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Application of Air Purifier Filter Unit to Remove Particulate Matter in Semi-Outdoor System

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Abstract

$PM_{2.5}$ and its chemical compositions are more concerned due to their impact on human health. This research characterizes particulate matter with the size of 2.5 μm and smaller ($PM_{2.5}$) and total suspended particle (TSP) in three locations at Faculty of Engineering, Kasetsart University (Bangkhen Campus, Bangkok). Air purifier filter unit was utilized to collect particulate matter in order to determine the toxic metal components such as arsenic, cadmium, chromium, nickel, and lead by using the inductively couple plasma optical emission spectrometer (ICP-OES). The results showed that the daily average concentrations of indoor $PM_{2.5}$ at locations L01, L02, and L03 were 61.5, 50.4, and 78.8 μg/m^3, respectively. For all locations, only arsenic was found at location L03. With the concentration of 7 ng/m^3 which were higher than the WHO standard. The air purifier filter unit helped to improve indoor air quality by reducing concentration of $PM_{2.5}$. The average removal efficiency at locations L01, L02, and L03 proved to be 11.8%, 21.2%, 40%, respectively. However, the downstream concentration of $PM_{2.5}$ was still higher than the indoor air quality standard (IAQ). Therefore, the air purifier filters should be further modified to improve the removal efficiency.

Keywords : Air purifier; Air pollution; $PM_{2.5}$; Heavy metal

Introduction

Currently, people from several cities of Thailand expose to particulate matter (PM) such as PM_{10} and $PM_{2.5}$ [1]. The concentration of PM often exceeds the National Ambient Air Quality Standards (NAAQS) of Thailand. The size of PM varies from a few nanometers (nm) to tens of micrometer (μm). The particulate matter composes of biological and chemical compositions. Indoor particles are commonly categorized into coarse particles (PM_{10}), which have diameter between 10 and 2.5 μm, and fine particles ($PM_{2.5}$), which have diameter ≤ 2.5 μm. The coarse particles are emitted from the mechanical process and uncontrolled burning, dust, industrial process, construction, demolition, as well as wildfire. The fine particles are released from the combustion processes: power plants, gas together with diesel engines, and many industrial processes [2].

Exposure to fine particles can cause short-term health effects such as cough, sneeze, runny nose, shortness of breath, irritation of eye, nose, throat as well as lung. Moreover, it can aggravate lung disease, causing asthma attacks, and acute bronchitis, and may increase susceptibility to respiratory infections. Long term exposure to fine particles may increase rates of chronic bronchitis, mortality of lung cancer, heart disease, and reduce lung function [3].

Several studies have shown that heavy metals are the major components of PM related to the adverse health effects through inhalation [4]. The heavy metal contaminated particulate matter may cause inflammation, lung disease, health disease, and cardiovascular disease or even cancer [5]. According to the International Agency for Research on Cancer (IARC), some heavy metals are also considered as carcinogens [6].

The most effective way to improve indoor air quality is reducing the sources of air pollutants and then exhausting them to the outdoor. It is possible to dilute the concentrations of air pollutants by ventilation system. However, the opportunity for dilution using outdoor air is limited by weather conditions as well as contaminants in the outdoor air.

Filter design selection (including filtration efficiency calculation and filter selection) is the key to collect the indoor $PM_{2.5}$ concentrations, whereas the ambient $PM_{2.5}$ concentration is an important design parameter in the filter design process.

The fractional removal efficiency for the pollutants is an helpful parameter to determine the efficiency of air purifier filter unit. The most widely used fibrous media air filter test method for duct mounted particles filters is ASHRAE Standard 52.2, which evaluates the removal efficiency for particles having diameter of 0.3 to 1.0 μm. This method reports the removal efficiency as a minimum efficiency reporting value (MERV) ranging from 1% to 16%, based on average removal efficiency across 3 ranges of particle sizes: 0.3-1.0 μm, 1-3 μm and 3-10 μm [7].

For this reason, in this research, field test is expected to provide useful information for the application of air purifier filter unit to remove particulate matter in a semi-outdoor system. The purposes of this study are to analyze the concentration of $PM_{2.5}$ as well as $PM_{2.5}$ filtration performance, and to determine the concentration of TSP-related heavy metal. This study is expected to provide some results which could guide the development of air purifier filter system.

Materials and Methods

Study Site

The study area was at Faculty of Engineering, Kasetsart University (Bangkhen Campus). In order to estimate the risk of PM to health caused by pollution derived from fine particles, $PM_{2.5}$ samples were collected in three different locations: semi-outdoor and indoor environment in Chuchat Kamphu Building (Building 14). This study emphasized on accessing the differences of population exposing to $PM_{2.5}$ in relation to heavy metal element without considering indoor characteristics and personal behaviors.

The three studied locations included L01, L02, and L03. L01 was the auditorium seating area located on the 1st floor of the building 14. L02 was the main corridor of the Department of Environmental Engineering located on the 9th floor of the building 14. For L03, it was the main entry lobby area located on the 1st floor of the building 14. All of these locations had no air conditioning system, fresh air supply system, and indoor air purifier filter. Those 3 locations are shown in Figure 1.

Figure 1 Sampling location

Development of air purifier filter and performance test

The arrangement of the air purifier filter unit, inlet air, particle filter and air blower is shown in Figures 2. The schematic diagram of the experiment is presented in Figure 3. The system was operated by using the negative pressure airflow. The inlet air has flowed from the outside through the primary filter (coarse filter) which was installed at the inlet air grilles. The secondary filter (fine filter) was collected as the treated specimen in this study and samples were recorded across the secondary filter.

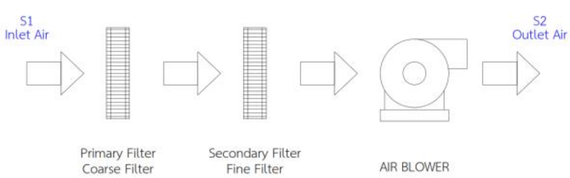

Figure 2 Assemble air filter selection

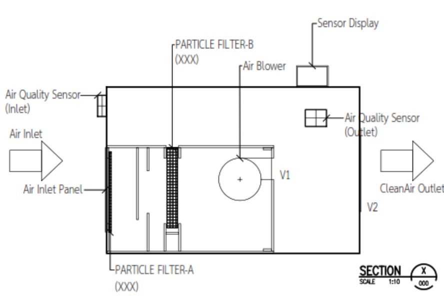

Figure 3 Schematic diagram of the experiment

Specification of air purifier filter unit and particle filter are given in Table 1. The particle concentration sensors were installed at the inlet air grilled and the outlet after the secondary filter positions to measure $PM_{2.5}$.

Table 1 Specification of air purifier filter unit

Air purifier unit	
Dimension	350 x 600 x 395 mm.
Air flow rate	40 LPS 84.75 cfm
Inlet air grill Outlet air grill	100 x 200 mm. (2 sets) 50 x 180 mm. (2 sets)
Particle filter (Fine filter)	
Dimension (W x H x D)	215 x 190 x 25 mm.
Removal particles size	> 0.10 μm

Sampling Method

$PM_{2.5}$ samples were collected in 3 locations during the late of winter and the early of summer (January-March). The total suspended particle (TSP) was collected from air purifier filter unit (pore size of 0.1 μm) that was modified from the vehicle air purifier filters. The air was continuously flowed through the air purifier with the flow rate of 40 L/sec. The samples at each location were collected every 24 h for 7 days. Plantower digital universal particle concentration sensor (Model PMS5003ST) was used for monitoring the semi-outdoor mass concentration of $PM_{2.5}$ with controller for continuous measuring during the samping period. The instrument work on the principle of scattering of light to give the real-time measurements. The particle sensor had been calibrated and verified experimentally by Faculty of Science, Mahidol University. Field measurement was conducted during January 27, 2021 to March 10, 2021. Six samples were collected to analyze daily average concentration of particulate matters and heavy metal contents.

Sampling points were located at the corner of each location at a height of approximately 0.9 m above the floor.

Analytical methods for heavy metal elements

Before conducting field test and sampling, blank filters (air purifier filters) were weighted using electronic weighing (GF-3000 Analytical Balance) to determine the TSP mass. Heavy metal elements (Arsenic (AS), cadmium (Cd), chromium (Cr), nickel (Ni) and lead (Pb)) of the TSP on air filters were measured using inductively couple plasma optical emission spectrometer (ICP-OES, Optima 7300 DV – Perkin Elmer, USA.), which has the characteristics of a low detection limit, high accuracy, and fast analysis. It can analyze multiple elements simultaneously.

Results and Discussion

The collection of $PM_{2.5}$ using air purifier filters

The concentration of $PM_{2.5}$ was compared using the standard for outdoor $PM_{2.5}$ as the reference. The results showed that the concentrations of $PM_{2.5}$ at the locations L01, L02, and L03 ranged from 38.0 to 82.9 μg/m^3, 27.3 to 78.8 μg/m^3, and 18.8 to 196.0 μg/m^3, respectively. The average mass concentration of $PM_{2.5}$ was found to be 1.44-2.25 times higher than the limitation (35 μg/m^3) of National Ambient Air Quality Standards (EPA/NAASQ), Thailand [8].

The removal efficiency of air purifier filters was shown in Table 2. It was found that the $PM_{2.5}$ removal efficiency at location L01 was about 11.8%. The $PM_{2.5}$ removal efficiency at locations L02 and L03 were 21.2% and 40.0%, respectively. These results indicated that the air purifier was not successfully removed $PM_{2.5}$ from the inlet air.

Table 2 Average $PM_{2.5}$ removal efficiency of each location

Location	$PM_{2.5}$ Inf. (μg/m^3)	$PM_{2.5}$ Eff. (μg/m^3)	Particle removal efficiency (%)
L01	61.5±3.89	54.2±3.76	11.8±0.92
L02	50.4±8.20	39.5±4.86	21.2±3.75
L03	78.8±19.81	45.5±5.28	40.0±11.26

As shown in Figures 4-6, the highest $PM_{2.5}$ concentration of 291 μg/m^3 was found in the ambient air at location L03 on March 9, 2021, while the lowest $PM_{2.5}$ concentration of 6 μg/m^3 was found at location L03 on March 3, 2021. The highest $PM_{2.5}$ removal efficiency was found to be 51% (at location L03 on 9th March 2021). Meanwhile, the lowest removal efficiency was 9% at L01 on 1st February 2021. According to the previous research, using the ultrafine glass fiber filter media as the cabin air filters, it was founded that the PM was accumulated on the surface of the fiber, which improved the overall particulate collection efficiency of the filter media. At the same time, the airflow resistance also increased with the solids fraction of filter media [9]. Therefore, the service time of the filter was decreased and need to be changed more often.

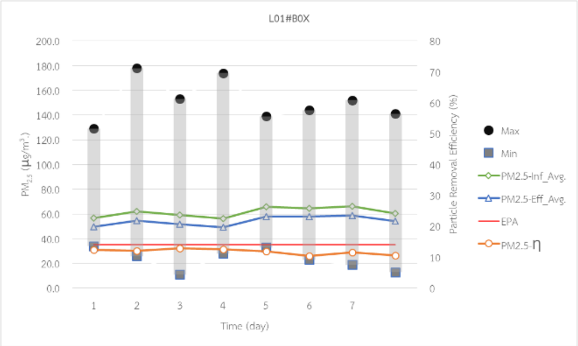

Figure 4 $PM_{2.5}$ concentration and removal efficiency of air purifier filters (location L01)

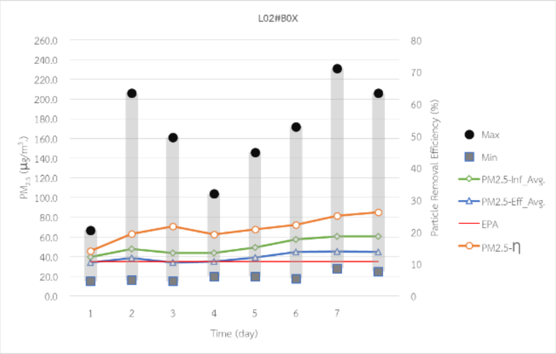

Figure 5 $PM_{2.5}$ concentration and removal efficiency of air purifier filters (location L02)

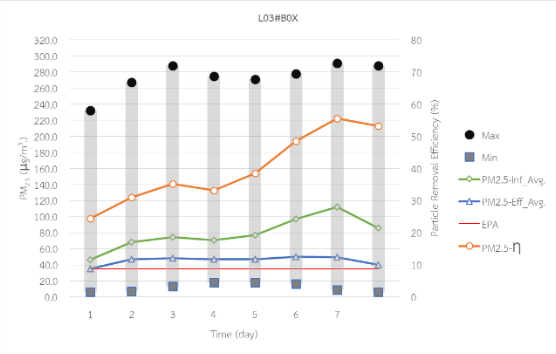

Figure 6 $PM_{2.5}$ concentration and removal efficiency of air purifier filters (location L03)

The heavy metal concentration in TSP

Table 4 shows the contents of heavy metal components in TSP in ambient air. It was found that almost of samples did not contain heavy metal. Only location L03 contained As of 7 ng/m^3 in ambient air. This concentration level was greater than the WHO limit of 6.6 ng/m^3. It is known that As is a carcinogenic and toxic substance [10]. It can cause acute, subacute, and chronic effects such as lung cancer [11]. The excessive As in the ambient air at the main entry lobby of building (L03) may come from the construction site. The outdoor air may carry As through the corridor into the lobby. Arsenic has been reported to present in the ambient air in suburban, urban, and industrial areas. The average total concentrations of As in the ambient air range from 0.02 to 0.4 ng/m^3 in the rural area and 3 to 200 ng/m^3 in the urban areas [6], which is consistent with this study.

Table 5 presents the concentrations of heavy metals in TSP, compared with previous studies. The concentration of As in the residence in Nanjing, China [4] was lower than that in this study, whereas the concentrations of Cd, Cr, Ni, and Pb were higher than this study. Moreover, the concentration of As at the Faculty of Science, Kasetsart University (Bangkhen) [12] was almost equal to the concentration of As found at L03 locations in this study. Nevertheless, the concentrations of Cr, Ni, and Pb were higher than this study and the concentrations of Cr and Pb were very higher than the standard value due to the effect from Vehicle emissions is also an important source of pollution, because the studied area have been located on the first floor of building near the roadside.

Table 4 Concentration of heavy metals in ambient air (ng/m^3)

Heavy metal	L01	L02	L03	WHO	Thai
As	ND	ND	7.0	6.6	-
Cd	ND	ND	ND	5	-
Cr	ND	ND	ND	2.5	-
Ni	ND	ND	ND	25	-
Pb	ND	ND	ND	150	1500

Table 5 Average TSP and heavy metal concentrations in this study and other studies

Site	TSP	$PM_{2.5}$	As	Cd	Cr	Ni	Pb
This study							
L01	36.00	61.5	ND	ND	ND	ND	ND
L02	50.36	50.4	ND	ND	ND	ND	ND
L03	110.90	78.8	7.0	ND	ND	ND	ND
Concentration limit							
WHO			6.6	5	2.5	25	150[a]
Kasetsart University (Bangkhen) [12]							
Faculty of Science (R2)	647.22	-	12.1	-	210	8.37	1660
Nanjing, China [4]							
Residence,	-	107	6.82	0.15	6.24	78.49	4.97

Concentrations of TSP and $PM_{2.5}$ are in μg/m^3; concentrations of heavy metals are in ng/m^3

a : average 3 month (EPA)

Risk assessment of heavy metals to human health

Inhalation through the respiratory system is the main route of exposure to indoor $PM_{2.5}$. According to the IARC, As, Cd, Cr and Ni are classified as human carcinogens which cause lung as well as nose and nasal sinus cancer, while Pb is classified as noncarcinogen which is not associated with risk cancer. Health risk assessment of inhalation exposure route is introduced as follow:

Lifetime average daily dose (LADD, mg/kg-d) is used for carcinogenic material. The exposure dose rate calculation is expressed in Equation (1) [13].

$$LADD = (C \times IR \times ED \times EF \times ET) / (BW \times AT) \qquad (1)$$

where C represents the concentration of the pollutants (mg/m^3); IR is the respiration rate (m^3/d); ED is the duration of exposure (day); BW is the body weight (kg); and AT is the average exposure time (day).

The exposure of the metal element is assessed after LADD is calculated. Cancer risk (R) can be calculated as shown in Equation (2) [13].

$$R = LADD \times SF \qquad (2)$$

where SF is the intensity of carcinogenic chemical (d/mg-kg).

Table 6 Cancer risk assessment of particle metal elements

C	7×10^{-6}	mg/m^3	
IR	15.6	m^3/d	[14]
ET	1	h/d	
EF	260	d/y	
ED	40	year	[15]
BW	80	kg	[14]
AT	70	year	[14]
LADD	2.27×10^{-8}	mg/kg-d	
SF	1.5	d/mg-kg	[16]
R	3.40×10^{-8}		

According to Equation (2), the cancer risk of As, Cd, Cr and Ni was found to be 3.40×10^{-8}, as shown in Table 6. This value was lower than the average risk acceptance of 10^{-6}. As per the USEPA, for carcinogenic heavy metal, the threshold value for cancer risk is 10^{-6}. The cancer risk > 10^{-6} is unacceptable, whereas the cancer risk $\geq 10^{-3}$ is considered to be serious and is a priority for attention.

Conclusions

The concentrations of $PM_{2.5}$ observed in this study were higher than the standards of NAASQ (average 24-h) and the Notification of The National Environmental Board of Thailand. Arsenic was detected in TSP. The concentration of As was higher than that of the WHO standard. Moreover, the carcinogenic risk (R) of As was lower than 10^{-6}. This indicated that heavy metal elements from the indoor air did not affect people's health.

The utilization of air purifier filter unit also helped to improve the indoor air quality with the $PM_{2.5}$ removal efficiency 11.8% - 40.0%. However, the concentration for both exhaust air and indoor air quality did not comply with NAASQ and IAQ standards.

As a result, the development of air purification should be further studied including the service time of each component in the system as well as the maintenance costs of high control indoor air quality.

Acknowledgement

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References

[1] Pollution Control Department. 2019. Plan for solving dust pollution problems.

[2] USEPA. 2013. America's Children and the Environment. 3rd Edition, Washington, DC, USA.

[3] USEPA.2003. Particle Pollution and Your Health. [Accessed August, 20 2021]. Avaible from: https://www.airnow.gov/sites/default/files/2018-03/pm-color.pdf.

[4] Fang, Yuanyuan, Dan, Miaomiao, Chunqian. 2018. Heavy metal characteristics and health risk assessment of $PM_{2.5}$ in three residential homes during winter in Nanjing, China, Building and Environmental.143, 339-348.

[5] Yuan, Fang, Songmin, Wenjie. 2021. Source analysis of heavy metal elements of $PM_{2.5}$ in canteen in university in winter, Atmospheric Environmental. 244, 117879.

[6] International Agency for Research on Cancer (IARC). 2012. Arsenic, Metals, Fibers, and Dusts, Volume 100C, A Review of Human Carcinogens. [Accessed August, 21 2021]. Available from: https://publications.iarc.fr/Book-And-Report-Series/Iarc-Monographs-On-The-Identification-Of-Carcinogenic-Hazards-To-Humans/Arsenic-Metals-Fibres-And-Dusts-2012.

[7] USEPA. 2018. Residential Air Cleaners, A Technical Summary. 3rd Edition, Washington, DC, USA.

[8] ASHRAE 2016. ANSI/ASHRAE Standard 62.1-2016 Ventilation for Acceptable Indoor Air Quality, Atlanta, GA: ASHRAE.

[9] Xin, Junjie, Xuan, Chaojun. 2021. Performance optimization of airliner cabin air filters, Building and Environment, 187, 107392.

[10] World Health Organization (WHO). 2010. Preventing Disease Through Healthy Environments, Exposure to Arsenic : A Major Public Health Concern. [Accessed August, 25 2021]. Available from: https://www.who.int/ipcs/features/arsenic.pdf

[11] WHO. 2000. Air Quality Guidelines for Europe, 2nd edition (WHO regional publications. European series ; No.91). [Accessed August, 20 2021]. Available from: https://apps.who.int/iris/handle/10665/107335.

[12] Suthasinee M. 2010. Health Risk Assessment of Heavy Metals in the Offices' Indoor Air. (master's thesis, Kasetsart University).

[13] USEPA. 1989. Risk Assessment Guidance for Superfund : Volume I, Human Health Evaluation Manual (Part A), Washington, DC, USA.

[14] USEPA. 2011. Exposure Factors Handbook : 2011 Edition, Washington, DC, USA.

[15] USEPA. 1991. Risk Assessment Guidance for Superfund : Volume I, Human Health Evaluation Manual (Part B), Washington, DC, USA.

[16] USEPA. 2002. Integrate Risk Information System (IRIS), Chemical Assessment Summary : Arsenic inorganic ; CASRN 7440-38-2. [Accessed August, 26 2021]. Available from: https://iris.epa.gov/static/pdfs/0278_summary.pdf.