Control of workers' exposure to xylene in a pesticide production factory

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Background: Acute and chronic exposure to xylene can result in a range of negative health effects. However, xylene is widely used and emitted in the air of workplaces.

Objectives: To evaluate xylene vapor concentrations to guide the design and evaluation of a local exhaust ventilation (LEV) system to reduce exposure in a pesticide production factory.

Method: A real time volatile organic compound (VOC) monitor was used to determine the workers' time-weighted average (TWA) exposure. A LEV system was designed, and then, workers' exposure to xylene vapor was evaluated.

Results: We found that worker's exposure to xylene (4.7 ± 5.5 ppm) was lower than the standards recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) and the Occupational safety and health administration (OSHA). Despite the low TWA exposures, the short-term exposures for some workers were higher than STEL levels. Three canopy hoods were designed and installed with capture velocities of $0.508 \text{ m second}^{-1}$ and duct velocity of $10.16 \text{ m second}^{-1}$.

Conclusion: We found that an exhaust ventilation system had a significantly reduced occupational exposure to xylene vapor.

Keywords: Industrial ventilation, Pesticide factory, Workers' exposure, Xylene

Introduction

Xylene ($\text{C}_6\text{H}_4(\text{CH}_3)_2$) is an aromatic hydrocarbon widely used in the printing, rubber, paint, leather, and chemical industries. It is a colorless, sweet-smelling liquid or gas referred to as "dimethyl benzene" that exists in three isomeric forms: *ortho*-, *meta*-, and *para*-xylene.¹ Global production of xylene in 2010 was nearly 44 million metric tons, with approximately 10% (or 3.5 million tons) used as the isomer mixture xylene.^{2,3} U.S. manufacturers had an estimated annual production capacity of 18 billion pounds of mixed xylene in 2006.⁴

The majority (>90%) of mixed xylene isomers are blended into petrol and gas oil, with smaller amounts used for printing, pharmaceuticals, perfumes, cleaning agents, paints and coatings, fabricated items, and pesticides.^{2,5}

Experts expect the global xylene demand to grow 4.4% annually between 2011 and 2015 and 3.2% between 2015 and 2020.⁶ Xylene is classified by the Environmental Protection Agency (EPA) as hazardous air pollutant, although it is widely used and emitted in the air of workplaces. Both acute and

chronic exposure to xylene causes negative health effects, which are influenced by the quantity of the chemical and length of exposure.¹

Xylene exposure can occur via inhalation, ingestion, eye, or skin contact.¹ Xylene vapor is absorbed rapidly via the lungs, and xylene liquid and vapor are absorbed slowly through the skin. Concomitant exposure to xylene affects hematological parameters, liver size, liver enzymes, auditory memory, visual abstraction, and vibration threshold in the toes.^{7,8} Long-term occupational exposures can result in dizziness, fatigue, tremors, poor coordination, anxiety, inability to concentrate, sleep disruption, headaches, irritability, depression, agitation, extreme tiredness, and impaired short-term memory.^{9–12} Other effects of chronic exposure include labored breathing, impaired pulmonary function, increased heart palpitations, severe chest pain, possible kidney effects, asthma-related symptoms, and reduced grasping and muscle power in the extremities.^{13–15} Acute inhalation exposure to mixed xylenes is associated with shortness of breath and irritation of the nose and throat; gastrointestinal effects (e.g. nausea, vomiting, and gastric discomfort); mild transient eye irritation; and neurological effects (e.g. impaired short-term memory, impaired reaction time,

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decreases in numerical ability, and alterations in equilibrium and body balance).^{13,16}

Depending on the feasibility of implementation, exposure to xylene vapor in industrial environments can be controlled in various ways including process enclosure, local exhaust ventilation (LEV), general dilution ventilation, and personal protective equipment.^{17,18}

While xylene exposure is an occupational health concern in the United States (e.g. in 2010, 5 838 tons of xylene were emitted into the air from industrial sources), there is no published information about the use of xylene in Iran.¹⁹ A walkthrough survey in an Iranian pesticide production factory identified workers who reported suffering from headaches, sleep disturbances, eye irritation, dizziness, fatigue, and depression.

Due to the lack of available information, the objectives of this study were to (1) measure the concentration of xylene in the breathing zone of workers in a Northern Iranian factory, (2) design a LEV system to reduce exposure to xylene, and (3) evaluate the effectiveness of the LEV system to reduce exposure to xylene. Results from this study can be used to give information about evaluation and control of xylene vapor in similar workplaces to managers and occupational health organizations.

Methods

Setting

The factory selected for this project employs approximately 100 workers in diverse settings (e.g. office, laboratory, storehouse workers), including a mixture of permanent and seasonal workers. This study was carried out in a pesticide-packing saloon area in the factory. Thirteen workers and one supervisor were responsible for filling and capping machinery, and in the process, were exposed to xylene vapors daily.

Measurement of xylene vapors

Pure xylene (*o*-xylene), mixed xylene, and solvesso were all used to produce liquid pesticides in this factory. However, only mixed xylene was used during the study period. To measure workers' exposure to xylene vapor, a real-time monitor was placed in the breathing zone of workers (within 30 cm of their mouth and nose). A portable Phochem 5000+ EX volatile organic compound (VOC) monitor measured temporal patterns and average exposure to xylene vapor concentrations using frequent measures for the duration of one complete work shift. Although gas chromatography (GC) is a good option for assessing VOCs concentrations, its high cost per sample analyzed, low accessibility, and need for highly trained operators present limitations. Due to these restrictions, we used direct reading methods, including photoionization (PID). This method has been used in previous research. In a recent study,

Rismanchian *et al.* analyzed xylene isomers using GC-mass and a Phochem PID lamp, finding a strong relationship between the actual concentrations of xylene vapors and the PID measured concentrations.²⁰ Similarly, Atabi *et al.* and Li *et al.* used a PID detector for measuring benzene and VOCs. They equipped Phochem VOC monitor with a PID detector to measure real-time concentrations of VOCs and evaluate personal exposures to organic solvents using a correction factors (CF).^{21–23}

In this study, the Phochem VOC monitor was calibrated and the CF was obtained in the lab before sampling. Xylene vapor concentration measurements were collected in workers breathing zones following the measurement protocol provided by Li *et al.* and the National Institute for Occupational Safety and Health (NIOSH).^{22,24}

Measurement of vapor was carried out for 1 minute in the workers breathing zone and repeated every 15 minutes for 8 hours, resulting in 32 distinct measurements. Measurements were completed over a week and then averaged to determine the mean exposure to xylene vapors per worker per shift.

Ventilation system design

A LEV system was designed and installed to reduce occupational exposure to xylene vapor. The LEV system was installed in a fixed position close to the source of the xylene vapor. It had five key components: (1) a hood that allowed the effective capture of the contaminant; (2) ductwork to transport the contaminated air away from the workplace; (3) a fan providing negative air pressure to draw in contaminated air; (4) an air-cleaning device to remove air contaminants; and (5) a source of make-up air to replace air removed from the workplace.

Flow and static losses calculations methods

The calculations of the LEV system were performed according to the velocity pressure method recommended by the American Conference of Governmental Industrial Hygienists (ACGIH). In this method, all losses (frictional and dynamic) are a coefficient of velocity pressure in system. Coefficients of entry losses for hoods (f_h – friction of hood) were determined according to the form and structure of the hoods and their entrance angles. Hood entry loss (h_e) was calculated by multiplying hood coefficient and velocity pressure. Some joints, elbows, branches, and dampers were used in this LEV system. The pressure loss of these parts was calculated by multiplying their coefficients by velocity pressure and entering the value to the calculated sheet recommended by ACGIH. System features were determined using calculations based on the velocity pressure method. In these calculations, an average temperature of 298.15 K (25°C), air pressure of 760.5 mm Hg, and

relative humidity of 72% were assumed for system functions. We estimated static pressure losses and adjusted flow rates according to the average air temperature and ambient pressure. Balancing pressure loss among the parallel branches was key in designing local ventilation systems and was achieved by changing the diameter of the ducts of the air flow rates of the hoods in the system.²⁵

Hood and duct selection method

The ACGIH recommended hood was selected for the worktables to collect pollutant vapors. This hood with exhaust flow captured polluted air from the source without interference with other processing machinery and workers activities. Ducts' paths were selected based on production process, position and height of machines, the balancing of the pressure losses in different ductworks, safety, appearance, and functionality.

Fan and cleaner selection method

The first step was to correct airflow according to the indoor air temperature and the atmospheric pressure using the American NIOSH's standards. According to the average workplace temperature and barometric pressure in the factory (298.15 K and 760.5 mm Hg, respectively), we calculated temperature and pressure coefficients of 1.012 and 0.989, respectively. The static pressure loss and systems airflow, according to velocity pressure method, were used to select suitable fans. The static and total pressures of fan and the required power of the fan in the system were also calculated. A fan was selected based on the xylene, other vapors, and workplace conditions. Finally, the dimensions and technical characteristics of the ventilator, including static pressure, flow rate, and velocity pressure, were calculated using NIOSH standards.

Collected pollution samples were cleaned by an activated carbon bed before being re-released into the atmosphere. This cleaning method was chosen based on the density and concentration of polluted air, collector's value, maintenance costs, and collector

limitations.²⁶ However, a recent study has found that compost ceramic ball biofilter can also reduce xylene vapor in ventilated air.³⁴

Statistical methods

The Wilcoxon signed ranks test was used to test for a significant difference in the mean personal exposure before and after the use of the ventilation system.

Results

Study participants

Table 1 provides demographic information for study participants. Worker age ranged from 21 to 60 years and job experience ranged from one to 10 years (mean 5.3 years). Four workers were responsible for bottle capping and two workers were responsible for packing. Six of the 13 workers were current smokers and one (bottle cap employee) had a history of obstructive lung disease.

Primary measurement of xylene concentration

As shown in Table 2, the primary measurements of xylene vapors found a mean concentration of 4.7 ± 5.5 ppm (ranging from 0.3 to 10.3 ppm). This value is below the ACGIH and Occupational safety and health administration (OSHA) recommended levels recommended for time weighted average (TWA) personal exposures. The highest mean concentrations were for the first four workers [9.2, 10.2, 10.4, and 9.4 ppm, respectively]. Maximum one-minute xylene concentrations varied from 0.8 ppm for worker No. 14 to 186.0 ppm for worker No. 2. Minimum one-minute concentrations varied from 0.0 ppm for worker No. 1 to 0.9 ppm for workers No. 3, 5, and 6. In spite of the low TWA xylene concentration in this factory, among some employees short-term exposure levels (STEL) were higher than recommended by the ACGIH.¹⁷

Local exhaust ventilation designing

Based on worker symptoms and the measurements of xylene vapor concentrations, a LEV system was designed and installed in this factory.

Table 1 General information of workers

Worker code	Working position	Age	Work experience	Smoking	Lung disease
1	Bottle supply	54	8	Yes	Normal
2	Feeding bottles on to the conveyor belt	60	7	No	Normal
3	Filler operator	58	7	Yes	Normal
4	Bottle capping	42	7	No	Normal
5	Bottle capping	46	6	No	Normal
6	Bottle capping	44	5	No	Normal
7	Bottle capping	22	1	No	Normal
8	Bottle cap checking	53	1	Yes	Obstructive lung disease
9	Leakage control	26	1	No	Normal
10	Packing	28	4	No	Normal
11	Packing	36	7	Yes	Normal
12	Quality control	36	8	Yes	Normal
13	Labeling	21	1	No	Normal
14	Supervisor	47	10	Yes	Normal
Mean		40.9	5.3		

Hood selection

To collect xylene vapors from the source of production, one canopy hood for the filling unit and two canopy hoods for the capping units, similar to VS-903 hood type recommended by the ACGIH's, were designed and installed on top of a conveyor belt. These hoods with exhaust flow capture polluted air without interfering with processing machinery or occupational tasks (Fig. 1). Capture velocity of $0.508 \text{ m second}^{-1}$ (100 fpm) was chosen for filling and capping units' hoods.²⁵

Ducting system and air flow calculations

A duct velocity of $10.16 \text{ m second}^{-1}$ (2000 fpm) was selected for small ducts and a velocity of $15.24 \text{ m second}^{-1}$ (3000 fpm) for main duct. Duct dimensions and flow rates were calculated according to the duct velocities (Table 3).

Calculation and fan selecting results

A static pressure loss to cleaner of 41.20 mm WG (1.622 in WG) and a corrected flow rate of

Figure 1 Hoods and duct works designed for packing saloon

$8437.3 \text{ m}^3 \text{ hours}^{-1}$ (4966 cfm) were calculated. Fans were centrifugal with radius blades and a diameter of 838 mm, static pressure of 63.25 mm WG, rotating velocity of 15.37 rps, and a total power of 2.3 hp.

Table 2 Descriptive statistics of workers' exposure before and after use of local exhaust ventilation (LEV) system

Worker No.	Measurement time (B, before; A, after)	N	Min (ppm)	Max (ppm)	Mean (ppm)	S.D.
1	B	530	0.0	58.6	9.2	9.4
	A	530	0.1	9.9	0.6	0.8
2	B	600	0.7	186.0	10.2	18.7
	A	600	0.1	11.3	0.7	0.9
3	B	839	0.9	161.0	10.4	13.2
	A	839	0.2	2.0	0.7	0.3
4	B	720	0.7	72.7	9.4	9.9
	A	720	0.2	56.4	1.4	4.1
5	B	539	0.9	41.7	5.0	4.5
	A	539	0.2	44.4	1.9	4.5
6	B	780	0.9	53.9	3.8	4.8
	A	780	0.2	2.8	0.8	0.5
7	B	780	0.6	41.6	2.8	2.7
	A	780	0.2	10.8	1.0	0.7
8	B	540	0.4	77.6	4.0	7.3
	A	540	0.2	5.9	0.8	0.8
9	B	840	0.3	68.7	4.2	6.5
	A	840	0.1	4.7	0.7	0.6
10	B	720	0.2	46.9	2.0	2.6
	A	720	0.1	1.9	0.4	0.2
11	B	600	0.2	7.9	1.2	1.1
	A	600	0.1	1.8	0.4	0.2
12	B	838	0.1	8.4	1.3	1.1
	A	840	0.1	1.8	0.4	0.2
13	B	747	0.1	42.3	1.5	2.4
	A	747	0.1	5.2	0.3	0.3
14	B	124	0.1	0.8	0.3	0.2
	A	124	0.1	0.4	0.2	0.1

Table 3 Characteristic of duct works in designed local exhaust ventilation (LEV) ventilation system

Hood No.	Branch/main	Straight run (cm)	Duct and elbow diameter (mm)	Elbows	(R/D)	Entries
1	1-A	140	254	1-90°	2	–
2	2-A	85	254	1-60°	2	1-30°
3	3-B	30	356	1-60°	2	–
4	4-B	30	102	–	–	1-30°
–	B-C	9	356	1-60°	2	1-30°
–	A-C	37	356	–	–	–
–	Main	658	457	4-90°	2	–
–	Stack	1725	457	3-90°	2	–

Secondary measurement of xylene concentration

After designing and installing the LEV system, worker exposure to xylene was measured using the same methodology to evaluate the effectiveness of the ventilation system. Table 2 presents descriptive statistics for xylene concentrations in the workers' breathing zone before and after the use of the LEV ventilation system.

Worker exposure to xylene was reduced after the LEV system was installed, with analyzes revealing a statistically significant difference in the before and after mean exposure concentrations for all workers ($P=0.001$). The largest reduction in xylene vapor exposure occurred for worker No. 1 (94.3%) and the smallest was for worker No. 14 (29.3%) (Table 4).

Discussion

Results of the current study showed that prior to the installation of the LEV system, time-weighted occupational exposure to xylene vapors was below standards recommended by the ACGIH and OSHA.¹⁷ The occupational values, for xylene based on a TWA for daily exposures are 100 ppm, are recommended by Occupational Safety and Health Organization, NIOSH, and ACGIH. The short-term exposure limit (STEL) (less than 15 minutes) is 150 ppm.¹⁷ In addition to the TWA and STEL values, NIOSH has set an Immediately Dangerous to Life and Health (IDLH) value of 900 ppm for a 30 minutes exposure.¹³ The odor threshold for xylene is 1 part per million (ppm).¹⁷ Similar studies in aviation, refinery industries, tile and floor covering companies, painters, and car bodywork repair companies have found similar low levels of xylene exposure as the current study.^{25,27,28}

The short-term exposures to xylene among for two workers (No. 2 and 3, were 186 and 161 ppm, respectively) were higher STEL levels recommended by the ACGIH.¹⁷ These employees worked close to the filling machine and had complaints of exposure to

xylene vapors. This finding is in line with a similar study that reported dockyard workers complaining as a result of short-term exposure to VOCs.²⁹ We found the mean reduction of xylene vapor in the workers' breathing zone after installation of LEV system was 76% (highest reduction 94.3%). Other studies have also concluded that LEV systems were reliable and effective methods for reducing contaminant vapors indoor microenvironments.^{18,30–33,35} However, current designed local ventilation system decreased xylene vapor particularly in a pesticide industry more efficient than those reported for other vapors in different industries.

In comparison, a study by Jafari *et al.* in a paint manufacturing factory reduced mean xylene concentrations to less than 50% of the primary concentrations with the installation of an LEV system.³⁰ We selected a canopy hood for filling unit and two canopy hoods for capping units, and were able to reduce exposure even more significantly (76%).

Conclusion

We found that the installed exhaust ventilation system resulted in a significant reduction of workers' exposure to xylene vapor in a pesticide factory in Northern Iran where we found elevated short-term exposure to xylene among workers. These findings may be useful to administrators in similar factories in Iran and elsewhere, providing guidance for the evaluation and control of xylene vapors in occupational environments. Furthermore, this is the first study of xylene exposure in Iran. National occupational hygiene organizations can use these results to create regulations for the control of xylene vapor in the pesticide industry.

Disclaimer Statements

Contributors MM was the supervisor for sampling of vapor, designing the local exhaust ventilation, and statistical analysis. He edited the paper. YB did field

Table 4 Mean workers' exposure reduction before and after local exhaust ventilation (LEV) installation

Worker No.	Paired differences (before–after)				
	Mean (ppm)	S.D.	Reduction (%)	Z	Significance
1	8.7	8.6	94.3	−21.0	0.000
2	9.5	17.8	93.0	−20.7	0.000
3	9.6	12.9	93.0	−25.0	0.000
4	8.0	5.8	85.1	−21.0	0.000
5	3.1	0.02	62.5	−15.1	0.000
6	2.9	4.8	78.0	−24.2	0.000
7	1.8	2.2	64.5	−22.3	0.000
8	3.2	6.5	79.5	−18.5	0.000
9	3.5	6.0	84.0	−24.3	0.000
10	1.6	2.5	81.6	−23.1	0.000
11	0.8	0.9	67.3	−19.8	0.000
12	0.9	0.9	69.8	−23.6	0.000
13	1.2	2.1	81.0	−22.8	0.000
14	0.1	0.1	29.8	−4.4	0.000

sampling, ventilation designing, and calculations, and prepared the paper.

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Conflicts of interest We have found that local exhaust ventilation is the best method to control occupational exposure of workers to Xylene vapor in pesticides production factories.

Ethics approval Ethical approval was not required.

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