

SOURCE ESTIMATION OF ANTHROPOGENIC AEROSOLS COLLECTED BY A DRUM SAMPLER DURING SPRING OF 2002 AT GOSAN, KOREA

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1. INTRODUCTION

Asia is one of the major sources of not only mineral dust, but also anthropogenic aerosols. Especially, northeast Asia was known to emit a large amount of anthropogenic pollutants due to its high population density and increasingly high rate of energy consumption. Recently this region has received much attention in the atmospheric chemistry point of view, and several activities have been under way. Because Korea peninsula is located in the middle of westerly wind latitude region of northeast Asia, many studies on the influence of long-range transport (LRT) have been actively performed there. Many previous works investigated the contributions of emission sources to PM_{2.5} and PM₁₀ aerosols in the northeast Asia. Source apportionment results were primarily derived from various statistical methods, such as the chemical mass balance (CMB), factor analysis and multiple linear regression methods. However, most of previous chemical analysis of aerosol source apportionment studies was based on the results of aerosol sampling of relatively long sampling time. Therefore, in order to estimate aerosol source appointment, it is important to collect the continuous aerosol chemistry data in subdivided size range. In addition, the efficiency of factor analysis can also be improved by using the time-resolved data. This study is mainly to determine source apportionment using the time-resolved drum sampler data of size-segregated trace elements, and to assess the effect of anthropogenic aerosol sources on the chemical and physical characteristics of atmospheric ambient aerosols collected at Gosan.

2. EXPERIMENT

2.1 SAMPLING SITE AND PERIOD

Atmospheric aerosol samples were collected at the Gosan site (33° 17' N, 126° 10' E, 70m asl) located at the western tip of Jeju Island (see Figure 1) from 29 March to 30 May 2002. This site is known for the ideal location to study the long-range transport of air pollutants in the Northeast Asia.

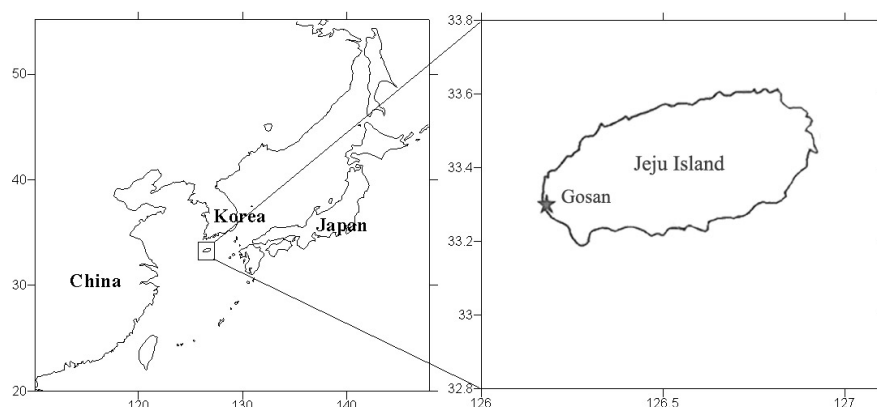


Figure 1. Location of Gosan sampling site.

2.2 SAMPLING AND ANALYSIS

An 8-Stage Davis Rotating Unit for Monitoring (DRUM) impactor was used to collect time resolved aerosol data. The DRUM impactor, developed by investigators from the University of California, Davis (UCD), was installed at the sampling site. The equivalent aerodynamic cut-off diameters of 8-stages were 0.09, 0.26, 0.34, 0.56, 0.75, 1.15, 2.5, 5.0, and $12\mu\text{m}$, respectively. This sampler is a modified version of the original instrument described by Cahill et al. (1985). It was altered by using a slit jet instead of circular jet for each stage, and increasing the flow rate from 5 to 10L/min. During the operation, aerosol samples were collected on Apiezon grease coated strips on rotating drums moving at $\sim 1\text{mm}$ each 3 hours, giving 3 hour temporal resolution in analysis (Reid et al, 2003). The collected impaction substrates were analyzed by the synchrotron X-ray fluorescence (S-XRF) utilizing a white light of energy 6-15 keV at beamline 10.3.1 at the Advanced Light Source of Lawrence Berkeley National Laboratory. S-XRF analysis of the strip samples was described in detail elsewhere (Reid et al., 1994) and is summarized as follows; the strip samples were scanned with a beam spot size of $1.0 \times 1.0\text{ mm}$ and X-rays were detected with an energy dispersive Si(Li) X-ray detector located 5cm away from the sample. The beam dwelt at each point on a sample for 30 seconds before the sample was moved to the next location. Using these parameters, a sensitivity of $\sim 0.1\text{ ng/m}^3$ for transition metals was achieved for the rotating drum sampler strips. Data reduction was performed offline using a well-accepted international XRF code, AXIL to generate the elemental profiles with an atomic number >10 . Bulk elemental concentrations of Na through Cu were measured. However, as light elements like Na emit low energy X-rays, attenuation and interference make detection difficult and significantly increase the measurement uncertainty. Therefore, in this study light elements, which have the high uncertainty, were not used. Only 19 elements, such as S, Si, Al, Fe, Ca, Cl, Cu, Zn, Ti, K, Mn, Pb, Ni, V, Se, As, Rb, Cr and Br were analyzed.

3. RESULTS AND DISCUSSION

3.1 ATMOSPHERIC CONDISION

The criteria air pollutants and meteorological condition were measured at the Gosan air pollution monitoring station of Ministry of Environment and the Gosan high latitude meteorological observatory, respectively as shown in figure 2. During the measurement period, the average wind speed was 6.5m/s, and southeastern and south to southwestern winds from Southern China, Japan and the North Pacific Ocean were dominant. Two Asian dust (AD) outbreaks were observed from 8~10 April and at 17 April. The data during the Asian dust period are excluded from the following analysis, because high soil contents could greatly influence the composition of fine particles.

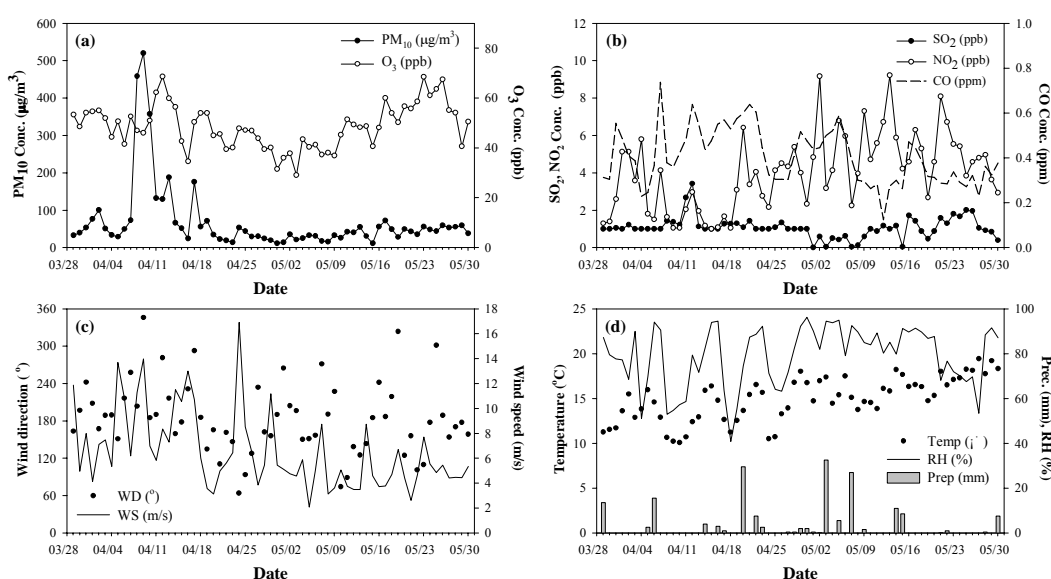


Figure 2. Air quality and meteorological conditions at Gosan during the measurement period from March 28 to May 30 2002. ((a) PM₁₀ and O₃ (b) SO₂, NO₂ and CO, (c) wind speed (WS) and wind direction (WD), (d) relative humidity (RH), precipitation and temperature).

3.2 AEROSOL MASS SIZE DISTRIBUTION

Summarized in Table 1, average concentration of trace elements during NAD period were measured to be Si: 5039 ng/m³, Al: 2487 ng/m³, Fe: 1727 ng/m³, S: 2148 ng/m³, Cl: 1547 ng/m³, K: 1125 ng/m³, and Ca: 1113 ng/m³. The concentration of Ti was 244.2 ng/m³ and the others including Zn, Mn, Cu, Pb, Br, Rb, V, Cr, Ni, As, and Se, were between 1.12 ng/m³ and 70.47 ng/m³. More than 50% of major soil components, such as Al, Si, Fe, Ca, Ti, Cr, Cu, and Br, were distributed in stage 1 (5~12 μm), and more than 60% of K, Mn, Zn, As, Rb existed between stages 1 and 3 (1.15~12 μm). On the other hand, about 30% of S, Br, and Pb were found in the stage 4 (0.75~1.15 μm) and about 20% of S, V, and Ni were distributed between the stages 6 and 8 (0.09~0.34 μm).

Table 1. Average concentrations of trace elements for each size range during the non-Asian Dust period.

(ng/m ³)										
Stage	Al	Si	Fe	S	Cl	K	Ca	Ti	V	Cr
1	1452±1753 (58.4%)	2768±2957 (54.9%)	881±654 (51.0%)	267±192 (12.4%)	979±768 (63.3%)	414±345 (36.8%)	599±564 (53.8%)	131±76.0 (53.4%)	1.90±1.60 (30.5%)	2.38±1.60 (50.3%)
2	418±336 (16.8%)	891±646 (17.7%)	391±342 (22.7%)	98±49 (4.6%)	359±285 (23.2%)	187±141 (16.6%)	249±223 (22.3%)	52.8±35.0 (21.6%)	0.91±0.83 (14.5%)	0.90±0.68 (19.0%)
3	403±484 (16.2%)	830±886 (16.5%)	317±404 (18.4%)	297±264 (13.8%)	187±207 (12.1%)	219±208 (19.5%)	193±218 (17.4%)	40.8±43.1 (16.7%)	0.91±0.89 (14.5%)	0.87±1.35 (18.4%)
4	129±198 (5.2%)	289±394 (5.7%)	91±138 (5.3%)	641±688 (29.9%)	9.9±10.8 (0.6%)	153±150 (13.6%)	45.2±67.1 (4.1%)	12.1±16.1 (5.0%)	0.62±0.49 (9.9%)	0.30±0.31 (6.4%)
5	46±74 (1.9%)	98±145 (1.9%)	27±42 (1.6%)	161±116 (7.5%)	3.1±3.0 (0.2%)	49.5±38.9 (4.4%)	16.5±25.0 (1.5%)	4.1±5.4 (1.6%)	0.17±0.12 (2.7%)	0.13±0.14 (2.7%)
6	25±52 (1.0%)	64±121 (1.3%)	12±28 (0.7%)	537±554 (25.0%)	4.9±5.4 (0.3%)	76.4±103 (6.8%)	6.1±14.4 (0.5%)	1.9±3.1 (0.8%)	1.12±1.22 (17.9%)	0.06±0.10 (1.3%)
7	8±19 (0.3%)	20±38 (0.4%)	5±10 (0.3%)	62±42 (2.9%)	1.4±1.2 (0.1%)	16.2±18.1 (1.4%)	3.0±6.3 (0.3%)	1.0±1.3 (0.4%)	0.13±0.13 (2.1%)	0.02±0.04 (0.5%)
8	5±6 (0.2%)	80±74 (1.6%)	2±4 (0.1%)	85±40 (4.0%)	1.4±1.6 (0.1%)	9.0±8.0 (0.8%)	1.3±2.1 (0.1%)	1.1±0.5 (0.5%)	0.50±0.28 (8.0%)	0.07±0.17 (1.4%)
Total	2487 (5.38%)*	5039 (10.9%)*	1727 (3.74%)*	2148 (4.65%)*	1546.6 (3.35%)*	1124.5 (2.43%)*	1113.3 (2.41%)*	244.2 (0.53%)*	6.25 (0.01%)*	4.72 (0.01%)*
Stage	Mn	Ni	Cu	Zn	As	Se	Br	Rb	Pb	
1	16.1±13.1 (42.3%)	1.03±0.73 (26.4%)	32.1±137.5 (84.9%)	30.0±78.7 (42.5%)	1.04±1.47 (27.9%)	0.15±0.161 (13.4%)	11.2±13.2 (68.4%)	3.27±4.75 (32.8%)	9.63±11.4 (30.1%)	
2	7.98±7.58 (21.0%)	0.42±0.29 (10.7%)	0.97±0.68 (2.6%)	4.64±2.64 (6.6%)	0.55±0.66 (14.7%)	0.11±0.14 (10.1%)	1.25±1.29 (7.6%)	2.07±3.42 (20.7%)	2.42±1.98 (7.6%)	
3	8.29±12.6 (21.8%)	0.51±0.37 (13.1%)	1.16±1.04 (3.1%)	13.6±14.6 (19.2%)	0.69±0.77 (18.5%)	0.23±0.22 (20.2%)	0.93±1.15 (5.7%)	2.63±5.83 (26.4%)	5.98±5.57 (18.7%)	
4	3.49±4.47 (9.2%)	0.31±0.21 (7.9%)	1.10±0.93 (2.9%)	13.3±12.4 (18.8%)	0.65±0.54 (17.4%)	0.31±0.29 (27.4%)	1.26±0.86 (7.7%)	1.02±1.47 (10.2%)	10.0±12.4 (31.3%)	
5	0.91±1.11 (2.4%)	0.15±0.14 (3.9%)	0.28±0.22 (0.7%)	2.59±1.68 (3.7%)	0.20±0.13 (5.3%)	0.07±0.04 (6.4%)	0.22±0.10 (1.3%)	0.37±0.37 (3.7%)	1.50±1.75 (4.7%)	
6	0.91±2.15 (2.4%)	0.46±0.49 (11.6%)	0.45±0.70 (1.2%)	4.12±8.41 (5.8%)	0.39±0.65 (10.5%)	0.17±0.23 (15.2%)	1.10±1.92 (6.7%)	0.26±0.40 (2.6%)	2.13±5.16 (6.7%)	
7	0.23±0.36 (0.6%)	0.15±0.16 (3.9%)	0.20±0.17 (0.5%)	0.91±0.48 (1.3%)	0.10±0.06 (2.6%)	0.04±0.02 (3.6%)	0.18±0.11 (1.1%)	0.19±0.11 (1.9%)	1.21±0.32 (0.6%)	
8	0.11±0.14 (0.3%)	0.89±2.16 (22.6%)	1.54±3.32 (4.1%)	1.51±1.79 (2.1%)	0.12±0.06 (3.1%)	0.04±0.02 (3.7%)	0.21±0.10 (1.3%)	0.18±0.03 (1.8%)	0.13±0.15 (0.4%)	
Total	38.02 (0.08%)*	3.92 (0.01%)*	37.77 (0.08%)*	70.67 (0.15%)*	3.73 (0.01%)*	1.12 (0.00%)*	16.34 (0.04%)*	9.97 (0.02%)*	32.01 (0.07%)*	

() : {[Average concentration at each stage]/[Total average concentration]}×100

()* : {[Total average concentration of each element]/[PM₁₀ mass concentration]}×100

3.3 THE ESTIMATION OF SOURCES BY FACTOR ANALYSIS

Except the AD periods, in which aerosols were mainly influenced by soil components, factor analysis (SPSS 8.0 for windows release by SPSS Inc, 1997) was

used to find the group of elements having similar behavior and to identify the possible sources of aerosol for each size range. First of all, the number of factor was determined according to the eigenvalue and variance, and then factor rotation was conducted using Varimax method. Table 2 shows the calculated eigenvalues and cumulative variances with the elements involved in each factor. The sources were estimated by the comparison of major elements in each factor with the source profile shown in Figure 4.

Table 2. Factor loading matrix of factor analysis*.

Stage	Factor	Involved components	Eigen value	Cumulative variance %
Stage1 (5.0~12 μ m)	1	Fe, Mn, K, Al, Ca, Ti, V, Rb	10.3	54.19
	2	Zn, Cu (Ni, Pb)	2.46	67.14
	3	Cl, Br (S)	1.66	75.87
	4	As, Se	1.30	82.71
Stage2 (2.5~5.0 μ m)	1	Fe, Mn, Al, K, Si, Ti, Ca, V, Cr, Ni, Rb	11.05	58.14
	2	Cl, Br, S	2.11	69.22
	3	As, Se	1.65	77.91
	4	Cu, Zn (Ni)	1.08	83.58
Stage3 (1.15~2.5 μ m)	1	Al, Ti, Fe, Si, V, K, Ca (Rb, Pb, Mn, Ni)	10.02	52.74
	2	As, Cr, Se, Mn	2.54	66.10
	3	Zn, S, Ni, Pb	1.72	75.16
	4	Cl, Br	1.23	81.62
Stage4 (0.75~1.15 μ m)	1	Ti, Ca, Fe, Al, Si, Mn, Rb, V (K, Cr, As)	11.63	61.19
	2	Ni, Zn, Pb (Cu, Br, Se)	2.22	72.88
	3	S, Se, K (Cl, Br, As)	1.69	81.77
Stage5 (0.56~0.75 μ m)	1	Ti, Fe, Al, Si, Ca, Mn, Rb (V, K, Cu)	10.48	55.15
	2	S, Se, Zn, Br (Pb, As, Cu)	3.08	71.37
	3	Ni, Cr (Cu, Pb)	1.22	77.77
	4	Cl (As, Br, Rb)	1.02	83.14
Stage6 (0.34~0.56 μ m)	1	Ca, Ti, Fe, Al, Si, Mn, Rb (As, Cu, Cr)	13.43	70.69
	2	S, V, Cl, K (Se, Ni)	1.95	80.98
	3	Zn, Pb (Ni, Br, Mn)	1.04	86.47
Stage7 (0.26~0.34 μ m)	1	Ti, Fe, Ca, Al, Si, Mn	8.19	43.1
	2	S, V, K	2.64	56.97
	3	Cu, Cr, Ni	2.20	68.53
	4	Pb (Zn, S)	1.24	75.03
	5	Se, As	1.02	80.37
Stage8 (0.09~0.26 μ m)	1	Fe, Ca, Mn, Al, Ti	4.88	25.68
	2	Ni, Cr, Cl (Cu, Zn)	3.37	43.41
	3	Pb, Zn, Cu	2.51	56.64
	4	V, S	1.30	63.47
	5	As, Se, Br	1.17	69.63
	6	Si (K, Al, S)	1.03	75.04

* Rotation method : Varimax with Kaiser Normalization

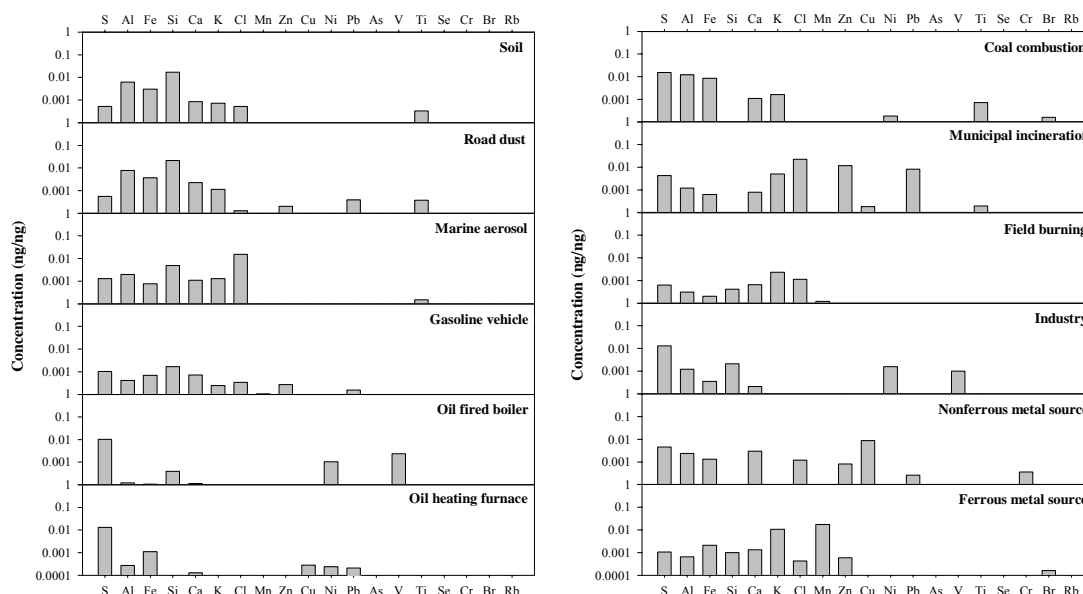


Figure 4. Source profiles used in this study with were resolved from its previous works: soil (EPA profile 41350), road dust (EPA profile 41130), marine aerosol (Watson, 1979), gasoline vehicle (Watson et al, 1994), oil fired boiler (EPA 13505), oil heating furnace (Mamuro et al, 1979b), municipal incineration (EPA profile 17106), field burning (EPA profile 42320), coal combustion (Gladney et al., 1976; Mamuro et al, 1979b), industrial source (EPA profile 13504), nonferrous metal source (Mamuro et al, 1979a) and ferrous metal source (Watson, 1979).

As a result of the factor analysis summarized in Table 2, four factors had eigen values greater than 1 and described more than 80% of total variance at the size range of stage 1 (5.0~12 μ m), stage 2 (2.5~5.0 μ m), stage 3 (1.15~2.5 μ m), stage 4 (0.75~1.15 μ m) and stage 5 (0.56~0.75 μ m). Three and five factors accounted for more than 80% of the variance at stage 6 (0.34~0.56 μ m) and stage 7 (0.26~0.34 μ m), respectively. Finally, six factors explained about 75% of the variance at stage 8 (0.09~0.26 μ m).

The first factor between stages 1 and 3 (1.15~12 μ m) was related to Fe, Mn, K, Al, Ca, Ti, V, and Rb. And these elements are mostly known as the composition of soil (EPA profile 41350) and road dust (EPA profile 41130) as shown in figure 4. In addition, the factor including Cl, Br and S was also observed at the same size range, and it was inferred to sea-salt (Watson, 1979) considering that it was mainly distributed in the coarse size range. The other factors concerned with Cu, Zn, Ni, Pb and Se existed all over the stages. From the source profiles of previous works (Mamuro et al, 1979a), it was estimated to be nonferrous metal source. Similarly, a factor including As and Se was observed at most stages except stage 6, and another factor involved with Fe, Ti, Al, Ca and Mn was revealed between stages 4 and 8. The former was assessed to coal combustion source because As and Se are known as the indicator of coal combustion (Gladney et al., 1976; Mamuro et al., 2002). The latter was inferred to ferrous metal source from the source profile (Watson, 1979). Therefore, this study revealed that several anthropogenic sources, such as ferrous and nonferrous metal sources and coal

combustion emission, could affect to ambient aerosols in wide size ranges from submicron to coarse particles.

Factor concerned with V, Ni and S was revealed in two size ranges, stage 3 (1.15~2.5 μm) and between stages 6 and 8 (0.09~0.56 μm). Because V and Ni were known as the indicator of oil combustion (Song et al., 2001), it was inferred to oil combustion source. However, the twofold distribution of this factor implied that oil combustion sources could be originated from different emission sources. On account of the distributed size range and accompanied elements, the one in the coarse size was estimated to the industrial oil combustion source like oil heating furnace (Mamuro et al., 1979), emitted in relatively closer region. On the other hand, the one in the fine size was inferred to the domestic source such as oil fired boiler (EPA profile 13505) transported long distance. Especially, as noticed above, in stage 6 (0.34~0.56 μm), S, V and Ni were remarkably increased during the AD periods implying similar plume effect by the strong parallel airflow. This fact obviously suggests that aerosols from the oil combustion source could be long-range transported in the submicron size range. In the very fine size range between stages 7 and 8 (0.09~0.34 μm), two factors were observed in addition. One was mainly concerned with Pb, Zn and S, and the other was involved with K and S. From the source profiles, the former was regarded as the emission source related to municipal incineration (EPA profile 17106) or gasoline vehicle (Watson et al, 1994) and the latter was inferred to field burning source according to the EPA profile 42320.

In this study, factor rotation was used to make the interpretation of factors easy. However, because it generally assigns an element involved with several factors to only one factor which has the largest eigenvalue, it not only increase the factor indeterminacy, but also make it difficult to reflect the impacts of more than two sources. Therefore, in order to improve the source appointment analysis, some elements which were commonly related to several sources were assumed to exist also in the other factors.

Overall, natural sources, such as soil and sea-salt, primarily existed in the coarse size range between stages 1 and 3 (1.15~2.5 μm). On the other hand, the sources concerned with a municipal incineration, gasoline vehicle, industry and field burnings were mainly distributed in the fine size range from stages 5 to 8 (0.09~0.75 μm). Moreover, coal combustion, nonferrous and ferrous metal source and oil combustion sources were observed in both coarse and fine particle range. Especially, oil combustion sources revealed the distinct characteristics in two size ranges indicating that it could be originated from the different emission sources.

4. SUMMARY AND CONCLUSION

The continuous monitoring of size-segregated trace elements was performed using a DRUM impactor at Gosan, Jeju Island, Korea, from 29 March to 30 May 2002.

For the NAD data, factor analysis was performed for each size range in order to find the element groups that have similar behavior and to identify the aerosol source. As a result of factor analysis, 3 or 6 factors described more than 70% of total variance at

each stage. In order to estimate the source of each factor, major elements involved with the factors were compared with the marker elements of various sources. For example, coal combustion source was distinguished by As and Se, and oil combustion source was characterized by S, V, and Ni. On the other hand, some peculiar cases were also observed. Sea-salt aerosol was classified to the factor concerned with Cl and Br, and field burning source was identified by S, K and Si in factor analysis because most other elements were already separated to other major sources like soil. Therefore, these elements could be used the marker elements of these sources in case various sources simultaneously affect aerosol samples.

The source identification showed that natural aerosol sources, such as soil and sea-salt, as well as diverse anthropogenic sources affected to the ambient aerosols during the NAD periods. The anthropogenic sources included gasoline vehicle emission, oil and coal combustion, municipal incineration, field burning, and ferrous and nonferrous metal sources. From factor analysis soil, sea salt, coal combustion, and nonferrous metal source were identified in the coarse particle range (2.5~12 μ m). On the other hand, the emission of nonferrous and ferrous metal source, oil and coal combustion mostly affected the accumulative mode particles in the size of 0.56~2.5 μ m. Finally, in the submicron particle range (0.09~0.56 μ m), municipal incineration, gasoline vehicle, and field burning were also influenced the atmospheric aerosol composition.

This study identified the influence of various anthropogenic sources to ambient aerosol at Gosan during the measurement period. Possible aerosol sources were estimated by comparing the measured data with source profiles of previous works. DRUM sampler data can never improve source estimation analysis. However, it is needed to obtain the source profiles of emission around Gosan in order to improve the accuracy of source appointment.

ACKNOWLEDGEMENT

This work was supported by the project of Ministry of Environment, Korea; "Long Range Transport of Toxic Trace Substances: Identification and Impact Analysis" and in part by the Korea Science and Engineering Foundation (KOSEF) through the Advanced Environmental Monitoring Research Center at Kwangju Institute of Science and Technology.

REFERENCE

- [1] Cahill T. A., Goodart, C., Nelson, J. W., Eldred, R. A., Nasstrom, J. S., Feeny, P. J. (1985) Design and evaluation fo the DRUM impactor, in Proceedings of the International Symposium on Particulate and Multi-Phase Processes, edited by T. Ariman and T. Nejat, Taylor and Francis, Philadelphia, Pa., vol. 2, 319-325.
- [2] Gladney, E. S., J. A. Small, G. E. Gordon, W. H. Zoller, 1976, Composition and Size distribution of In-Stack Particulate Material at a Coal-Fired Power Plant, Atmospheric Environ,m 10:1071-1077.
- [3] Han, J. S., K. J. Moon, J. Y. Ahn, Y. D. Hong, Y. J. Kim, S. Y. Ryu, S. S. Cliff and

- T. A. Cahill, 2004, Characterization of ion components and trace elements of fine particles at Gosan, Korea in spring time from 2001 to 2002, *Environmental Monitoring and Assessment*, 92, 73-93.
- [4] Mamuro, T., A. Mizohata, T. K., 1979a, Elemental Compositions of Suspended Particles Released from Iron and Steel Works, *Annual Report of the Radiation Center of Osaka Prefecture* 20: 19-28.
- [5] Mamuro, T., A. Mizohata, T. K., 1979b, Elemental Compositions of Suspended Particles Released from Various Boilers, *Annual Report of the Radiation Center of Osaka Prefecture* 20: 9-17.
- [6] Mamuro, T., A. Mizohata, T. K., 1979c, Elemental Compositions of Suspended Particles Released from Various Small Sources (I), *Annual Report of the Radiation Center of Osaka Prefecture* 20: 37-45.
- [7] Mamuro, T., A. Mizohata, T. K., 1979d, Elemental Compositions of Suspended Particles Released from Various Small Sources (II), *Annual Report of the Radiation Center of Osaka Prefecture* 20: 47-53.
- [8] Mamuro, T., A. Mizohata, T. K., 1979e, Elemental Compositions of Suspended Particles Released in Glass Manufacture, *Annual Report of the Radiation Center of Osaka Prefecture* 20:19-28.
- [9] Mitsuo U., Akifumi Y., Hiroaki M., Kimio A., and Itsushi U., 2002, Transport of mineral and anthropogenic aerosols during a Kosa event over East Asia, *Journal of geophysical research*, vol. 107, no. D7.
- [10] Reid, E. A., Reid, J. S., Meier, M. M., Dunlap, M. R., Cliff, S. S., Broumas, A., Perry, K., Maring, H., 2003, Characterization of African dust transported to Puerto Rico by individual particle and size segregated bulk analysis, *Journal of Geophysical Research*, 108(D19), 8591.
- [11] Reid, J. S., Cahill, T. A., and Dunlap, M. R., 1994, Geometric/Aerodynamic Equivalent Diameter Ratios of Ash Aggregate Aerosols Collected in Burning Kuwaiti Well Fields, *Atmospheric Environment*, 28(13), 2227-2234.
- [12] Seinfeld, J. H. and S. N. Pandis, 1998, *Atmospheric chemistry and physics from air pollution to climate change*, John Wiley & Sons, Inc., New York, 901-912.
- [13] US EPA, 1987, Protocol for applying and validating the CMB model, EPA-450/4-87-010.
- [14] Watson, J. G., 1979, Chemical Element Balance Recetor Model Methodology for Assessing the Source of Fine and Total Suspended Particulate Matter in Portland, Oregon, Ph. D. Thesis, Oregon Graduate Center, Beaverton.
- [15] Watson, J. G., Chow, J. C., Lu, Z., Fujita, E. M., Lowenthal, D. H., Lawson, D. R., Ashbaugh, L. L., 1994, Chemical Mass Balance source apportionment of PM₁₀ during the Southern California Air Quality Study, *Aerosol Science and Technology* 21:1-36.
- [16] Song, X. H., Polissar, A. V., Hopke, P. K., 2001, Sources of fine particle composition in the northeastern US, *Atmospheric Environment*, 35:5277-5286.