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Characteristics and relationship of PM, PM10, PM2.5 concentration in a polluted city in northern China

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Abstract

Ground measurements of particulate matter (PM), PM_{10} and $PM_{2.5}$ were recorded using a ten-channel Quartz Crystal Microbalance (QCM) Cascade Impactor in a polluted city, Shijiazhuang, northern China for the period Jan. – Mar. and Jun. 2007. The spectra characteristics in the concentrations of PM are analyzed. PM, $PM_{2.5}$ and PM_{10} monthly variations are researched. PM mass concentration is similar with Beijing and four times higher than some clean sites. Mass and number concentration relationships between $PM_{2.5}$ and PM_{10} are analyzed and calculated. The mass concentration ratio of $PM_{2.5}$ to PM_{10} is 0.7. The ratio of the number concentration to mass concentration of $PM_{2.5}$ is 76,419. These relationships are used to calculate $PM_{2.5}$ number concentration by PM_{10} mass concentration for daily publication observation. Then the diurnal variation of $PM_{2.5}$ number concentration is analyzed from Jan. – Mar. 2007. This attempt provides a new way to analysis fine particles feature by using regular daily observations of PM_{10}.

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Keywords: PM; mass concentration; number concentration; polluted city

1. Introduction

Particulate matter (PM) has already emerged as one of the most critical pollutant and been made global concern

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especially in China. Particles with aerodynamic diameters less than 10 μm are defined as PM_{10}. $PM_{2.5}$ is aerodynamic diameters less than 2.5μm. Recently, rapid increasing PM_{10} especially $PM_{2.5}$ have several environmental impacts which include polluting environment and climate, and causing problem related health.

The mass concentration and number concentration as well as particle size distribution are the main characteristic of PM. They could reflect on source, life time and physical and chemical properties of PM [1]. Currently published daily aerosol measurement are mainly based on mass concentration (PM_{10}, $PM_{2.5}$), but number concentration is more and more important in evaluation aerosol effect on climate, ecology and human life. In this filed, researches are making emphasis on particle number concentration and particle size distribution gradually. It is also known that fine aerosol ($PM_{2.5}$) is mainly contributed to aerosol particles by number concentration and it is more effect on health than mass concentration [2, 3]. That is the reason that number concentration is more significant effect on respiratory than mass concentration. Therefore, accurate number concentration and size distribution are important on assessment of health.

2. Observation site, instruments and data

The observation area, Shijiazhuang is located at the east margin of Eurasia, in middle latitudes, and lies on the transition zone of the east slope of the Taihang Mountain and Heibei plain. At the same time, Shijiazhuang, lying at southwest of Beijing, is the capital of Hebei province. Because of the special geographical climate conditions and rapid development of this city, Shijiazhuang is a serious polluted city.

The PC-2 Quartz Crystal Microbalance (QCM) Cascade Impactor is used to measure aerosol concentrations (mass concentration: mg/m^3). It measures the change of an electrode surface through the piezoelectric effect of quartz crystal [4]. The range in the diameter for each level is shown in Table 1. In this research, observations were made about once per hour. Before making measurements at Shijiazhuang, the calibration of QCM observation already was done and the results showed that the measurements made with the QCM are reliable. Based on the mass concentration results, assuming that the aerosol particle density is 2 g/cm^3, the number concentration and other related parameters can be calculated. In this research, PM observation has been done in Shijiazhuang for the period Jan. – Mar. and Jun. 2007 and obtained 356 samples in these four months.

Apart from these observation data, PM_{10} mass concentration by Environmental Protection Agency (EPA) observation from Jan. – Mar. 2007 also is used to attempt on expanded application for regular data.

Table 1. The range in diameter for levels of aerosol measurements with the QCM

Level	1	2	3	4	5	6	7	8	9	10
Aerosol diameter(μm)	25.0	12.5	6.4	3.2	1.6	0.8	0.4	0.2	0.1	0.05

3. Results and discussion

3.1. PM size distribution

PM average mass density distribution and average number density distribution are analyzed from the QCM observations (Fig. 1: double logarithm coordinate). The average mass density distribution shows a double-peak curve. The average number density distribution tends to have a linear distribution and basically belongs to the Junge size distribution. In Figure 1, the black line represents the results for Shijiazhuang, and the grey line represents the aerosol observations for the atmospheric background station of Linan (Zhejiang province, China, located at Yangtze River Delta) in 2002, for which the aerosol number concentrations are obtained with the same QCM used in Shijiazhuang. Comparing these two lines, the aerosol mass density of particles around 0.1 μm and 10 μm in diameter observed in Shijiazhuang is larger than that in Linan, and the number density distribution of Shijiazhuang is less than that of Linan in all observed ranges. These results indicate a large difference in aerosol characteristics between Shijiazhuang and Linan. The particle density of Shijiazhuang for smaller (around 0.1 μm) and bigger (around 10 μm) particles is greater than that in Linan. Therefore, although the average number density in Shijiazhuang is less than that in Linan, the average mass density in Shijiazhuang is larger than that in Linan for the same scale.

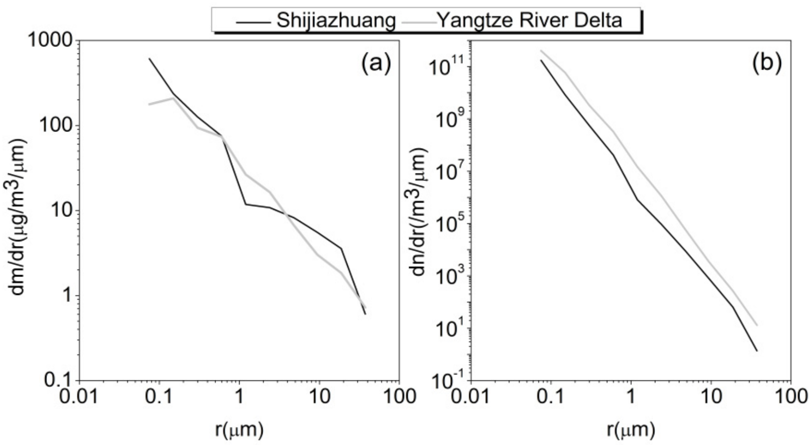

Fig. 1. (a) The average mass density spectrum of aerosols in Shijiazhuang and Linan. (b) The average number density spectrum of aerosols in Shijiazhuang and Linan. The black real line is observation results in Shijiazhuang. The grey real line is observation results in Linan (Zhejiang province, China) which is located at Yangtze River Delta. They are all observed by the same QCM.

3.2. Monthly variation of PM, PM_{10} and $PM_{2.5}$

The monthly distribution of mean PM, PM_{10} and $PM_{2.5}$ mass concentration averaged for the observation period is shown in Figure 2 in the form of box plots. The highest monthly mean concentration of PM (267μg m^{-3}), PM_{10} (211μg m^{-3}) and $PM_{2.5}$ (150μg m^{-3}) are observed in February. PM, PM_{10} and $PM_{2.5}$ mass concentration show the lowest value in June (143, 107 and 62.9μg m^{-3} respectively). On average, from Jan. to Mar., the high value is gradually accumulated and continued and is similar with Beijing observation from 2001-2003 [5]. But it is four times higher than observation results of clean site on the land [6] and near to coast [7]. At the same time, $PM_{2.5}/PM_{10}$ ratio is highest (71%) in February (Tab. 2). Compare with Beijing, $PM_{2.5}/PM_{10}$ ratio almost match in winter each other [5]. These mean that Shijiazhuang is serious polluted city and similar with Beijing.

Table 2. Average mass ratios of different sizes.

Ratio(%)	JAN (n^*=34)	FBE (n=192)	MAR (n=89)	JUN (n=41)
$PM_{2.5}/PM$	38.9	56.2	57.3	44.0
PM_{10}/PM	65.8	79.0	82.7	74.8
$PM_{2.5}/PM_{10}$	59.2	71.1	69.3	58.8

* Numbers of samples.

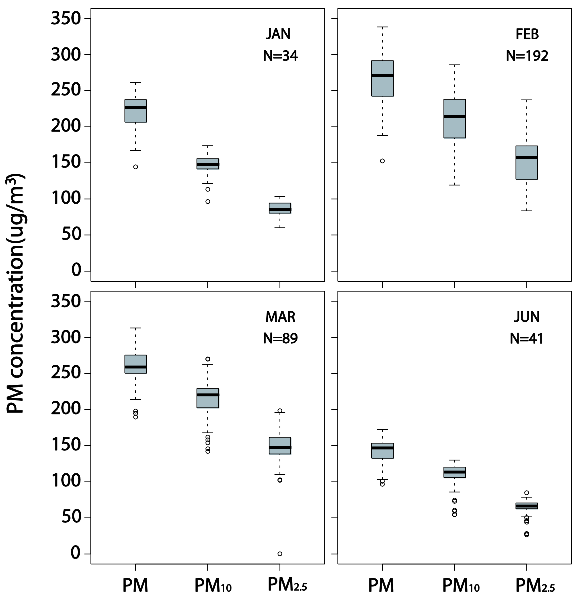

Fig. 2. Box plot showing the monthly distribution of PM, PM10 and PM2.5 mass concentration for the period Jan. – Mar. and Jun. 2007. The boxes represent 25th and 75th percentiles and the whiskers represent the 5th and 95th percentiles. The horizontal line inside each box represents the median value. N represents the number of observation sample.

3.3. The relationship of mass concentration and number concentration between PM10 and PM2.5 aerosols

PM_{10} is the daily aerosol measurement made by EPA. According to the results from the QCM, the number concentration of $PM_{2.5}$ accounts for more than 99% of the observational range of the QCM. Therefore, $PM_{2.5}$ contributes an important proportion of the aerosol number concentration. In order to apply the data obtained in this study to the daily PM_{10} measurement results, we use the 356 sample data of QCM measurements in the winter of 2007 for further analysis. The relationship between the mass concentration of PM_{10} and $PM_{2.5}$, and the relationship between mass concentration and number concentration of $PM_{2.5}$, are analyzed. The results can be used to calculate the number concentration of $PM_{2.5}$ from the regular measurements of PM_{10}.

According to the QCM results, the ratio of the number concentration between $PM_{2.5}$ and PM_{10} is 0.7 (Fig. 3(a)). The obvious relationship between the mass concentration and number concentration of $PM_{2.5}$ is shown in Figure 3(b). The ratio between number concentration and mass concentration of $PM_{2.5}$ is 76,419.42. Thus, the relationship between the mass concentration of PM_{10} and number concentration of $PM_{2.5}$ is established. These results allow for the effective use of the daily observational data.

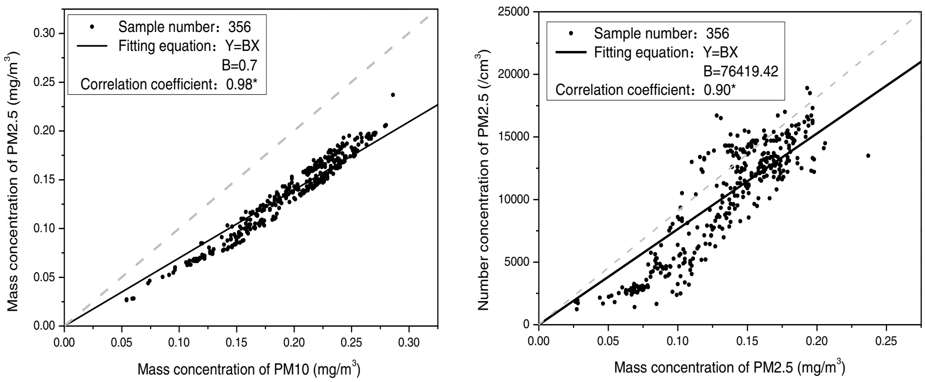

Fig. 3. (a) The relationship between the mass concentrations of $PM_{2.5}$ and PM_{10}; (b)The relationship between the mass concentration and the number concentration of $PM_{2.5}$.

3.4. Application on daily publication PM_{10}

Through the relationship between PM_{10} mass concentration and $PM_{2.5}$ number concentration of the previous section, average diurnal variation of $PM_{2.5}$ number concentration is calculated and analyzed (Fig. 4). There are two valleys in whole day. Around 14:00-19:00, it is lowest value period. Because the number concentration is mainly contributed by fine particles, this means the particle scale is not too small in this period. On the other hand, the fine particles accumulate around 7:00-9:00 obviously.

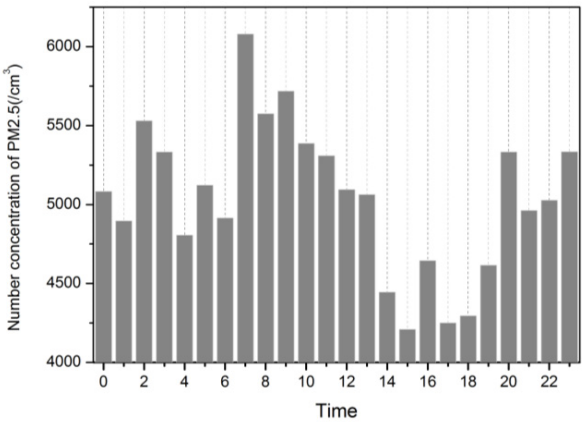

Fig. 4. Average diurnal variation of PM2.5 number concentration for the entire observations period.

4. Conclusions

In this paper, PM spectra distribution, monthly variations of PM, PM_{10} and $PM_{2.5}$ mass concentration are researched. The results show that the average mass density spectrum distribution of PM has a double peak. The average number density spectrum distribution of PM in the observational range is close to linear and belongs to the Junge distribution. PM mass concentration is similar with Beijing and four times higher than some clean sites. The relationships between mass and number concentration of PM_{10} and $PM_{2.5}$ are analyzed. The relationship between mass concentration of PM_{10} and number concentration of $PM_{2.5}$ is established and is applied it to daily PM_{10} observation. Daily publication observation about aerosol is mass concentration of PM_{10}. Based on the former analyzed relationship between PM_{10} and $PM_{2.5}$, number concentration of $PM_{2.5}$ could be calculated and the diurnal variation also is showed. This attempt provides a new way to analysis the feature of fine particles ($PM_{2.5}$) by using EPA regular observations.

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