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Distribution Characteristics of Dust and Heavy Metals in the Atmosphere Around the Steel Industrial Complex

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Abstract

In Dangjin, Chungcheongnam-do, there are not only power plants and large steel complexes, but also small and medium-sized air pollutant emission facilities. The dust generated by these facilities has a very small particle size and a large surface area due to condensation and physical and chemical reactions, and is discharged containing various harmful substances. Therefore, this study analyzed the distribution of particulate matter and heavy metal concentrations by particle size in the vicinity of the steel complex, residential area, and reference point using an eight-stage Cascade Impactor. Overall, the direct impact sites with a short distance from the steel complex had the highest concentration, followed by the indirect impact sites, and the non-impact sites had the lowest concentration, indicating that they are directly affected by the steel complex. The atmospheric dust concentration distribution showed a bimodal distribution with a minimum value around the 1.1 to 2.1 μm particle diameter. However, during the yellow dust event, the maximum concentration was biased toward coarse particles. The proportion of PM2.5 in the dust tended to be higher in winter, while the ratio between PM2.5 and PM10 was relatively higher in spring. Regardless of the location of the impact point, heavy metals in the dust were dominated by iron and aluminum, followed by zinc, lead, and manganese.

Keywords: *Steel Industrial Complex, Dust, Particle Size Distribution, Heavy Metals*

1. INTRODUCTION

Dust is one of the major air pollutants and has been studied extensively for its physical and chemical properties. Depending on the mechanism of generation, dust can be categorized into primary aerosols, which are emitted directly into the atmosphere from fuel combustion and production processes, and secondary aerosols, which are gaseous pollutants that are converted into particulate matter through physical and photochemical reactions in the atmosphere after being emitted, and their size is continuously distributed in a wide range from a few ㎚ to several hundred μm in diameter [1].

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In addition, dust can be categorized by size, and the 'Special Act on the Reduction and Management of Fine Dust' classifies dust as fine particulate matter (PM10) and ultrafine particulate matter (PM2.5) [2]. Fine particulate matter refers to particles with an aerodynamic diameter of 10 μm or less, and ultrafine particulate matter refers to particles with an aerodynamic diameter of 2.5 μm or less.

Ultrafine particles are so small that they are not filtered out of the nose, mouth, and bronchi, causing diseases such as allergic rhinitis, emphysema, asthma, and alveolar damage, and have been reported to increase premature mortality [3, 4]. In 2013, the International Agency for Research on Cancer (IARC) newly designated PM2.5 as a Group 1 carcinogen, and in 2014, the World Health Organization (WHO) reported that as many as 7 million people died prematurely due to fine particulate matter in a single year, significantly raising concern and awareness. According to the results of a social survey conducted by Statistics Korea in 2022 among nearly 36,000 South Koreans, fine dust topped the list of environmental issues that people feel anxious about at 64.6%, an improvement from 72.9% in 2020, but still higher than climate change (45.9%) and radiation (53.5%).

Chungcheongnam-do is geographically located in the west-central part of South Korea, with an average elevation of 100 meters, making it the lowest terrain in the country. It is also located downstream of China's monsoon belt. According to 2020 data from Korea's Clean Air Policy Support System (CAPSS), it has the fourth highest dust emissions among 17 local governments. In particular, when categorized by city, county, and district, Dangjin was the largest emitter of air pollutants, except for Seoul, Incheon, and Busan [5].

In the case of Dangjin, there are not only small-scale iron and steelmaking companies, but also large power plants using coal as the main raw material and large steel complexes using iron ore and lignite as the main raw materials. In addition, there are many large air pollution emission facilities such as power plants in the neighboring areas of Seosan, Taean, and Boryeong, which are expected to affect Dangjin.

It is well known that the concentration distribution of heavy metals in the atmosphere is usually correlated with the particle size of fine dust, and studies have been conducted using various multistage separation collectors [6]. Most of the studies were conducted based on PM2.5 and PM10, but since the deposition point of fine dust is actually different depending on the particle size, more detailed measurement by dust particle size is needed.

In order to understand how pollutants emitted from the large steel complexes in Dangjin affect the surroundings, this study divided them into direct impact sites (Private Environmental Monitoring Center in Dangjin), indirect impact sites (Work's comprehensive welfare center and Chungnam techno park in Dangjin), and non-impact sites (Hanseo university in Seosan) according to distance, and analyzed the dust distribution and heavy metal composition at these sites to compare the degree of impact of the steel complexes.

2. METHODS

2.1 Measuring points

The dust measurements were divided into four periods, as shown in Table 1. The first measurement was conducted from April 7 to June 10, 2021 (spring), the second measurement was conducted from November 11 to December 22, 2021 (winter), the third measurement was conducted from November 7 to December 15, 2022 (winter), and the fourth measurement was conducted from April 19 to May 16, 2023 (spring). Each measurement was taken two to four times and arithmetically averaged, and the measurement period was approximately 7 days before and after rainfall, and the direct, indirect, and non-affected sites were measured simultaneously. Rainfall greatly affects the concentration of fine dust. As shown in Table 1, the dust measurement periods were timed to avoid rainfall, but some measurements may have been affected by rain. In addition, since yellow dust has a significant impact on dust concentrations, dust and heavy metal concentrations were analyzed once during the yellow dust period to determine the extent of this impact.

The direct impact point is the Private Environmental Monitoring Center in Dangjin, located 1.3 km south of Steel Complex A. The Hanseo University Engineering Building, which was selected as a non-impact point, is a residential area with few other pollutant emission sources besides the four-lane round-trip road. Two indirect impact points were selected: the first is the Dangjin Work's comprehensive welfare center, located about 5.2 km southeast of Steel Complex A. There are many air pollutant emission facilities in the form of small and medium-sized enterprises in the vicinity. The second indirect impact point was selected as Chungnam Technopark in Seokmun Industrial Complex, which is located about 8.9 km southeast of B Thermal Power Plant and about 0.8 km southwest of C Energy Corporation.

In the first measurement period, measurements were made only at the direct impact point (PEMC); in the second measurement period, measurements were taken at the direct impact point (PEMC) and the non-impact point (HU); and in the third measurement period, measurements were made at the direct impact point (PEMC) and indirect impact point (WCWC). Finally, the fourth measurement period was conducted at the direct impact point (PEMC) and the indirect impact point (CTP).

Table 1. Overview of measurement points, date, and weather

Points	Location	No. of measurement	Rainfall	Asian dust	Period	Season	Abbreviations
Direct Impact Points (DIP)	Private Environmental Monitoring Center in Dangjin (PEMC)	1st (4 times av.)	×	×	'21.4.7 ~ 6.10	Spring	DIP(PEMC)-1st-S
		2nd (4 times av.)	○	×	'21.11.11 ~ 12.22	Winter	DIP(PEMC)-2nd-W
		3rd (2 times av.)	○	×	'22.11.7 ~ 12.15	Winter	DIP(PEMC)-3rd-W
		4th (2 times av.)	×	×	23.4.19 ~ 5.16	Spring	DIP(PEMC)-4th-S
		1st (1 time)	×	○	'21.4.7 ~ 6.10	Spring	DIP(PEMC)-1st-S-AD
Indirect Impact Points (IIP)	Work's comprehensive welfare center in Dangjin (WCWC)	1st (2 times av.)	○	×	'22.11.7 ~ 12.15	Winter	IIP(WCWC)-1st-W
	Chungnam techno park in Dangjin (CTP)	1st (2 times av.)	×	×	23.4.19 ~ 5.16	Spring	IIP(CTP)-1st-S
Non-Impact Points (NIP)	Hanseo university in Seosan (HU)	1st (4 times av.)	○	×	'21.11.11 ~ 12.22	Winter	NIP(HU)-1st-W

2.2 Dust sampling

Dust samples were collected using an Anderson Low Volume Air Sampler (AN-200, Sibata, Japan) with a circular 80 mm diameter quartz filter (QM-A, Whatman, UK). To reduce errors due to humidity, the filter paper was thoroughly dried at 105°C for at least 2 hours and then dried in a desiccator at 20(±5.6)℃ for at least 24 hours. Dust was collected and stored in a desiccator at 20(±5.6)°C for 24 hours. The filter paper was weighed using a balance (Mettler Toledo, model MS105DU) that can accurately measure the weight to 10^{-5} g. To calculate the concentration of dust by particle size, the difference in weight of the filter paper before and after sampling was measured and the concentration of particulate matter by particle size was calculated considering the flow rate and sampling time.

For dust sampling by aerodynamic diameter, an eight-stage, low-volume Ambient Cascade Impactor (ACI series 20-800) from Andersen was used. The aerodynamic diameter of the eight-stage ACI is 9.0 μm or more at stage 0, and 5.8 to 9.0 μm, 4.7 to 5.8 μm, 3.3 to 4.7 μm, 2.1 to 3.3 μm, 1.1 to 2.1 μm, 0.65 to 1.1 μm, and 0.43 to 0.65 μm sequentially from stage 1 to stage 7.

Heavy metals were analyzed by Inductively Coupled Plasma Spectrometry. To extract heavy metals prior to heavy metal analysis, pretreatment was performed using microwave acid digestion method according to Air

Pollution Process Test Standards ES01102.a. In the first measurement period, a total of eight components including Fe, Al, Cr, Mn, Ni, Pb, Cd, and As were analyzed, and in the second through fourth measurement periods, Cu, Ti, V, and Zn were additionally analyzed for a total of 12 heavy metal components.

2.3 Wind rose

To determine the wind direction, we utilized data from the Automatic Weather System (AWS) operated by the Korea Meteorological Administration. The AWS observations of Sinpyeong for a total of 10 years from 2013 to 2023 show that the prevailing winds are from the west-north, south-southwest, and southwest, with a wide distribution of wind directions based on the prevailing winds.

2.4 Particle size distribution

Since the particles captured by the Ambient Cascade Impactor (ACI) have different particle size ranges, the histogram only shows the amount captured in each stage, and the interpretation of the concentration is unclear [7]. Therefore, the concentration distribution of atmospheric aerosol particles captured by the ACI by particle size is convenient to interpret by expressing the data as a log-normal distribution by converting the wide range of particle size to logarithm [8]. In other words, the weight of the particles captured in each section is divided by the logarithm of the particle size in each section to display the concentration [7].

3. RESULTS AND DISCUSSION

3.1 Dust distribution by particle size

The dust concentrations at each of the four measurement periods are shown in Table 2. The average concentrations for the first, second, third, and fourth measurement periods at the direct impact points were 87.50 μg/m^3, 77.38 μg/m^3, 82.4 μg/m^3, and 55.20 μg/m^3, respectively, with the highest average concentration of 133.20 μg/m^3 occurring during the yellow sand event. In addition, the indirect impact points, WCWC, had 77.30 μg/m^3, CPT had 47.05 μg/m^3, and HU, a non-impact point, had 41.53 μg/m^3. Overall, the direct impact points with a short distance from the steel complex had the highest concentration, followed by the indirect impact point, and the non-impact point had the lowest concentration, indicating that they are directly affected by the steel complex.

Table 2. PM concentration by particle size (unit: μg/m^3)

Particle size range (μm)	DIP					IIP		NIP
	(PEMC)					(WCWC)	(CTP)	(HU)
	Asian dust	Non Asian dust						
	1st	1st	2nd	3rd	4th	1st	1st	1st
9.0 ~ 50	14.50	11.39	8.55	6.85	9.35	4.5	7.00	1.93
5.8 ~ 9	11.06	8.40	7.30	5.80	5.95	4.00	5.15	2.80
4.7 ~ 5.8	21.71	11.08	9.95	8.50	7.50	7.4	7.15	4.97
3.3 ~ 4.7	35.75	11.22	10.03	8.75	9.15	7.05	10.10	6.30
2.1 ~ 3.3	32.80	9.64	7.40	7.00	6.45	5.60	4.15	4.25
1.1 ~ 2.1	10.71	6.77	7.55	11.9	3.05	10.5	2.75	5.23
0.65 ~ 1.1	2.03	9.27	11.6	17.10	3.75	17.95	4.05	7.15
0.43 ~ 0.65	1.11	10.77	9.28	9.65	5.45	12.3	4.10	5.70
~ 0.43	3.53	90.00	5.73	6.95	4.55	8.00	2.60	3.20
Total	133.20	87.50	77.38	82.4	55.20	77.30	47.05	41.53

The results of the analysis of dust concentrations by particle size at the three impact points are shown in Figure 1. Figure 1(a) shows the dust concentration by particle diameter at the direct impact site (including the yellow period sample), and Figure 1(b) shows the dust concentration by particle diameter at the indirect impact site and the non-impact site. As shown in Figure 3, all sites exhibited a typical bimodal concentration distribution with high concentrations in the 0.43-0.65 μm range, followed by a decrease, and then the highest concentrations in the 4.7-5.8 μm range. However, the dust during the yellow dust period showed a normally distributed particle size distribution with a slope toward the coarse particle region, where the concentration increased proportionally to the particle size, peaked in the 4.7-5.8 μm range, and then decreased.

It is known that dusts originating from soil are mostly coarse, while dusts of anthropogenic origin generated by combustion of fossil fuels or chemical reactions are mostly fine [9]. Therefore, since there is a lot of dust from automobile fuel combustion and dust emitted from chemical reactions or chemical processes in factories in the atmosphere at normal times, the ultrafine particles around 0.3 μm and dust generated from human activities and residential areas have a high share around 4.5 μm, resulting in a bimodal distribution. As for the diameter of emission particles emitted from automobiles, it is reported that the number of particles around 0.1 μm is the highest for diesel vehicles, and the mass concentration is the highest around 0.2 μm [10]. In addition, it has been reported that the mass concentration of PM10 due to tire wear in the process of road driving is highest around the 2.5 μm particle diameter [11]. On the other hand, when yellow dust occurs, the ratio of fine and coarse particles is significantly different due to the increase in fugitive dust originating from the soil, and the concentration of fine particles in the atmosphere is judged to be different from normal, with a high share of coarse particles around 4.5 μm.

The particle diameter distribution of PM10 in urban air shows a bimodal distribution with peaks on both sides centered around 2 μm due to differences in the generation and destruction mechanisms of particles [12]. In this study, the particle size distribution of PM10 in the atmosphere showed a bimodal distribution with a minimum value centered around the particle size of 1.1 to 2.1 μm during normal times, and the particle size distribution of PM10 in the atmosphere was biased toward coarse particles due to the increased share of coarse particles during yellow dust events.

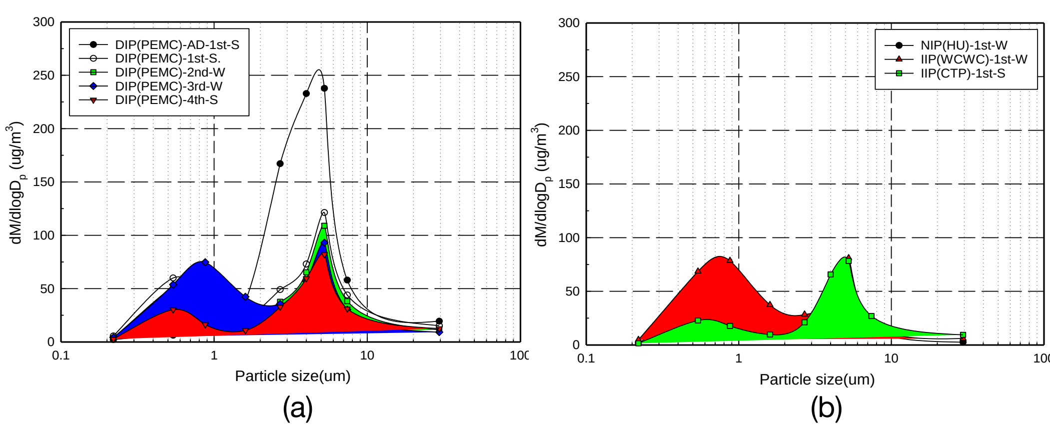


Figure 1. Particle size distribution by impact point. (a) Direct impact point (Asian dust and non Asian dust period), (b) Indirect impact points and non-impact points

3.2 Particular matter ratio

Atmospheric dust has different primary sources depending on its size. Large dust (dust with a diameter greater than 2.5 μm, which accounts for the majority of the total suspended dust mass) is mostly generated by mechanical action and is therefore a primary pollutant. Particulate matter (dust with a diameter of 2.5 μm or less) is mostly formed and emitted by chemical reactions or produced by photochemical reactions in the atmosphere. Particulate matter is therefore a mixture of primary pollutants and secondary pollutants (substances produced by chemical transformations in the atmosphere) [9].

Figure 2 shows the percentage of particle size by impact point from the steel complex. The percentages of

PM10 and above, PM2.5 to PM10, and PM2.5 were 10.9%, 51.4%, and 37.3% for the yellow dust events in the direct impact area, resulting in a PM2.5/PM10 ratio of 0.423. However, the percentages of PM10 and above, PM2.5-PM10, and PM2.5 at the non-impacted site in the absence of yellow dust were 4.6%, 33.9%, and 61.5%, resulting in a PM2.5/PM10 ratio of 0.645. Therefore, it can be seen that most of the suspended dust in the atmosphere during yellow dust events is coarse dust. This is because the distribution of ultrafine particles and coarse particles in the air during non-yellow dust is bimodal, but the distribution of coarse particles increases significantly during asian dust events. In addition, the PM2.5/PM10 ratio at the direct impact site ranged from 0.507 to 0.696 (average 0.603) and the PM2.5/PM10 ratio at the indirect impact site ranged from 0.441 to 0.746 (average 0.601), showing no significant difference in the PM2.5/PM10 ratio between the two sites. In terms of PM2.5/PM10 ratio, the results were similar to those of Lee et al. [13], who reported high PM2.5/PM10 ratios in industrial areas and roadside areas, but different from those of Lee et al. [14], who reported PM2.5/PM10 ratios of more than 70% in major industrial areas in Cheonan, Korea. In addition, a relative comparison of the ratio by dust particle size in spring and winter showed that the ratio of PM2.5 was higher in winter, and the ratio of PM2.5-PM10 was relatively higher in spring. This is believed to be due to the fact that in winter, dust of anthropogenic origin produced by combustion of fossil fuels or chemical reactions is dominated by fine dust [9].

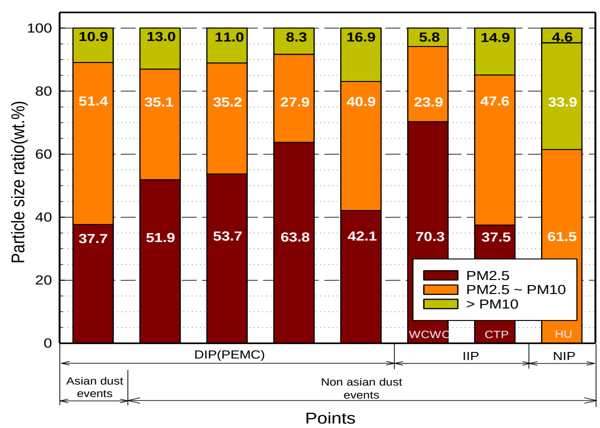


Figure 2. Particle size ratio by impact point

3.3 Heavy metals in dust

The content of heavy metals in dust from the three impact sites classified by distance from the steel complex is shown in Table 3. The concentrations of Al, Fe, and Mn were relatively high when yellow dust occurred at the direct impact site, and other heavy metals were characterized by very low metal content. In the case of the direct impact site, Fe and Al showed high concentrations of 1.5481 ~ 4.7049 μg/m^3 and 0.6089 ~ 2.1624 μg/m^3, respectively, followed by Zn, Pb, and Mn, and the remaining components showed very low concentrations. In the case of indirect impact points, Fe and Al were the highest at WCMC (1.3852 μg/m^3 and 0.3544 μg/m^3, respectively), but Al and Fe were the highest at CPT (1.5596 μg/m^3 and 1.2977 μg/m^3, respectively). This was followed by Zn and Mn, with the remaining elements showing very low concentrations. In the HU, Fe and Al were 0.5254 μg/m^3 and 0.1497 μg/m^3, respectively, followed by Zn and Pb, and the rest of the elements showed very low concentrations.

Table 4 shows the concentration characteristics of Fe by particle size, which showed high concentrations at most points of heavy metals in fine dust. As shown in Table 4, the concentrations of iron at the directly affected, indirectly affected, and unaffected sites ranged from 1.5481 to 4.7049 μg/m^3, 1.2977 to 1.3852 μg/m^3, and 0.5254 μg/m^3, respectively, indicating that they are directly affected by the steel complex. It can be seen that the Fe component in the dust captured during the yellow dust period is mostly present in the dust (1.1-5.8 μm) in the PM2.5 neighborhood. In the case of direct impact sites, most of the Fe was found in the dust (3.3-50 μm) above PM2.5, while in the case of indirect impact sites and non-impact sites, most of the Fe was found in the dust (2.1-9 μm) above PM10. This is believed to be due to the fact that in the case of the direct impact site, the dust in the coarse particle region was more likely to be transported by wind due to the close distance to the steel industrial complex, while in the case of the indirect impact site, the distance from the steel industrial complex was some distance away, so it was not easy to be transported by wind. In addition, in the case of non-affected sites, it was found to be widely distributed over most of the perimeter.

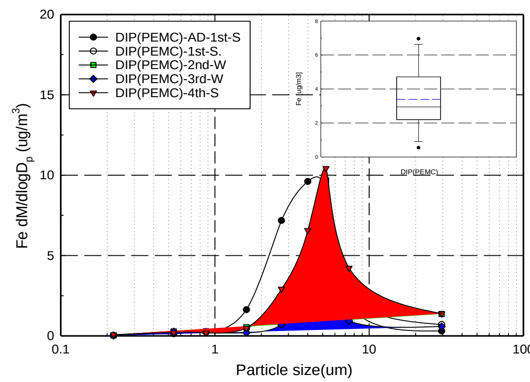
Table 3. Concentration of heavy metals in PM collected at impact points (unit: $\mu g/m^3$)

Heavy metals	Direct impact point					Indirect impact points		Non impact point
	(PEMC)					(WCWC)	(CTP)	(HU)
	Asian dust	Non Asian dust						
	1st	1st	2nd	3rd	4th	1st	1st	1st
Fe	4.8512	2.9230	4.1264	1.5481	4.7049	1.3852	1.2977	0.5254
Al	6.4864	1.2064	0.6089	0.2454	2.1624	0.3544	1.5596	0.1497
Zn	N.D	N.D	0.0566	0.0853	0.1540	0.1487	0.0575	0.0049
Mn	0.1276	0.0519	0.0061	0.0361	0.0608	0.0849	0.0390	N.D
Pb	0.0057	0.0147	0.0472	0.0361	0.0200	0.0400	0.0150	0.0092
As	N.D	N.D	0.0039	0.0159	0.0100	0.0200	0.0940	0.0017
Ti	N.D	N.D	0.0048	0.0143	0.0812	0.0227	0.0562	N.D
Cu	N.D	N.D	0.0068	0.0123	0.0180	0.0200	0.0590	N.D
Cr	0.0349	0.0373	0.0021	0.0022	0.0026	0.0100	0.0008	N.D
Ni	0.0079	0.0130	0.0010	0.0015	0.0021	0.0100	0.0012	0.0009
V	N.D	N.D	0.0004	0.0012	0.0040	N.D	0.0033	0.0001
Cd	N.D	0.0017	0.0006	0.0006	0.0005	N.D	0.0003	0.0003

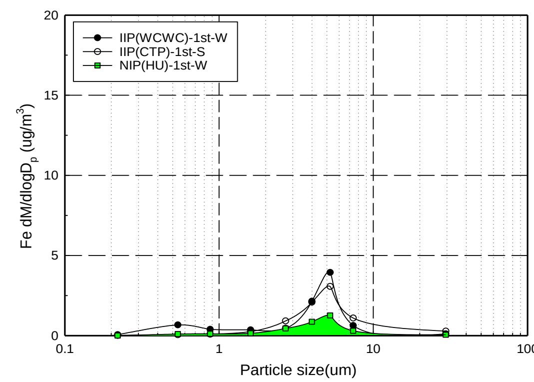
Table 4. Fe concentration by particle size (unit: $\mu g/m^3$)

Particle size range (μm)	Direct impact point					Indirect impact points		Non impact point
	(PEMC)					(WCWC)	(CTP)	(HU)
	Asian dust	Non Asian dust						
	1st	1st	2nd	3rd	4th	1st	1st	1st
9.0 ~ 50	0.2264	0.5219	1.0141	0.4360	1.0275	0.0805	0.2060	0.0397
5.8 ~ 9	0.3683	0.4810	0.7193	0.1775	0.8060	0.1210	0.2055	0.0574
4.7 ~ 5.8	0.7985	0.6669	0.8841	0.2660	0.9525	0.3615	0.2790	0.1150
3.3 ~ 4.7	1.4749	0.5784	0.7742	0.3600	1.0090	0.3280	0.3150	0.1330
2.1 ~ 3.3	1.4091	0.3850	0.4300	0.1355	0.5735	0.0920	0.1835	0.0879
1.1 ~ 2.1	0.4566	0.1303	0.1520	0.0545	0.1355	0.1015	0.0660	0.0403
0.65 ~ 1.1	0.0594	0.0549	0.0649	0.0465	0.0430	0.0860	0.0205	0.0260
0.43 ~ 0.65	0.0231	0.0448	0.0497	0.0475	0.0355	0.1150	0.0130	0.0173
~ 0.43	0.0349	0.0599	0.0381	0.0250	0.1225	0.1000	0.0085	0.0088
Total	4.8512	2.9230	4.1264	1.5481	4.7049	1.3852	1.2977	0.5254

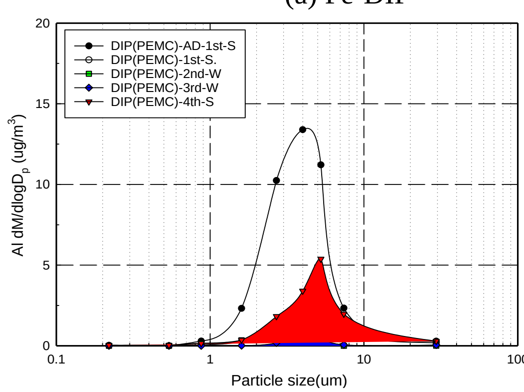
Figure 3 shows the content of heavy metals in dust by particle size. Of the 12 heavy metals (Fe, Al, Zn, Mn, Pb, As, Ti, Cu, Cr, Ni, V, Cd) in the dust analyzed in this study, Cr, Pb, Cu, Ni, V, Cd, and As were present in trace amounts or were not detected. In the case of Fe, the highest concentration was found at the dust particle diameter of 4.7 ~ 5.8 μm regardless of the impact site, and based on the highest concentration, the concentration at the indirect impact site was about 38% of the direct impact site, while the non-impact site was significantly lower at about 12% of the direct impact site, indicating that it was directly affected by the steel complex. In the case of Al, the highest concentration was found at the dust particle diameter of 4.7 ~ 5.8 μm regardless of the impact site, similar to iron. However, except for the yellow dust event, the difference in concentration between the direct and indirect impact sites was not significant, and only the concentration of the non-impact site was significantly lower. In the case of Mn, like Fe and Al, the highest concentration was found at the dust particle diameter of 4.7 ~ 5.8 μm regardless of the impact site. However, except for the yellow dust event, the concentration difference between the direct and indirect impact sites was not significant, and only the concentration at the non-impact site was significantly lower. In addition, unlike other heavy metals, it was characterized by a discrete concentration distribution.



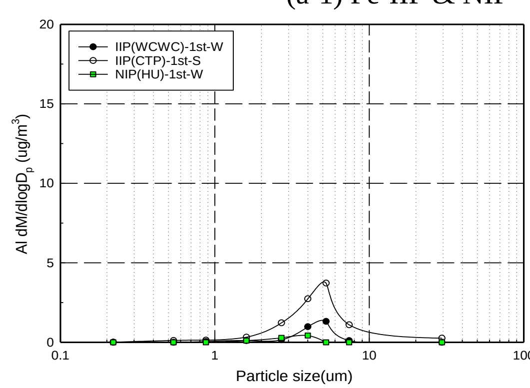
(a) Fe-DIP



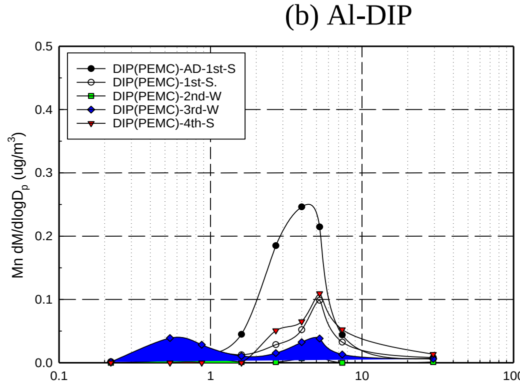
(a-1) Fe-IIP & NIP



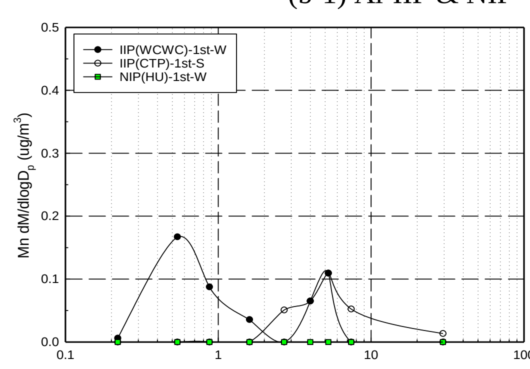
(b) Al-DIP



(b-1) Al-IIP & NIP



(c) Mn-DIP



(c-1) Mn-IIP & NIP

Figure 3. Heavy metal concentration by particle size. (a) Direct impact points, (b) Indirect impact points and Non-impact points

3.4 Percentage of heavy metals in total dust

Figure 4 shows the ratio of the total amount of heavy metals to the total amount of dust in the air at each impact point. The average total concentration of dust was 75.64 μg/m³ (133.2 μg/m³ during the yellow dust event) at the direct impact site, 62.17 μg/m³ at the indirect impact site, and 41.52 μg/m³ at the non-impact site, respectively. In addition, the average total concentration of heavy metals by impact point was 4.59 μg/m³ (11.51 μg/m³ when yellow dust occurred) at the direct impact point, 2.61 μg/m³ at the indirect impact point, and 0.69 μg/m³ at the non-impact point, respectively. Therefore, the ratio of heavy metals in total dust was 6.07 in the direct impact point (8.64 in the direct impact point when yellow dust occurred), 4.20 in the indirect impact point, and 1.66 in the non- impact point, respectively. It can be seen that the proportion of heavy metals in the total amount of dust increases as the concentration of airborne dust increases, regardless of the impact point. This is because the density of heavy metals in the composition of airborne dust is relatively larger than other components.

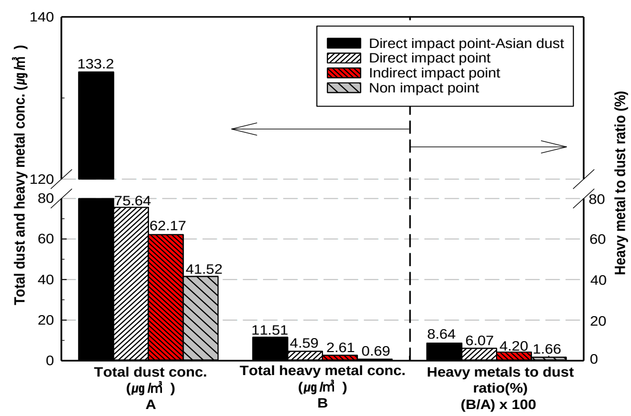


Figure 4. Mass ratio of heavy metals contained in dust by impact point

3.5 Seasonal Distribution of Dust and Heavy Metals

Figure 5 is a box plot of the concentration distribution of dust and heavy metals in the air during spring and winter in an area within a radius of about 35 km from the Dangjin Steel Complex. This shows the seasonal distribution of dust and heavy metals in the area near the complex. As shown in Fig. 7, the dust concentration distribution in terms of maximum to minimum (mean ± standard deviation) values ranged 51.79～104.81 (76.75±21.3781) μg/m³ in spring, and 61.17～100.90 (79.03±16.3852) μg/m³ in winter. In spring, the mean concentration was lower than in winter, but the standard deviation was large, indicating a wide range between the minimum and maximum concentrations. In addition, the concentration distribution of heavy metals in terms of maximum to minimum (mean ± standard deviation) values ranged 3.05～10.68 (5.24±2.7837) μg/m³ in spring, and 0.73～6.32 (3.90±2.0412) μg/m³ in winter. For heavy metals, concentrations were higher in spring than in winter, with intermittent very high concentrations.

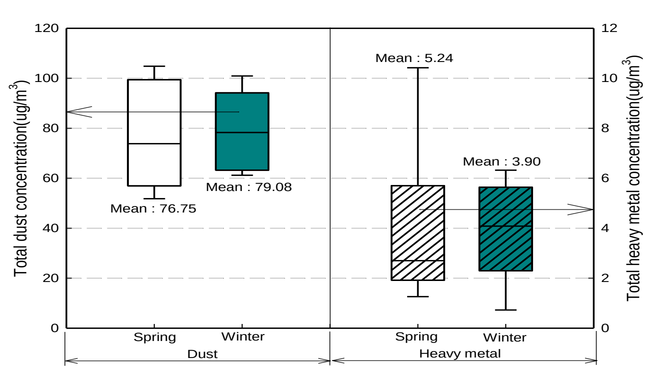


Figure 5. Comparison of dust and heavy metal concentrations in spring and winter in the area surrounding Dangjin Steel Complex (within about 35 km radius)

4. CONCLUSION

To determine the impact of dust emitted from the steel complex in Dangjin, Chungcheongnam-do on the surrounding area, the distribution characteristics of dust and heavy metals in the vicinity of the steel complex (direct impact site), residential areas (indirect impact site), and reference points (non-impact site) were investigated using an eight-stage Cascade Impactor, and the results are as follows.

The average dust concentrations for the 1st, 2nd, 3rd, and 4th periods at the direct impact points were 87.50 μg/m^3, 77.38 μg/m^3, 82.4 μg/m^3, and 55.20 μg/m^3, respectively, with the highest concentration of 133.20 μg/m^3 during the yellow dust period. Among the indirect impact points, 77.30 μg/m^3 was found at WCWC, 47.05 μg/m^3 at CPT, and 41.53 μg/m^3 at HU, a non- impact points.

The dust concentration distribution characteristics by particle size showed a typical bimodal distribution with high concentrations in the range of 0.43 to 0.65 μm at all measurement points, followed by a decrease, and then the highest concentration in the range of 4.7 to 5.8 μm. However, during the yellow dust period, the distribution was normalized toward coarse particles with the highest concentration in the range of 4.7 to 5.8 μm.

The average PM2.5/PM10 ratios for the direct, indirect, and non-impact points were 0.603, 0.601, and 0.645, respectively, indicating higher concentrations of fine particulate matter at the non-impact sites.

Regardless of the impact point, heavy metals in the dust were highest in Fe and Al, followed by Zn, Pb, and Mn, with very low concentrations in the remaining components.

For dust, the average concentration was 76.75 (51.79 to 104.81) μg/m^3 in spring and 79.03 (61.17 to 100.90) μg/m^3 in winter, showing no significant difference. However, for heavy metals, the average concentration was 5.24 (3.05 to 10.68) μg/m^3 in spring and 3.90 (0.73 to 6.32) μg/m^3 in winter, showing a trend of higher concentration in spring than in winter.

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