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Potential Exposure to VOCs Caused by Dry Process Photocopiers: Results From a Chamber Study

D.-J. Hsu,[1] H.-L. Huang,[2] C.-H. Chien,[3] T.-S. Lin[4]

[1] Department of Occupational Safety and Health, Chang-Jung Christian University, Tainan 711, Taiwan
[2] Department of Occupational Safety and Health, Chia-Nan University of Pharmacy and Science, Tainan 717, Taiwan
[3] Kaoshan Industrial Safety and Health, Inc., Tainan, Taiwan
[4] Department of Environmental Engineering and Health, Yuanpei University of Science and Technology, Hsin-Chu City 300, Taiwan

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The exposure to volatile organic compounds (VOCs) in indoor environments has been attracting some attention in a long-term stand, probably because most people spend most of their time, up to 80%, in indoor environments. In addition, the exposure to the indoor VOCs is believed in strong association with the Sick Building Syndromes (SBS) (Norback et al. 1995). There are hundreds of VOCs already identified in typical non-industrial indoor environments (Ayoko 2004), including aromatic hydrocarbons, alkenes, alcohols, aliphatic hydrocarbons, aldehydes etc. (ECAIAQIM 1997). The health effects of VOCs include immune effects (e.g. asthma and allergy), cellular effects (e.g. cancer), cardiovascular effect, neurogenic and sensory effects, and some respiratory effects other than immunological effects (Molhave 2003). Unfortunately, the role of VOCs in SBS complaints is not clearly understood (Ayoko 2004).Thus more studies, such as the exposure assessment of indoor VOCs, are still necessary.

In addition, the association between SBS and the presence of photocopier was also identified (Hetes et al. 1995; Sundell et al. 1996). Wolkoff et al. (1992) found the increases of perceptions of headache, mucous membrane irritation and measurable damage to the conjunctival epithelium among 30 volunteers exposed to office equipment (e.g. photocopier) inside a chamber. Dry process photocopiers can release VOCs, ozone and particulates into indoor environments (Brown 1999). Several investigations reported that the concentration of benzene (B) in photocopy centers, for example, usually ranged from 20 to 100 $\mu g/m^3$, but might be as high as 4000 $\mu g/m^3$ (Lee et al. 2005) which was much higher than the typical value (4 ~ 15 $\mu g/m^3$) found indoors (Ayoko 2004). The cancer factor of benzene is 2.73 x 10^{-2} mg/kg-day (USEPA 1998), makes an exposure of 20 $\mu g/m^3$ to benzene for 8 h/day approximately elevates the cancer risk of 7.8 x 10^{-5}.

Additionally, dry process photocopiers, including laser printers, have been become the central operation of modern offices and probably they are also available in home environments including in college dormitory. In Taiwan, the dry photocopiers are also very common in small individual shops. This phenomenon implies that the scenario of the exposure to the indoor VOCs becomes more heterogeneous. In other words, these dry process photocopiers may usually maintain at the idle state rather than at the copying state. Thus, the

Correspondence to: T.-S. Lin, 306 Yuan-Pei Street, Hsin-Chu City, Taiwan 300

emission of VOCs from these machines during their idle state and their possible health hazard should be of crucial concern, which may be probably assessed by utilizing their emission factors. The standard procedure to evaluate the emission of pollutants from photocopiers has been, therefore, required in order to provide a rationale base to assess the indoor exposure to VOCs. Although the procedure has been suggested by US EPA (Leovic et al. 1998), few studies with limited machines were conducted to establish the emission rates. Hence, this paper presents the emission rates of benzene (B), toluene (T), ethylbenzene (E), xylene (X) and styrene (S) from dry process photocopiers in the idle state by examining three brands with a total of 17 photocopiers inside a chamber following the recommended procedure by USEPA (Leovic et al. 1998). These data are further used to preliminarily estimate the possible health risk.

MATERIALS AND METHODS

Three brands of dry process photocopiers (X(n=9), R(n=3), S(n=5)) were chosen for this study because they are the most popular in Taiwan. The experimental chamber was made of stainless steel with a dimension of 2.2 (L) x 2.2 (W) x 2.3 (H) m. This chamber passed the gas tightness test to warrant no leakage occurring during the experiments. In addition, the testing atmosphere was controlled by a custom-made auto-control system to maintain its temperature of 25 ± 0.5 °C and a relative humidity of 50 ± 0.5%. An electrical fan was placed and operated to assure the atmosphere homogeneously inside the chamber during our experiments. Our preliminary tests proved that the practice of the electrical fan would not release VOCs into the testing atmosphere by sampling and analysis of the air with the exactly procedure which was employed to study the photocopiers with an exception of no photocopier placed inside. The procedure used to evaluate photocopiers followed what recommended by US EPA (Leovic et al. 1998). The air samples were collected duplicate with Perkin-Elmer thermo-desorption tubes containing of 250 mg Tenax-TA (60/80 mesh) after 0, 30, 60, 90, 120 and 626 minutes of the photocopiers powered on, but, without operation. The sampling flow rate and sampling time were 140 ~ 150 mL/min. and 5 minutes for each test, respectively. These samples were analyzed by an Agilent 6850 Series GC system equipped with a flame ionization detector and a thermo-desorption system (Perkin-Elmer ATD 400). In order to guarantee the analytical results, some samples were, randomly, analyzed by a mass detector. The chromatograms were comparable and the chemicals were confirmed. The cold trap operating temperature was -30 °C and was raised to 250 °C for three minutes. The carrier gas was nitrogen and Agilent 19091J-413/E column (30 m × 0.32 mm i.d. × 0.25 μm) was used. The column temperature was held at 40 °C for five minutes, after which it was raised to 100 °C for five minutes, and then increased to 200℃ where it was held for two minutes. The calibration curve for laboratory analysis was established with the stock solution of benzene, toluene, ethylbenzene, xylenes and styrene, which was diluted with methanol to produce eight different concentrations. The correlation (R^2) values of the regression of BTEXS were 0.998, 0.999, 0.999, 0.998, 0.999, respectively. The lowest concentration of the stock solution was analyzed seven times to determine the analytical limit of detection (LOD). The analytical LOD was defined as three times of standard deviation and the values for BTEXS were 0.8, 0.7, 0.5, 0.7, and 0.7 $\mu g/m^3$, respectively. To confirm the 100% adsorption of the VOCs with PE tubes, tests were performed and no breakthrough was found in any of the tubes.

RESULTS AND DISCUSSION

The concentrations of BTEXS inside the testing chamber at various time are shown in Table 1. In general, Brand X photocopiers would release more VOCs into the environment than the other two brand photocopiers during the idle state with an exception of toluene which was significantly emitted by all tested photocopiers. The emission factors of BTEXS of these photocopiers can be estimated with a simple linear regression model and the results are presented in Table2. These emission factors, again, indicate that Brand X significantly emitted more pollutants, except for toluene, than the other two brands did. For example, the emission factors of benzene of Brand X, R, S photocopiers were 120.2, 80.2, 86.8 μg/hr, respectively.

The levels of these organic compounds in rooms may be estimated by their emission rates using the following equation:

$$C_t = \frac{G-(G-QC_0)e^{-\frac{Q(t-t_0)}{V}}}{Q}, \qquad (1)$$

where G is the emission rate, Q the ventilation rate, V the room volume, C_0 the concentration at time t_0, and C_t the concentration at time t. The typical air exchange rate (AER) for homes varies from 0.25 to 0.5 turnover/hour (US EPA 1999). Considering that the normal work hour (8 hours), the fluctuation of concentrations of BTEXS at varying air exchange rates can be simulated by using equation (1). Assuming the initial concentrations of BTEXS are zero indoor, the estimated concentrations of BTEXS in a 30 m^3 volume rooms after eight hours of one idle photocopier, at AER 0, 0.25, and 0.5, respectively, are shown in Table 3.

The long term exposure to benzene may result in leukemia, and a red blood cell decrease leading to anemia (ATSDR 1997). The health effects of toluene are tiredness, confusion, weakness, memory loss, nausea and hearing and color vision loss (ATSDR 2000). If people were exposed to high levels of ethylbenzene, xylene and styrene; dizziness, throat and eye irritation, tightening of the chest, and a burning sensation in eye could be observed (ATSDR 1992; ATSDR 1995; ATSDR 1999). Benzene is also classified as Group 1 carcinogens; the unit risk is determined to be 2.73 x 10^{-2} mg/kg-day (USEPA 1998). Thus, the estimated cancer risk owing to exposure to idle photocopiers ranges from 8 x 10^{-5} to 1.3 x 10^{-4}. For the non-carcinogenic health risk can be expressed by the hazard index (HI). The HI may be derived from the minimum risk levels. The minimum risk levels (MRL) for intermediate/chronic duration inhalation are suggested as 0.004, 0.08, 1.0, 0.1 and 0.06 ppm for benzene, toluene, ethylbenzne, xylene and

Table 1. The levels of BTEXS ($\mu g/m^3$) inside the chamber with time.

	Benzene		
Time (minute)	X	R	S
0	2.9 ± 3.3	13.4 ± 13.1	8.7 ± 10.2
30	11.8 ± 10.9	11.8 ± 7.6	25±14.8
60	17.6 ± 7.1	23.4 ± 9.1	33.3 ± 19.0
90	26.8 ± 14.4	25.8 ± 8.8	48.7 ± 25.8
120	37.7 ± 15.5	40.4 ± 18.2	62.1 ± 25.6
626	121.7 ± 46.5	90.0 ± 24.0	104.6 ± 49.8
	Toluene		
	X	R	S
0	19.1 ± 24.5	46.4 ± 15.9	10.3 ± 16.4
30	35.8 ± 3705	61.8 ± 30.1	6.6 ± 10.4
60	48.6 ± 51.0	102.4 ± 50.7	10.9 ± 9.7
90	82.2 ± 125.2	133.5 ± 60.1	19.7 ± 18.7
120	123.4 ± 205.5	174 ± 43.9	39 ± 37.3
626	205.4 ± 213.5	374.6 ± 15.3	130.4 ± 182.1
	Ethylbenzene		
	X	R	S
0	1.3 ± 3.6	2.7 ± 39.	1.1 ± 1.8
30	20.4 ± 24.7	2.0 ± 3.0	2.6 ± 3.3
60	34.4 ± 35.8	5.8 ± 9.1	6.2 ± 5.0
90	49.1 ± 50.6	7.5 ± 10.5	9.8 ± 7.0
120	65.7 ± 66.1	7.8 ± 12.5	15.8 ± 4.6
626	263.7 ± 232.6	34.5 ± 29.7	35.7 ± 15.2
	Xylene		
	X	R	S
0	3.4 ± 5.6	6.2 ± 6.0	4.8 ± 8.2
30	27.5 ± 30.0	8.6 ± 9.7	12.7 ± 7.8
60	43.6 ± 41.6	20.7 ± 14.0	21.0 ± 9.2
90	62.8 ± 55.9	26.2 ± 18.4	24.7 ± 11.5
120	83.8 ± 71.0	31.9 ± 20.1	31.6 ± 9.9
626	315.8 ± 259.3	86.8 ± 59.5	64.2 ± 18.0
	Styrene		
	X	R	S
0	0.4 ± 0.4	2.1 ± 2.4	0.4 ± 0.4
30	5.2 ± 6.7	1.4 ± 1.8	2.4 ± 3.4
60	9.4 ± 9.5	3.9 ±5.5	5.0 ± 6.9
90	17.7 ±15.9	7.5 ± 11.5	7.4 ± 7.8
120	25.1 ± 22.2	8.6 ± 13.7	11.7 ± 8.4
626	0.4 ± 0.4	2.1 ± 2.4	0.4 ± 0.4

Table 2. Emission factors (μg/hour) of BTEXS for different brand photocopiers.

	benzene	toluene	ethylbenzene	xylene	stryene
X	120.2 (0.99)*	180.3 (0.86)	340.6 (1.00)	320.6 (1.00)	100.2 (0.99)
R	80.2 (0.96)	334.0 (0.95)	33.4 (0.99)	80.2 (0.97)	33.4 (0.99)
S	86.8 (0.85)	133.6 (0.99)	33.4 (0.94)	53.4 (0.92)	26.7 (0.95)

* Correlation (R^2)

Table 3. Estimation of BTEXS concentrations after a photocopier idle for eight hours.

	Q = 0				
	benzene	toluene	ethylbenzene	xylene	stryene
X	32.1	48.1	90.8	85.5	26.7
R	21.4	89.1	8.9	21.4	8.9
S	23.2	35.6	8.9	14.2	7.1
	Q = 0.25				
	benzene	toluene	ethylbenzene	xylene	stryene
X	31	46.5	87.9	82.7	25.8
R	20.7	86.2	8.6	20.7	8.6
S	22.4	34.5	8.6	13.8	6.9
	Q = 0.5				
	benzene	toluene	ethylbenzene	xylene	stryene
X	30	45	85	80	25
R	20	83.4	8.3	20	8.3
S	21.7	33.3	8.3	13.3	6.7

styrene, respectively (ATSDR 2004). The calculated HI based on the simulated levels of BTEXS ranges from 1.9 to 3.3.

It's noteworthy; there are usually four to eight photocopiers in the copy room located in libraries in Taiwan. This phenomenon implies that the VOCs levels in those spaces might be four to eight times higher than these estimates. In addition, the individual office with a volume of 15 ~ 20 m^3 is very common in many colleges in Taiwan. Considering that most graduate students and researchers work long hours in their office with a laser printer, the personal exposure to BTEXS in the office should be at several times higher risk than those described above. This paper clearly points out that one may pose a severe health risk when he works in a small office with a dry process photocopier even this machine is in idle. Further studies on assessment of the exposure to BTEXS owing to dry process photocopier including laser printers in individual work space are also warranted. The preventive measures should be considered to reduce the levels of BTEXS from dry process photocopier, thus personal exposure can be abated.

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