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Potential Volatile Organic Compound Exposure from Dry Process Photocopiers in Operation-Idle Mode

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The advent of electronic equipment, such as personal computers, printers and photocopiers, has rapidly changed the office environment. Many studies have shown that the operation of office equipment will increase indoor air pollutant concentrations that may result in health complaints from exposed workers (Wolkoff et al. 1992, Wolkoff et al., 1993; Wolkoff 1999). Some studies clearly indicated the strong correlation between Sick Building Syndrome (SBS) and the presence of photocopiers (Hetes et al. 1995, Sundell et al. 1996). Additionly, 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. photocopiers) inside a chamber. Therefore, the effects of photocopiers on indoor air quality have gained considerable attention during the recent years.

During photocopier operation, toner is transferred onto copy paper from toner cartridge and then fused at high temperature to form photocopied images. As a result, volatile organic compounds (VOCs) are emitted from toner due to the heat generated in photocopiers. In order for immediate operation, photocopiers are designed to maintain at a relatively high temperature in idle mode (i.e., photocopier powered but not operating). Thus, VOCs will be emitted whenever photocopiers are powered, regardless photocopiers are in operation or not. Many studies reported the emission characteristics of photocopiers in operation mode (i.e., producing copies) while only some discussed the emission in photocopier-idle mode (Hsu et al 2005). The investigation of pollutant emissions from photocopiers is usually carried out in a controlled chamber, so that the emission can be characterized at a particular chamber temperature, humidity and ventilation rate. This chamber technology enables the emission of photocopiers in operation and idle modes to be evaluated separately. Studies have indicated that VOCs emission from photocopier in idle mode was substantially lower than that in operation mode (Brown 1999; Hsu et al. 2005, Tuomi et al. 2000). However, the study design does not necessarily reflect the scenario in office environments for the following reasons: (1) unlike photocopy centers, photocopiers in offices, except rare cases, do not make a large volume of copies lasting hours or longer; (2) photocopiers in offices are usually switched on as workday starts and remain in idle mode for occasional uses until workday ends. Consequently, the investigation

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of photocopier emission and its effect on indoor air quality (IAQ) should be carried out in a scenario similar to the practice in office environments. Additionally, the issues of IAQ and the health of exposed workers have become even more important as the proportion of workforce working in office environments has increased during recent decades in industrialized countries

This paper reports the VOCs level from photocopiers in idle-operation-idle mode and comparisons were made with the VOCs level in idle mode only. This study design would allow researchers to gain more information on how photocopiers in offices affect the indoor air quality. Among the VOCs already identified during photocopier operation, benzene, toluene, ethylbenzene, xylenes and styrene (BTEXS) were the focus in the present study, due to their ubiquitous sources and potential health effects (Leovic et al. 1998, Lee et al. 2001, Lee et al. 2006).

MATERIALS AND METHODS

Three brands of dry process photocopiers (X(n=9), R(n=3), S(n=5)) were selected 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. The preliminary tests indicated that the electrical fan would not release VOCs into the testing atmosphere. The procedure to evaluate photocopiers followed what recommended by US EPA (Leovic et al. 1998). The experiments started with an initial operation of a photocopier to produce 99 copies, which took about four to five minutes, and then it was remained in the idle mode for the rest of these experiments. Duplicate air samples were collected with Perkin-Elmer thermo-desorption tubes containing of 250 mg Tenax-TA (60/80 mesh) at 0, 30, 60, 90, 120 and 626 minutes since the experiment started. 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 (BTEX), 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 times are shown in Table 1. In general, Brand X photocopiers would release more VOCs into the environment than the other two brand photocopiers; however, the largest amounts of benzene and toluene were released from the photocopiers of Brands S and R, respectively. Compared with the dry process photocopiers in idle mode only (Hsu et al 2005), the operation will significantly reduce the VOCs levels in the ambient environment (Table 1). The emission factors of BTEXS of these photocopiers in the idle-operation-idle mode can be estimated with a simple linear regression model and the results are presented in Table 2. These emission factors, again, indicate that the operation of photocopiers would significantly abate their emission of VOCs, except for benzene (Brand S) and ethylbenzene (Brand X). One may expect that the overall abatement of BTEXS as a result of the oxidation reaction between ozone and these compounds since ozone will be enormously introduced into the ambient during the copy process (Hetes et al. 1995). In fact, the ozone level inside the test chamber was monitored with a direct-reading instrument in our experiments and the ozone concentration was found to be significantly elevated during the copying process and then dramatically degraded. It is noteworthy that ozone could not be detected anymore 60 minutes after the copying process. If only the data obtained at 90, 120 and 626 minutes of the experiments are utilized to estimate their emission factors (i.e. the effect of ozone is neglected), these emission factors are about 2 % to 20 % (11.71 ± 8.5 %) lower than those shown in Table 2. This phenomenon implies that the abatement of BTEXS emission in idle mode after the copy process may be as a result of the operation itself (e.g. to elevate the machine temperature) rather than the oxidation of BTEXS by ozone which was produced during the operation as well.

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

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

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 concentrations of BTEXS inside the chamber may be also estimated using the above equation. The results are significant lower than the observations and thus imply that the copy process will emit large amounts of BTEXS which is consistent to the report data (Brown et al. 1999). The emission factors regarding the photocopiers during operation period may be estimated by using the first sampling results (t = 0) or

Table 1. The levels of BTEXS (μg/m³) inside the chamber with time.

		Benzene	
Time (minute)	X	R	S
0	5.7 ± 10.8	6.9 ± 5.9	26.3 ± 39.3
30	7.8 ± 6.9	23.9 ± 12.6	69.0 ± 62.5
60	12.6 ± 11.3	19.2 ± 11.8	72.8 ± 47.4
90	21.0 ± 14.4	23.8 ± 14.1	86.3 ± 55.7
120	26.1 ± 17.0	33.8 ± 19.1	106.4 ± 57.4
626	85.9 ± 57.0	64.0 ± 13.7	199.3 ± 71.9
		Toluene	
	X	R	S
0	31.5 ± 38.8	38.8 ± 24.3	3.2 ± 5.8
30	27.4 ± 38.0	81.3 ± 49.0	16.7 ± 22.9
60	23.2 ± 33.9	82.2 ± 80.1	19.1 ± 23.1
90	32.3 ± 42.1	98.0 ± 83.2	22.4 ± 30.8
120	50.04 ± 80.3	113.4 ± 95.4	25.4 ± 35.6
626	56.9 ± 68.7	228.0 ± 161.6	47.9 ± 65.6
		Ethylbenzene	
	X	R	S
0	119.8 ± 143.7	18.3 ± 16.4	8.6 ± 9.6
30	132.9 ± 154.3	19.7 ± 17.1	15.2 ± 12.7
60	139.5 ± 159.3	18.5 ± 16.6	17.8 ± 10.4
90	154.0 ± 168.5	21.8 ± 17.4	22.6 ± 12.5
120	165.0 ± 181.0	22.1 ± 17.1	25.2 ± 11.5
626	332.5 ± 321.8	37.8 ± 31.2	47.0 ± 13.6
		Xylene	
	X	R	S
0	145.0 ± 163.8	30.4 ± 25.8	17.5 ± 14.6
30	157.7 ± 172.3	42.0 ± 26.1	28.4 ± 13.8
60	163.6 ± 173.6	41.4 ± 24.3	35.2 ± 12.9
90	181.1 ± 185.5	45.0 ± 28.1	38.2 ± 14.0
120	194.8 ± 199.0	51.3 ± 27.7	42.4 ± 12.4
626	377.5 ± 346.8	95.7 ± 68.7	79.5 ± 26.7
		Styrene	
	X	R	S
0	46.9 ± 56.8	14.6 ± 12.6	5.3± 6.4
30	50.9 ± 58.5	16.2 ± 14.1	11.5 ± 10.5
60	50.3 ± 58.1	13.8 ± 12.1	13.4 ± 10.3
90	57.5 ± 63.3	17.9 ± 10.8	16.9 ± 14.7
120	60.0 ± 67.1	18.9 ± 10.0	19.0 ± 11.5
626	117.3 ± 110.6	32.4 ± 19.6	35.1 ± 14.3

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

			Idle after 99 copies		
Brand	benzene	toluene	ethylbenzene	xylene	stryene
X	86.8 (1.00)*	227.1 (1.00)	30.7 (0.80)	247.1 (1.00)	73.5 (1.00)
R	52.1 (0.95)	20.7 (0.99)	180.3 (0.97)	64.8 (0.99)	19.4 (0.98)
S	160.3 (0.95)	36.1 (0.96)	38.7 (0.93)	58.1 (0.97)	27.4 (0.95)
			Idle only**		
	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)
** Data from Hsu et al. 2005.

using the intercepts obtained from the above regression model. The values obtained from the regression model show much better estimates of the BTEXS levels (104.33 ± 9.67%) inside the testing chamber and therefore are presented in Table 3. 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 in a room of 30 m^3 volume. The photocopier produces 10 copies at the beginning of every hour and is in idle mode for the remaining 50 minutes of the hour. After eight hours, the concentrations of BTEXS in this room, at air exchange rate of 0, 0.25, and 0.5 are shown in Table 4, respectively.

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 are 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 1.4 x 10^{-4} to 4.7 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 (MRL) and 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 styrene, respectively (ATSDR 2004). The calculated HI based on the simulated levels of BTEXS ranges from 1.3 to 5.4.

Table 3 Emission factors (μg/copy) during the copy process.

Brand	benzene	toluene	ethylbenzene	xylene	Styrene
X	0.77	13.71	3.35	16.43	5.21
R	1.86	2.05	7.41	4.06	1.63
S	6.39	1.62	1.53	3.01	1.18

Table 4 Estimation of BTEXS concentrations after eight-hour operation-idle-operation process (V = 30 m^3).

Brand			Q = 0		
	benzene	toluene	ethylbenzene	xylene	Styrene
X	25.21	97.12	17.15	109.74	33.51
R	18.85	10.96	67.85	28.08	9.49
S	59.79	13.94	14.41	23.5	10.42
			Q = 0.25		
	benzene	toluene	ethylbenzene	xylene	Styrene
X	24.23	93.8	16.56	105.99	32.36
R	18.22	10.58	65.56	27.12	9.16
S	57.77	13.47	13.92	22.7	10.07
			Q = 0.5		
	benzene	toluene	ethylbenzene	xylene	Styrene
X	23.58	90.64	15.99	102.4	31.27
R	17.61	10.22	63.37	26.2	8.85
S	55.84	13.02	13.46	21.93	9.73

Air exchange rate: $hour^{-1}$

The operation of a dry process photocopier will significantly abate the VOCs emission during the idle mode after the operation; however, the abatement cannot compensate the emission of VOCs during the copy process and a significantelevation of VOCs levels later. The emission rates of VOCs from a dry process photocopier are independent to the copy rates as well as the surrounding temperature (Brown 1999). The composition of toner may significantly affect the emission of VOCs from a dry process photocopier (Henschel et al 2001). This may also explain the variation observed in our experiments in addition to the difference among photocopiers of different manufacturers. This paper clearly points out that office workers may be exposed to a significant amount of VOCs and thus at a great health risk. Therefore, the regulation of dry process photocopiers including laser printers and, in particular, the formula of toners should be of consideration.

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