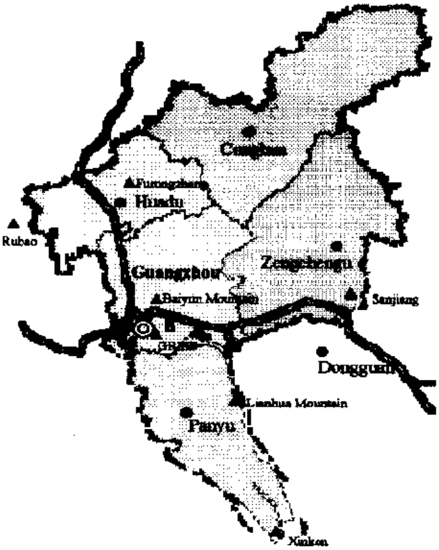

Fig. 1 Locations of air quality monitoring sites in Guangzhou area from June 27 to July 7 in 1998

Intensive field measurement was conducted during June 27 to July 7 in 1998. Seven air quality monitoring sites were set up in an area of 200 km by 200 km(Fig. 1). Southeast wind was dominant during measurement period. Thus, Xinken and Lianhuashan were located in upwind direction of Guangzhou, Furongzhang and Rubao were in downwind direction. Baiyunshan was adjacent to Guangzhou City with altitude of 380 m high. In general, these sites were far from big local emission sources and the air was relatively clean. In site Lianhuashan, Baiyunshan and GRIEP (Guangzhou Research Institute of Environmental Protection), NO_x and O_3 were measured in situ continuously with time resolution of 1 min. In other four sites, NO, NO_2 and O_3 were measured manually at 7:00, 9:00, 11:00, 13:00, 15:00 and 17:00 by using the national standard analytical methods published by Chinese State Environmental Protection Agency. Air quality in street was evaluated in July 1998 in Dongfeng Street, Guangzhou City. The vertical profiles of NO_x, CO and O_3 were measured continuously with a time resolution of 15 minutes at height of 5, 15, 25 and 35 meter. CO concentration at 1.5 meter high was measured manually along the street in daytime. Traffic flow and vehicular types were counted manually at the same time.

3 Results and discussion

3.1 Traffic characteristics and vehicle emission

With fast economic growth since 1980, the vehicle population increased dramatically in Guangzhou urban area with an increase rate of 16.5%/a. Total amount of vehicle in 1995 was 460,000, and it reached to 610,000 in 1997, ranked at the second place in China, only next to Beijing. Car and motorcycle were the dominant types of vehicle in the city, which were 15.6% and 53.1% respectively in 1995, and motorcycle was up to 2/3 of vehicle population in 1997, which was very unique in cities of China.

Road condition was not compatible with the fast increase of vehicle population. Total length of road increased at rate of 8.1% during 1980 and 1994. It was 1404 km in 1994 and reached to 1809 km in 1995. The urban traffic network was established initially, consisting of an inner circle, 2 express highways, 13 urban main roads, and 10 exiting roads to outside the city. Fast increase of vehicular population resulted in heavily traffic congestion. The average traffic flow was 46868/d and 1953/h with maximum flow 6800/h and 94210/d in Guangzhou urban area. The traffic flow was kept at a high level about 2000—3100/h during 8:00—21:00 with two peaks at 8:00—10:00 and 17:00—19:00, respectively, and it was low from midnight to early morning. Car and motorcycle were major vehicles driving in urban area and had almost the same contribution to the traffic flow, and heavy-duty vehicles had minor contribution.

Table 1 shows the measurement results in October 1997, together with the driving cycle in Beijing and Shanghai City. The data was collected for 5120 minutes and the driving distance was about 1579 km. As traffic flow increased these years, the average driving speed was getting slow.

It was 14 km/h in 1997, lower than 20 km/h in Beijing and 17 km/h in Shanghai (Cheng, 1997). The driving cycle in Guangzhou was worse than that in Beijing and Shanghai: low average driving speed, high idle and acceleration frequency, therefore, vehicle would emit more pollutants in Guangzhou. The emission share rates of CO and NO_x from vehicle in total emission was 84.8% and 42.3%, which revealed that vehicular emission became a dominant source of air pollution in urban area.

Table 1 Driving cycle in urban area of Guangzhou (1997), Beijing (1997), and Shanghai (1996)

City	Maximum acceleration speed, m/s	Maximum speed, km/h	Average speed, km/h	Percentage, %			
				Idle	Acceleration	Decrease	Equal
Guangzhou	1.9	50.38	14.14	17.77	29.11	27.16	25.95
Beijing	1.3	65.25	19.98	16.25	25.29	30.85	27.34
Shanghai			17	27			

3.2 Air quality in street canyon

NO_x and CO concentrations in traffic dense area were much higher than in other areas and showed the continuously increasing tendency(Fig.2). The maximum annual average concentration of CO in traffic dense area was 6.0 mg/m^3 in 1994 and NO_x reached 0.268 mg/m^3 in 1996. The air in street was highly impacted by vehicular emission. GRIEP (Guangzhou Research Institute of Environmental Protection) conducted a survey in main streets of Guangzhou during January 16—22, 1995. 6 samples were collected every day in each sampling site. The results showed that NO_x and CO concentrations were in a range of 0.17—0.70 mg/m^3 and 3.0—10.0 mg/m^3 with the average of 0.32 mg/m^3 and 5.1 mg/m^3, respectively. CO concentrations in 67% sampling sites and all NO_x concentrations exceeded second class of NAQS

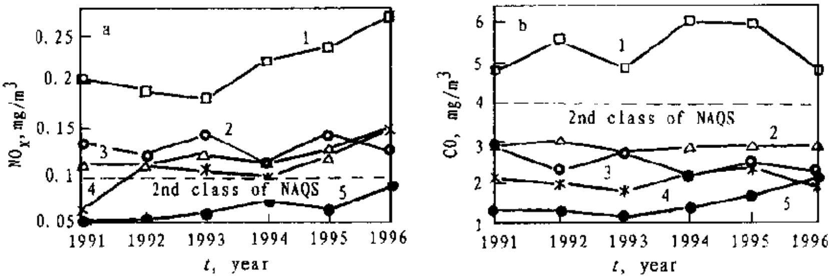

Fig.2 Annual mean concentration of NO_x and CO in different function areas of Guangzhou

a: 1. Traffic 2. Industrial 3. Urban 4. Residential 5. Rural

b: 1. Traffic 2. Urban 3. Industrial 4. Residential 5. Rural

To study street air quality in detail, a diffusion experiment was conducted in Dongfeng Street during July 14—August 10, 1998. Both horizontal and vertical concentration profile of CO was measured, as well as vertical profile of NO and O_3. The CO concentration in Dongfeng Street was extremely high, it was in range of 0.69—72.1 mg/m^3, with an average of 9.0 mg/m^3. Fig.3 shows the average CO concentration changes in north and south sides of the street. CO concentration was low during 23:00—6:00, it increased since 7:00 and reached maximum at 9:00, then it was fluctuant with traffic flow. Since the dominant wind direction was southern, the CO concentration in south side of the street was generally higher than that in north side.

Fig.4 shows the vertical profile of CO, NO, NO_2 and O_3 concentration at height of 5, 15, 25 and 35 (roof) meter. It can be seen that primary pollutants CO and NO concentrations decreased with height and had a sharp decrease at roof. Below the roof, two concentration peaks were observed with corresponding to traffic flow changes. However, CO and NO concentration changed smoothly above roof with only one peak in the morning, which characteristic indicated well mixed of air and less influence from traffic emission. In contrast to primary pollutants, NO_2 and O_3 concentrations increased with height in general and had a sharp increase above the roof, although O_3 concentration changes were not well characterized because it was highly impacted by local traffic emission. NO_2 concentration was very high above roof in daytime with an average of 15.6 $\mu g/m^3$ and maximum of 40.0 $\mu g/m^3$, as a consequence, O_3 concentration above roof was relatively high, its average was 65.2 $\mu g/m^3$ and maximum reached 97.7 $\mu g/m^3$, indicated strong oxidation capacity in atmosphere. The high NO_2 and O_3 concentration in traffic dense area also give an indication of photochemical pollution in Guangzhou area, particularly in its suburbs and downwind direction area.

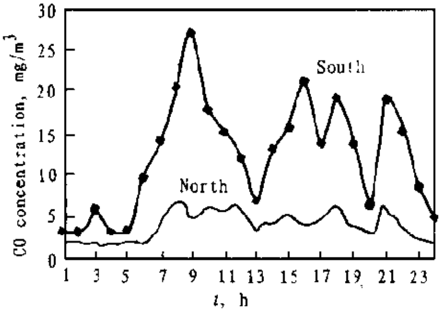

Fig. 3 Diurnal variation of CO concentration in south and north side of Dongfeng Street

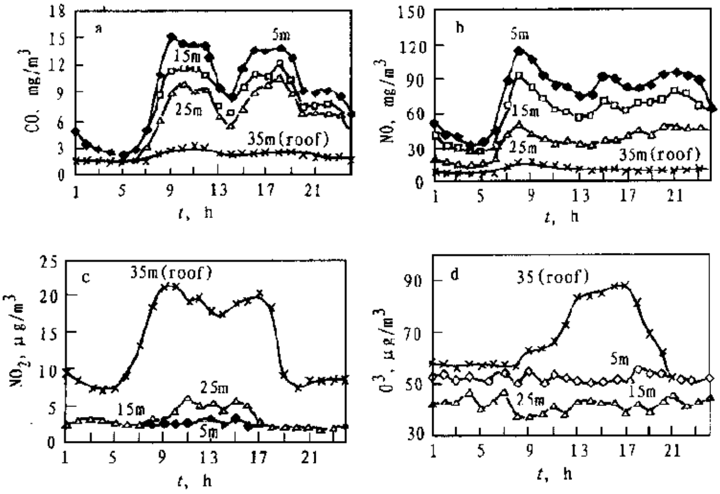

Fig. 4 The vertical profile of CO, NO, NO_2 and O_3 concentration at height of 5, 15, 25 and 35 (roof) meter during July 14-August 10 in Dongfeng Street

3.3 Urban air quality

With rapid urbanization and industrialization, urban air quality was getting worse and the main pollutant was changed. Fig. 6 shows the changes of annual mean concentrations of NO_x and SO_2 since 1980. At the beginning of the 1980's, SO_2 was the main pollutant, and its concentration was much higher than NO_x. It fluctuated between 50—100 $\mu g/m^3$ since then and was lower to 60 $\mu g/m^3$ in 1996. NO_x concentration, however, showed a continuously increasing tendency. Its concentration was 0.151 $\mu g/m^3$ in 1996, ranking first place in China. Variation of NO_x/SO_2 ratio, shown in Fig. 5, revealed that annual mean NO_x concentration caught up with SO_2 since middle of the 1980's, particularly in summer. In Beijing, NO_x concentration was observed to be higher than SO_2 after 1993 (Zhang, 1997; 1998). The high NO_x/SO_2 ratio was an extremely important signal of photochemical pollution in a city, which was still suffering from heavy air pollution from coal burning. This phenomenon showed that air pollution in Guangzhou has shifted from coal-related pollution to traffic-related pollution.

NMHC/NO_x ratio in Guangzhou area was relatively low, compared with that in Beijing (Zhang, 1998). The ratio varied from 13 in traffic condensed area to 76 in suburbs with a mean of 31 and 39 in 1995 and 1998, respectively, which range was close to the ratio 7.9—69 in cities of the United States (Committee on Tropospheric Ozone Formation and Measurement, 1991). Therefore, NO_x was identified as key precursors for photochemical oxidant formation.

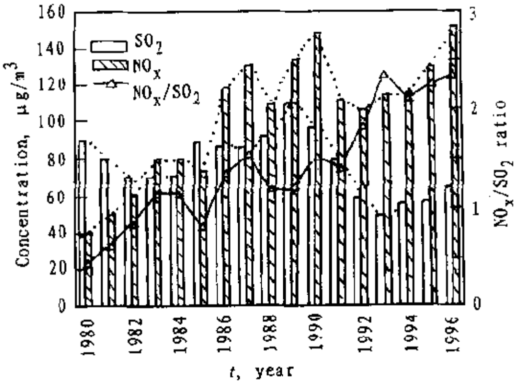

Fig.5 Annual mean SO_2 and NO_x concentration and NO_x/SO_2 since 1980

Table 2 shows O_3 concentration level and its frequency exceeding national air quality standard NAQS in Guangzhou area, together with O_3 concentration level in Beijing. In October, meteorological factors were favorable for O_3 production: high temperature, strong radiation and low humidity. The maximum O_3 concentration reached 170.2 ppb in October 1995 and 156.9 ppb in October 1998 with the frequency exceeding second class of NAQS 17.5% and 11.3%, respectively, indicating that O_3 pollution in Guangzhou was as serious as the case in Beijing (Tang, 1995; Zhang, 1998). Although temperature was higher and radiation was stronger in July than in October, the high humidity and frequent thunderstorm interfered the formation of photochemical smog, thus O_3 concentration in July was lower than in October, and its frequency exceeding second class of NAQS was also much lower in July.

Spatial distribution of O_3 concentration was observed in Guangzhou area(Fig.6). In October 1995, it was found that O_3 concentration was higher in suburbs than in downtown areas. Spatial variation of O_3 concentration along the prevailing wind direction was observed in July 1998. O_3 concentration was very high in up-wind direction (Sanjiang and Xinken). As the air mass went northerly, O_3 concentration decreased gradually and reached minimum at downtown area of Guangzhou, then O_3 concentration increased again in down-wind direction (Furongzhang). In Furongzhang, about 30 km north to Guangzhou City, the O_3 concentration was generally higher than that in Guangzhou downtown area, even higher than that in Lianhuashan, about 30 km southeast to Guangzhou. The spatial distribution of O_3 showed that O_3 pollution was a regional environmental problem, it can only be controlled in a view of regional policy.

Table 2 O_3 concentration and its frequency exceeding NAQS in Guangzhou and Beijing area

	Date	Average Conc., ppb	Maximum Conc, ppb	Frequency exceeding NAQS, %		
				>60 ppb	>80 ppb	>100 ppb
Beijing	1993.06	46.2	160.8	30.0	15.4	7.2
Guangzhou	1998.07	27.0	142.7		2.8	1.8
	1998.10	48.5	156.9		11.3	4.0
	1995.10	56.1	170.2	36.8	17.5	8.3

The serious O_3 pollution in the area was identified to highly correlate with fast increases of vehicle population in recent years. The continuous rapid growth of vehicle population was expected in near future. Different scenarios were assumed, in which relative emission rate of vehicle was changed from 0.2 to 2.0 of the emission in 1995. The numerical simulation showed that O_3 concentration of both daily average and maximum was elevated and the area of high O_3

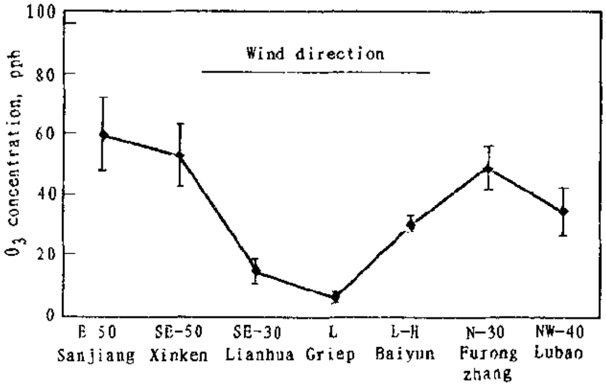

Fig. 6 The spatial distribution of O_3 average concentration along the southeast wind direction during June 30—July 7, 1998

concentration was expanded widely as vehicular emission increased. The maximum increase of O_3 was found in downtown area. If vehicular emission increased 100% in Guangzhou, the average concentration and maximum concentration of O_3 will increase 60%—100%.

4 Conclusion

Total amount of vehicle was 610000 in 1997 with an increase rate of 16.5%/a in Guangzhou urban area, however, total length of road was only 1809 km in 1995 with growth rate 8.1%/a. This incompatible increase rate resulted in heavy traffic congestion and low traffic flow. The average driving speed was only 14 km/h in urban area with high frequency of idle and acceleration. As a result, Guangzhou suffered from serious NO_x pollution and vehicular emission was identified as a main source for air pollution in urban area.

Air quality in street was much worse than other urban areas, and CO and NO_x concentration exceeded 2nd class of NAQS frequently and substantially. In Dongfeng Street, the concentration of primary pollutant CO and NO showed an upward flux, while the concentration of NO_2 and O_3 showed a downward flux. Below the roof, the changes of CO and NO were highly correlated with traffic flow. Above the roof, NO_2 and O_3 showed very clear photochemical behaviors, indicating potential photochemical smog pollution even in upper air of traffic dense area.

Photochemical smog pollution was serious in general, spatial and seasonal distribution of O_3 was observed in Guangzhou area. O_3 concentration was low in downtown area, but it was high in suburbs and downwind direction of cities. The concentration of O_3 was kept at high level in autumn, its formation was restrained in summer due to frequent thunderstorm and high humidity. The numerical simulation showed the average concentration and maximum concentration of O_3 would increase 60%—100% if vehicular emission increased 100% in Guangzhou.

References

Cheng C H, Zhu R F, 1997. Shanghai Vehicle, 1—10

Committee on Tropospheric Ozone Formation and Measurement, 1991. Rethinking the ozone problem in urban and regional air pollution. Washington, D. C.: National Academy Press

Editorial Board of China Environmental Yearbook, 1995. China environmental yearbook 1995. Beijing: China Environmental Yearbook Inc.

Tang X Y, Li J L, Chen D H, 1995. Pure and Applied Chemistry, 67:1465—1468.

Zhang Y H, Shao M, Hu M, 1997. 90th Annual Meeting of Air & Waste Management Association. Toronto, Canada. June 1997

Zhang Y H, Shao K S, Tang X Y, Li J H, 1998. Acta Scientiarum Naturalium Universitatis Pekinensis, 34 (2—3):392—400