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Effects of Secondary Dust Lifting on Ambient Particulate Matter in Open-yard Stockpile

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Dust emission from open-yard stockpile is an important source of atmospheric particulate pollution. However, there were few literatures on on-site sampling analysis to study the effects of secondary dust lifting on atmospheric particulate matter concentration in open-yard stockpile. Field testing was the most effective means of verifying the accuracy of wind tunnel tests and numerical simulation methods. In order to study the contribution of secondary dusts to the ambient particulate matter pollution in the open-yard stockpile, field tests are carried out on three typical stockpiling sites of Haihua thermoelectric coal-fired power plant surface coal pile, Open-air soda ash heap in Haihua soda ash plant and Yingyang flavour and fragrance company boiler coal stack. The test results show that the contribution rates of thermal power plant coal pile to particulate matter 2.5 micrometres or less in diameter ($PM_{2.5}$) and particulate matter 10 micrometres or less in diameter (PM_{10}) are 34.3 % and 26.1 %, the contribution rates of soda plant slag pile to $PM_{2.5}$ and PM_{10} are 22.3 % and 36.2 % respectively, and is greatly influenced by the local wind direction and wind speed. The research results provide a solid field test data basis for identifying the contribution of secondary dust to the surrounding atmospheric environment and the law of dust diffusion, which is of great significance for winning the blue sky war.

1. Introduction

Large amounts of particulate matter are released into the atmosphere in urban areas where population and industry are developed. They may be primary particles (such as combustion) that are directly emitted by a single source, secondary suspensions of already settled particles, or transformed from a series of gaseous precursors of emission sources in the atmosphere (Sierra et al., 2014).

The dust generated by the open-yard stockpile under the action of wind is the most serious pollution to the atmospheric environment in the surrounding area (Du et al., 2018). Hydrometallurgical processing of copper slag was investigated by Miganei et al. (2017) because of extraction of metals as Zn, Cu, Ni, Co, Mo, Cr, V and Fe in total content about 5 %. Many industrial enterprises have accumulated and continue to accumulate man-caused waste of production processes that not only pollute the atmosphere and, washed away by rain and snow, pollute the water basin of nearby areas (Niyazbekova et al., 2018). Among the wind erosion dust emissions from open-yard stockpile, wind blowing on the stack accounts for 30 % of the emissions, 40 % of stockpiling activities, and 30 % of on-site equipment transport activities. The factors affecting wind erosion and dust emission are the density of the stockpile, the surface shell, the particle size of the material, the moisture content and the geometrical shape of the stack, among which the most important are the turbulent kinetic energy of the wind and the particle properties of the material vulnerable to wind erosion (Zhang et al., 2012).

Park and Lee (2002) estimated the pollution degree of dust diffusion to the surrounding atmospheric environment by analysing the concentration and composition of atmospheric particulates collected in large open-yard stockpiles. Chalvatzaki et al. (2010) found that meteorological conditions (especially wind speed and temperature) have a great impact on PM_{10} concentration through measurement and research. Hilton and Cleary (2013) proposed a new method to simulate the dust and diffusion of bulk materials in the application of diffusion model to simulate and analyse air flow through open-yard stockpile. The simulation results are in agreement with the empirical formulas given by German Association of Engineers.

Farimani et al. (2011) applied computational fluid dynamics software to simulate the flow field of a wind-blown individual pile to assess its impact on the surrounding environment. Maurer et al. (2006) designed a wind tunnel

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test device that specifically measures the mass concentration of wind erosion dust. The system of wind tunnel test and research was designed by Neuman et al. (2009), and the vertical distribution of PM_{10} under different emission sources was obtained for a series of surface treatments for tailings slag.

Sanderson et al. (2014) conducted the wind tunnel tests, and measured the PM_{10} emission rate of the large open storage yards for smelting slag by controlled volume method, and obtained the concentration distribution of PM_{10} in the vertical direction at low wind speed (Duan et al., 2016). Studies have shown that the dust emission from open storage yards has an important impact on the concentration of total suspended particulate matter in the local area (Yeh et al., 2010). Therefore, it is necessary to reduce the $PM_{2.5}$ and PM_{10} emissions in the open storage yards by covering the surface of the pile and setting the windshield (Xu et al., 2017).

With the enhancement of computer performance and the improvement of atmospheric diffusion model and fluid turbulence model, numerical simulation had become an important method to study the dust diffusion law of large open-yard stockpile (Duan et al., 2017). However, there were few literatures on on-site sampling analysis to study the effects of secondary dust lifting on atmospheric particulate matter concentration in open-yard stockpile. Field testing was the most effective means of verifying the accuracy of wind tunnel tests and numerical simulation methods. Three representative stockpiles in Shandong Province were selected in the study, and the sampling points were set for data collection and analysis in the absence of manual work. The purpose of this study was to provide important field test data for studying the contribution of $PM_{2.5}$ and PM_{10} to the concentration levels of $PM_{2.5}$ and PM_{10} in the surrounding environment caused by secondary dust in open-yard stockpile.

2. Materials and methods

2.1 Overview of the research area

Weifang Coastal Economic and Technological Development Zone is located in the southern of Laizhou Bay. Salt chemical industry, petrochemical industry and fine chemical industry are the main industries in this region, and thermal power plants are also matched. Weifang coastal economic and technological development zone is the largest base of raw salt and bromine production in China. During the salt chemical production process, a large amount of waste residue is produced. These wastes contain a lot of harmful waste residue pile produces a large amount of suspended particulate matter, which diffuses and migrates to the surrounding atmosphere. Especially under the action of wind, its diffusion range is greatly increased, which has a serious impact on the surrounding and even distant atmospheric environment. In addition, the suspended particulate matter produced by coal-fired stack yard of thermal power plant and boiler coal yard of enterprise also pollutes the surrounding atmosphere, and these particulate matters contains trace elements harmful to the surrounding environment and human body (Papagiannis et al., 2014). The three typical stockpiling yards of the open-pit coal pile of Haihua Thermal Power Coal-fired Power Plant, the open-air soda waste pile of Haihua Soda Plant and the boiler coal pile of Yingyang Fragrance Company were selected for on-site test research (in Figure 1).

Weifang is located in the north temperate monsoon zone, close to land and sea, and belongs to the warm temperate monsoon type semi-humid climate. It has four distinctive seasons, windy spring, rainy summer, dry autumn and freezing winter. We found that the average annual temperature of Weifang is 12.6 ℃, the average annual rainfall is 615.3 mm and the annual average wind speed is about 3.0 m/s (Liu, 2017).

2.2 The research overview of stockpile and distribution of sampling points

The geometric dimensions of the studied yard are as follows: the coal stockpile of the thermal power plant is about 560 m * 30 m * 8 m, the waste stockpile of the soda plant is about 500 m * 500 m * 20 m, and the coal stockpile of the fragrance company is about 36 m * 25 m * 4 m.

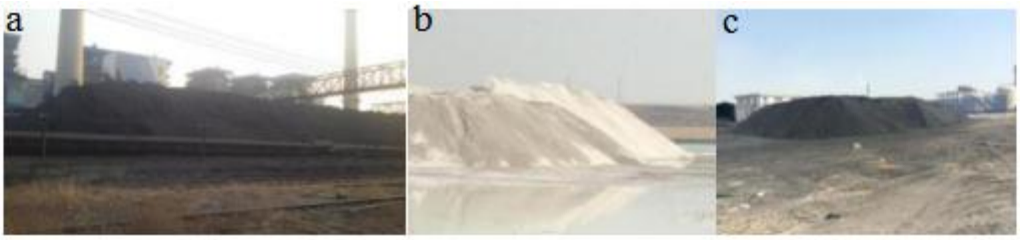

Figure 1: The panoramagram of stockpile: a) the coal stockpile of the thermal power plant; b) the waste stockpile of the soda plant; c) the coal stockpile of the fragrance company

Each sampling is based on the idea of arranging at least one point in the upwind direction and several points in the downwind direction according to the local meteorological forecast and meteorological data of many years, which accurately estimate and deduce the types, components and quantities of particulate matter emitted from the yard. Due to the influence of the wires, some points have to be properly adjusted on this sampling time is spring, autumn and winter, all of which are relatively dry climates with large dust emission and easy collection of particulate matter. The sampling sites are well-known chemical industrial zones with complex emissions, which increases the difficulty of particle source analysis. The sampling points are arranged as high as possible above 2 m, but due to the limitation of objective conditions, some sampling points are arranged at a lower position. The data of PM_{10} and $PM_{2.5}$ are collected simultaneously to compare their differences and correlations.

2.3 Sampling scheme and instrument

The sampling sites are located in the town of Dajiawa, Binhai District, Weifang City. There are about 4,000 permanent residents nearby. The 24 h samples of $PM_{2.5}$ and PM_{10} near the research site were collected to analyse and estimate the concentration levels and composition of $PM_{2.5}$ and PM_{10}. The medium-flow sampler (Laoying 2050 atmospheric sampler, 100 L/min), is designed and manufactured by the Laoshan Institute of Applied Technology and equipped with $PM_{2.5}$ and PM_{10} particle cutters. The glass fibre filter membrane is produced by Yancheng Tianyue Instrument Co., Ltd.
Sampling time: The fragrance company coal stockpile is from 18:00 on March 23, 2015 to 18:00 on March 24, 2015; the thermal power plant is from 21:30 on March 24, 2015 to 21:30 on March 25, 2015, and the soda plant is from 17:00 on March 26, 2015 to 17:00 on March 27, 2015. There were 11 sampling points in the three yards, and 12 samples of $PM_{2.5}$ and PM_{10} were obtained. The contribution rate of particulate matter in the environment is avoided by primary dust when no man-made operation is selected for field sampling. Sampling height: The three sampling points of the thermal power plant are set at 1.5 m, the four sampling points of the soda plant are set at 4 m, and the fragrance companies are all set at 4 m.

3. Results and discussions

3.1 Analysis of sampling result in thermal power plant

The concentration of $PM_{2.5}$ and PM_{10} at sampling point No.1 is the highest among three points. The reasons are: a): The cleaning operation next to the sampling point is frequent. Due to the lack of effective sealing means between the ash pipe and the cleaning tanker, a large amount of fine ash and slag is leaked, resulting in a high concentration of surrounding PM. b): Cleaning tanker passing by the sampling point generates a lot of road dust.

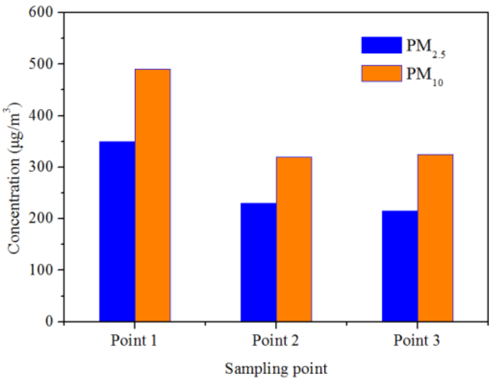

Figure 2: Testing results of the thermal power plant

Table 1: The meteorological factors at the thermal power plant during sampling period

Time	Temperature(°C)	Pressure(kPa)	Wind speed(m/s)	Wind direction
3:30	6.2	101.09	0.4	Southwest
9:30	25.0	103.39	0.5	East
15:30	21.5	103.11	2.8	East
21:30	10.8	103.11	1.1	East

The concentration of $PM_{2.5}$ and PM_{10} at sampling point No.2 was not significantly different from that at sampling point No.3, although it is close to the artificial lake. On the one hand, due to the traffic of vehicles at the entrance of sampling point No.2, vehicle emissions increase the concentration of surrounding particulate matter. On the other hand, lake water may have a poor capture effect on $PM_{2.5}$ and PM_{10}, which indicates that the effect of increasing humidity is not ideal for preventing $PM_{2.5}$ from spreading.

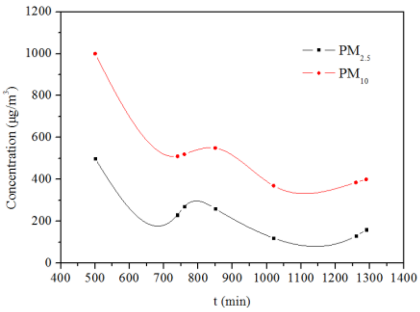

Figure 3: The monitoring results of sampling point No.1 at the soda plant

The concentration of $PM_{2.5}$ and PM_{10} decreases with the increase of the distance from the three sampling points, which is consistent with the simulation results of PM_{10} diffusion in open-air refuse dumps by Greek scholar Chalvatzaki et al. (2010) using the 1995 version of the American EPA air quality prediction model. The result is that the concentration of PM_{10} increases within 100 m of the downwind direction of the dominant wind and decreases when the distance is greater than 100 m. The sampling points 2 and 3 in this study that the distance from the coal pile is more than 100 m are in the downwind direction of the dominant wind, and the concentration of the sampling points 3 is less than 2 points, which is consistent with the trend of the simulation results. The accuracy and reliability of the simulation study of Chalvatzaki are verified, and the diffusion law of $PM_{2.5}$ in the open dump is estimated based on the measurement of $PM_{2.5}$ concentration at the same time. The contribution rate of $PM_{2.5}$ and PM_{10} to the environment is 34.3 % and 26.1 % respectively.

3.2 Analysis of sampling results in the soda plant

In the process of sampling, the concentration of particles at the sampling point 2 located in the north of the reactor is the highest when the dominant wind direction is south wind, and the concentration of particles at the downwind direction increases significantly, which indicates that the wind direction has an important influence on the diffusion of particles. The other three sampling points have little difference in $PM_{2.5}$ and PM_{10} concentrations. The more uniform diffusion of $PM_{2.5}$ and PM_{10} from the stack site to the surrounding atmosphere may be due to the influence of atmospheric turbulence. The contribution rate of $PM_{2.5}$ and PM_{10} to the environment is 22.3 % and 36.2 % respectively.

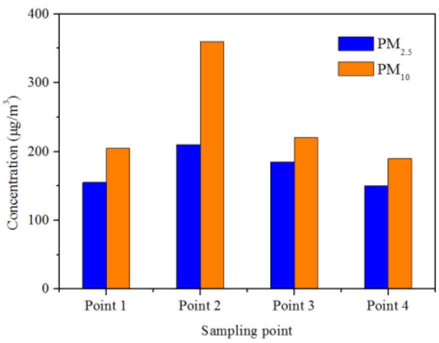

Figure 4: The testing results of the soda plant

The average daily concentrations of $PM_{2.5}$ and PM_{10} at sampling point No.3 were 183 μg/m³ and 234 μg/m³, while the average concentration of $PM_{2.5}$ and PM_{10} at sampling point 4 were 147 μg/m³ and 190 μg/m³, which far exceeded the latest national environmental air quality standard GB 3095 - 2012 limits of 35 μg/m³ and 50 μg/m³.

The trend of $PM_{2.5}$ and PM_{10} is consistent from the two real-time concentration monitoring charts, which indicates that the source of $PM_{2.5}$ and PM_{10} is likely to be the same emission source. Therefore, it can be inferred that the sampled stack has an important contribution to the ambient atmospheric particulate matter concentration.

Table 2: The meteorological factors at the soda plant during sampling period

Time	Temperature(°C)	Pressure(kPa)	Wind speed(m/s)	Wind direction
17:10	26.0	102.81	2.6	Southwest
22:45	11.0	102.80	3.5	South
4:40	8.0	103.30	1.0	Southwest
11:11	27.0	103.20	0.7	Southeast

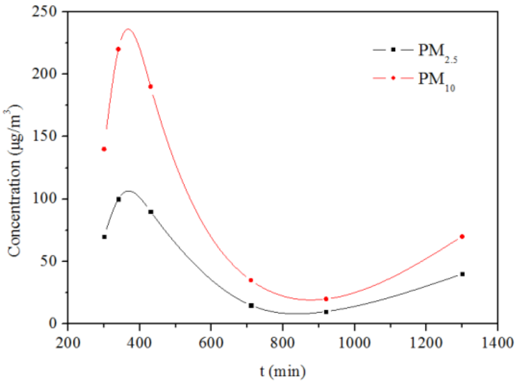

Figure 5: The monitoring results of sampling point No.1 at the thermal power plant

3.3 Analysis of sampling results in the fragrance company coal stockpile

Although the distance and azimuth between the four sampling points and the stack site are quite different according to the sampling results, the $PM_{2.5}$ and PM_{10} concentrations at each sampling point are not significantly different, which is due to the frequent changes of wind direction during the sampling period.

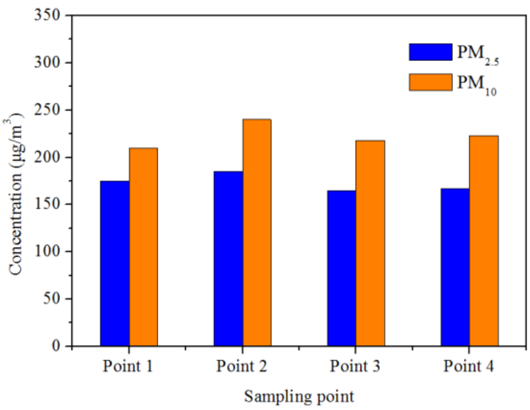

Figure 6: Testing results of the fragrance company coal stockpile

Table 3: The meteorological factors at the fragrance company coal yard during sampling period

Time	Temperature(°C)	Pressure(kPa)	Wind speed(m/s)	Wind direction
18:00	10.0	103.11	3.4	East
24:00	9.5	103.23	1.7	South
6:00	8.0	103.42	2.1	Southeast
12:00	20.1	103.30	1.5	Northwest

4. Conclusions

Atmospheric $PM_{2.5}$ and PM_{10} samples of 11 sampling points with different orientations and different distances were collected in three different types and scales of the yard. The $PM_{2.5}$ and PM_{10} daily average concentration values of each sampling point and the instantaneous value of the particulate matter concentration in a certain

period of time were obtained, which provided important field test data for studying the contribution of dust collection to the ambient atmospheric particulate pollution. This study quantitatively analyzed the influence of the concentration of the secondary dust to the surrounding atmospheric environment is quantified, and provided important field test data for studying the contribution of PM2.5 and PM10 to the concentration levels of PM2.5 and PM10 in the surrounding environment caused by secondary dust in open-yard stockpile. The contribution rates of thermal power plant coal pile to $PM_{2.5}$ and PM_{10} are 34.3 % and 26.1 %, the contribution rates of soda plant slag pile to $PM_{2.5}$ and PM_{10} are 22.3 % and 36.2 % respectively.
The trace elements and content analysis of the samples will be carried out in the future research, and the correlation between $PM_{2.5}$ and PM_{10} of the open-air piles and $PM_{2.5}$ and PM_{10} in the surrounding environment will be further analysed.

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