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A Study on the Contribution of Fugitive Dust to the Residential Area near the Port of Incheon

Ki-Joon Jeon, Jin-Chul Bang and Yong-Won Jung*
Department of Environmental Engineering, Inha University
#253 YongHyun-dong, Nam-gu, Incheon, 402-751, Korea

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Abstract

Simple mass balance method was developed to estimate the contribution of two major fugitive dust sources in the Port of Incheon to a nearby residential area in this study. Using the relatively small number of TSP data as well as the data on mass fraction of Fe and organic materials in the sampled dust, our simplified method demonstrated its ability to estimate the contribution of each fugitive source to a specific location including the residential area with relatively reasonable accuracy. It is clear from this study that this simple method can be applied to the situation where two major fugitive dust sources are responsible for the high TSP concentration around the source area and there are clear marker chemicals representing the characteristics of the fugitive dust sources.

Key words : Fugitive dust, Receptor method, TSP, Scrap metal, Animal feed stuff

1. BACKGROUND

As the second largest port in Korea, the Port of Incheon has served to import the raw materials necessary for the development of Korean economy for almost half centuries. The raw materials being imported include grains, animal feed stuffs, cement, wood, scrap metal, etc, which are relatively cheap and bulky. Handling of these bulk cargos, however, has emitted fugitive dust during the series of loading and unloading processes for the bulk materials especially at strong wind current conditions in the port area with average wind speed of 3.3 m/s and maximum wind speed of 16.8 m/s on an annual average basis because of the powdery property of the bulk materials in most cases. Furthermore, some of the bulk materials such as animal feed stuffs and scrap metals have been handled in the open area simply because of the ease of handling at the sacrifice of environment. For example, in case of handling animal feed stuffs, strong wind currents emits dust from several points in the storage cycle, such as material loading onto the pile, and load-out from the pile. The movement of the trucks and loading equipment in the storage pile area is also a substantial source of dust. Storage piles are usually left uncovered, partially because of the need for frequent material transfer into or out of storage.

Therefore, there have been frequent complaints from people in the nearby residential area due to the fugitive dust emitting from the handling activities of bulk cargos in the Port of Incheon. In fact, animal feed stuffs and scrap metals are considered to be two major sources

* Corresponding author.
E-mail : jungyw@inha.ac.kr

of fugitive dust in the Port of Incheon in terms of both handling amount and dust emission potential arising from their powdery property. The question is how to estimate the contribution or impact of these particle emission sources to a certain residential area with reasonable accuracy. This is a very important task to determine the proper control measure in a sense that depending on the contribution of each particle source, control methods may be different.

This study focused on the development of simple methodology to estimate the impact of two distinct major dust emission sources such as animal feed stuffs and scrap metals on the residential area nearby the port of Incheon by using relatively small number of sampling data, which had been taken for nearly 2 month period during the fall of 1995. In fact, the bulk cargo terminals in the Port of Incheon will be moved to the new terminal to be constructed with modernized facilities to handle these bulk cargos for the protection of environment.

2. METHOD OF ANALYSIS

In general, to estimate the contributions of particulate emission sources to a certain receptor, the method of chemical mass balance has commonly been used (Seinfeld, 1986; Hopke, 1985; Cass and McRae, 1983; Alpert and Hopke, 1981; Alpert and Hopke, 1980). If the method of chemical mass balance is to be successful, one must know the emission rate and composition of each and every particulate source. This is, however, almost an impossible task especially when the number of particle sources is large and there are no specific marker chemicals indicating the sources of the particles. However, as in the case of the Port of Incheon, when the contributions of two major particulate emission sources are expected to be far greater than those from other particulate sources and there exist clear markers representing the characteristic of particulate sources, one may simplify the method and calculate the contribution of these two particulate emission sources with reasonable accuracy without resorting to such a rigorous receptor method as the method of chemical mass balance. In other words, for the case of scrap metals, marker would be Fe_2O_3, while for the case of animal feed stuff marker would be organic components, which may be starch and cellulose.

Theoretically, the TSP (total suspended particulate) concentration at a certain sampling location very near to the Port of Incheon may be considered to be sum of the dust emitted from scrap metal handling, animal feed stuff handling, and other particulate sources nearby industrial facilities and traffic. Therefore, in case that these two major particulate sources are not in operation or their contributions to a certain location are assumed to be negligible, one may argue that the TSP concentration at a certain location may be the contributions of particulate sources other than scrap metal and animal feed stuff. We will refer to the TSP concentration of this case as background concentration in a local sense for our convenience in this study. In other words, we considered only three particulate sources roughly in this study. Based upon this reasoning, one may define, for example, the relative contribution of the dust from scrap metal handling to a specific sampling location can be defined as follows:

$$C_{1j} = \frac{P_1}{TSP_j} \qquad (1)$$

$$TSP_j = P_1 + P_2 + P_3 \qquad (2)$$

where

C_{1j} = the relative contribution of the fugitive dust emitted from scrap metal handling to the j-th sampling location

P_1 = the contribution in TSP coming from fugitive dust emitted from scrap metal handling to the j-th sampling location

P_2 = the contribution in TSP coming from fugitive dust emitted from animal feed stuff handling to the j-th sampling location

P_3 = the contribution in TSP coming from other particulate sources to the j-th sampling location

TSP_j = the concentration in TSP at the j-th sampling location

Similarly, for the relative contribution of the dust from animal feed stuff handling, one can write

$$C_{2j} = \frac{P_2}{TSP_j} \tag{3}$$

Since mass concentration of Fe in TSP collected at j-th sampling location is considered to be the sum of the Fe concentration in the dust coming from scrap metal handling and that in the background aerosols at the j-th sampling location, one may write the following simple mass balance on Fe.

$$P_1 \cdot X_1 = TSP_j \cdot Y_1 - Fe_b \tag{4}$$

where

X_1 = the mass fraction of Fe in P_1

Y_1 = the mass fraction of Fe in TSP_j

Fe_b = the background concentration of Fe

Rearranging Equation (4), one can get

$$C_{1j} = \frac{P_1}{TSP_j} = \frac{Y_1}{X_1} - \frac{Fe_b}{TSP_j \cdot X_1} \tag{5}$$

X_1 can be measured by chemical analysis of the dust collected by using high volume sampler at middle of the scrap metal handling location in the Port of Incheon, where the dust is expected to mostly come from the scrap metal handling. Here it was assumed that the chemical composition of dust does not vary with particle size. Since large particles tend to settle faster than small particles, this assumption is essential. Y_1 can also be measured by chemical analysis of the dust collected by using high volume sampler at the j-th sampling location. Therefore, one may calculate the relative contribution of the dust from the scrap metal handling facility to the j-th sampling location approximately using Equation (5). Once relative contribution is obtained, contribution can be calculated by multiplying relative contribution by TSP_j.

Similarly, one may calculate the relative contribution of the dust emitted from animal feed stuff handling to a certain location. In the case of the dust emitted from animal feed stuff, marker is organic materials. Using same reasoning as used in the case of Fe, mass balance on organic materials leads to

$$P_2 \cdot X_2 = TSP_j \cdot Y_2 - Org_b \tag{6}$$

where

X_2 = the mass fraction of organic materials in P_2

Y_2 = the mass fraction of organic materials in TSP_j

Org_b = the background concentration of organic materials

Rearranging Equation (6), one can get

$$C_{2j} = \frac{P_2}{TSP_j} = \frac{Y_2}{X_2} - \frac{Org_b}{TSP_j \cdot X_2} \tag{7}$$

The relative contribution data gives an information on the relative contribution of each particulate source to the specific location, while contribution data provide us with the absolute magnitude of contribution of the dust concentration from the each particulate source to the specific location. In this study, both definitions were used to explain the degree of dust pollution near the port more clearly.

3. MEASUREMENT

3.1 Measurement of particulate concentrations

To estimate the degree of the air pollution by fugitive dust near the Port Incheon, the TSP concentrations were measured. The reason that we chose TSP instead of PM_{10} is that in the case of fugitive dust, the particles larger than 10 μm in aerodynamic diameter occupies larger mass fraction in the particle size distribution than the particles less than 10 μm in aerodynamic diameter, so called PM_{10}. The recent study carried out in our laboratory also confirmed that PM_{10} concentration could not represent the degree of air pollution by fugitive dust (Chun, 1999). In fact, the effective cutpoint of standard high volume sampler has been known to be 30 μm aerodynamic diameter. Therefore, in this study, this means that we implicitly considered the particles less than 30 μm aerodynamic diameter only to estimate the degree of air pollution by dust, assuming that the particles that are 30 to 100 μm in aerodynamic diameter are likely to settle within a few hundred feet from the fugitive dust sources and do not affect the particle concentration in the residential area much (U.S. EPA, 1985).

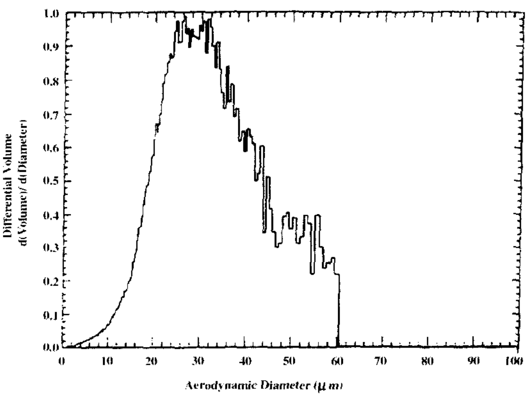

Fig. 1. Particle size distribution of soy bean shell dust.

Fig. 1 shows the size distribution of the dust of soy bean shell taken from the fraction passed through US sieve No. 230, which was measured by Aerosizer (TSI, Inc.). Here, Fig. 1 represents the relative mass fractions of the particles as a function of aerodynamic diameter. As shown in Fig. 1, one can see that the mass fraction of the particles less than 30 μm in aerodynamic diameter occupies fairly large fraction in the case of soy bean shell. TSP concentrations were measured by using high volume sampler (Wedding Co.). After sampling the dust for approximately 24 hour, the filter was taken, dried in the desiccator until threshold at the relative humidity 50%, and weighed. By dividing the measured dust weight by the cumulative air flow during sampling period, particle mass concentration was calculated.

3.2 Sampling locations

Seven sampling locations were chosen based on the distance from the Port Incheon and wind direction, as shown in Fig. 2. Animal feed stuffs are handled mostly near pier 1, which is the location A_1 in Fig. 2 and scrap

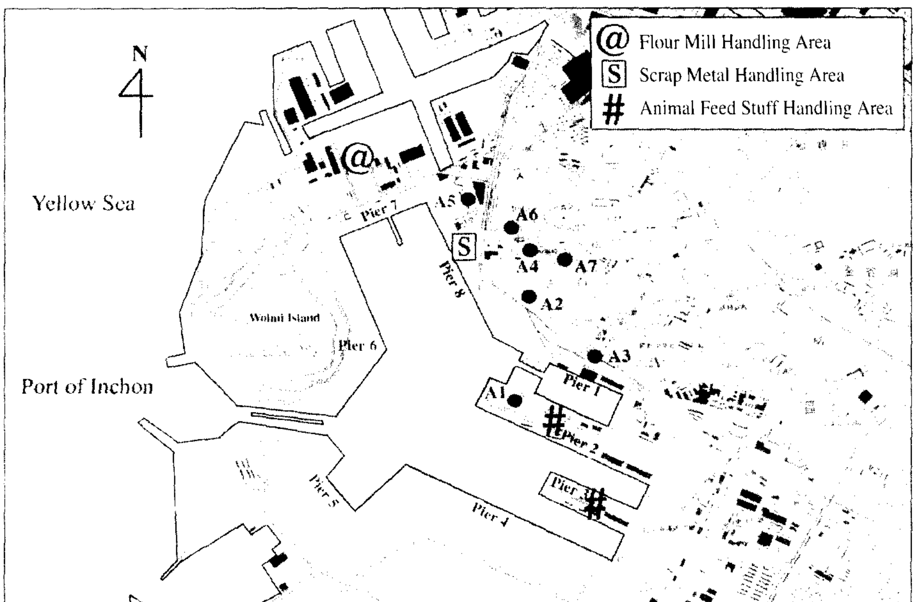

Fig. 2. Schematic diagram of sampling locations.

Table 1. Information on the sampling locations and measured TSP concentrations.

Sampling location	Sampling time and date	Weather condition	TSP ($\mu g/m^3$)	Approximate distance from the animal Feed stuff handling area (m)	Approximate distance from the animal Feed stuff handling area (m)
A_3	26 hours, 9.18.1995	sunny and clear	289	540	862
A_1	25 hours, 9.18.1995	sunny and clear	670	0	810
A_5	21 hours, 9.19.1995	sunny and clear	208	1,178	413
A_4	22 hours, 9.20.1995	sunny and clear	153	885	398
A_6	22 hours, 9.20.1995	sunny and clear	152	1,028	383
A_7	22 hours, 9.20.1995	sunny and clear	205	930	578
A_2	22 hours, 9.21.1995	sunny and clear	404	660	465
A_3	26 hours, 10.05.1995	partly cloudy, strong wind	335	540	862
A_2	24 hours, 10.05.1995	partly cloudy, strong wind	161	660	465
A_2	24 hours, 10.11.1995	sunny and clear	382	660	465

metals are handled in pier 8. Among seven sampling locations, A_1 and A_3 are located inside the Port Incheon. The approximate distance from the two major fugitive dust sources to the sampling locations is listed in Table 1.

3.3 Heavy metal concentrations

Six heavy metal components, Fe, Cu, Cd, Cr, Zn, and Pb, were analyzed for the sampled dust to investigate the effect of scrap metal handling on the heavy metal concentrations in the air near the Port of Incheon area. First, a part of the filter was taken and put into the extracting acid. After extracting heavy metal components from the sampled dust by using ultrasonicator, solid fraction was separated from the solution using a centrifuge. The heavy metal concentrations in the extracted solution were measured by ICP (Inductively Coupled Plasma, SEIKO ICP7000) and converted to the mass concentration in $\mu g/m^3$.

3.4 Organic material concentrations

To measure the mass fraction of organic materials in the dust, the following simple and cheap procedure was employed. First, a part of filter was taken and put into the muffle furnace. After burning the filter at 500°C for 20 minutes, the filter was weighed and the reduced mass was calculated, which gives the data on the organic material mass fraction in the sampled dust. In this study, it was assumed that all the organic materials including the ones in the animal feed stuffs as well as those from the other sources, for example, the products of incomplete combustion of fuels were completely burned out in the muffle furnace.

4. RESULTS AND DISCUSSION

4.1 Measured TSP concentrations

The measured TSP concentration data were listed in Table 1 and shown in Fig. 3 according to the distance from the sampling location A_1, respectively. As shown in Fig. 3, TSP concentrations inside the Port of Incheon were higher than those outside the port. More

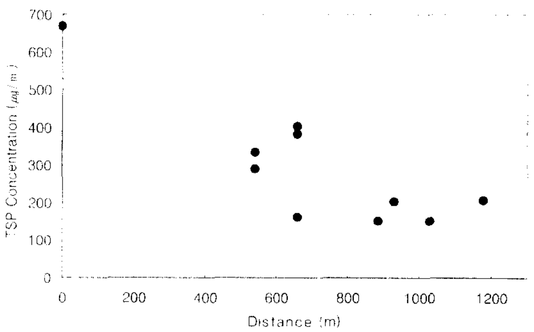

Fig. 3. TSP concentration vs. distance from the sampling location A_1.

importantly, it is clear that as the distance from sampling location A_1 increases, the TSP concentration decreases first but beyond the certain distance remains almost constant, having almost the same values as measured from the other areas in city of Incheon in 1990. This implies that fugitive dust from the port clearly affect the TSP concentration nearby residential area such that the extent of impact decreases with increasing distance, showing the typical qualitative trend of the fugitive dust.

The TSP concentration at sampling location A_1 was found to be 670 μg/m³, which is much higher than the air quality standard of 300 μg/m³ on a daily average basis back in 1995 in Korea. The reason for high TSP concentration at sampling location A_1 is that animal feed stuff handling mainly took place at A_1 or near A_1. This result clearly indicates that fugitive dust problem is severe in this area, even though A_1 area is a work place. The TSP concentrations measured twice at sampling location A_3, another sampling location inside the port, were 289 and 335 μg/m³, respectively, which were also considerably high compared to TSP data at other areas in Incheon.

The TSP concentrations outside the port were found to be relatively low compared to those inside the port except for the case of sampling location A_2, which is the nearest sampling location to the port. The TSP concentrations at sampling location A_2 were measured three times repeatedly to account for the other effects such as weather condition or maybe the amount of handling activities of scrap metal and animal feed stuff. The measured TSP concentrations were 404, 161, and 382 μg/m³, showing the large magnitude of scattering in data. This may be explained in connection with the direction of the prevailing wind and wind speed as well as the amount of handling activities. Namely, one set of TSP data was taken at sampling point A_2 and A_3 using two high volume samplers at the same date, as listed in Table 1. Therefore, this data may imply that prevailing wind at the time of sampling blew from A_1 to A_3 rather than A_1 to A_2. We actually observed the strong wind blew strongly to the direction of A_1 to A_3 approximately at the time of sampling. It is also believed that under this condition, some or all of the activities in bulk cargo handling including animal feed stuff handling as well as scrap metal handling were temporarily stopped or reduced to comply with the regulation on fugitive dust. This explanation will be further clarified by using the measured data of Fe and organic material concentration in TSP later.

4.2 Contributions of the scrap metal handling

The measured heavy metal concentrations at the sampling locations were summarized in Table 2. Also included in Table 2 are the concentrations of Fe and Pb in the ambient air sampled from other areas at least 3 km far away from the port. These data obtained at four different sampling locations that are expressed as B_1, B_2, B_3 and B_4 in Table 2 were the results of the separate study taken by Inha University. It is noted from Table 2 that heavy metal concentrations including Pb and Zn are noticeably higher near the port area than other areas in Incheon. This trend may be due to the fact that the dust emitted from scrap metal handling is the silt composed of oxidized metal components and paint debris of old ships, or possibly due to the particles emitted from the tail pipe of many heavy duty

Table 2. Heavy metal concentrations measured at the sampling locations. (unit: μg/m³)

Sampling location	Fe	Pb	Cu	Cd	Cr	Zn
A_1	4.74	1.05	0.30	0.0	0.04	1.14
$A_2(1_{st})$	9.99	2.63	0.77	0.0	0.04	5.37
$A_2(2_{nd})$	23.49	2.54	0.41	0.0	0.04	3.19
$A_2(3_{rd})$	24.91	6.40	1.44	0.18	0.06	14.81
$A_3(1_{st})$	10.21	1.62	0.42	0.0	0.02	1.99
$A_3(2_{nd})$	7.99	1.74	0.27	0.0	0.03	1.71
A_4	3.70	2.17	0.65	0.02	0.02	4.34
A_5	10.32	2.73	0.86	0.0	0.46	4.87
A_6	12.03	1.81	0.62	0.0	0.22	3.10
A_7	8.11	2.00	0.58	0.0	0.02	4.31
$*B_1$	1.30	0.54				
$*B_2$	1.92	0.81				
$*B_3$	1.50	0.66				
$*B_4$	2.93	1.77				

$*B_1$, B_2 and B_3: approximately 10 km far away from the port of Incheon.
$*B_4$: approximately 3 km far away from the port of Incheon.

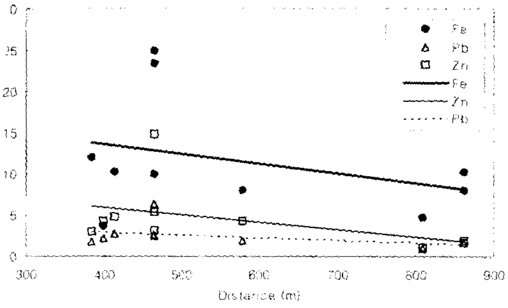

Fig. 4. Heavy metal concentration vs. distance from the scrap metal handling area (Lines in the figure represent least squares fitting of the data for each heavy metal).

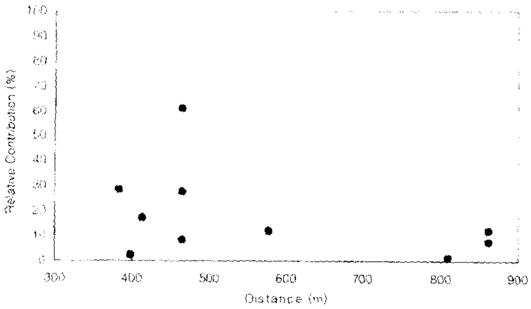

Fig. 5. Relative contribution of scrap metal dust vs. distance from the scrap metal handling area.

vehicles being operated for transportation near the port area (Kim *et al*., 1997). Fig. 4 shows that as the distance from the scrap metal handling area increases, the concentrations of Fe, Pb, and Zn decrease. In particular, the degree of decrease in Fe concentration with the increase in distance is larger than that of Pb and Zn on the whole. This implies that the best marker chemical for the fugitive dust from scrap metal handling would be Fe, as mentioned in the development of the simple method in this study.

Both the relative contribution and the contribution of the dust from scrap metal handling to the each sampling location were calculated by using Equation (5) and listed in Table 3. Here, Fe mass fraction X_1 was taken as the value of 0.21, which was obtained from previous study (Cho, 1994). The sampling location where the dust sample was obtained in the previous study was at the middle of scrap metal handling area, and thus it was assumed that the dust emitted from the scrap metal handling had the characteristics of Fe mass fraction of 0.21 throughout this study. The reason for not having TSP data at the scrap metal handling area in this study was that we were not allowed to sample the dust at the scrap metal handling area at that time. As a background concentration of Fe near the port, Fe concentration at sampling location B_4 about 3.0 km far away from the port, was chosen, since B_4 is the closest sampling location among the sampling locations to measure background concentrations, which may closely represent the characteristics of the background metal concentration near the port area. Fig. 5 shows that the relative contribution of the dust from scrap metal handling to given locations decreases with the increase in distance to scrap metal handling area. It is also noted that the relative contribution of the dust from scrap metal handling is the highest at the sampling location A_2 with the value of about 60%, whereas the measured TSP concentration is only 161 μg/m³ at A_2. This will be explained more clearly later.

Table 3. Relative contributions of scrap metal dust to the sampling locations.

Sampling location	TSP (μg/m³)	Fe (μg/m³)	Fe/TSP (%)	Relative contribution (%)
A_1	670	4.74	0.70	1.22
A_2(1_{st})	404	9.99	2.47	8.27
A_2(2_{nd})	161	23.49	14.59	60.82
A_2(3_{rd})	382	24.92	6.52	27.42
A_3(1_{st})	289	10.21	3.53	12.00
A_3(2_{nd})	335	7.99	2.39	7.20
A_4	153	3.70	2.42	2.41
A_5	208	10.32	4.96	16.93
A_6	152	12.03	7.92	28.52
A_7	205	8.11	3.95	12.04

4.3 Contribution of the animal feed stuff handling

As for the contribution of the dust from the animal feed stuff handling, the mass fractions of organic materials in sampled dust are listed in Table 4. As shown in Table 4, the mass fraction of organic materials in the dust sampled at A_1 area, which is about 0.70, is the highest among the sampling locations. Since sampling location A_1 is the main handling area of animal feed stuff in the port, it is conceivable to have high organic material mass fraction in the sampled dust at A_1 compared to that in the sampled dust outside the port. Furthermore, remaining 30% in mass in the sampled dust at sampling location A_1, which corresponds to approximately 201 μg/m³ in TSP, may be the contributions of both background TSP concentration near the port area and small unknown fugitive dust sources near the sampling location A_1 inside the port other than animal feed stuff handling and scrap metal handling. Nonetheless, it was assumed that the fugitive dust emitted from the animal feed stuff handling area had the organic material mass fraction of 0.70.

Also included in Table 4 are the relative contribution of the dust from animal feed stuff handling to each sampling location, which was calculated by using Equation (7) assuming that organic mass fraction of the dust from animal feed stuff handling area was approximately 0.70.

Here, as a background concentration of organic materials in the dust, the value of 43 μg/m³ was chosen, which was obtained from the sampling location A_7. Table 4 shows that organic material mass concentration of 43 μg/m³ is the smallest among those obtained from other sampling locations. Although A_7 is not the farthest sampling location away from the animal feed stuff handling area, it is likely that the contribution of the fugitive dust from the animal feed stuff handling or some other organic dust emission sources may be minimal by the following reason. In fact, pier 7 in the port also deals with some organic bulk materials such as flour for flour mill companies nearby, as shown in Fig. 3, which may affect the organic material mass concentration nearby areas by some fugitive dust in the processes, even though relatively modernized conveying systems are used for flour loading and unloading in pier 7 and nearby flour mill companies. This may be the reason why the organic material contributions to

Table 4. Relative contributions of animal feed stuff dust to the sampling locations.

Sampling location	TSP (μg/m³)	Organic material (μg/m³)	Organic material (%)	Relative contribution (%)
A_1	670	468	69.85	90.80
$A_2(1_{st})$	404	181	44.91	49.02
$A_2(2_{nd})$	161	94	58.39	45.35
$A_2(3_{rd})$	382	215	56.28	64.46
$A_3(1_{st})$	289	123	42.56	39.63
$A_3(2_{nd})$	335	98	29.25	23.50
A_4	153	51	33.33	7.49
A_5	208	74	35.58	21.34
A_6	152	72	47.37	27.32
A_7	205	43	–	0

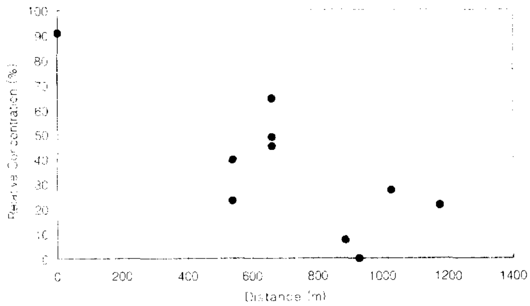

Fig. 6. Relative contribution of animal feed stuff dust vs. distance from the animal feed stuff handling area.

sampling locations A_5 and A_6 are higher than those to sampling location A_7, despite their being the two farthest sampling locations to A_1.

Fig. 6 shows that relative contributions of the fugitive dust from animal feed stuff handling decreases clearly with the increase in the distance form the animal feed stuff handling area by and large.

4.4 Analysis on the calculated contributions and TSP concentrations

The TSP concentrations coming from each particulate source were calculated and listed in Table 5, which gives the more clear information on the contributions of each particulate source on the specific area. It is found from Table 5 that the fugitive dust from animal feed stuff handling is largely responsible for the high

Table 5. Contributions of particulate sources to the sampling locations.

Sampling location	TSP_j	P_1 (Scrap metal)	P_2 (Animal feed stuff)	P_3 (Background)
A_1	670	8.17	608.36	53.47
$A_2(1_{st})$	404	33.41	198.04	172.50
$A_2(2_{nd})$	161	97.92	73.00	0
$A_2(3_{rd})$	382	104.74	246.24	31.02
$A_3(1_{st})$	289	34.68	114.53	139.78
$A_3(2_{nd})$	335	24.12	78.73	232.16
A_4	153	3.69	11.45	137.85
A_5	208	35.21	44.39	128.40
A_6	152	43.35	41.53	67.12
A_7	205	24.68	0	180.32

TSP concentrations near the port area. Nonetheless, in view of the high heavy metal concentrations in the dust from scrap metal concentration and their hazard to human health, the environmental impact of scrap metal dust on the port area could be larger than that of animal feed stuff dust, despite its smaller contribution in TSP concentration near the port. Among the sampling locations, A_2 turned out to be the most polluted area where the contributions of both animal feed stuff dust and scrap metal dust are high as shown in Table 5. This result is conceivable in view that A_2 is closely located to both scrap metal handling area and animal feed stuff handling area and thus there should be more possibilities for the fugitive dust to settle in this area than other area.

It is noted in Table 5 that the sum of contribution in TSP of the dust from animal feed stuff handling and that from scrap metal handling exceeded the TSP measured second time at A_2 by about 10 μg/m^3, which corresponds to about 6% in TSP at A_2. This discrepancy in mass balance may be explained as follows: (1) The mass fraction of Fe in the dust from the scrap metal handling may vary depending on the weather condition as well as the extent of oxidation of the scrap metal being handled. (2) The mass fraction of organic materials in the dust from animal feed stuff handling may also vary depending on the weather condition and the kind of animal feed stuffs. Since the sampling of dust was not carried out simultaneously for eight different sampling locations including scrap metal handling area, the above possibilities may exist, leading to the violation in mass balance by using a constant value in mass fraction of Fe, 0.21, in Equation (4) and that of organic materials in the dust, 0.70, in Equation (6), respectively, throughout this study. For example, 10% error in mass fraction of Fe in the dust from scrap metal handling leads to about 10% error in the contribution of the dust from scrap metal handling area to the specific locations in view of Equation (4). As a result, it is expected that in some case the violation in mass balance may occur inevitably.

As mentioned earlier, the second TSP data of sampling locations A_3 and A_2 were taken at the same day, which was October 5, 1995. In fact, A_2 is the nearest sampling location to the scrap metal handling area, while A_3 is the farthest sampling location. However, the distances from the animal feed stuff handling area to A_2 and A_3 are about same as shown in Table 1. Table 5 shows that for both cases, contributions of animal feed stuffs are about same, whereas contributions of scrap metal handling are quite different from each other. It is remarkable that the contribution of 97.9 μg/m^3 from scrap metal handling to sampling location A_2 corresponds to about 61% relative contribution to the measured TSP concentration of 161 μg/m^3 at A_2, which is relatively low TSP concentration in this study. The TSP concentration at A_3 is 335 μg/m^3 about twice as high as that at A_2, but the contribution of scrap metal handling is only 24.1 μg/m^3, which is about one fourth of the contribution to A_2 at the same day. This clearly supports the two possibilities, which was mentioned earlier: (1) The prevailing wind at the day blew from scrap metal handling area to A_2, which was clearly observed by us. Therefore, it is likely that relatively polluted background particle concentration near the port was diluted with the strong westerly wind from seaside, where TSP concentration is very low. (2) At strong wind current condition of the day, all the handling activities for bulk cargos might be temporary stopped or reduced except for scrap metal handling.

As for the TSP concentration measured at sampling location A_3, as shown in Table 5, the contribution of other particulate sources including background particle concentration near the port was found to be about 232.2 μg/m^3, which is too high to be considered as background particle concentration of the day near the port in view of the TSP concentration measured at sampling location A_2, which is located at the upstream side of A_3 in terms of wind direction. Therefore, it implies that there may be other fugitive dust sources somewhere between A_2 and A_3, which may be the fallen dust during transportation on the paved road. This can only be addressed by the identifying the particle source and its marker chemical, which should be time consuming and costly.

In summary, it is clear that the simple method used in this study can give us an relatively accurate information on the extent of dust pollution near the port and contributions of two major particle sources to residential area.

5. CONCLUSIONS

Simple mass balance method was used to estimate the contributions of two major fugitive dust sources to a certain area in this study. Using the relatively small number of TSP data as well as the data on mass fraction of Fe and organic material in the sampled dust in this study as well as from the previous study, our simplified method successfully demonstrated the ability to estimate the degree of the contribution of each fugitive dust source to a specific location including residential area near the Port of Incheon with relatively reasonable accuracy. It is clear that this simple method can be applied in the situation where two major fugitive dust sources are responsible for the high TSP concentration around the source area and there are clear marker chemicals representing the characteristics of the dust source.

From the analysis of contribution data, it was found that sampling location A_2 was the most polluted area by the fugitive dust, suggesting the need of the control strategy and technologies for the fugitive dust from the port of Incheon. Further detailed analysis using more marker chemicals from other fugitive dust sources inside and outside the port will be able to give us more clear information on the contribution of fugitive dust sources to the specific area near the port. Nonetheless, it is concluded that this method clearly shows the applicability in estimating the contribution of each particulate source to the specific area near the port of Incheon with relatively small number of data and minimum efforts. The fact that the data were not obtained simultaneously in this study due to the limitation in the number of equipments and personnel may be the major shortcoming of this study. For this reason, it is advisable that further systematic study should be carried out with the data collected at all sampling sites simultaneously, if possible.

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