A Comparison Analysis of Chemical Composition of Aerosols in the Dust and Non-Dust Periods in Beijing

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ABSTRACT

Dust events occurred frequently in Beijing in recent years. In this work, 120 aerosol samples were collected in two typical dust events (21–22 March and 15 May) and a non-dust period in Beijing from March to May 2001. Samples were analyzed for major elemental components by the Proton Induced X-ray Emission (PIXE) method. Results show that the enrichment factors of crustal elements such as Mg, Al, and Ti had little differences between the dust period and the non-dust period in Beijing, while the enrichment factors of other elements that have a relation to anthropogenic emissions were very low during the dust period. The results derived by using multivariate factor analysis from the observation data show that the sources such as soil dust, industry, and fuel combustion were among the major contributors to the particles in Beijing.

Key words: dust, aerosol, chemical composition, Proton Induced X-ray Emission method

1. Introduction

More and more attention to Asian dust storms has been paid due to their significant influences on both the global climate (Tegen and Fung, 1994; Tegen et al., 1996; Sokolik and Toon, 1996) and environment (Qian et al., 1997; Zhang et al., 2000). Dust storms in Northwest China can inject a large amount of desert dust into the atmosphere year after year (Chun et al., 2001; Qian et al., 1997). These particles injected by dust storms can be transported thousands of miles away and distributed over the Pacific Ocean, which may alter the chemical and radiative processes in the remote troposphere (Wang et al., 2000; Yi et al., 2001). The size distributions and chemical composition of particles are the key properties in determining the radiative effect of mineral dust particles on climate (Sokolik et al., 1998; Sokolik and Boon, 1999; Zhang et al., 2001). In order to simulate the radiative effect of dust particles on climate, it is very important to investigate the chemical properties and size distribution of dust particles in Asia (Yabuki et al., 2002). Now, more and more scientists from different countries have been cooperating to study Asian dust storms in recent years (Zhang et al., 1993; Yoshino, 2000; Kanai et al., 2002).

Sand-dust events occurred frequently in the north of China in 2000 and 2001. There were 15 and 18 dust storms in China in 2000 and 2001, respectively (Zhang et al., 2002). These dust storms severely affected traffic, atmospheric environment quality, and people's daily life in local and downstream areas (Ye et al., 2000; Zhou, 2001; Zhang et al., 2003). Zhang et al. (2002) described new characteristics below for these sand-dust events: higher frequency, stronger intensity, larger influencing areas, earlier occurring time, and longer lasting periods.

In China, there are three kinds of definitions of dust weather. The first is the dust storm. If visibility is less than 1 km, it is called a dust storm (Qian et al., 1997). If visibility is less than 200 m and the wind force is greater than category 9 (v>20 m s^{-1}), it is a heavy dust storm. If the visibility is less than 50 m and the wind force is greater than category 10 (v>24 m s^{-1}), it is an extra-heavy dust storm. The second is uplifting-dust weather. If the visibility of dusty days caused by surface wind is between 1 km and 10 km, it is called uplifting dust weather. The third is floating-dust weather. The visibility of floating-dust weather is less than 10 km, which is caused by dust

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floating in the air after the dust storm or uplifting-dust weather. In spring 2001, various observations were conducted in Asian and Pacific regions in the Asia–Pacific Regional Aerosol Characterization (ACE-Asia) period. In this paper, chemical characteristics of particles by size-segregated aerosol samples in Beijing during March–May 2001 are analyzed.

2. Observation and Analysis

The experimental site was located on the top of a two-storey building, about 6 meters high above the ground, which is 50 m west of the 325-m Meteorological Tower (39°58′N, 116°22′E), outside the North Third Ring Road in Beijing.

The aerosol samples were obtained using the cascade sampler (made in PIXE company) with 8 levels of < 0.25, 0.25–0.5, 0.5–1, 1–2, 2–4, 4–8, 8–16, and $>16\ \mu$m. The flow rates at the beginning and the end of each sampling were recorded, and the average of the two flow rates was used as the flow rate for the samples. The flow rate was about 1.2 L min^{-1}. 15 groups (120 samples) of aerosol samples were collected in the dust period and the non-dust period.

The collected samples were analyzed by Proton Induced X-Ray Emission method (PIXE) in the Institute of Low Energy Nuclear Physics, Beijing Normal University. The PIXE analyses were carried out by 2.5 MeV proton bombardments with a beam of 30–40 nA. Elemental concentrations of particles for 19 elements were determined, which are Mg, Al, Si, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Se, Br, and Pb. This method has been widely used to study dust particles from the desert regions in China (Zhang et al., 1993) and aerosol pollution (Zhu and Wang, 1998; Zhang et al., 2003).

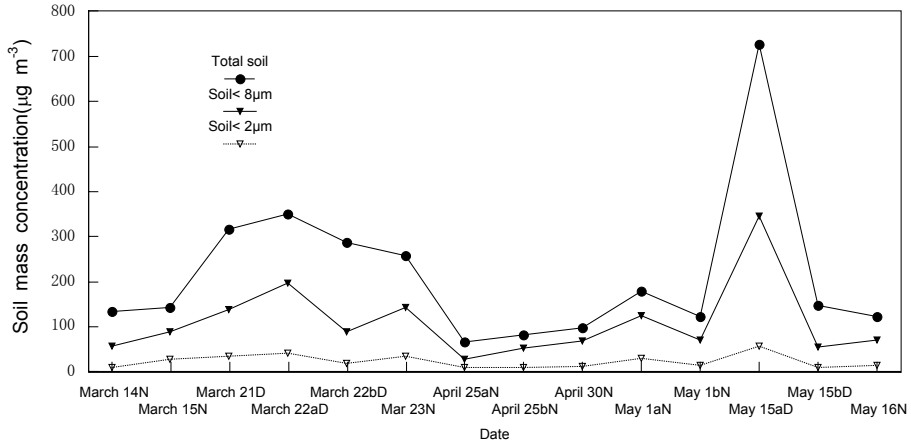

Fig. 1. Soil mass concentrations in 2001 in Beijing (D and N in the X-axis indicate the dust and non-dust periods, respectively, while a and b denote two different sampling time periods in the same day).

Table 1. Observation time in the dust and non-dust periods in 2001.

Sample number	observation time	Weather condition
March 14N	1800 LST 14 March –0800 LST 15 March	Non-dust event
March 15N	0800 LST 15 March –1800 LST 15 March	Non-dust event
March 21D	1700 LST 21 March –0800 LST 22 March	Dust event
March 22aD	0800 LST 22 March –1800 LST 22 March	Dust event
March 22bD	1800 LST 22 March –0800 LST 23 March	Dust event
March 23N	0800 LST 23 March –1800 LST 23 March	Non-dust event
April 25aN	0840 LST 25 April –1800 LST 25 April	Non-dust event
April 25bN	1800 LST 25 April –0800 LST 26 April	Non-dust event
April 30N	2320 LST 30 April –0900 LST 1 May	Non-dust event
May 1N	0900 LST 1 May –1800 LST 1 May	Non-dust event
May 1N	1800 LST 1 May –0800 LST 2 May	Non-dust event
May 15aD	1500 LST 15 May –1900 LST 15 May	Dust event
May 15bD	1900 LST 15 May –0800 LST 16 May	Dust event
May 16N	1700 LST 16 May –0800 LST 17 May	Non-dust event

3. Results and Discussion

The observation time is listed in Table 1. Letters N and D in the first column of Table 1 indicate non-dusty and dusty days, respectively, while a and b denote two different sampling time periods in the same day. The visibility on 21–22 March and 15 May 2001 was less than 10 km. According to the classification in the introduction, the observed dust events on 21–22 March and 15 May 2001 were uplifting-dust weather. The samples taken in these two dust events are regarded as the dust period and in other periods as the non-dust period.

According to Malm et al. (1994), the soil mass concentration of aerosols can be estimated by summing the elements predominantly associated with soil, plus oxygen for the normal oxides, and the formula for the calculation of soil mass concentrations by elemental concentrations is

$$C_{\text{soil}} = 2.2C_{\text{Al}} + 2.49C_{\text{Si}} + 1.63C_{\text{Ca}} + 2.42C_{\text{Fe}} + 1.94C_{\text{Ti}}\,, \quad (1)$$

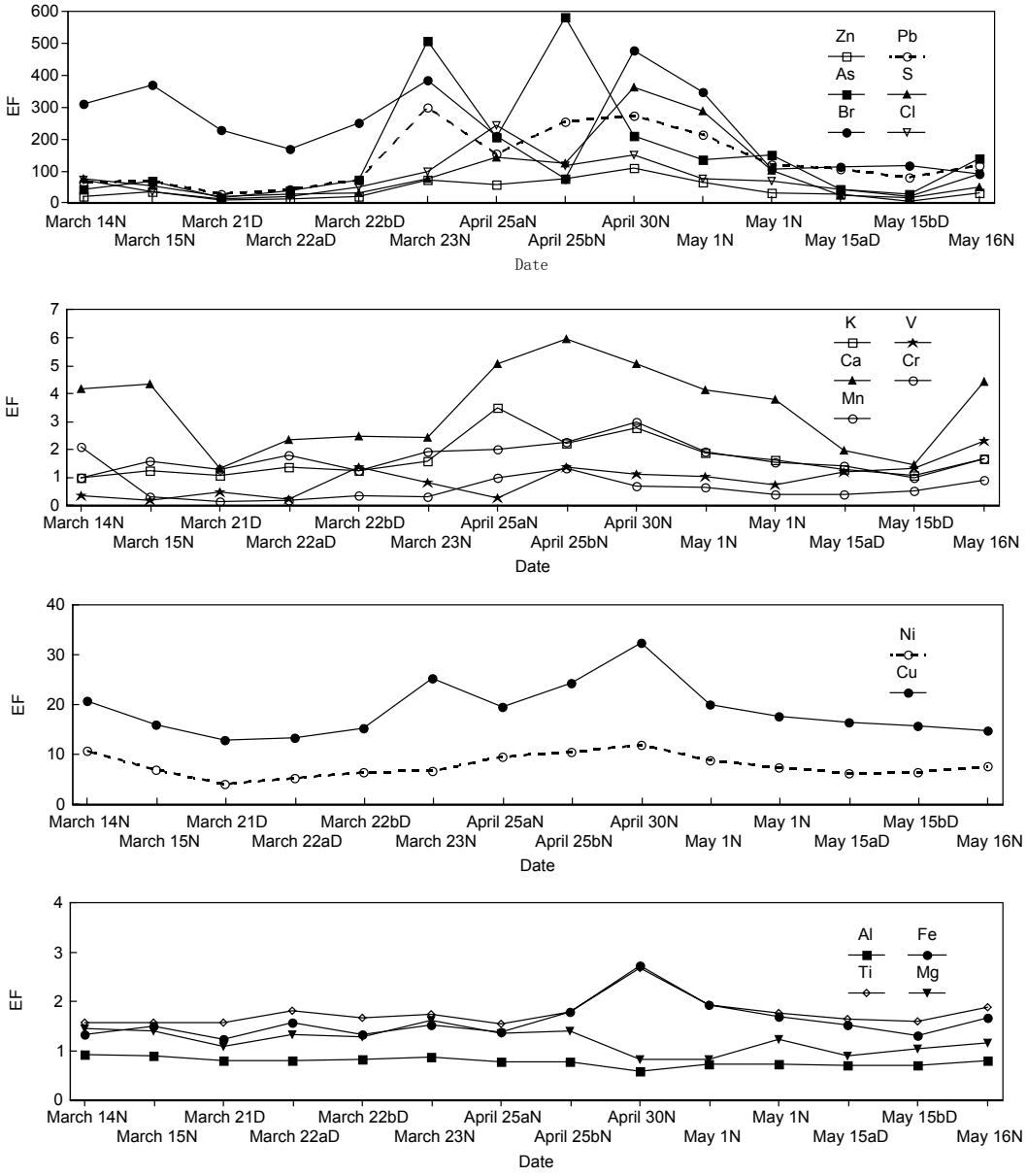

Fig. 2. Enrichment factors of elements of particles in 2001 in Beijing (D and N in the X-axis indicate the dust and non-dust periods, respectively, while a and b denote two different sampling time periods in the same day).

The calculated soil mass concentrations in Beijing in 2001 are shown in Fig. 1. Results show that the total soil mass concentrations of particles on 21–22 March was 288.4–350.2 μg m^{-3} and reached a maximum of 726.8 μg m^{-3} on 15 May in the dust period and were 113.8–257.4 μg m^{-3} in the non-dust period. The total soil concentration means all particles from 8 levels of the instrument of cascade. On 15 May 2001, the soil mass concentrations of particles with diameter less than 8 μm (PM8) reached 344.9 μg m^{-3}, while the soil mass concentrations of particles with diameter less than 2 μm (PM2) reached 57.4 μg m^{-3}. The average of the soil mass concentration of PM2 in the non-dust period was 18.4 μg m^{-3}. This demonstrates that the pollution by fine dust particles was severe in Beijing.

The enrichment factor of element in aerosols is an important index to study the origin of aerosols, which is defined as

$$I_{\rm EF} = (C_{\rm x}/C_{\rm r})_{\rm a}/(C_{\rm x}/C_{\rm r})_{\rm c} \ , \qquad (2)$$

where $C_{\rm x}$ is the concentration of element x, $C_{\rm r}$ is that of a reference element, the subscript a refers to particles in the atmosphere, while c to a reference material. Usually, Al, Si, or Fe is chosen as the reference element. Here Si is selected as the reference element to calculate the enrichment factors of elements in particles in Beijing (Winchester et al., 1981).

Figure 2 shows the enrichment factors of elements in particles in 2001 in Beijing. Enrichment factors of most elements decreased in the dust period and increased in the non-dust period obviously. But the ranges of variation are different. The enrichment factors of soil elements such as Al, Mg, Fe, and Ti had very little changes in the dust period and non-dust period, while the enrichment factors of Ca, K, and Mn decreased in the dust period and increased in the non-dust period obviously. The enrichment factors of other elements such as Cl and S, which have a good relation to human activities, decreased in the dust period and greatly increased in the non-dust period.

In order to compare the enrichment factor in the dust period with that in the non-dust period, a ratio R for element x is defined as following:

$$R = (I_{\rm EF,x})_{\rm ND}/(I_{\rm EF,x})_{\rm D} \ , \qquad (3)$$

where ND and D indicate the non-dust periods and dust periods, respectively. The ratios calculated using the above formula are shown in Table 2. The analyzed elements can be classified into three groups. The first group consists of elements associated with soil dust with $R < 1.3$, which includes Mg, Al, Ti, V, and Fe. The second consists of elements associated with local sources with $R > 2.0$, which includes S, Cl, Ca, Cr, Zn, As, and Pb. The third consists of elements associated with soil dust and local sources with $1.3 < R < 2.0$, which includes K, Mn, Cu, Ni, Se, and Br.

In order to investigate the origin of the aerosols and to validate the results obtained from enrichment factors, a factor analysis method (Koutrakis et al., 1987) was applied to the dust particle dataset. 15 elements (without V, Cr, Se, and Br) from the total 19 measured elements whose concentrations are all higher than the detection limit in every sample are chosen to perform a principal factor analysis (PFA).

Table 3 shows the factor loading matrix derived from the varimax rotation, which provides considerable information about the origins of the elements. It is sufficient to retain only three factors that explain 90% of the total variance. Factor 1 explains 61%, factor 2, 21%, and factor 3, only 8%. The crustal elements, including Mg, Al, Si, Ca, Fe, Ti, and Mn, are highly correlated in factor 1, indicating that their major sources are soil dust. K, Ni, and Cu are also highly correlated in factor 1, indicating that their major sources are probably the local soil dust. Zn, As, Pb, and Cl are highly correlated in factor 2, indicating that their major sources are industry. S is highly correlated in factor 3, indicating that its major source is fuel combustion. Receptor concentrations of atmospheric aerosols from a mixed origin in a fixed site are often influenced by transports, metrological conditions, and their lifetime in the atmosphere. Therefore, it is very important to understand the chemical composition of particles in order to find the exact source of dust particles in Beijing, which is also helpful in study-

Table 2. The ratio R for different elements.

Element	R
Mg	1.11
Al	1.02
S	5.97
Cl	3.53
K	1.60
Ca	2.28
Ti	1.11
V	1.00
Cr	2.66
Mn	1.39
Fe	1.23
Ni	1.55
Cu	1.43
Zn	3.60
As	5.77
Se	1.36
Br	1.49
Pb	2.68

Table 3. Varimax rotated factor matrix.

Element	Factor 1	Factor 2	Factor 3
Mg	0.959	0.026	–0.073
Al	0.991	0.021	–0.033
Si	0.987	0.023	–0.022
S	0.028	0.320	0.897
Cl	0.212	0.663	0.368
K	0.941	0.214	0.138
Ca	0.932	–0.025	0.070
Ti	0.991	0.024	0.012
Mn	0.914	0.277	0.123
Fe	0.988	0.048	0.045
Ni	0.936	0.032	0.094
Cu	0.891	0.358	0.131
Zn	–0.014	0.898	0.292
As	–0.076	0.914	–0.164
Pb	0.239	0.868	0.175

ing radiative properties of dust particles. A further study is needed to know the contribution from different sources quantitatively.

4. Summary

In this paper, the chemical composition of particles in the dust period with that in the non-dust period are analyzed and compared. Results show that in the dust period, the soil mass concentration of particles increased sharply, which resulted in obvious impacts on urban air quality. The difference of the enrichment factors of crustal elements is small between the dust and non-dust periods. The enrichment factors of other elements that have a relation to anthropogenic emissions considerably decreased in the dust period. Factor analysis on the observation data shows that the sources such as soil dust, industry, and fuel combustion were among the major contributors to the concentration of particles in the dust season in Beijing. This work suggests that it is important to determine the chemical composition of particles in order to find out the sources precisely.

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ERRATUM

On Page 34 of Issue No. 1, Vol. 21, the title should read **"Physical Mechanism and Model of Turbulent Cascades in a Barotropic Atmosphere"**. We apologize for this carelessness.