Journal of Environmental Sciences Vol. 12, No. 1, pp. 39—46, 2000

ISSN 1001—0742
CN11—2725/X

Article ID: 1001-0742(2000)01-0039-08

Assessment of traffic related air pollution in urban areas of Macao

HE Dong-quan[1], ZHOU Zhong-ping[1], HE Ke-bin[1], HAO Ji-ming[1*], LIU Yang[1], WANG Zhi-shi[2], DENG Yu-hua[2]

(1. Department of Environmental Science and Engineering, Tsinghua University, Beijing 100084, China; 2. Faculty of Science and Technology, University of Macao)

Abstract: A method that enables the user to assess air pollution originated from vehicle emission in the urban center was described by taking Macao as an example. The method involved the use of mathematical models for the calculation of urban pollutant emissions and concentrations, of which a revised MOBILE5 was adopted to calculate the emission factors and two dispersion models of CAR and OSPM were used to calculate the long term and short term concentrations within street canyons, respectively. The results show consistency with the monitoring data, and some conclusions of controlling vehicle emissions are given based on the calculation results.

Key words: air pollution; traffic; urban area; Macao

CLC number: X823 **Document code**: A

1 Introduction

In recent years, more and more cities have suffered from air pollution caused by vehicle discharge. Many of the pollutants from vehicles, not only have direct harmful effects on human health, vegetation and material, but also act as precursors to form toxic aerosol as well as photochemical smog, which is more harmful to air quality(Seinfeld, 1986).

The situation mentioned above is more notable for districts with high population density and complex streets topology. Macao, located in littoral of South China(longitude 113°32′—113°35′E, latitude 22°07′—22°13′N), is just such a typical city since there are about 0.48 million people living in 6.9 km^2 area. Macao has a typical tropical oceanic climate that is humid and warm. Its annual average temperature is 22.3℃, and annual average wind speed is 3.5 m/s with Southeastern wind prevailing in summer and Northwestern wind prevailing in winter.

Macao has an economy that features manufacturing, tourism and construction. Tourism and gambling contributed 39% and 27% to the total GNP in 1991. Most of the industries are clean and cause few environmental problems. Compared with this, Macao has large vehicle population(Table 1), whose emissions are great impacting the urban environment.

Table 1 Vehicle population in Macao

Type	Motor bike	MC	LDV	HDV
Population	15236	17734	39621	3753

Notes: MC——the motorcycle; LDV——Light duty vehicle; HDV——heavy duty vehicle

For the purpose of assessing traffic-related pollution in Macao, China's new air quality standards(GB3095-1996) are assumed and are listed limits for some pollutants in Table 2. Because Macao is an economically flourishing zone where tourism is important, the most stringent standards should be applied.

Since no routine monitoring of vehicular pollutants is conducted in Macao, some short term monitoring was performed by research members of this project from Macao University at some sites where the traffic related pollution was expected to be serious. The results reveal that in daytime about 44% of the monitored CO hourly concentrations exceeds the second class standards and 29%

* Corresponding authour

is over the third class level. In contrast 69% of the NO_x hourly measurements exceeds the second class standard and the peak concentration occurred at the rush hour. The peak values of CO and NO_x are 36.8 ppm and 336.25 ppb, respectively.

Because of the big gap between exiting air quality and the standards, a comprehensive environmental control strategy is required to control traffic pollution. Within this framework, it is necessary to specify current vehicle use, emission control levels, traffic performance and pollutant concentrations in Macao and find the main factors which contribute to the air pollution. This paper describes a method accomplished it.

Table 2 China atmospheric quality standards for air pollutants

Pollutants		Limit, mg/m^3		
	Average time	Class I	Class II	Class III
TSP	Annual	0.08	0.20	0.30
	Daily	0.12	0.30	0.50
NO_x	Daily	0.10	0.10	0.15
	Hourly	0.15	0.15	0.30
CO	Daily	4.00	4.00	6.00
	Hourly	10.00	10.00	20.00
O_3	Daily	0.12	0.16	0.20

2 Methods

The method developed in this project has been applied to the urban core of Macao where high traffic density, crowded buildings and poor air quality exit. Some mathematical models for vehicle emission calculations and pollutant dispersion simulation were employed and the pollutants taken into account were CO and NO_x.

The calculation of vehicle emissions focuses on the determination of vehicle emission factors. In this research, a revised MOBILE5 model developed by US Environmental Protection Agency (USEPA) was used to calculate vehicle emission factors in Macao. Other data such as vehicle traffic flow, traffic time distribution and the composition of the vehicle fleet were either acquired from the Macao municipal government or gathered on site.

For the purpose of maintaining air quality, the urban center of Macao should be the focus because that is where traffic-related pollutant concentrations exceed the air quality standards. Since high concentration of CO and NO_x always occur in street canyons, in this research, the calculation of pollutant concentrations was focused on the pollutant dispersion within street canyons. Two mathematical models were adopted to calculate the long term and short term concentrations respectively: the CAR model developed by Dutch was used for long term calculations and OSPM model developed by Denmark was used for short term calculations.

Finally, based on the calculation results, factors that contribute to the high pollutant concentrations in urban center in Macao were analyzed, and corresponding countermeasures were recommended to control the vehicle emissions.

3 Vehicle emissions calculation

In this research, vehicle emissions are used for input into the dispersion models as well for analyzing the reasons of serious air pollution in Macao. They can be calculated by multiplying the estimated emission factors by traffic flow in the street canyons. The traffic flow data in rush hour were gained from Macao government, whereas the daily time variation of traffic was investigated on site. The trend(Fig.1) can be characterized by the daily work cycle with three peaks: morning peak at 9:00, a middy peak at 14:00 and an afternoon peak at 16:00 which corresponds to the time people go to work and return home.

The vehicle emission factors for NO_x and CO in the Macao urban area were estimated by using a revised MOBILE5 model developed by USEPA. The vehicle types as well as their operating situations were taken into consideration. To construct the revised model, information and data from Macao were substituted for functions in MOBILE5 so the model would estimate emission factors appropriate for Macao vehicles. The most significant changes were in the following areas:

Basic emission levels: The basic emission levels in MOBILE5 were changed to make them appropriate for Macao vehicles. Because of the lack of monitoring data on vehicle emission characteristics in Macao, the basic emission levels were estimated either from laboratory testing results of similar vehicle type in China or by directly matching control technology with appropriate US vehicle technologies. For example, current Macao light-duty gasoline vehicles are assumed to have emission characteristics similar to those for US vehicles produced in the late 1970s. Emission characteristics are also a function of the cumulative mileage.

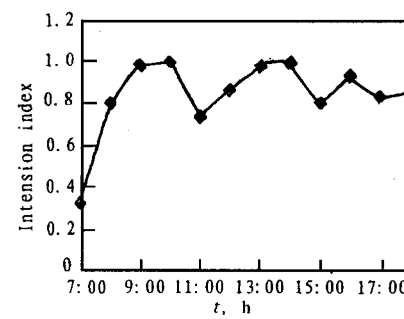

Fig.1 Time variation of traffic flow in Macao

Vehicle registration distribution: The vehicle registration distribution represents the ages of in-use vehicles. Macao's situation is significantly different from those default assumptions in MOBILE5. Therefore, the local data, supplied by Macao government, were used to substitute for the MOBILE5 default values.

Other parameters: Other parameters such as ambient temperature, fuel characters, vehicle traveling speed, cold/hot star fraction, percentage of air conditioning, trailer towing and overloading were determined based on information from Macao.

The results are listed in Table 3. The emission factors in Macao are generally higher than those in American but a little lower than those in China since most of the vehicles in Macao are imported from Japan and Korea whose technology is more advanced than that in China. CO emission factors vary greatly with the travel speed; when travel speed increase from 20 km/h to 35 km/h, the emissions decrease by 42.4%, whereas NO_x changes very little with speed. Furthermore, Macao does not have an inspection/maintenance (I/M) program, which means that the emission characteristics of in-use vehicles will deteriorate quickly. This is an other reason that the emission factors of vehicles in Macao are so high.

Table 3 Vehicle emission factors in Macao(g/km)

Situation	Pollutants	Seasons	LDGV	LDGT	HDGV	LDDV	LDDT	HDDT	MC
Congestion (V=20 km/h)	CO	Winter	37.4	64.1	115.5	2.6	2.0	29.3	28.8
		Summer	50.5	85.8	147.5	2.6	2.0	29.3	28.8
		Average	43.9	75.0	131.5	2.6	2.0	29.3	28.8
	NO_x	Winter	1.58	2.11	3.94	0.73	0.84	11.87	0.13
		Summer	1.55	2.05	3.62	0.73	0.83	11.86	0.12
		Average	1.56	2.08	3.78	0.73	0.83	11.87	0.13
Busy (V=30 km/h)	CO	Winter	44.2	76.0	117.3	2.1	1.6	23.7	22.6
		Summer	32.8	56.7	91.9	2.1	1.6	23.7	22.6
		Average	38.5	66.4	104.6	2.1	1.6	23.7	22.6
	NO_x	Winter	1.51	2.00	3.74	0.66	0.76	10.80	0.12
		Summer	1.54	2.06	4.07	0.66	0.76	10.80	0.14
		Average	1.53	2.03	3.90	0.66	0.76	10.80	0.13
Free (V=40 km/h)	CO	Winter	25.1	44.3	65.2	1.5	1.2	17.1	16.4
		Summer	33.7	59.2	83.2	1.5	1.1	17.1	16.5
		Average	29.4	51.8	74.2	1.5	1.1	17.1	16.4
	NO_x	Winter	1.52	1.97	3.95	0.58	0.67	9.52	0.14
		Summer	1.55	2.03	4.30	0.58	0.67	9.53	0.16
		Average	1.54	2.00	4.13	0.58	0.67	9.52	0.15

Notes: LDGV——light duty gasoline vehicle, ; LDGT——light duty gasoline truck; HDGV——heavy duty gasoline vehicle; LDDV——light duty diesel vehicle; LDGT——light duty gasoline truck; HDGV——heavy duty gasoline vehicle; MC——motorcycle.

4 Simulation of pollutants dispersion

4.1 Simulation of long term concentrations

In this research, the long-term concentrations of pollutants in the main streets in urban center of Macao were calculated by the CAR model. This model, developed by Dutch, was used to calculate long term pollutant concentrations within street canyons. The basic output includes annual percentile values and average concentrations of non-reactive air pollutants. The basic principles of this model are that although the short term pollutant concentration values are strongly affected by the buildings in the streets, the long term average concentration pattern is much less sensitive to these than is often assumed. Furthermore, it was found that the ratio of the annual average levels to the high percentiles of the frequency distribution of concentrations did not vary very much from street to street(Eerens, 1992). The CAR model calculates the pollutant dispersion by dividing streets into some different types. For each type of the street, an experiential equation was adopted to calculate the pollutant concentration originating from the local traffic; the annual average concentration and percentile values are calculated by adding the background level to the local concentration.

The input data, such as length, width and the traffic flow on these roads are listed in Table 4. Other parameters inputted include emission factors of LDV and HDV, which were determined by the revised MOBILE5 model, traffic flow, street canyon topologies, ambient pollutant concentrations as well as meteorological conditions.

The simulated concentrations within some main streets in the urban center of Macao are shown in Fig.2 and Fig.3.

Table 4 Traffic flow on main roads in the center of Macao

Name of the street	Length, m	Width, m	Traffic flow(rush hour, veh/h)		
			Car	Trucks and buses	Motorcycle
Alnirante coast	164	18	875	1215	713
Horta E costa	392	20	650	570	435
Marginaldopatane	492	18	720	1590	1176
De almeida Road 1	212	10	820	885	150
De almeida Road 2	204	10	2110	1215	480
Rua de Street	260	12	560	375	375
Bela vista	648	18	730	614	310
Avenda da Street	856	16	1220	338	345

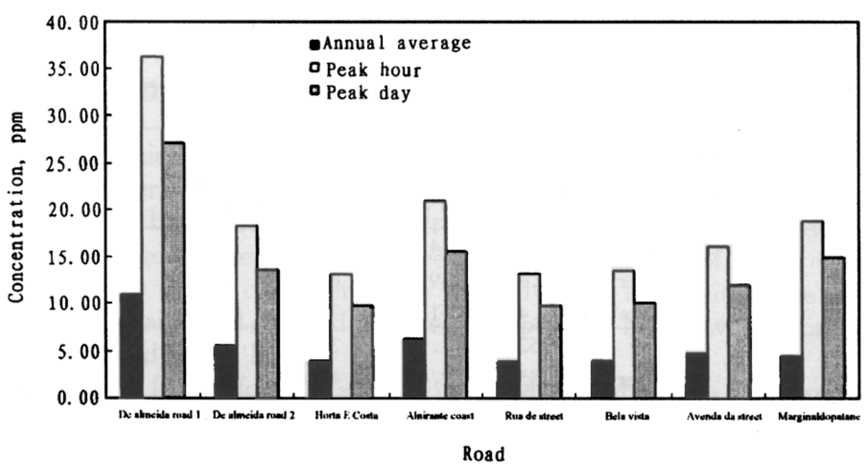

Fig.2 Long term CO concentration in street canyon of Macao

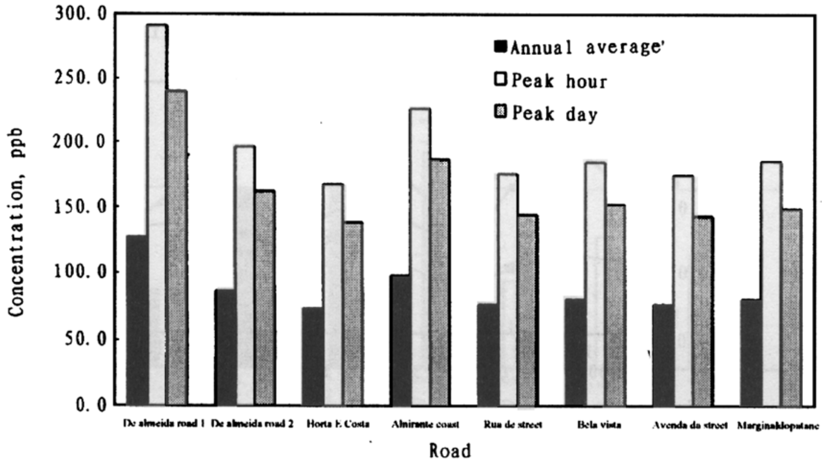

Fig. 3 Long term NO_x concentration in street canyon of Macao

4.2 Simulation of short term concentrations

In this research, the OSPM model, developed by Denmark, was adopted to calculate the short term concentrations of non-reactive pollutants in street canyon. OSPM assumes the concentrations of pollution arising from the traffic in the street as the sum of two contributors: a direct contribution caused by transport of pollutants by wind flow directly towards the receptor and a recirculation components which is due to transport and dispersion of pollutants by the wind vortex created in the street canyon.

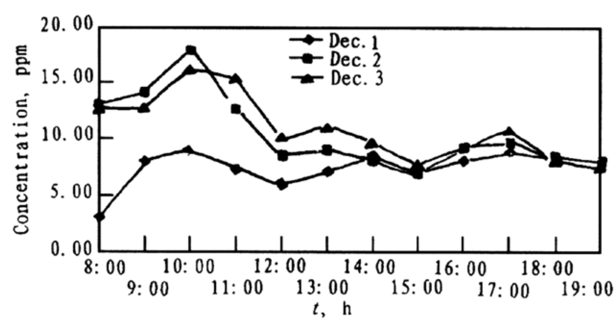

Fig. 4 CO concentration in the street canyon in Macao(Leeside)

The direct contribution is calculated using a simple Gaussian plume model. The emission field is treated as a number of infinitesimal line sources aligned perpendicular to the wind direction, the contribution from the recirculation part is calculated assuming a simple box model. The box recirculation zone is assumed as shape of a trapezoid, and the concentration is solved by the mass balance.

Based on the monitoring results, the most serious pollution appears in the Campo section of DE Almeida Street which originated not only from the overloading traffic flow, but also from the street topology(narrow street with height/width ratio over 2). Therefore, this road section was selected in this project to study the dispersion of pollutants.

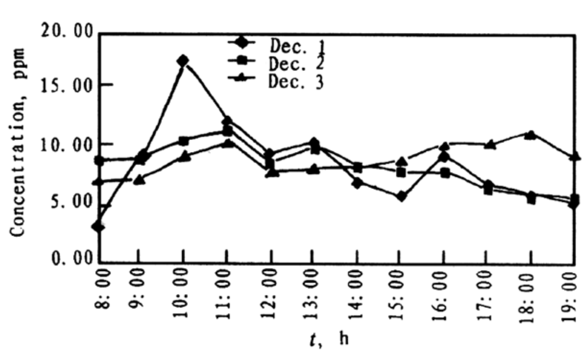

Fig. 5 CO concentration in street canyon in Macao(Windside)

The input parameters to OSPM include emission factors which were calculated by the revised MOBILE5 model, traffic flow and composition, street characteristics as well as meteorological conditions. All information used here is based on the investigation in Macao.

According to the meteorological data supplied by Macao, OSPM model was used to calculated the hourly average concentration within the street canyon during Dec. 1 to 3, the results are shown in Fig.4—Fig.7. In addition, the potentially dangerous meteorological conditions for vehicle pollutants dispersion were studied(Fig.8—Fig.11).

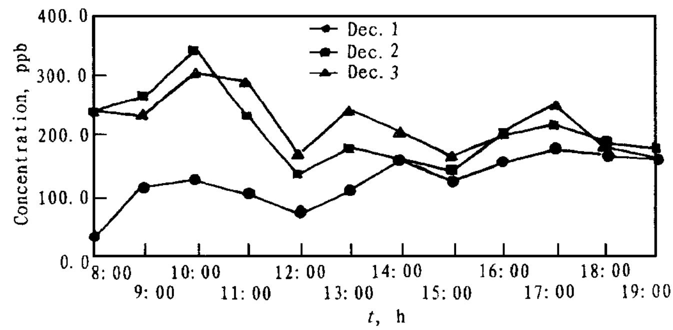

Fig.6 NO_x concentration in street canyon of Macao(Leeside)

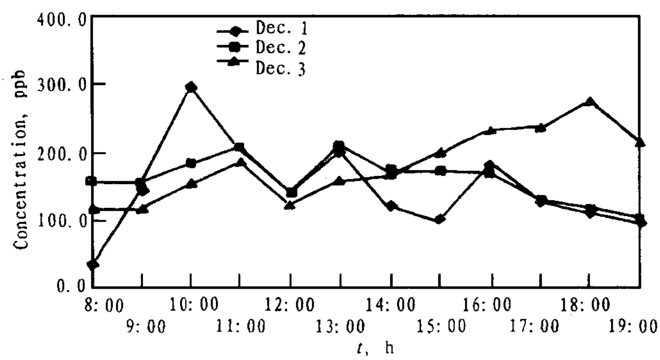

Fig.7 NO_x concentration in street canyon of Macao

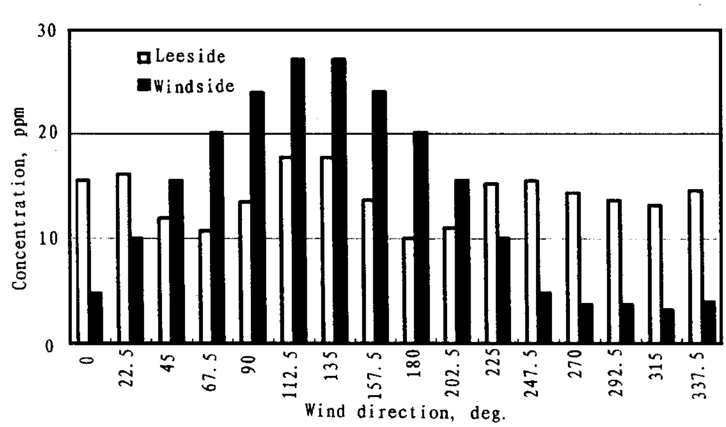

Fig.8 Different CO concentrations variation with the wind direction(V = 3m/s)

5 Discussion

The aim of this study is to assess the traffic-originated pollution in the center of Macao and to find out the main elements resulting in high pollutant concentrations so as to develop control strategies for dealing with the air pollution. Because of the lack of monitoring data, the dispersion model must be tested to determined if it is suitable to the situation in Macao.

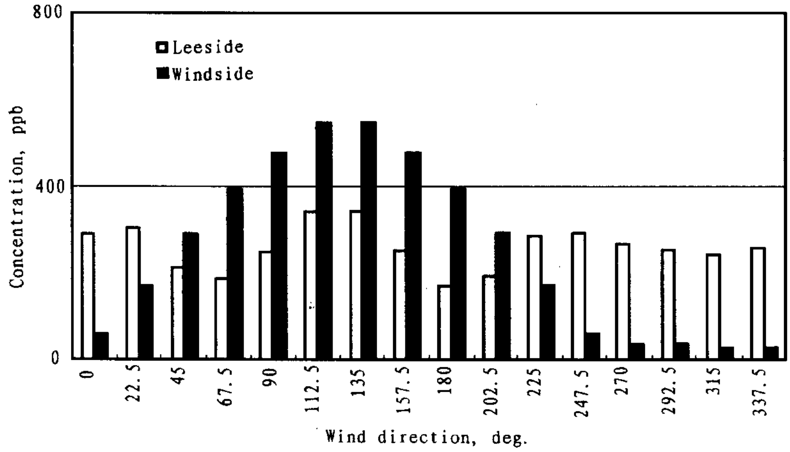

Fig.9 Different NO_x concentrations variation with the wind direction(V = 3m/s)

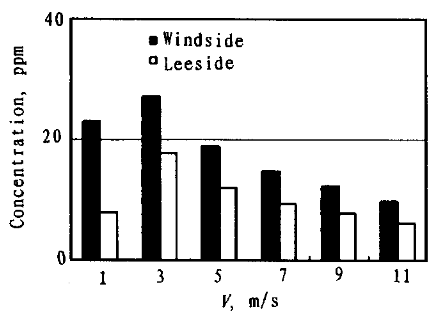

Fig.10 CO concentration variation with the wind speed in street canyon

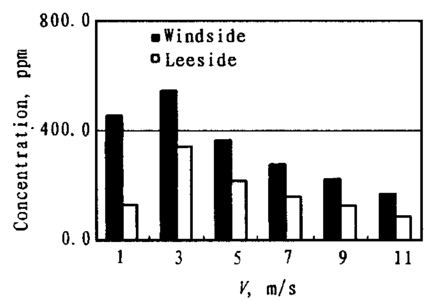

Fig.11 NO_x concentration variation with the wind speed in street canyon

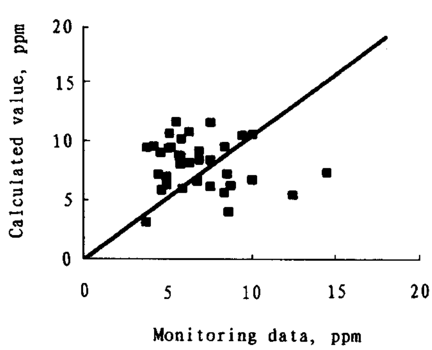

Fig.12 Relativity between calculation by OSPM and monitoring (CO)

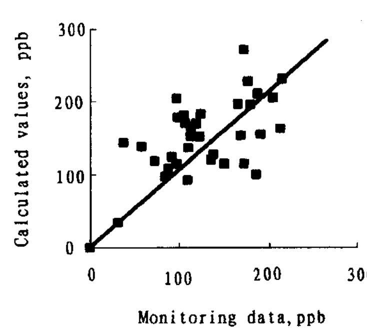

Fig.13 Relativity between calculation by OSPM and monitoring (NO_x)

Since there is no long term routine monitoring for vehicle pollutants in Macao, the results from the CAR model can not be fully verified. But because of the geographical similarity of Macao and Netherlands(they are all littoral, oceanic climate and have similar economic situation and urban street topology), the authours believe that the CAR model which was used well in the Netherlands, should provide the useful results in Macao. Whereas verification should be performed in the future.

Because the monitoring site used to verify the calculation was very near to the road and the air flow was not stable, there was concern that monitoring error may cause a discrepancy. However, the modeling results are in accord with the monitoring data. The relationship of hourly average concentrations calculated with the monitoring data is shown in Fig. 12 and Fig. 13. The slopes of regressed correlative trend line are 1.08 for CO and 1.04 for NO_x, and the correlative indexes are 0.54 and 0.58 respectively. This means that the OSPM model is compatible for calculating the pollutant dispersion in the street canyons in Macao.

Since no other industry in Macao causes serious pollution, the calculated results reveal that the pollution from vehicle emission in the urban center of Macao is critical. For long term simulation, among the eight streets analyzed, CO and NO_x annual average concentration in two streets exceed the third class national air quality standards. All of the streets exceeded the second class standards. For short term concentrations calculated in the canyon of DE Almeida street, there are 21 hours of CO concentration and 48 hours of NO_x concentration exceeding the national second standard among 72 total hours calculated. The study of potentially dangerous meteorological conditions shows that under the most critical meteorological conditions (wind angle: 135° wind speed: 3 m/s), the CO and NO_x concentration would reach 28 ppm and 500 ppb respectively, which are far beyond the third class national standards. All of these results call for the control of vehicle emissions.

6 Conclusion

As mentioned above, in this research, revised MOBILE5, CAR and OSPM model were used to calculate the emission factors and pollutant dispersion, respectively, in urban center of Macao. These models work well and reflect the status of traffic-related pollution in the urban area of Macao. Since the main purpose of this research is to find out the major factors that cause the serious air pollution in urban area of Macao and supply a scientific basis for the policy making, these models are suitable to fulfill such work.

The pollution originating from vehicle emissions in Macao is serious, primarily due to high vehicle emissions and urban canyon topology. Since the shape of urban area can not change quickly. Strategies for controlling the traffic-related pollution should focus on the reduction of the vehicle emissions. The greatest emissions come from (1) heavy traffic flow at rush hour; (2) low emission control level; (3) traffic congestion and barriers to traffic flow and (4) the absence of an I/M program. Some feasible options can be adopted as follows:

Reduce the traffic flow in the main roads where high pollutant concentrations occur frequently; reduce the emissions from the newly produced vehicles either by importing vehicles with high technology engines or which are equipped with emission control equipment; adopt an I/M program to reduce the in-use vehicles emissions; change the composition of fuels for vehicle fleets to promote the use of natural gas and liquefied petrol gas; establish a system to forecast the air quality to protect the people from the harm of air pollution.

All these options should be studied and an appropriate plan should be developed to quickly deal with pollution in the urban center of Macao.

References:

Eerens H C, 1992. Atmospheric Environment 27B[J], 389—399.

Seinfeld J H, 1986. Atmospheric chemistry and physics of air pollution[M]. New York: John Willey.

(Received for review September 2, 1998. Accepted November 9, 1998)