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Predictive Factors of Particulate Matter Indoor Air Pollution and Its Effect on Workers' Lung

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ABSTRACT

Objective: This study was conducted to assess the mean level of indoor particulate matter (PM) air pollution at photocopy shops in Kota Bharu, Kelantan and its predictive factors toward the pulmonary effect to the workers.
Method: This is a cross sectional study measuring indoor particulate matters of PM2.5, PM10 and ultrafine particle (UFP) and the lung functions of the workers.
Results: Mean particulate matters of PM2.5, PM10 and UFP at photocopy shops were 31.10 µg/m^3, 82.13 µg/$m^3$and 14158 particles/m^3 respectively. Significant predictor factors for the concentration of PM2.5, PM10 and UFP were the dimension of the building, total number of daily paper printed, number of photocopy machines, total daily working hours, humidity level and total number of exhaust fans. For lung function test of the workers, the duration of working hours and their FEV1/FVC had shown an inverse relationship.
Conclusion: This findings suggested that particulate matters in the photocopy shops were significantly influenced by the building factors and photocopying processes; and their effects on the workers were related to duration of exposure during working time; therefore a better design workplace and work process standard operating procedure are needed to reduce pollutants and their effects on health.

Keywords: *indoor air quality, particulate matter, lung function test, photocopy shops.*

1. INTRODUCTION

Air pollution generally is divided into outdoor and indoor. The level of both indoor and outdoor air pollutions are interrelated and can influence each other (Rajagopalan and Brook, 2012). Since human started living in the house, most of indoor air pollution comes from human activities, such as cooking, lighting the house and heating. Later, when human moved into the modernization era, there were many new inventions such as paint, furniture, carpet, house equipment and industrial machine which further contributed toward increasing indoor air pollution (Koivisto et al., 2010; McGarry et al., 2011; Wang et al., 2012; Elango et al., 2013).

Air pollutions, both indoors and outdoors, are major environmental health problems affecting everyone in developed and developing countries as in Air Quality Guidelines Global Update 2005, by the World Health Organization (WHO) (WHO, 2006). Since the year 1993, Environment Protection Agency (EPA) and WHO have ranked today's indoor air quality as one of the top five risks to public health (EPA, 1993). Indoor air pollution is estimated to cause approximately 4.3 million premature deaths meanwhile outdoor air pollution is estimated to cause 3.7 million deaths worldwide per year (WHO, 2014). EPA studies of human exposure to air pollutants indicate that level of pollutants in indoor air are 2-5 times higher compared to outdoor's level, and occasionally it can reach 100 times higher than outdoor's level (Weschler, 2009).

Most of the humans spend most of their daily time indoor, for example Americans spend over 90% of their time indoor including time at home, office, school, library, supermarket, shopping centre and restaurant (EPA, 2011). Researches in this field found particulate matters (PM) in indoor air are increasing with the introduction of electrical appliances particularly printers and photocopy machines. Studies done in photocopy centres have shown the presence of high levels of particulate matters in these work places compared with other indoor air pollutants that are within the permitted-level (Bello et al., 2012; Byeon and Kim, 2012; Elango et al., 2013; Kiurski et al., 2015).

History of photocopy industries started when Chester Carlson, invented a process called electro photography in year 1937 to speed up and increase his daily workload (Schein, 2013). This electro photography process using the electrostatic phenomenon that can attract toner particles to make copies of the papers or documents. This process can be further divided into two, either using direct or indirect electrostatic copies process.

In indirect electrostatic copy process, very bright light is beamed to the original document, example page on the book, so that it can make a shadow of the black and white characters on the page. Then this "electrical shadow" will be captured by photoconductive surface, such as a selenium drum or a photoconductive belt with charges. When this selenium drum or a photoconductive belt runs over a toner, it will attract the toner particles. To complete the process, the new blank paper is given high electric charges so that it attracts the charged toner particles away from the photoconductive surface. Then, image in form of toner particle is rapidly transferred onto a paper which will pass through two hot rollers or fuser unit where the heat and pressure from the rollers fuse the toner particles permanently onto the paper (Kiurski et al., 2015).

In the direct electrostatic copy process, it is the same with the indirect process, only that the "electrical shadow" will be directly beamed to the blank page which electrostatically attracts the toner particles. For the both electrostatic process to work, they require the addition of toner or carrier (Kiurski et al., 2015). The carrier powder consists of carbon black pigment in a resin binder, dyes, fine spheres of sand, glass and steel. It is the toner ingredient, paper product and copying process that is causing the air pollution, such as ozone (O_3), nitrogen oxides (NO), nitrogen dioxide (NO_2), carbon monoxide (CO), carbon dioxide (CO_2), sulphur dioxide (SO_2), volatile organic compounds (VOCs), paper particles and toner particles (Terzano et al., 2010; Elango et al., 2013; Kiurski et al., 2015).

Indoor air pollution has been acknowledged as one of the causes of occupational disease, especially towards the lung, eye and skin diseases. Recent studies have shown these indoor air pollutants also contribute to cardiovascular and nervous system diseases in workers over a period of time (Terzano et al., 2010; Astell-Burt et al., 2013). EPA has produced guidelines and standard toward improvement of ambient air quality to be used since 1970. Although there are standard and guidelines for indoor air quality, people and workers are still lack of knowledge about it. There are also unexplored attitude and practice factors.

The objectives of this study were to explore mean level of indoor air particulate matter pollution inside the photocopy shops in Kota Bharu, Kelantan and its predictive factors towards pulmonary effect to the workers, and to assess level of knowledge, attitude and practice among photocopy shop workers.

2. MATERIALS AND METHODS

This was a cross sectional study conducted from July 2015 till October 2015. Photocopy shops were selected by simple random sampling method from a list of the photocopy shops licensed by Kota Bharu Municipal Council (MPKB). For photocopy shop workers sampling, all workers at the selected photocopy shop were invited to join the study. There were 102 licensed photocopy shops operated in Kota Bharu but only 46 photocopy shops were needed for this study from the sample size calculation. All eligible and consented respondents who fulfilled the inclusion and exclusion criteria were included in this study.

Measurement of particulate matters indoor air pollution was done using a real-time measurements with a surrogate measurement technique according to Industry Code of Practice (ICOP) on Indoor Air Quality 2010 (DOSH, 2010). Lighthouse handheld 3016-IAQ particle counter was used to measure levels of particulate matters sized 2.5 micrometer (µm) (PM2.5), 10 µm (PM10), temperature and relative humidity inside the photocopy shop during the study. This machine was able to measure particle from 0.3 till 10 µm in size with built-in temperature and relative humidity measurement ability. The counting efficiency of this equipment is 50% at 0.3 µm; and 100% for particles > 0.45 µm (per ISO 21501-4).

The flow rate of measurement in this equipment was 0.1 cubic feet per minute (CFM). There were 6 channel sizes that could be monitored using this equipment, which were channel sizes 0.3, 0.5, 1.0, 2.5, 5.0 and 10.0 µm. Result of PM2.5 and PM10 particle counter measurement was automatically switched to approximate density in µg/m^3 for mass concentration monitoring in this study. For temperature and humidity monitoring, metric unit was used. Temperature and relative humidity were measured in Celsius (°C) and percentage (%) respectively.

For the level of UFP in this study, measurement was done using TSI's P-Trak® Ultrafine Particle Counter (UPC) 8525. This equipment could measure the particle size ranged from 0.02 to 1 µm with the air flow of 700 cubic centimeter per minute, (cm^3/min). It could read up to 500000 particles/cm^3 maximum during air sampling. Measurement of this UFP indoor air pollution was also done in real-time measurements using a surrogate measurement technique according to Industry Code of Practice (ICOP) on Indoor Air Quality 2010 guideline.

Measurement of lung function test was done using hand held spirometry from Medical International Research (MIR), Italy, model MIR Mini Spir Light that approved by FDA, ERS, and ATS. This equipment used bi-directional digital turbine flow sensor and could measure maximum up to ± 16 L/s of flow range. Its volume accuracy was ± 3% or 50 ml with flow accuracy of ± 5% or 200 ml/s and this equipment dynamic resistance was at 12 L/s: <0.5 cmH^{2}O/L/s. Vital capacity (VC), forced vital capacity (FVC), and forced expiratory volume (FEV1) were measured at time intervals of 1 seconds, forced expiratory flow 25–75% (FEF 25–75) and maximal voluntary ventilation (MVV) were also done to all selected subjects. Measurements were done according to ATS and ERS spirometry standardization recommendation (Laszlo, 2006; Redlich et al., 2014). Each participant used new and sealed disposable turbine flowmeter.

For assessment of knowledge, attitude and practice (KAP) of indoor air pollution among workers at the photocopy shop, a Malay IAQ-KAP questionnaires that had been developed and validated earlier were used. The Cronbach's alpha values for knowledge, attitude and practice were 0.75, 0.80 and 0.62 respectively. This questionnaires were given to all workers in the selected photocopy shops during the first session of particulate matter air sampling and re-checking for completion or answering their doubts at the fourth session of air sampling, usually during closure time of the shops. All data from particulate matter sampling, lung function test and KAP were analysed using IBM SPSS Statistics version 22.

This study has obtained ethical clearance from Human Research Ethics Committee (HREC) Universiti Sains Malaysia, JEPeM Code: USM/JEPeM/14110434 on 4th March 2015.

Statistical analysis started with data cleaning, then analysis continued with descriptive data for the socio-demographic, occupational history, particulate matters level, lung function test and IAQ-KAP of the workers. Particulate matter level variable of the study was then compared with allowable international air quality standard using one sample t-test to find significant difference from the standards. All predictive factors for the indoor particulate matter were analysed using simple linear regression (SLR), variables with p-value less than 0.05 taken as a significant predictive factor. The analysis then proceed with multiple linear regression (MLR), predictive factors with p-value less than 0.25 were included into model to find significant predictive factors for the particulate matter of indoor air pollution when all factors taken into consideration.

For lung function test of the workers, data were compared with predictive value that calculated by software from Medical International Research (MIR) when age, height and weight factor were taken into consideration using t-test analysis. Predictive factors for lung function test then were analyzed using SLR, followed by MLR analysis.

3. RESULTS

A total of 34 photocopy shops fulfilled the inclusion and exclusion criteria for the study with a total of 66 printing workers; which consisted of 31 men (47%) and 35 women (53%). For socio-demographic characteristics, mean age of the workers in this study was 31.5±9.74 years old. The number of respondents with higher level of educational status was 33 (50%) and 71.2% or 47 respondents were the employees and the 28.8% or 19 respondents were the owners (Table 1). Mean working experience respondents in this study was 60.2±74.75 months and mean daily working duration was 9.0±1.41 hours.

The mean level of PM2.5 found in this study was 31.1±201.11 µg/m^3 (Table 2) which was two times higher compared with allowable level set by the U.S. Environmental Protection Agency (EPA) for their ambient air pollution level (Cao, 2013). Significant predictive factors for PM2.5 found in this study were total pages photocopied or printed on that day, total number of photocopy machines available in the shop and dimension of the shop.

Table 1: Sociodemographic characteristics of the respondents

	Mean (SD)	n (%)
Age	31.5 (9.74)	
Mean working experience (months)	60.2 (74.75)	
Daily working time (minute)	542.7 (84.48)	
Gender		
Men		31 (47.0%)
Women		35 (53.0%)
Educational status		
Primary		1 (1.5%)
Secondary		32 (48.5%)
Tertiary		33 (50.0%)
Employment status		
Employees		47 (71.2%)
Employer		19 (28.8%)

Table 2: Particulate matters level measured in the photocopy shops

	Mean (SD)	min	max
PM2.5 (µg/m³)	31.1 (20.11)	11.0	98.1
Shop with air-conditioner	37.5 (22.47)	14.1	98.1
Shop without air-conditioner	20.6 (8.22)	11.0	44.8
Morning PM level	33.7 (21.1)	8.8	101.9
Noon PM level	30.4 (19.2)	9.3	94.3
Afternoon PM level	30.3 (21.5)	8.4	99.5
Evening PM Level	30.0 (20.3)	9.2	96.6
PM10 (µg/m³)	82.1 (31.05)	40.2	215.2
Shop with air-conditioner	85.2 (29.05)	47.2	144.5
Shop without air-conditioner	77.2 (34.10)	40.2	215.2
Morning PM level	90.3 (33.01)	36.6	149.9
Noon PM level	92.8 (75.25)	45.2	634.7
Afternoon PM level	73.1 (27.32)	36.4	152.4
Evening PM Level	72.4 (31.34)	34.7	159.8
Ultrafine particles (particle/m³)	14158 (6557)	4724	68724
Shop with air-conditioner	14106 (6708)	4724	32925
Shop without air-conditioner	14244 (6438)	7082	29334
Morning PM level	17433 (8928)	3545	38667
Noon PM level	13000 (7072)	2484	30676
Afternoon PM level	14822 (12236)	5810	68724
Evening PM Level	11377 (7432)	3793	33621

About 10.9% of the PM2.5 level of indoor air pollution was explained by the dimension of the shop, 6.8% explained by the number of sheets printed or copied daily and 6% explained by total number of photocopy machine inside the shop. When all factors were taken into consideration using multiple linear regression model, dimension of the shop was significantly contributing toward PM2.5 indoor air pollution level. Correlation coefficient (R) dimension of the shop toward indoor air pollution was 0.331 and correlation

determinant (R^2) was 0.109. An increase of 1 m^2 dimension of the shop will reduce 1.07 µg/m^3 of PM2.5 indoor air pollution levels in the shop.

For PM10, the mean level found in this study was 82.1±31.05 µg/m^3 (Table 2), also higher compared with allowable level set by the U.S. EPA (Cao, 2013). Significant predictive factors for PM10 found in this study were mean working hours in minutes per day and total number of exhaust fans available in the shop. It was noted that 10.9% of the PM10 indoor air pollution was explained by working hours and 6.2% explained by total number of exhaust fan. Although UFP still doesn't have its own standard level, it is important to know its level in view of UFP has a much higher number concentration and surface area than larger particles compared with fine particles at similar mass concentrations in the air, enhanced oxidant capacity, greater inflammatory potential and higher pulmonary deposition efficiency. In this study mean UFP level found in indoor air was 14158±6557 particles/m^3 (Table 2) with significant predictive factors were total daily working hours, total pages printed or copied per day, humidity level and total mark for knowledge in KAP study, which 21.4% was explained by total pages print/copy per day, 13.3% by humidity level, 11.2% by total daily working hours and 7.2% by total mark for knowledge in KAP study.

Lung function test results showed both actual values of FEV1 and FVC were significantly lower from the predictive value that calculated by software when age, height and weight factors were taken into consideration. For FEV1 the mean difference from predictive value was -0.599 litre with p-value <0.001, (95% CI: -0.4063,-0.7700) and for FVC the mean difference from predictive value was -0.740 litre with p-value <0.001, (95% CI: -0.5125,-0.9666) (Table 3). FEV1/FVC result showed that the longer daily working hours of the workers would significantly lower their FEV1/FVC value when all other factors were taken into consideration, with p-value 0.027, correlation coefficient (R) 0.342 and correlation determinant (R^2) 0.117.

Table 3: Lung function test results of the respondents

	Mean actual (SD)	Mean predicted (SD)	p-value*	Mean different (95% CI)
FEV1	2.9 (0.72)	3.5 (0.57)	<0.001	-0.59
Male	3.1 (0.63)	3.8 (0.39)		(-0.777,-0.406)
Female	2.5 (0.72)	2.9 (0.42)		
High school education	3.0 (0.84)	3.6 (0.55)		
Tertiary level education	2.9 (0.57)	3.5 (0.62)		
Employees	2.9 (0.79)	3.5 (0.63)		
Employers	3.0 (0.60)	3.6 (0.49)		
FVC	3.4 (0.76)	4.2 (0.72)	<0.001	-0.74
Male	3.5 (0.85)	4.2 (0.67)		(-0.967,-0.512)
Female	2.9 (0.76)	3.4 (0.56)		
High school education	3.5 (0.85)	4.2 (0.67)		
Tertiary level education	3.4 (0.66)	4.2 (0.81)		
Employees	3.4 (0.80)	4.1 (0.79)		
Employers	3.5 (0.73)	4.3 (0.59)		
FEV1/FVC	85.6 (10.88)	84.2 (2.65)	0.431	1.41
Male	85.5 (11.86)	83.5 (2.27)		(-2.168,4.992)
Female	85.6 (8.61)	85.7 (2.96)		
High school education	85.1 (13.75)	84.8 (2.52)		
Tertiary level education	86.1 (7.20)	83.2 (2.51)		
Employees	85.8 (11.25)	85.1 (2.50)		
Employers	85.2 (10.57)	82.6 (2.15)		

DISCUSSION

In this study, there was a significant high PM2.5 level in indoor air compared with allowable international ambient air quality standard by U.S EPA and this result was similar to almost other results found in previous studies (Koivisto et al., 2010; McGarry et al., 2011; Bahruddin et al., 2013; Elango et al., 2013). Although total pages photocopied or printed on that day, total number of photocopy machines available in the shop and dimension of the shop were the significant predictive factors for the high level of PM2.5 indoor air pollution, only the dimension size of the shop was found significant the final model of multiple linear regression analysis. This finding was parallel with the physic concept of gas distribution that distribute equilibrium in an enclosed space, i.e. the higher the dimension size of the area the lower the concentration of PM2.5 level compared with the lesser dimension size of the shop.

For PM10 indoor air level, it was also higher than allowable indoor air quality standard, similar to other studies that monitor PM10 level at the photocopy shops (Elango et al., 2013; Kiurski et al., 2015). The significant predictive factors for PM10 levels were mean working hours in minutes per day and total number of exhaust fan available in the shop that influenced the PM10 level inside the shop. The higher the mean working hours meant the longer they opened the shop, there would be more work they have been doing. This would contribute directly in producing more particulate matters and would increase the level of PM10 in the photocopy shops. Since PM10 particles are bigger, they move at slower speed and shorter travelling distance in the air before fall to the ground, the exhaust fan would help in removing more PM10 particles out of the photocopy shops compared with those without them.

Worldwide, there are still no standards for the UFP concentration level and researches are progressively and continuously working on a better understanding about UFP or this nanoparticle. Nanoparticles in air pollution were heavily discussed since year 2000 (Utell and Frampton, 2000; Zhiqiang et al., 2000) and since then there have been many developments of UFP handheld equipment to measure UFP concentration at the working area. And it will take years for the study to be conducted and discussed before the new regulations for allowable UFP level been approved. In this study significant predictive factors found were total daily working hours, total pages printed or copied per day, humidity level and the total score for knowledge in KAP study. These findings were similar to findings in previous studies (Bello et al., 2012; Wang et al., 2012; Sidani et al., 2013).

A study of lung function of the workers at the photocopy shops done in Selangor state in 2013 showed a significant difference level of lung function (Bahruddin et al., 2013). Control workers have significantly higher reading of lung function compared to the worker at photocopy shops. This result similar with this study where the longer the daily working time of the workers the lower their lung function in view of longer duration of exposure to air pollutants. But the study by Elangoo et al., at the photocopy shop workers in India showed no significant differences of lung function between photocopy shop workers and the control although there was a higher level of particulate matter in indoor air (Elango et al., 2013). This was due to the ambient air pollution in India was higher compared with other country (Balakrishnan et al., 2014). This resulted of control workers lung function was also reduced due to daily exposure to severe ambient air pollution that make the difference of lung function between control and photocopy industry workers were not significant in their studies.

For the knowledge of the workers on indoor air pollution, the mean total knowledge score was good, where 57.6% of the workers have good knowledge (Table 4). This contradicted with most of the studies done previously that showed usually correspondent has a low knowledge on the air pollution (Sidani et al., 2013). One of the most appropriate explanation for this finding was, Malaysia since year 1998 had yearly episodes of haze with severe haze episodes in 1998, 2003 and 2015 (De Pretto et al., 2015). Due to this yearly haze phenomena, people were indirectly obtained education about air pollution and it has been repeated for past 18 years without they realized it.

Attitude and practice of respondents towards indoor pollution in this study was about the same with almost all of the studies been done before, where only a less than 50% of respondents in this study have a good attitude and practice towards indoor air pollution. It was common where workers would choose the easiest and cheapest way to do their work, although it would harm the environment and people. For example, in this study, they would wait until the quality of the copied page was not acceptable, then they would service the photocopy machine, ignoring the guidelines and standard operating procedure given by the manufacturer. Another widely reason given was, they postponed the service time of their machine due to lack of time in fulfilling customer orders.

Table 4: Knowledge, attitude and practice score of the respondents

	n (%)	Mean score (SD)	Median	% with good score
Knowledge		22.8 (2.31)	23	57.6%
Male	31 (47%)	23.4 (2.54)		
Female	35 (53%)	22.3 (1.96)		
High school education	33 (50%)	21.9 (2.45)		
Tertiary level education	33 (50%)	23.7 (1.84)		
Employees	47 (71%)	22.7 (2.34)		
Employers	19 (29%)	22.9 (2.27)		
Attitude		29.8 (2.71)	30	48.5%
Male	31 (47%)	29.4 (2.70)		
Female	35 (53%)	30.1 (2.71)		
High school education	33 (50%)	29.6 (2.51)		
Tertiary level education	33 (50%)	30.0 (1.84)		
Employees	47 (71%)	29.8 (2.86)		
Employers	19 (29%)	29.7 (2.36)		
Practice		4.8 (6.96)	35	47.0%
Male	31 (47%)	34.9 (7.65)		
Female	35 (53%)	34.7 (6.39)		
High school education	33 (50%)	35.4 (8.22)		
Tertiary level education	33 (50%)	34.3 (5.64)		
Employees	47 (71%)	34.1 (6.98)		
Employers	19 (29%)	36.5 (6.80)		

CONCLUSION

Particulate matters level in the photocopy shops are significantly influenced by the building factors and photocopying processes; and their effects on the workers related to the duration of exposure during working time. A better design of workplace with a spacious working area and good ventilation is vital to reduce the concentration of the pollutants. The duration of working hours should be limited to certain hours to reduce the exposure to the pollutants, and the better practice should be encouraged to the workers by giving proper education in order to reduce the effects of the pollutants to health.

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