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Research paper

Ultrafine Particles Measurement in Printing Industry Across West Malaysia

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Abstract

Ultrafine particles (UFPs) emission generated from devices such as printer and photocopy machines are known as potential risks to human health. However, limited information is available to study UFPs exposure generate from larger printer. Thus, this study aimed to determine the concentration of UFPs such as particle number (PN) and lung deposited surface area (LDSA) and investigates the influence of physical environment factors on UFPs in two types of offset lithographic printing rooms such as monochrome and color, across West Malaysia. The measurements of PN and LDSA were taken by using a condensation particle counter and the diffusion charger dosimeter during the printing activities. The mean values for PN and LDSA are 22215 particles/cm^3 and 43 µm^2/cm^3, respectively. The exposure of UFPs from the monochrome room was found to be significantly higher than the color room ($p < 0.001$ for PN; $p < 0.001$ for LDSA) due to variation in the ventilation system. Based on correlation analysis, the physical environment factors, such as relative humidity, temperature, and air movement, were observed to influence the UFPs concentrations in printing room. The findings imply that a good selection of the ventilation system is important to minimize worker's exposure to UFPs emission.

Keywords: *airborne particulate matter, health effects, indoor air quality, offset lithography printer, ultrafine particles*

1. Introduction

Particulate matter (PM) exposure level commonly used to determine the condition of the indoor air quality either in residential or workplace environment [1][2][3]. The increase in concern and attention given to particulate matter issue are because of their various fraction size of particles and diversity of health effects as published in scientific research papers over the past decade [4][5][6]. Cardiopulmonary, respiratory diseases, and cancer issues are among the health effects associated due to short and long-term exposure to ultrafine particles (UFP) [7]. UFP is a particulate matter with an average aerodynamic diameter of below 100nm [8] and has been reported to give more inflammatory response compared to other class of particles size [9]. Recently, several studies have investigated the exposure of UFP emitted from printer and photocopy machine [10][11][12]. In study to examines the UFP conducted by Betha et al. (2011) at commercial printing center, National University of Singapore reported the particle number (PN) concentration range from 1230 – 9780 particles/cm^3 [13]. A cross-sectional comparative study conducted among photocopy worker in Selangor, Malaysia indicate UFP exposure was four (4) times higher in exposed group compare to control group. The mean of PN for exposed group was 14567 particles/cm^3 [14]. In study to determine particle emission from desktop 3D printer by Stephen et al. (2013) found PN concentration ranges from 9684 – 27838 particles/cm^3 [15]. Kagi et al. (2007) highlighted that concentration of UFP were increased in the study to determine UFP emission from laser printer/ink-jet printer in office environment [11].

In general, the UFP emission from office environment devices such as laser and photocopy machine is known. However, limited information is available to study UFP exposure in long period printing activities especially involving mass production environment related to offset lithography printer. Invented and patented for almost centuries years ago [16], the offset lithography is still the most preferred printing technique used in commercial printing business due to the low cost but able to produce high quality output as desired. Forecasted to reach USD 980 billion by 2018, the global printing industry market is expected to be a comprehensive business [17]. Malaysia Investment Development Authority (MIDA) reported in 2013 there were about 1000 small and medium scale domestic-oriented companies engaged in general printing and publishing business in Malaysia. Printing and publishing industry have recorded to earn about RM 33.2 million investment in 2013 [18]. Risk assessment done by Kiurski et al. (2012) highlighted the printing industries are the sources of pollution to the environment and human [19]. Thus, it is essential to conduct a study on UFP emission long working hour printing activities especially involving mass production printing to fill the knowledge gap on UFP emission between office environment and industrial environment.

The objective of this study is to determine the concentration of UFP in terms of PN and lung deposited surface area (LDSA) in

Table 1: Sampling site information

Location	Measurement Day	Room volume, m^3	Types of entrance	Ventilation Type	Printing Output	No. of printer	No. of worker
Central Region							
K1	4	1294	PVC curtain	Pull Type	Color	1	2
K2	3	1746	Sliding Door	Pull Type	Color	3	7
K3	4	2372	Sliding Door	Pull Type	Monochrome	4	4
K4	3	597	PVC curtain	Air condition	Monochrome	2	2
Southern Region							
J1	3	495	Sliding Door	Air condition	Color	1	1
J2	3	643	PVC curtain	Fan	Monochrome	9	8
Northern Region							
A1	3	300	PVC curtain	Air condition	Color	3	2
A2	3	NA	Open	Fan	Monochrome	8	8
P1	3	335	PVC curtain	Air condition	Color	3	2
P2	3	NA	Open	Fan	Monochrome	5	5
East Coast Region							
T1	3	484	Sliding Door	Air condition	Color	2	3
T2	3	NA	Open	Fan	Monochrome	5	5

two types offset lithography printing room such as monochrome and colour. This study also investigates the correlation between physical environment factors and UFP emission in the printing room.

2. Methodology

2.1. Sampling Site

Six (6) colour and six (6) monochrome printing rooms located at a printing industry premise across West Malaysia were selected for sampling study from December 2014 to April 2015. Sampling was conducted in working hours start from 9.00 to 17.00. The measurements were conducted hourly except during lunch hour (13.00 – 14.00). The description details of the printing rooms are presented in Table 1 such as the business operation, entrance, printer details, and ventilation information.

2.2. UFP Measurement

The measurement of PN and LDSA were taken by using handheld condensation particles counter (CPC) and diffusion charger dosimeter (DC). Handheld CPC model 3800 (Kanomax, Inc., USA) was used in this study to measure PN in the printing room. CPC growing aerosol sample in the chamber that contain supersaturated alcohol which condensed to sizeable is enough for optical count. By using 100% reagent grade of isopropyl alcohol (IPA), the CPC Model 3800 is capable to measure particles in the size range from 15 nm to 1000 nm. The concentration measured are in the range of 0 to 100000 particles/cm^3. Air flow setup at 0.7 L/min and program mode were selected in this study.

LDSA is considered as a potential new metric to represent UFP concentration that have been discussed in several studies recently. The traditional way to report the particulate matter in mass basis is view as irrelevant nowadays for the UFP fraction. This is because smaller particles actually have low mass concentration but larger surface area. The role of surface area in determining the potential toxicity of particles have also discussed numerously in many studies [20]. In the experiment conducted by Oberdörster (2001), a strong correlation was found between the percentage of rat with lung tumor and particles surface area. National Institute for Occupational Safety and Health (NIOSH), US also recommended to use multimetric approach in order to assess the ultrafine particles exposure in the workplace [21]. LDSA in this study was measured using a portable handheld partector (Naneos Particle Solutions GmbH, Switzerland), which is a miniature device that work on diffusion charging technology where particles are charged in a unipolar corona diffusion charger and the ions are removed in an ion trap. The particle charge is detected without particle deposition through induced currents in an induction stage. Since induction only occurs in the presence of a charge gradient, the particle charger is operated in a pulsed mode. The charge level acquired by particles in a unipolar diffusion charger is proportional to the alveolar LDSA concentration. Partector measured particles in the size range from 10 nm to 10 µm and the concentration range from 1 to 20000 $µm^2/cm^3$. The sampling rate for partector is 1 Hz.

2.3. Physical Environment Factors Measurement

Physical environment factors that were measured in this study were temperature (T), relative humidity (RH), and air movement (AM). The instrument used was temperature humidity meter model 971 (Fluke, UK). Temperature unit was in Celsius (˚C) and the percentage for relative humidity. Air movement in the sampling location was measured using VelociCalc® Air Velocity Meters model 9515 ((TSI, Inc., USA) in m/s unit. Particulate matter measurement devices were placed at 1.5 meters around worker breathing zone area. Table 2 is the summary of UFP instruments used in this study.

2.4. Statistical Analysis

Data were statistically analysed for descriptive statistics including mean, minimum, maximum, and standard deviation to characterize the exposure of UFP. Independent t-test was applied to measure the differences among the mean group of data. The relationship between physical environment factors and UFP were evaluated using Pearson product moment correlation. The analysis was performed using IBM statistical package for social sciences (SPSS version 20, USA

Table 2: The summary of UFP instruments

Parameter	PN	LDSA
Metric unit	particles/cm^3	$µm^2/cm^3$
Instrument principle	Condensation Particles Counter	Diffusion Charger
Manufacturer	Kanomax, USA	Naneos, Switzerland
Model	CPC 3800	Partector
Size range	15 nm – 1 µm	1-20,000 $µm^2/cm^3$
Concentration	0 – 100,000 particles/cm^3	10 nm to 10 µm
Flow rate	1 Hz	0.5 L/min

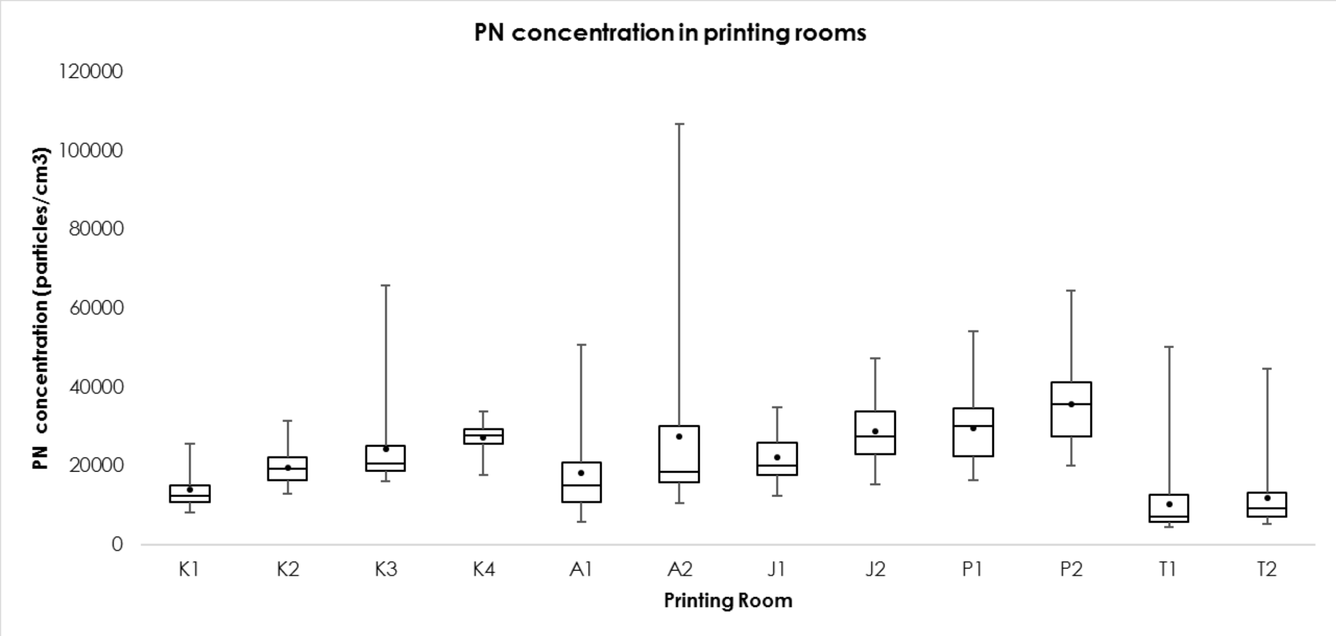

Fig. 1: PN concentration

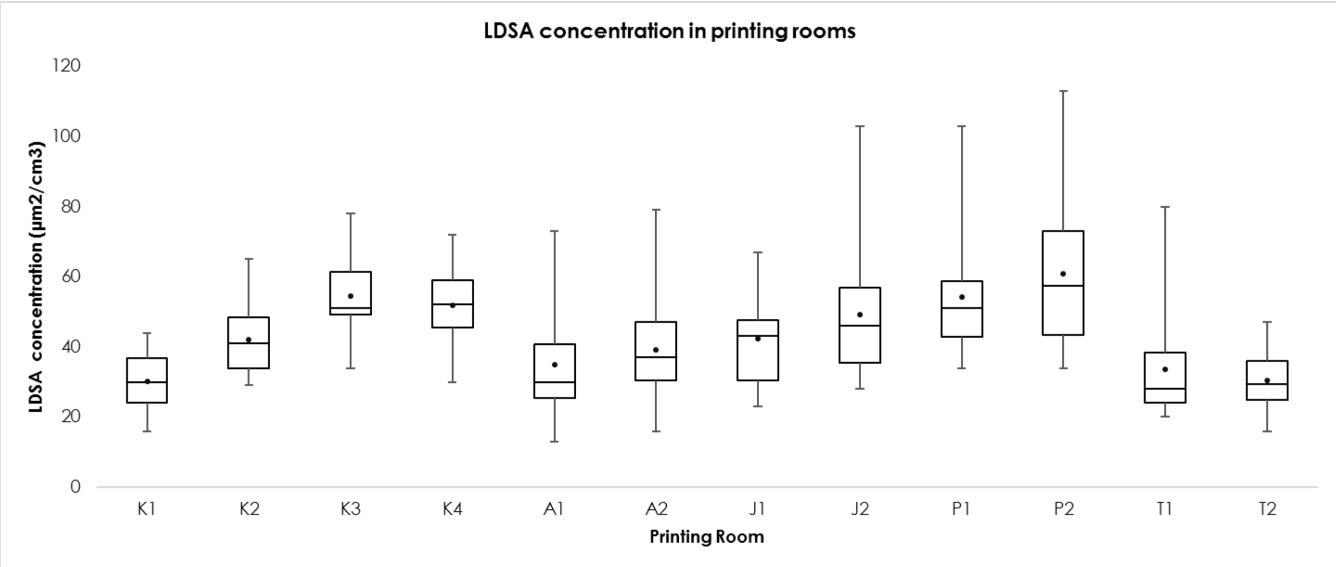

Fig. 2: LDSA concentration

3. Result and Discussion

3.1. Characteristic of UFP Concentrations and physical environment Factor

Figure 1 and 2 shown the average of PN and LDSA measured at 12 printing rooms in across of West Malaysia. The results obtained from the measurements showed that the ranges values of PN measured in K1, K2, K3, K4, A1, A2, J1, J2, P1, P2, T1, and T2 were from 8114 – 25614 particles/cm^3 (mean = 13876 ± 4555 particles/cm^3), 12950 – 31512 particles/cm^3 (mean = 19542 ± 4216 particles/cm^3), 16193 – 65783 particles/cm^3 (mean = 24186 ± 10632 particles/cm^3), 17715 – 33934 particles/cm^3 (mean = 27164 ± 4441 particles/cm^3), 5645 – 50849 particles/cm^3 (mean = 18299 ± 10953 particles/cm^3), 10629 – 106932 particles/cm^3 (mean = 27426 ± 21940 particles/cm^3), 12491 – 34895 particles/cm^3 (mean = 22155 ± 5984 particles/cm^3), 15195 – 47328 particles/cm^3 (mean = 28835 ± 9124 particles/cm^3), 16409 –54264 particles/cm^3 (mean = 29612 ± 8812 particles/cm^3), 20100 – 64609 particles/cm^3 (mean = 35626 ± 1134 particles/cm$^{3)}$, 4344 – 50309 particles/cm^3 (mean = 10214 ± 9447 particles/cm^3), and 5341 – 44650 particles/cm^3 (mean = 11892 ± 8886 particles/cm^3) respectively. The overall mean of PN was 22215 ±12528 particles/cm^3.

LDSA measurement taken in K1, K2, K3, K4, A1, A2, J1, J2, P1, P2, T1, and T2 were ranges from 16 – 44 µm^2/cm^3 (mean = 30 ± 8 µm^2/cm^3), 29 – 65 µm^2/cm^3 (mean = 42 ± 10 µm^2/cm^3), 34 – 78 µm^2/cm^3 (mean = 54 ± 11 µm^2/cm^3), 30 – 72 µm^2/cm^3 (mean = 52 ± 11 µm^2/cm^3), 13 – 77 µm^2/cm^3 (mean = 34 ± 15 µm^2/cm^3), 16 – 79 µm^2/cm^3 (mean = 39 ± 14 µm^2/cm^3), 23 – 67 µm^2/cm^3 (mean = 42 ± 12 µm^2/cm^3), 28 – 103 µm^2/cm3 (mean = 49 ± 19 µm^2/cm^3), 34 – 103 µm^2/cm^3 (mean = 54 ± 18 µm^2/cm^3), 34 – 113 µm^2/cm3 (mean = 61 ± 21 µm^2/cm^3), 20 – 80 µm^2/cm^3 (mean = 34 ± 15 µm^2/cm^3, and 16 – 47 µm^2/cm^3 (mean = 30 ± 9 µm^2/cm^3) respectively. The overall mean of LDSA was 43 ± 17 µm^2/cm^3.

Comparing with previous studies, the PN concentration in current study was found to be higher than PN concentration reported by Stephen et al. (2013), He et al. (2007), Betha et al. (2012), Bahruddin et al. (2015) and Mokhtar et al. (2013). Higher PN concentration was probably because of the printer size. Current study compromised larger size of printer compared to those in other studies, so the UFP generated were more because of the extra ink used as; this is as suggested by Lee and Hsu (2007). No comparison could be made for the LDSA concentrations from other studies because it is not included as a metric in assessing printing or photocopy particles emission. However, the important to measure the LDSA as an UFP metric was discussed in the methodology section.

Table 3: Mean of physical environment factor measurement.

Location - Parameter	Relative humidity (%)	Temperature (ºC)	Air movement (m/s)
K1	54	24	0.25
K2	50	25	0.16
K3	57	24	0.14
K4	59	28	0.20
A1	58	25	0.22
A2	63	31	0.25
J1	59	26	0.15
J2	55	26	0.16
P1	57	26	0.18
P2	65	32	0.18
T1	55	27	0.19
T2	60	32	0.18
Overall	**56**	**27**	**0.19**

3.2. Comparison between Monochrome and Color Printing Room

Table 4 present the mean values for PN and LDSA concentrations measured for colour and monochrome printing room. The results showed that PN concentrations from colour and monochrome rooms ranged from 4344 – 54264 particles/cm^3 (mean = 18747 particles/cm^3) and 5341 – 106932 particles/cm^3 (mean = 25878 particles/cm^3), respectively, while LDSA had been 13 – 103 µm^2/cm^3 (mean = 39 µm^2/cm^3) and 16 – 113 (mean = 48 µm^2/cm^3), respectively. The statistical results also demonstrated that the UFP from monochrome room had been significantly higher than those from colour (p < 0.001 for PN; p < 0.001 for LDSA).

Table 4: Comparison between monochrome and color room

Metric	Room Type	N	Mean	SD	P value
PN	Mono	150	25878	14076	< 0.001
	Color	142	18747	9701	
LDSA	Mono	150	48	18	< 0.001
	Color	142	39	15	

Betha et al. (2012) suggested that there are many factors influenced the UFP emissions from printing devices where the ventilation system is one of them. Compare to color room which equipped by proper ventilation as shown in table 1, the monochrome room only used fan or windows to ventilate the area. Thus, the UFP concentration in monochrome room is greater compare to color room. This finding is consistent with the study conducted by Lee and Hsu (2007) on the measurement of fine and ultrafine particles at 12 photocopy centres in Taiwan. They found that the concentration of particles formation was higher at the photocopy centre with inadequate ventilation. A study by H. Oh et al. (2014) on the characterization of indoor air quality and efficiency of air purifier in childcare centre at Korea described that ventilation type played an important role in reducing particles exposure. They highlighted that the childcare centre with mechanical ventilation air conditioning (MVAC) recorded low concentration compared to the childcare centre that was equipped with windows-type air conditioner. Similar finding was also reported by Utell et al. (2010) on characterization of indoor and outdoor ultrafine particles at a commercial building in Rochester, New York. Indoor environment with proper ventilation recorded low concentration of ultrafine particles compared to outdoor environment. The application of ventilation in reducing the ultrafine particle exposure was also experimented by Rim et al. (2012) while investigating the reduction of exposure to ultrafine particles by kitchen exhaust hoods. This imply a good choice type of ventilation system are needed to reduce exposure to UFP.

3.3. Relationship between UFP and Physical Environment Factors.

Table 5 presents the correlation analysis between UFP concentration and physical environment factors in this study. PN have positive relationship with LDSA (r =0.689, p < 0.01). In study by Spinazzè et al. (2015) to explored relevant measurements of UFP in urban environment, also highlighted similar relationship exist between PN and LDSA. Weak positive relationship established between UFP and relative humidity (r = 0.308 for PN and r = 0.180 for LDSA, p < 0.01). Same results also presented by N.Y. Yang Razali et al. (2015) in in study involved a selected school in Putrajaya, Malaysia. Inconsistency relationship between temperature and air movement with UFP are presented in this study. There is weak positive relationship between PN and temperature with r = 0.100, p < 0.05. However, the statistical correlation between temperature and LDSA do not exist. Similar situation occurs between air movement and UFP where negative weak correlation existed between air movement and LDSA (r = -0.200, p < 0.01) but no meaningful results with PN. Weak correlation between particulate matter and physical environmental factor was also demonstrated in a study carried out by Onat and Stakeeva (2013) to the determination of personal exposure of commuters in public transport to $PM_{2.5}$ and fine particle counts in Turkey. Similar weak correlation between total suspended solid (TSP) and temperature was also presented for indoor air quality levels in a University Hospital in the Eastern Province of Saudi Arabia [29]. The inconsistency results might influenced by little variation of the study that prevent the possible correlation obtained as suggested by Alshitawi et al. (2009).

Table 5: Correlation between UFP and physical environment factors

Total Mean	PN	LDSA	RH	T	AM
PN	1				
LDSA	0.689**	1			
RH	0.308**	0.181**	1		
T	0.100*	0.060	0.095	1	
AM	-0.082	-0.200**	-0.151**	0.114*	1

* Correlation is significant at 0.05 level (2-tailed)
** Correlation is significant at 0.01 level (2-tailed)

4. Conclusion

UFP concentrations were measured in two type printing rooms equipped with offset lithography printer such as monochrome and colour. The results showed that the ranges of concentrations for PN and LDSA were 4344 to 106932 particles/cm3 and 13 -113 µm2/cm3 respectively. In this study, exposure of ultrafine particles from monochrome room had been statistically and significantly higher than that of colour printing (p < 0.001 for PN; p < 0.001 for LDSA). Variation in ventilation type is possible factor to this kind of results. This imply that selection of ventilation type is crucial to reduces the UFP exposure. The physical environment factors were observed to influence the UFP through PN or LDSA based on statistical analysis. Further study need to stress about method of UFP measurement to establish results that represent actual worker exposure such as personal sampling.

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