Health risk analysis from volatile organic compounds and fine particulate matter in the printing industry

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Abstract
The association between the printing activity and the pollutant exposure of the workers was investigated in five consecutive working days, during 8 h work shift per day. Exposure concentrations of the total volatile organic compound and fine particulate matter were measured in the four voluntary printing factories in Thailand. Two types of the printing process, offset and digital printing, were compared. The 8 h average of particulate matter 2.5 in the field blank, Offset A, Offset B, Offset C printing and Digital printing D was 7.46, 21.51, 44.26, 77.92, and 42.08 µgm⁻³, respectively. The highest particulate matter level in the Offset printing C, 77.92 µgm⁻³ was due to the surrounded paper dust in the area. The 8 h average of total volatile organic compounds in field blank, Offset A, Offset B, Offset C printing and Digital printing D was 0.12, 2.68, 5.02, 21.86, and 0.67 ppm, respectively. The highest total volatile organic compound was 21.86 ppm in the Offset printing C because of the high production rate and the application of organic solvents in the cleanup process. Worker’s exposure to total volatile organic compound and particulate matter 2.5 in the offset printings was higher than in the digital laser printing. From the health risk evaluation, the workers in offset printings were at risk from total volatile organic compound exposure, Hazard quotient > 1. However, workers exposed to particulate matter exposures were not at risk, Hazard quotient < 1.

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**Introduction**

The occupational health impacts of the industrial workers due to indoor air pollutants in many industries around the world are of high concern. The air quality in the workplaces was regulated in many countries, applying the various standards of working environments. The ultimate goal is to prevent the health impact to industrial staff (NIOSH 1994; OSHA 2011; U.S. EPA 2017; WHO 2018). These include the various industrial activities where employees were potentially exposed to indoor air pollutants such as respirable particulate matter and volatile organic compounds in the working areas (Jodeh et al. 2020; Van Tran et al. 2020). Several related factors were also affecting indoor air quality, such as the efficiency of the air filtration control, the air ventilation, and loading of pollutants from various sources. Some pollutants can increase their concentration depending on the elevated indoor temperature and humidity (Lazovic et al. 2016; Luo et al. 2019). The particles or chemical vapors can be released from various equipment, tools, furniture, and activities performed within the building, such as renovations, additions, or cleaning, including the maintenance of equipment (Lee et al. 2001; Lin et al. 2017; Carrer and Wolkoff 2018; Vandoulakis et al. 2020; Parmaksiz et al. 2021).

Printing is one such industry that potentially releases PM$_{2.5}$ and VOCs. The sources of pollutants in the printing industry, i.e., paper dust, ink dust, and organic solvents were commonly found in the printing production process which
also includes pollutants from the office or personal printers (Kagi et al. 2007). Most of the pollutants are emitted from the storage, use, and disposal of chemicals and liquid/solid waste. Printing inks, toner, and cartridges contain volatile organic components that have the potential to generate odors and can cause serious health risks (Leung et al. 2005). There were many reports on the health impact of indoor air pollution in the printing press. For example, the exposure to PM$_{2.5}$ from the printing room significantly increased inflammation, fibrosis, apoptosis, and the abundance of pathogenic bacteria, indicating that exposure is a potential threat to individuals who spend a significant amount of time in printing rooms (Zou et al. 2020). A study in the printing industry in Serbia found that the presence of volatile organic compounds in the printing process had an adverse health effect on the workers (Kiurski et al. 2013). The indoor and outdoor BTEX released from the printing shop and photocopy center in the Saudi Arabia Kingdom were from ink solvents and toner in the printing process in addition to the outdoor traffic emissions (El-Hashemy and Ali 2018).

An offset lithographic process in which the printing and non-printing areas of the plate are both at the same level. It is invariably an offset process in that the image is transferred to an intermediate blanket cylinder from which it is transferred to the paper as distinct from those direct processes. Lithographic printing is based on the chemical repellence of oil and water. The image area is oleophilic (oil-receptive), so it attracts the ink while repelling water, whereas the obverse applies to the hydrophilic (water-receptive) non-image area. In digital printing, the image is created directly from digital data and transmitted by light to a photosensitive material to create an electronic image, using no films, plates, nor photo-chemicals. It relies on the ability of selenium to enhance its electrical conductivity on exposure to light, the same principle which photocopying works on (Occupational Safety and Health Branch 2004). Varn® Wash V-60 was used in the offset printing cleaning process as an organic solvent to clean up the printing head. Whereas the solvent was not applied in the digital printings process which the toner powder was used in printing and cleaning mode (Flint 2010).

In this study, TVOC and PM$_{2.5}$ in two types of printing processes, offset lithography printing, and laser digital printing were determined and the occupational health risk from such air pollutants was evaluated. This work was conducted from November to December 2019 before the COVID-19 pandemic in Bangkok Metropolitan, Thailand.

**Materials and methods**

**Sampling site characteristics**

The indoor air pollutants, TVOC, and PM$_{2.5}$ were sampled in four voluntary printing factories located in Bangkok, Nonthaburi, and Pathum Thani provinces of Thailand. The three governmental press sites that are sites A, B, and C, and one commercial factory (D) were selected for the study. Also, the field blank (E) was conducted at the administrative office of the Environmental Science Department of Chulalongkorn University. The characteristics of the studied sites are summarized in Table 1. Air sampling was carried out for over five working days, from 8 am to 5 pm at four printing presses and also at the field blank.

**PM$_{2.5}$ sampling**

The indoor PM$_{2.5}$ was sampled near the paper cutting unit as shown in Fig. 1a, with a personal pump (The Universal PCXR8 personal, SKC Inc., PA, USA), connected to a size-selective PMI Cascade. Particulate matter samples were collected on preweighted 37 mm PTFE filters (Zefluor®, Pall Laboratory) (Dong et al. 2020). The instrument was set up at a height relative to the employee’s respiration level and 1 m from the wall at a flow rate of 3.0 l/min$^{-1}$ (SKC 2013; Wang et al. 2016; Mandin et al. 2017).

**Table 1** Air sampling sites characteristics

| Site | Type of printing | Type of Ink | Paper consumption (sheet per month) | Pollutants | Ventilation | Sampling area (m²) |
|------|------------------|-------------|-------------------------------------|------------|-------------|------------------|
| A    | Offset           | Soy Ink     | 2,500,000                           | PM$_{2.5}$ | Non-air conditioning | 70               |
|      |                  |             |                                     | TVOC       | Non-air conditioning | 120              |
| B    | Offset           | Soy Ink     | 4,795,000                           | PM$_{2.5}$ | Non-Air conditioning | 250              |
|      |                  |             |                                     | TVOC       | Air conditioning    | 150              |
| C    | Offset           | Soy Ink     | 5,000,000                           | PM$_{2.5}$ | Non-air conditioning | 50               |
|      |                  |             |                                     | TVOC       | Air conditioning    | 30               |
| D    | Digital          | Laser toner | 1,900,000                           | PM$_{2.5}$ | Air conditioning    | 150              |
|      |                  |             |                                     | TVOC       | Air conditioning    | 200              |
| E    | Office           | Laser toner | 2000                                | PM$_{2.5}$ | Air conditioning    | 50               |
|      |                  |             |                                     | TVOC       | Air conditioning    | 50               |
Real-time continuous PM\textsubscript{2.5} concentrations were measured using the DustTrak II aerosol monitor (TSI 8530, TSI Inc., Shoreview, MN, USA) at a flow rate of 3.0 l\text{min}^{-1}\text{}}(Rivas et al., 2017; TSI Incorporated 2019). The sample was measured from 8 am to 5 pm at Offset printing C and Digital printing D.

**TVOC sampling**

Indoor TVOC samples were monitored near the printing machine while it was in the running process. The continuous real-time measurements were conducted by a photoionization detector (PID), Model: MiniRAE 3000+, RAE Systems, Honeywell Inc., Sunnyvale, CA, USA. TVOC concentrations were recorded every 30 min and were collected from five working days, from 8 am to 5 pm. The PID was equipped with a 10.6 eV lamp that had a sampling flow rate of 0.5 l\text{min}^{-1}\text{}}(Hori et al., 2015), a resolution of 0.1 ppm in the detected range of 0–15,000 ppm (Jia et al. 2019), and the average represented the TVOC concentration for that section (RAE System 2018).

The air sampling instruments were set up as shown in Fig. 1. The layout of sampling points for four printing sites is illustrated in Fig. 2. In Offset printing, A has non-airconditioning and in Digital printing D has air conditioning. The site characteristics details are summarized in Table 1. All sampling points are located near the emission sources and at least 1 m away from the wall.

**Data analysis**

PM\textsubscript{2.5} concentrations were analyzed by the Gravimetric method, the calculation followed NIOSH 0500 (NIOSH 1994). TVOC concentrations were calculated from the daily average of five measurement sampling points. All data were averaged with an interval time of 8 h. Statistical analysis was performed using SPSS version 22. The relationships between the distribution of PM in the printing press were tested with the nonparametric Kruskal–Wallis test.

**Health risk evaluation**

The health risk of PM\textsubscript{2.5} was evaluated based on the indoor particulate matter at non-carcinogenic risk and was performed only through the inhalation exposure pathway. Exposure concentration (EC\text{inh}) in the risk assessment was calculated using the following Eq. (1)

\[
EC(\text{inh}) = \frac{C \times ET \times EF \times ED}{AT}
\]

where \(C\) is concentrations of PM\textsubscript{2.5} as measured; \(ET\) is the exposure time as 8 h/day from the measured; \(EF\) is the exposure frequency as 250 days/year; \(ED\) is the exposure duration at 25 years for non-carcinogenic substances (U.S..
The Risk characterization of non-carcinogenic was calculated based on the Hazard Quotient (HQ) using Eq. (2)

$$HQ = \frac{EC}{RfC}$$

where RfC is the reference concentration of PM$_{2.5}$ using the WHO standard at 25 mg m$^{-3}$ (WHO 2006), TVOC reference concentration using standard in Kuwait, Malaysia, and Singapore standard indoor concentration at 3 ppm (Ahmed Abdul-Wahab et al. 2015), since Thailand did not have TVOC indoor air quality standards.

Hazard index (HI) means the sum of more than one hazard quotient for multiple substances, multiple exposure...
pathways, or both. The Hazard Index is calculated separately for chronic, subchronic, and shorter duration exposures as the sum of the hazard quotients using Eq. (3)

$HI = \sum_i HQ$

(3)

HI, value less than or equal to 1 indicates that the exposure is not likely to result in adverse non-carcinogenic effects. In the case of HI, value greater than 1, however, does not necessarily suggest a likelihood of adverse health effects but still potentially caused risk (U.S. EPA 2018).

**Result and discussion**

**PM$_{2.5}$**

The concentrations of PM$_{2.5}$ in an Offset printing A, B, C, Digital printing D press, and Office E were in the range of 20.47–26.65, 22.39–53.11, 64.10–94.10, 30.85–54.85, and 6.31–8.64 µgm$^{-3}$, respectively. Furthermore, the average results showed that exposure due to PM$_{2.5}$ in Offset printing A, B, C, Digital printing D, and Office E was 21.51 ± 1.74, 44.26 ± 11.11, 77.92 ± 11.85, 42.08 ± 7.81, and 7.46 ± 0.89 µgm$^{-3}$, respectively. The data PM$_{2.5}$ concentration and the comparisons of PM from five working days are shown in Fig. 3. Although PM$_{2.5}$ in all sites did not exceed the National indoor air quality standard and OSHA standard, 5 mg m$^{-3}$ (NIOSH 1998), the values in Offset printing B, C, and Digital printing D were higher than WHO air quality guideline, 25 µgm$^{-3}$ (WHO 2006). PM$_{2.5}$ releasing in Offset printing A was found the lowest among the other printing press. Its printing machine was located in an open space near the corridors and exits without an air-conditioning system, (Fig. 2a). There was ventilated by a fan system and dispersed particulate matter to the outside. There was some study about the air ventilation effect comparison between with and without air conditioning. (Ramlan et al. 2017) reported that the use of a fan in the printing premise was more suggested since the PM$_{2.5}$ level is slightly lower than the printing premise using air conditioning. However, diluting PM$_{2.5}$ and release to the environment may not be a good practice since PM$_{2.5}$ from printing could affect the outdoor ambient air levels and other pedestrian's health risks. On the other hand, PM$_{2.5}$ in Offset printing B and C was similar in their production size, four cutting paper machines, and the air conditioning system, but there were some differences in their pressroom arrangements, (Fig. 2b, c). In the Offset printing B, the cutting paper, folding, binding and wrapping were in separate sections in a widespread area. In contrast, the paper cutting, folding, and binding process in Offset printing C were close to the printing process in a small area (Table 1). For Digital printing D, the printing area was in the close system with an air conditioner turned on all the time (Fig. 2d). The indoor PM$_{2.5}$ level depended on the control system and the air exchange rate from the air conditioner system other substances may be drawn into the building from outside (OSHA, 2011). The major source of indoor particles in digital printing comes from paper cutting units and laser toner (Wang et al. 2016).

The working time and PM$_{2.5}$ concentration graphs were compared between the offset printing and digital printing from three consecutive days measurements, shown in Fig. 4. The time-series results of the Offset printing C in Fig. 4a were very high from 8.30 to 11.30 am, and then,
the pollutant levels were dropped during the lunch break and increased again at noon. This finding indicated that the pollutions were released during the working process. Then, it was around 4 pm, when workers finish their work, the indoor PM$_{2.5}$ values decreased rapidly. The monitoring data on Wednesday showed the highest PM$_{2.5}$ due to the high production rate and more activities than on Thursday and Friday. The Digital printing D shows a high concentration in the morning until noon, as shown in Fig. 4b. There was some part that automatically works in the digital printing process, so the pollutant occurred at the starting process and then gradually falls during the day.

**TVOC**

The average results showed that exposure due to TVOC in Offset printing press A, B, C, digital printing D, and Office E was 2.68 ± 0.89, 5.02 ± 3.02, 21.86 ± 6.82, 0.67 ± 0.08, and 0.12 ± 0.04 ppm, respectively. The average of 8 h TVOC concentrations in five consecutive working days is shown in Fig. 5. The three Offset printing A, B, and C had higher TVOC concentrations than the Digital printing D and in the Office, E. TVOC releasing trends were similar to PM$_{2.5}$, offset printing > digital printing >> office. The lowest TVOC concentration in the printing press 0.6 ppm was in Digital printing D, and the highest concentration in Offset printing
C was 27.7 ppm. Notably, the highest TVOC in Offset printing C was due to the high production rate (Table 1) and the application of organic solvents in the cleanup process.

The comparison of TVOC in different activities: printing, cleaning, and non-printing is shown in Fig. 6. From Fig. 6a, the average TVOC concentrations at the Offset printing A, B, and C were 2.5, 5.5, and 21.1 ppm, respectively. During the cleaning process, the average TVOC concentrations were higher than normal printing conditions in all three offset printings. TVOC in the working area during clean up with solvents were found 7.3, 20.3, and 35.5 ppm in Offset printing A, B, and C, respectively. The outlier demonstrates unusually high concentration at certain times which is shown in Fig. 6b. Finally, in a break or non-printing process, the average TVOC concentrations in Offset printing A, B, and C were 0.9, 1.6, and 6.5 ppm, respectively, which were relatively low values, in Fig. 6c. This finding reflected the relationship between the activity and the indoor TVOC levels. The major source was from the cleaning process. As an overall outcome, the Offset printing C had significantly higher TVOC concentrations than both Offset printing A and B, \( p = 0.0001 \) from the nonparametric Kruskal–Wallis test.

Furthermore, the time-series of TVOC concentration in Offset printing A, B, C, and Digital printing D are illustrated in Fig. 7. Significantly, TVOC released from digital printing release were very low in all working hours. TVOC in offset printings were high in the afternoon because of their clean-up printer head with an organic solvent. Indoor volatile pollutants of Offset printing A were lower than printing B and C because of their open-air diluted to the outside environment, as shown in Fig. 7a. In Offset printing B, Fig. 7b TVOC on Wednesday and Friday had a similar releasing trend. Particularly, there were low TVOC concentrations on Thursday because the printing process was shut down. In Offset printing, C, the TVOC average concentration profiles from Wednesday to Friday were likely similar, Fig. 7c. It can also be seen that high TVOC concentrations on Wednesday and Thursday have occurred from 3:00 pm to 4:30 pm (22–50 ppm). In Digital Printing D, there was not a cleaning process using an organic solvent like offset printing, so TVOC was very low, Fig. 7d. A small amount of indoor TVOC was found from a laser printer toner (Wang et al. 2016).

**Health risk exposure of pollutants in the printing process**

PM\(_{2.5}\) exposure concentrations were calculated from the measurement data in Fig. 3, followed Eq. (1) in materials and methods. Then, the health risk was evaluated as Hazard Quotient (Table 2) and Hazard Index (Table 3). HQ of PM\(_{2.5}\) was calculated with RfC 25 µgm\(^{-3}\)(WHO 2018). HQ of Printing A, B, D, and office E was lower than 1. HQ of Offset Printing C in 4 days from 5 days was more than 1, indicated the health risk. Hence, most of the PM\(_{2.5}\) HQ results may not reflect thoroughly the health risk of non-carcinogenic agents. Further calculation of HI, Hazard index, the summation of HQ of PM\(_{2.5}\), and TVOC was applied in the health risk evaluation, Table 3.

For TVOC, the health risk was calculated with the RfC of Asian standard 3 ppm (Ahmed Abdul-Wahab et al. 2015). The average five days HQ of TVOC in Offset printing C is higher than 1 as shown in Table 2. The workers in Offset printing C were considered at risk from the exposure to TVOC. In addition, HI, in Offset printing C, was more than 1 in all five working days, Table 3. Risk management should be recommended to the decision-maker in Offset printing C.
Fig. 7 Indoor TVOC profiles releasing from Printing Press: a Offset A, b Offset B c Offset C and d Digital D in five working days

Table 2 Daily PM$_{2.5}$ and TVOC Hazard Quotient of four printing presses and a field blank

| Printing press         | Parameter | Mon  | Tue  | Wed  | Thu  | Fri  | Avg  | Standard deviation | Coefficient of variation |
|------------------------|-----------|------|------|------|------|------|------|---------------------|------------------------|
| Offset printing A      | PM$_{2.5}$| 0.20 | 0.24 | 0.19 | 0.24 | 0.20 | 0.21 | 0.022               | 0.10                   |
|                        | TVOC      | 0.30 | 0.21 | 0.21 | 0.21 | 0.09 | 0.20 | 0.067               | 0.33                   |
| Offset printing B      | PM$_{2.5}$| 0.46 | 0.49 | 0.43 | 0.20 | 0.44 | 0.40 | 0.104               | 0.26                   |
|                        | TVOC      | 0.11 | 0.65 | 0.59 | 0.11 | 0.46 | 0.38 | 0.232               | 0.61                   |
| Offset printing C      | PM$_{2.5}$| 0.75 | 0.86 | 0.77 | 0.59 | 0.59 | 0.71 | 0.106               | 0.15                   |
|                        | TVOC      | 0.65 | 2.11 | 1.92 | 1.83 | 1.81 | 1.66 | 0.518               | 0.31                   |
| Digital printing D    | PM$_{2.5}$| 0.28 | 0.37 | 0.36 | 0.41 | 0.50 | 0.38 | 0.072               | 0.19                   |
|                        | TVOC      | 0.05 | 0.06 | 0.05 | 0.05 | 0.05 | 0.05 | 0.004               | 0.08                   |
| Office E               | PM$_{2.5}$| 0.06 | 0.06 | 0.07 | 0.08 | 0.07 | 0.07 | 0.007               | 0.11                   |
|                        | TVOC      | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.004               | 0.40                   |

Table 3 Hazard Index of four printing presses and a field blank

| Printing Press         | Mon  | Tue  | Wed  | Thu  | Fri  | Avg  |
|------------------------|------|------|------|------|------|------|
| Offset printing A      | 0.50 | 0.45 | 0.40 | 0.45 | 0.29 | 0.42 |
| Offset printing B      | 0.57 | 1.14 | 1.02 | 0.31 | 0.90 | 0.79 |
| Offset printing C      | 1.40 | 2.97 | 2.69 | 2.42 | 2.40 | 2.38 |
| Digital printing D     | 0.33 | 0.43 | 0.41 | 0.46 | 0.55 | 0.44 |
| Office E               | 0.07 | 0.08 | 0.08 | 0.09 | 0.08 | 0.08 |
In comparison with the other studies on TVOC and PM such as Gaur et al. 2018 reported the indoor environment in building, An et al. (2014) worked on health risk during e-waste dismantling processes, and Riediker et al. (2003) studied the exposure in the patrol car, and these works contained different implication and outcome. This study particularly concerns the health impact of printing industry workers. It is not about general pollutants in the building, be it pollutants from electronic waste or pollutants in vehicles, rather focuses on the daily exposure of workers to avoid the continuous process of pollutant release. Although there were some limitation in the sites’ accessibility, this work used the volunteer factories which represented the different printing processes and loadings. This study found the health risk from workplace air pollutants in different printing processes. The Offset printing C had the highest paper consumption due to its high demand for production in which the PM$_{2.5}$ concentration in the printing area was found highest. High TVOC concentrations in offset printing were from cleaning printer head with a solvent containing VOCs, and also the small area in the printing room of Offset printing C was due to inadequate ventilation in the working environment. The findings of this study could be useful as occupational safety information in the printing industry. The aim of this study is to build awareness of the exposure in offset printing and encourage the new technology to replace hazardous chemicals in the printing industry.

**Conclusion**

PM$_{2.5}$ concentrations in the offset printings were higher than in digital printing. The sources of particulate matter are mainly from the printing, binding, paper cutting, and folding processes which cause the diffusion of the particle in the indoor area. The major source of PM$_{2.5}$ was due to the surrounded paper dust in the working area. Although PM$_{2.5}$ in all sites did not exceed the National indoor air quality standard and OSHA standard 5 mg m$^{-3}$ (NIOSH 1998), the worker’s health risk still needs to be evaluated on an occupational safety basis. All study sites had a minimum space required by the Accommodation Services Division (ASD) standard based on the number of people working value 18.02319 m$^2$ per person (194 square feet per person) (Government of Manitoba, 2018). The average TVOC in offset printing was higher than the Asia standard, and the hazard quotient and hazard index were more than one, (HQ > 1). Therefore, workers in the offset printing process area were potentially at high risk.

To reduce health risk, the standard personal protective equipment should be recommended and also increase in more work shifts, and more number of workers on the weekday safe work procedures on the use, handling, storage, transportation, cleaning up and disposal of hazardous substances and safety information about the hazardous substances that they could be exposed to including the nature of hazards, exposure standards, possible routes of entry into the body and risks to health. The installation of Dust and VOCs indoor air control systems was recommended to rectify PM and VOCs buildup concentrations in the printing process rooms.

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**Declarations**

**Conflict of interest** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.

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