Source Apportionment of Hazardous Composition and In Vitro Cytotoxicity Test of Fine Particulate Matter ($PM_{2.5}$) at Different Area in Taiwan

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Introduction

Fine Particulate matter ($PM_{2.5}$) is of great importance in air pollution and has adverse health effects and the adverse health effects of $PM_{2.5}$ would be associated with its physicochemical properties such as size, surface area and chemical composition [1,2]. $PM_{2.5}$ could deposited on the deepest part of the lung and pass through the respiratory tract to the alveoli, then transferred to the blood caused health hazards [3]. Many Epidemiological studies have indicated that exposure to $PM_{2.5}$ can increase the risk of asthma, lung cancer, cardiovascular disease and chronic obstructive pulmonary disease (COPD), even the increase in mortality [1,4]. $PM_{2.5}$ composition is affected by natural sources and anthropogenic emissions [5,6]. Particularly, the contents of dioxin-like compounds and other pollutants existed in $PM_{2.5}$ is a crucial air pollutant on the basis of its adverse human health effects and degradation of visibility and the chemical composition of $PM_{2.5}$ is a key to fully understanding and assessing its impacts on climate, air quality. Positive matrix factorization (PMF) has become a factor analytic (FA) model of choice for quantitative source apportionment of contaminants in many air quality monitoring studies. It is necessary to investigate the distribution and composition of harmful pollutants to maintain the quality of public health and living environment. In this study, the PCDD/Fs major emission sources such as industrial boiler, municipal waste incinerators (MWI), electric arc furnace (EAF), the vicinity of stationary pollution sources (six sites) and other three sampling stations have been investigated regarding the distribution of PCDD/Fs, trace metals, carbon, water-soluble ions in $PM_{2.5}$. The PMF model has been used in this study to analyze the source apportionment of PCDD/Fs. In addition, we use an in vitro experiment to evaluate the cytotoxic potential of $PM_{2.5}$ composition on human lung carcinoma cell line A549. To analyze the source apportionment of PCDD/Fs and assess the impact on surrounding environment and human health, the cytotoxic effects of exposure to the $PM_{2.5}$ were measured by MTT assay. It was expected to investigate the toxic effects of different chemical compositions and PCDD/F concentration in $PM_{2.5}$ measured in Taiwan.

Materials and methods

To measure the chemical composition and PCDD/F concentration in $PM_{2.5}$ of flue gas and the ambient air, 12 sampling sites including one traffic sampling site in the center of Taipei basin (Site A), two background station (Sites B1 and B2) in the coastal and mountain area, three stationary emission sources (I1, I2 and I3) and six rural sites in the upwind and downwind areas of the stationary emission sources (Sites C, D, E, F, G and H) were selected in Taiwan during 2015 and 2016 (Fig.1). The traffic sampling site (Site A) was located on the campus of junior high school in Taipei City, which is situated in a volcanic basin in northern Taiwan and has a population of 3.0 million. B1 background site were located at Fuguei Cape at the northernmost tip of Taiwan (121°32'16"E 25°17'51"N; 17 m above mean sea level) and in close proximity to the eastern coast. B2 background site was on Lulin Mountain in central Taiwan (120°52'25"E 23°28'07"N; 2,862 m above mean sea level); far from residential areas and with no major anthropogenic sources of air pollutants in its vicinity, the mountain is exposed to negligible air pollution from human activities. Regarding the stationary emission sources, industrial boiler, MWI, and EAF located in the industrial region of Taoyuan county, Taipei city, and Miaoli county, respectively, were selected. In this study, the flue gas samples were collected for analysis of PCDD/Fs from three stationary pollution sources and ambient air samples in the vicinity of the three investigated industries simultaneously duration of 24 hours during summer season 2015. According to the direction of the monsoon, we set up the sampler at upwind and downwind site in the vicinity of stationary pollution sources (Sites C, D, E, F, G and H).

Sampling head of sampling device was used Cyclones Set device of Apex Instruments for $PM_{2.5}$ sampling of flue gas. About ambient air samples were using high volume sampling trains (Analitica HVS-$PM_{2.5}$ and Sibata HV-1000R) and set the flow rate at 500L/min to collect both vapor phase and solid phase of $PM_{2.5}$ compounds by using the quartz, Teflon filter and polyurethane foam (PUF). The main analysis components for the samples include metal elements, organic carbon (OC), elemental carbon (EC), water-soluble cation/anion and PCDD/Fs. To analyze the source apportionment of PCDD/Fs, the Principal Component Analysis (PCA) and Positive Matrix Factorization (PMF) model were evaluated. The cytotoxicity was measures by espousing the extracts of $PM_{2.5}$ which sampled at the traffic sampling site (A) and the background sampling site of ocean (B1). The water-soluble ions, metal and organic components were exposed to A549 lung cells and the cell viability was determined by MTT assay, respectively.

Results and discussion

The results show that the concentration of $PM_{2.5}$ in the flue gas of municipal waste incineration, industrial boiler and electric arc furnace is 340, 530, 350 $\mu g/m^3$, and PCDD/Fs concentration is 4.0, 0.5, 1.0 pg I-TEQ/Nm^3, respectively. The highest amount of PCDD/Fs in each gram of fine particulates matter is 11.8 ng I-TEQ/g in the flue gas of MWI (I1) (Fig. 2). The highest ambient concentration of $PM_{2.5}$ is 35.1 $\mu g/m^3$ at the downwind of the EAF (H), and the highest PCDD/Fs concentration of $PM_{2.5}$ is 21.4 fg I-TEQ/Nm^3 at the traffic sampling site (A) (Fig.3). Both $PM_{2.5}$ in the flue gas and atmospheric are mainly composed of water-soluble ions. The indicator compound of the fine particulate matter in flue gas was Cl^-, K; Ca, SO_4^{2-} and Zn, Fe of MSI, industrial boiler and EAF, respectively (Fig.4). According to the PCA estimation using the varimax in the factor analysis, the PC1 and PC2 had 31.7%, 26.6% variance (Fig.5). The result of PMF analysis estimated the sources of the atmosphere PCDD/Fs were 40% from coal combustion and metal smelting, 31% from open burning and waste incineration and 26% from traffic emission (Fig.6). The results of cytotoxicity assessment showed that the viability of A549 cell which exposed to the 20%, 40%, 60%, 80% and 100% dilution extracts, the water-soluble substances of local traffic pollution event is more than the long-range transport event to promote apoptosis. But also to promote apoptosis, while the metal substances of long-range transport event is higher than the metal substances of local traffic event to promote apoptosis (Fig.7). In addition to the soluble-ions, the metal and PCDD/F content in $PM_{2.5}$ collected from local traffic event is higher than the long-range transport event. However, the components of the extracts of $PM_{2.5}$ exposed to each unit of cells were also different. To further evaluate the reasons for the decline in cell viability, the statistical analysis of different components on the different extract were analyzed (Table 1). The significant correlation between molybdenum (Mo) and vanadium (V) concentrations and cell viability were observed. Regarding the cell test for water-soluble ions, NO_2^-, PO_4^{3-}, Ca^{2+} and total carbon were significantly correlated with cell viability which PO_4^{3-} is positive correlation. The results also showed that lower concentration of PCDD/Fs in the organic extract in long-range transport events had a great correlation with the cell viability. We considered that may be attributed to the fact that the organic matter in $PM_{2.5}$ transported from other nation with more complicated and unknown composition than the local traffic events which might have similar cytotoxic effects.

Acknowledgements

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References

1. Zou Y, Jin C, Su Y, Li J, Zhu B. (2016); *Environ. Pollut.* **212** 627-635.
2. Orona NS, Astort F, Maglione GA, Saldiva PHN, Yakisich JS, Tasat DR. (2014); *Toxicol. in Vitro* **28(5)** 796-802.
3. Zhang S, Li G, Tian L, Guo Q, Pan X. (2016); *Environ. Res.* **148** 15-23.
4. Zheng XY, Ding H, Jiang LN, Chen SW, Zheng JP, Qiu M, Zhou YX, Chen Q, Guan WJ. (2015); *Plos One* **10(9)** 0138146.
5. Perrone MG, Gualtieri M, Ferrero L, Porto CL, Udisti R, Bolzacchini E, Camatini M. (2010); *Chemosphere*,

78(11) 1368-1377.
6. Weinmayr G, Romeo E, Sario MDe, Weiland SK, Forastiere F. (2010); *Environ. Health. Perspect*, **118(4)** 449-457.

Fig.1 Locations of stationary emission sources and ambient air sampling sites in Taiwan.

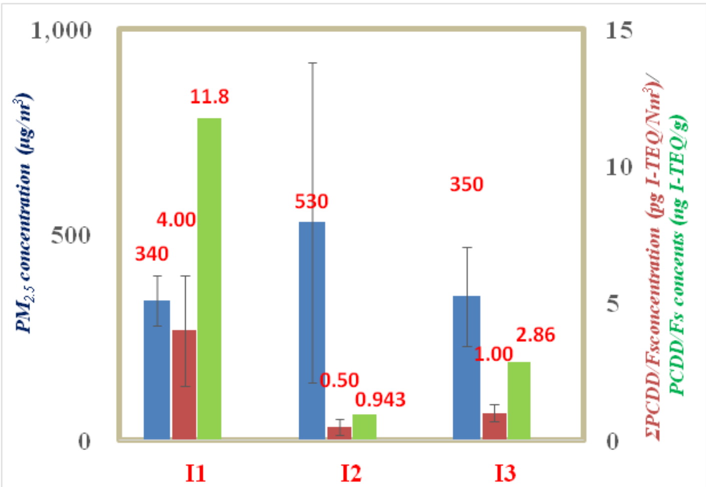

Fig.2 Variation of $PM_{2.5}$ and PCDD/F concentration measured in flue gas from different facilities.

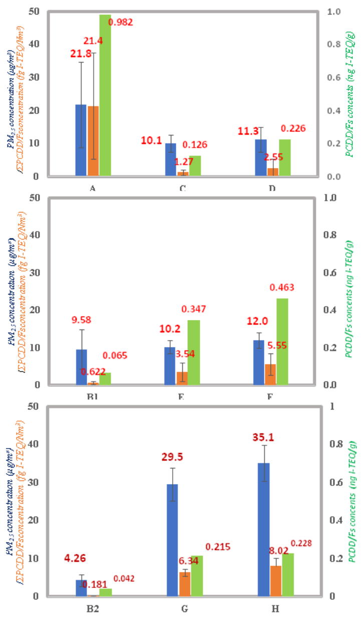

Fig.3 Variation of atmospheric $PM_{2.5}$ and PCDD/F concentration measured at different sampling sites.

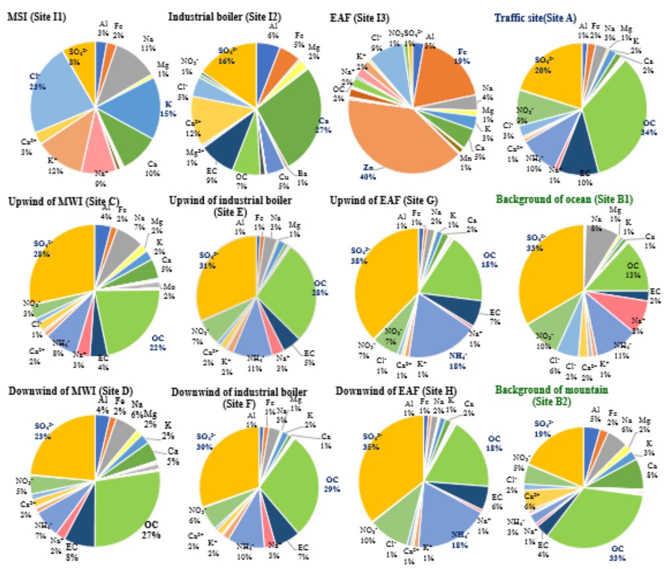

Fig.4 Chemical composition of $PM_{2.5}$ collected from flue gases and ambient air.

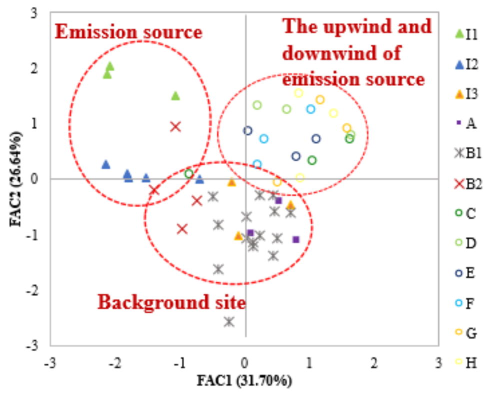

Fig.5 Factor scores scatter of $PM_{2.5}$ collected from flue gas and atmospheric in Taiwan by using PCA.

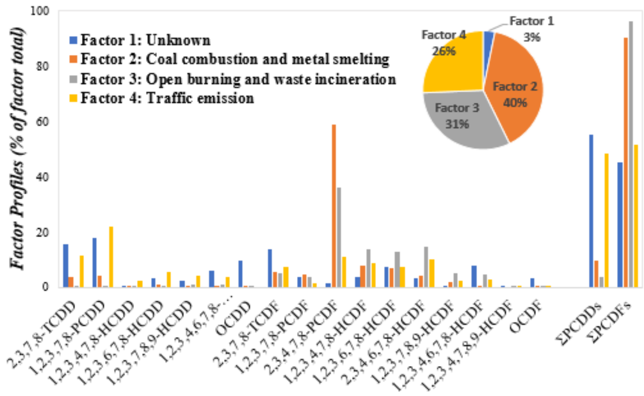

Fig.6 Source apportionment of atmospheric $PM_{2.5}$ in Taiwan by using PMF.

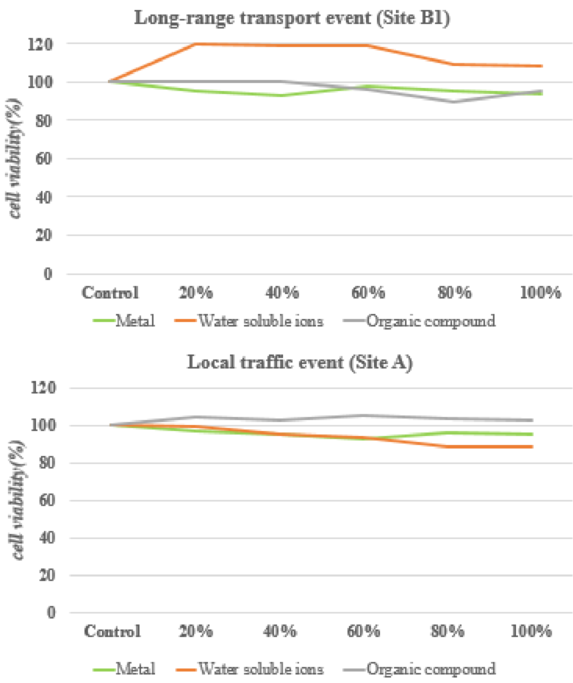

Fig.7 Cytotoxicity test via MTT assay of the atmospheric $PM_{2.5}$ samples from long-range transport and local traffic events.

Table 1 Association between each component in $PM_{2.5}$ and cell viability by Spearman correlation

					Metal				
	Al	**Fe**	**Na**	**Mg**	**K**	**Ca**	**Sr**	**Ba**	**Ti**
r	0.047	-0.045	0.402	0.236	0.203	-0.026	0.189	-0.117	-0.044
p-value	0.846	0.851	0.080	0.315	0.389	0.916	0.422	0.621	0.856
	Co	**Ni**	**Cu**	**Zn**	**Mo**	**Cd**	**Sn**	**Sb**	**Tl**
r	-0.272	0.376	-0.274	-0.382	**0.645**	-0.241	-0.262	-0.423	0.102
p-value	0.245	0.103	0.242	0.097	**0.003**	0.305	0.264	0.065	0.667
	V	**Cr**	**As**	**Y**	**Se**	**Zr**	**Ge**	**Rb**	**Cs**
r	**-0.504**	-0.290	0.051	-0.125	-0.017	-0.251	-0.114	0.290	0.364
p-value	**0.025**	0.214	0.831	0.599	0.947	0.284	0.630	0.214	0.115
	La	**Ce**	**Pr**	**Nd**	**Sm**	**Eu**	**Gd**	**Tb**	**Dy**
r	-0.009	-0.011	0.093	0.060	0.134	0.036	0.155	0.123	0.244
p-value	0.972	0.967	0.695	0.802	0.572	0.881	0.513	0.603	0.299
	Er	**Tm**	**Yb**	**Lu**	**Hf**	**Mn**	**Pb**	**Ga**	**Ho**
r	0.263	0.095	0.263	0.116	-0.215	-0.111	0.102	0.060	0.056
p-value	0.261	0.691	0.261	0.626	0.361	0.640	0.667	0.802	0.816
					Water soluble ions				
	Cl^-	**NO_2^-**	**NO_3^-**	**$SO_4^=$**	**PO_4^{3-}**	**Na^+**	**NH_4^+**	**K^+**	**Mg^{2+}**
r	-0.232	**-0.885**	-0.256	0.179	**-0.632**	0.023	0.011	0.128	0.124
p-value	0.324	**<0.001**	0.275	0.449	**0.003**	0.927	0.967	0.590	0.602
	Ca^{2+}	**TC**							
r	**-0.705**	**-0.806**							
p-value	**<0.001**	**<0.001**							
					Organic compound (PCDD/Fs)				
			Long-range transport event				***Local traffic event***		
r			**-0.72121**				0.47879		
p-value			**0.0186**				0.1615		