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Chemical composition and quantitative relationship between meteorological condition and fine particles in Beijing

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Abstract: The recent year's monitor results of Beijing indicated that the pollution level of fine particles $PM_{2.5}$ showed an increasing trend. To understand pollution characteristics of $PM_{2.5}$ and its relationship with the meteorological conditions in Beijing, a one-year monitoring of $PM_{2.5}$ mass concentration and correspondent meteorological parameters was performed in Beijing in 2001. The $PM_{2.5}$ levels in Beijing were very high, the annual average $PM_{2.5}$ concentration in 2001 was 7 times of the National Ambient Air Quality Standards proposed by US EPA. The major chemical compositions were organics, sulfate, crustals and nitrate. It was found that the mass concentrations of $PM_{2.5}$ were influenced by meteorological conditions. The correlation between the mass concentrations of $PM_{2.5}$ and the relative humidity was found. And the correlation became closer at higher relative humidity. And the mass concentrations of $PM_{2.5}$ were negtive-correlated to wind speeds, but the correlation between the mass concentration of $PM_{2.5}$ and wind speed was not good at stronger wind.

Keywords: meteorological conditions; quantitative relation; fine particles($PM_{2.5}$); Beijing

Introduction

Fine particles are air pollutants with complex chemical composition including poisonous materials. As they can be breathed in the man's lung deeply, and very difficult to be ventilated out, therefore they are very harmful to human health. Fine particles can also result in atmospheric visibility deterioration through light extinction. Current researches indicated that there is a good negative correlation between the atmospheric visibility and the mass concentration of fine particles. In recent years, the fine particle pollution has become one of the most important issues in air pollution research in China. However, studies in this field in China so far are still relatively weak. Thus an integrated monitoring of fine particles and simultaneous meteorological data will make it possible to investigate the linkage between mass concentrations of fine particles and the meteorological parameters, and to help in improving atmospheric visibility in Beijing.

For this purpose, Beijing Meteorological Bureau, in cooperation with Peking University, performed a monitoring of $PM_{2.5}$ and meteorology in 2001 at four seasons which were spring(March), summer(June), autumn(September), and winter(December). The sampling sites were the observation field of Atmosphere Exploration Base of China Meteorological Administration(AEBCMA), Peking University(abbreviated as PKU thereafter) and Beijing downtown site Dongsi (abbreviated as DS thereafter) Monitor Station. The atmosphere visibilities were read through the DPVS(Digital Photo Visibility System)(Xie, 1999) directly, other relevant meteorological data were available from routine observation at AEBCMA. Mass concentrations of $PM_{2.5}$ were monitored in real time by Anderson's CAMMS, samples collected by Anderson's RAAS-400 were used for chemical compositions of $PM_{2.5}$ including sulfate, nitrate, trace metals, crustals, EC and OC. Filter samples of $PM_{2.5}$ were collected with Anderson's RAAS-400 sampler. Elements, ion and OC/EC of $PM_{2.5}$ were analyzed by ICP, X-ray fluoresces and thermo-optical method.

1 Fine particles pollution characteristics

1.1 Mass concentrations of $PM_{2.5}$

The pollution level of $PM_{2.5}$ in Beijing City has been very serious. As China has not yet the national ambient air quality standard for $PM_{2.5}$, the standard proposed by US EPA (Environmental Protection Agency) in 1997, that is, day average concentration of 65 $\mu g/m^3$ and annual average of 15 $\mu g/m^3$, was adopted for assessment. From our measurement, the seasonal average mass concentrations of ambient $PM_{2.5}$ in Beijing ranged between 63 $\mu g/m^3$ to 167 $\mu g/m^3$, the annual average level were 110 $\mu g/m^3$, more than 7 time as the US air quality standards of $PM_{2.5}$.

The data in Fig. 1 also show that $PM_{2.5}$ had higher concentration in summer and winter. In summer time, the $PM_{2.5}$ may mainly come from secondary reaction that makes

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serious pollution at regional scale, while in winter AEBCMA at southern part of Beijing had much higher level of $PM_{2.5}$ because of more coal burning in that area.

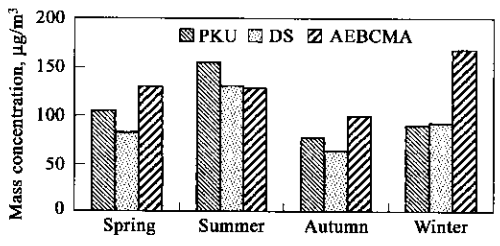

Fig.1 Mass concentrations of $PM_{2.5}$ measured at 3 monitor sites of Beijing City in 2001

1.2 Chemical compositions of $PM_{2.5}$

The chemical compositions of $PM_{2.5}$ showed very similar pattern at different site in Beijing. The annual average chemical composition in 2001 at PKU and DS is shown in Fig.2. At both sites the organics and crustal elements were the largest contributors to the $PM_{2.5}$ mass, sulfate and nitrate had also significant portion. The nearly identical chemical composition in Fig.2 hinted that the $PM_{2.5}$ pollution was a regional issue.

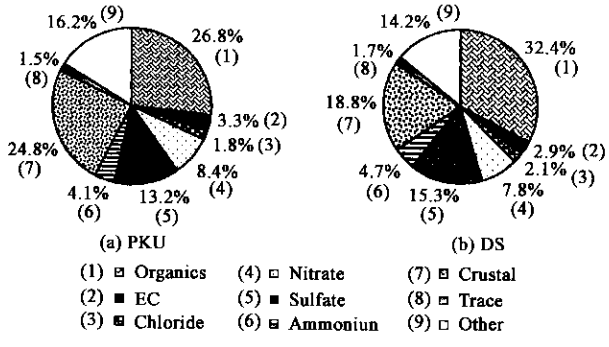

Fig.2 The chemical composition characteristics of $PM_{2.5}$ at PKU and DS in 2001

However, the chemical composition of $PM_{2.5}$ seemed to change with season. Using the data measured at AEBCMA as an example, the major chemical species in $PM_{2.5}$ showed different contribution to $PM_{2.5}$ in summer, autumn and winter (Fig.3). Similar to Fig.2, organics, sulfate and nitrate were main species in $PM_{2.5}$, the organics (OC) was the largest contributor. The ratio of OC to EC in atmosphere was used as an indicator for secondary pollution in the air, the ratios of OC/EC of $PM_{2.5}$ in Fig.3 were 7 to 11, much larger than the critical value of 2 (Liu, 2002), showing the existence of secondary pollution in Beijing.

2 The relation between $PM_{2.5}$ and meteorological conditions

2.1 Spring time

Beijing City in spring is dry and windy, and it is favorable for the out-spreading of pollutants. In the spring of 2001, Beijing had less precipitation, higher temperature, stronger wind and more dusty days than normal.

Fig.4 shows diurnal variation of $PM_{2.5}$ mass concentrations and humidity in breeze(wind speed less than 4 m/s) days. A good correlation between the mass concentrations of $PM_{2.5}$ and the relative humidity was found in these days. The variation of $PM_{2.5}$ concentrations with wind speeds are shown in Fig.5 for breeze day and Fig.6 for a day with stronger wind respectively. From these 2 figures, we knew that there was a close negtive-correlation between the mass concentrations of $PM_{2.5}$ and the wind speeds in breeze day, but Fig.6 shows that the negtive-correlation in stronger wind seemed not as good as the case in breeze.

2.2 The pollution features of fine particles in summer

The average temperature was 26.1℃ in summer of 2001 in Beijing, 1.3℃ higher than that in summer of common years(24.8℃), even 1.6℃ higher in June.

Fig.7 illustrates of relationship of $PM_{2.5}$ mass concentrations and humidity in summer at AEBCMA. The tendency of two curves was very similar from this figure, showing that there was an obvious correlation between the mass concentrations of $PM_{2.5}$ and humidity further.

Beijing had more precipitation and smog in summer than in other seasons, the relative humidity was therefore higher in summer. In no precipitation days in summer, the relative humidity was low, and particles diffusion was efficient, consequently the mass concentration of $PM_{2.5}$ was low. The relative humidity and the mass concentrations of $PM_{2.5}$ in the light rainy days were comparable to that in smog days. But the relative humidity in light rainy days was a little higher

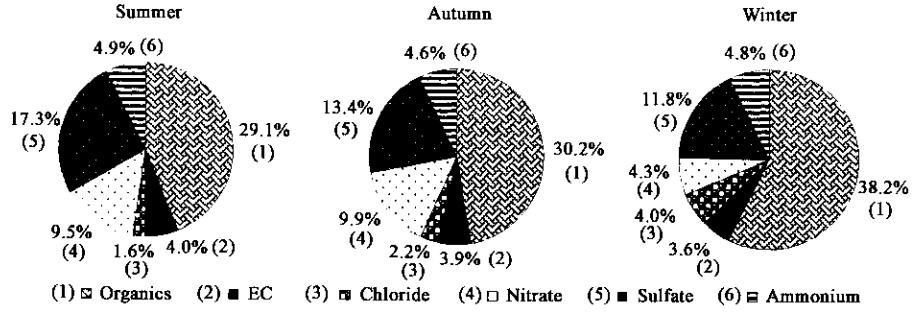

Fig.3 The chemical composition of $PM_{2.5}$ in summer, autumn and winter at AEBCMA(crustal and trace metals were not analyzed at the site)

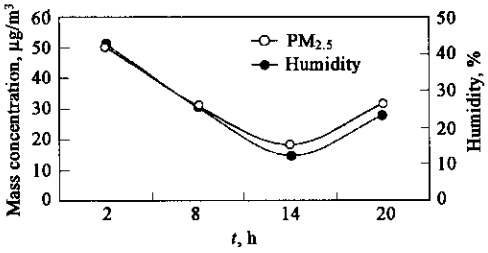

Fig. 4 The variation of $PM_{2.5}$ mass concentration and humidity in breeze days (average from March 28 to March 31)

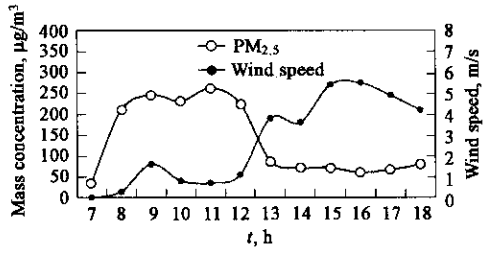

Fig. 5 The variation of $PM_{2.5}$ concentrations and wind speeds measured on March 16

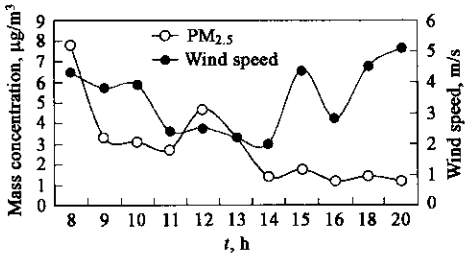

Fig. 6 The variation of $PM_{2.5}$ concentrations and wind speeds measured on March 25

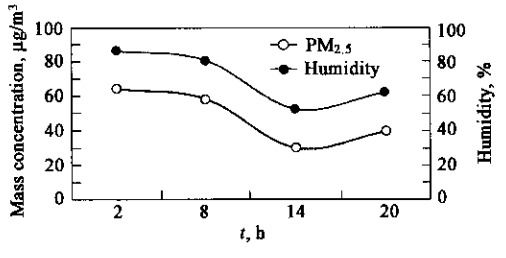

Fig. 7 The variation of $PM_{2.5}$ mass concentrations and humidity in summer in Beijing (average from June 16 to June 26)

than that in smog days, and the mass concentrations of $PM_{2.5}$ was a little lower than that in smog days, hinting played a role in wash-out of $PM_{2.5}$. Though relative humidity became very higher in heavy rain, the mass concentrations of $PM_{2.5}$ were significantly low as shown in Fig. 8. The mass concentrations of $PM_{2.5}$ dropped rapidly in the heavy rain, which started at three o'clock in this chart, and remained at low level during the heavy rain from eleven to thirteen o'clock in this chart, then the mass concentrations of $PM_{2.5}$ went up after heavy rain.

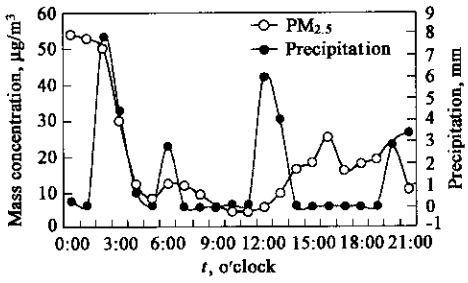

Fig. 8 The process of a heavy rain and variation of mass concentrations of $PM_{2.5}$ in summer of Beijing

2.3 Autumn time

In the fall, the humidity was still high, but lower than that in summer in Beijing. Fig. 9 to Fig. 11 were the results of $PM_{2.5}$ mass concentrations and some meteorological parameters in AEBCMA in autumn of 2001 by using Anderson's CAMMS real time monitor.

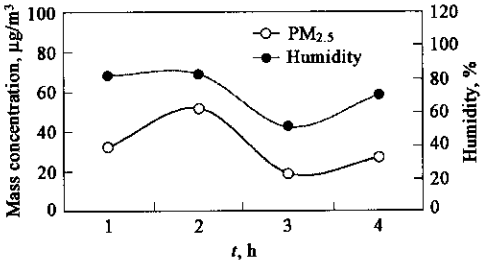

Fig. 9 Diurnal variation of the mass concentration of $PM_{2.5}$ and the relative humidity in foggy days in autumn of Beijing (average from September 12 to 16)

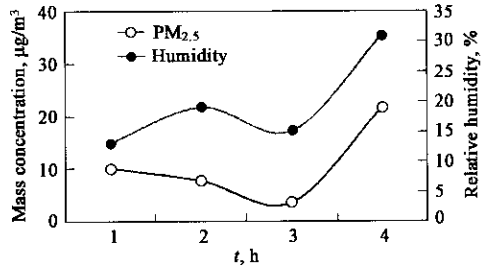

Fig. 10 Diurnal variation of the mass concentration of $PM_{2.5}$ and the relative humidity in no fog days when relative humidity is less than 30 percent in autumn of Beijing (Sep. 18)

The same as above, a good correlation between the mass concentration of $PM_{2.5}$ and relative humidity in foggy days in autumn is shown in Fig. 9. When relative humidity dropped to less than 30% in no fog days is shown in Fig. 10 (Sep. 18), the correlation was not as good as that in days with higher humidity. Fig. 11 give the case in no fog days when relative humidity is from 30% to 60% in autumn of Beijing (Sep. 19). It is interesting to find that correlation between the mass concentrations of $PM_{2.5}$ and relative humidity seemed to have dependency on relative humidity itself, and the

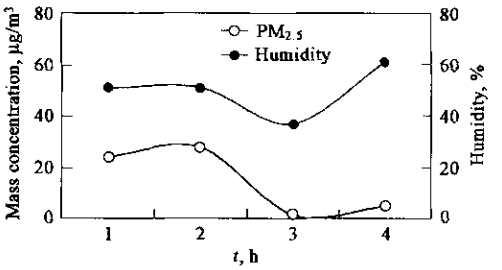

Fig.11 Diurnal variation of the mass concentration of $PM_{2.5}$ and the relative humidity in no fog days when relative humidity is from 30% to 60% in autumn of Beijing(Sep.19)

correlation was getting closer while relative humidity became higher.

2.4 Winter time

The $PM_{2.5}$ pollution in winter time was influenced by three major factors: (1) coal burning in winter made the primary emission of fine particles increase; (2) atmospheric inverse layer was the lowest in a year, and formed earlier but destructed later in a day, therefore fine particles could accumulate to higher concentrations in winter; (3) cold air of large scale from north of Beijing brought dry air with strong wind in Beijing. In this case the $PM_{2.5}$ could be very low.

The factors above made the $PM_{2.5}$ pollution level in winter varies greatly(Song, 2003). Fig.12 shows the mass concentrations of $PM_{2.5}$ measured in 5 d continuously at AEBCMA.

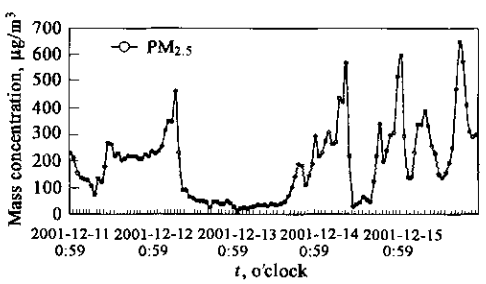

Fig.12 The variation of the mass concentrations of $PM_{2.5}$ in winter(from Dec.11 to Dec.15)

Fig.13 shows the average diurnal variation of the mass concentrations of $PM_{2.5}$ and wind speeds in breeze days in winter of 2001 observed at AEBCMA. From this chart, we knew that the mass concentrations of $PM_{2.5}$ decreased obviously when the wind speed was larger than 2 m/s. On the contrary, the mass concentration of $PM_{2.5}$ increased obviously when the wind speed was less than 1.5 m/s. This illustrated the negtive-correlation between the mass concentrations of $PM_{2.5}$ and wind speeds. Fig.14 plots the 3 d measurement of variation of $PM_{2.5}$ and wind speeds in December when strong wind in heavy sandy days occurred. The negtive-correlation was very obvious in the chart.

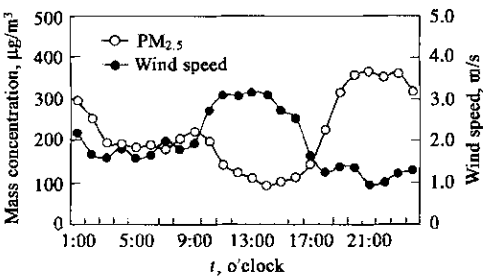

Fig.13 Diurnal variation of the mass concentrations of $PM_{2.5}$ and wind speed in breeze days in winter

2.5 Diurnal variation of $PM_{2.5}$ pollution

The average diurnal variation of $PM_{2.5}$ measured in summer at AEBCMA is given in Fig.15. The monitoring duration had high temperature and days with fog were more than 70% in June. The samples were taken in foggy and rainy days. From this chart, we could see the mass concentrations of $PM_{2.5}$ were higher at night and lower at daytime. And the highest level appeared between 2:00 to 8:00 in the morning, and the lowest values appeared between 14:00 to 16:00 in the afternoon. This was consistent with the weather condition in June. The fog in summer appeared after the midnight, and last till 7:00 or 8:00 in the morning. The humidity data of four times per day of AEBCMA in June of 2001 showed the average humidity at 2:00 and 8:00 in the morning was above 70%, while only 49.7% after 14:00 in

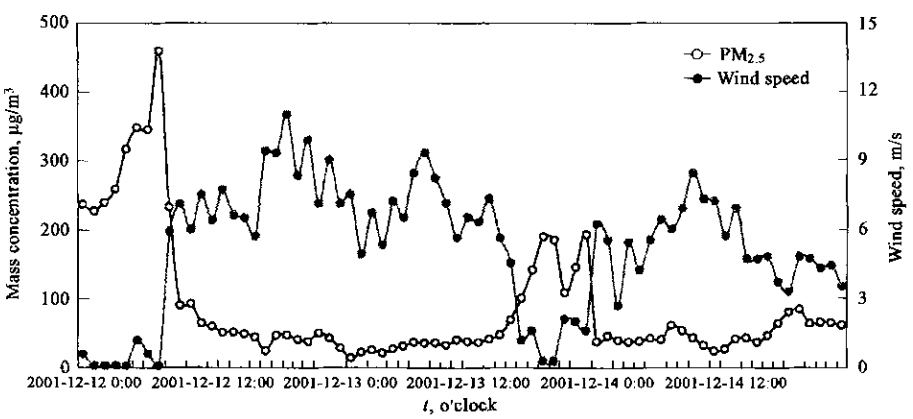

Fig.14 The variation of the mass concentration of $PM_{2.5}$ and wind speed in windy days in winter of Beijing(Dec.12—14)

the afternoon.

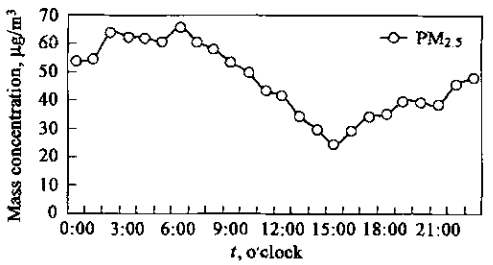

Fig.15 The diurnal variation of the mass concentrations of $PM_{2.5}$ in summer of Beijing (average from Jun. 16 to Jun. 26)

However, the diurnal pattern of $PM_{2.5}$ in winter was different (Fig.16). Fig.16 shows $PM_{2.5}$ began to be enhanced from 17:00 in winter, and reached its maximum around 21:00 to 23:00 in the evening, and then faded away. The inverse layer started to form after midday in winter, from when the wind speed began to slow down and then $PM_{2.5}$ pollution built up gradually. After midnight, wind speeds went up and the pollution in the inverse layer began to diffuse away. Also found in figure was a small peak between 7:00 and 11:00 in the morning, which was probably due to traffic emission in rush hours.

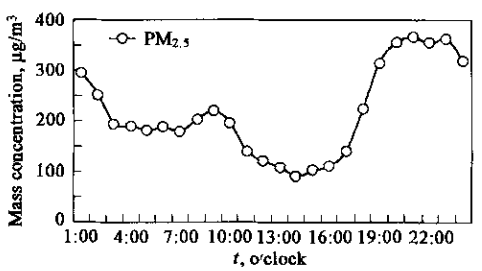

Fig.16 Diurnal variation of $PM_{2.5}$ mass concentrations in winter of Beijing (average of data in December)

3 Conclusions

The chemical composition of $PM_{2.5}$ was similar at different sites in Beijing but changed with seasons.

The mass concentrations of $PM_{2.5}$ in Beijing violated air quality standards proposed by US EPA, the major components of $PM_{2.5}$ were organics.

There was a correlation between the mass concentrations of $PM_{2.5}$ and the relative humidity. And the higher the relative humidity, the closer the correlation.

There was an negtive-correlation between the mass concentrations of $PM_{2.5}$ and the wind speeds when the wind speed less than 4 m/s. The correlation between the mass concentration of $PM_{2.5}$ and wind speed was not good at strong wind.

Epilogues:

$PM_{2.5}$ is a serious air pollutants but only the USA proposed its National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$. China has only NAAQS for PM_{10} so far. We do hope that the exploring the relations between the weather conditions and $PM_{2.5}$ levels may provide the necessary scientific basis for the establishment of NAAQS of $PM_{2.5}$ in China.

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