

Occupational Exposure of Toluene in Wood Furniture Manufacturing Environment: A Case Study

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ABSTRACT: Wood furniture manufacturing is one of the processes that use high quantity of solvent, especially toluene. Toluene is known to be a hazard substance listed by many organisations such as ACGIH, OSHA and NIOSH. The objectives of this research were to investigate the toluene concentration in the wood furniture manufacturing working environment compared with ACGIH TLV-TWA, to study the relationship between toluene concentration and the Frequency of Health Problems Score (FH Score) and to compare the FH Score between toluene-exposed workers and control groups. NIOSH method 1501 was used as a guideline for sample collection and analysis. Research questionnaires were developed in order to collect the Frequency of Health Problems Score (FH Score) from sample and control groups. It was found from the study that the average toluene concentration in the working atmosphere was 1.13 ppm. The maximum toluene concentration was 3.66 ppm. This number was lower than ACGIH TLV of toluene. The relationship between toluene concentration and the FH Score of the samples was found to be not statistically insignificant. However, the FH Score acquired from sample and control groups was found to be significantly different with a P-value of 0.004. This study showed that even if the workers are not exposed to the high concentration of toluene, this chemical can be accumulated in their bodies which might lead to many adverse health effects. Therefore, the employers should give attention to the toluene exposure in order to decrease the health risk of their workers.

Keywords: toluene, exposure, health problems, furniture, solvents, ACGIH TLV

Introduction

The furniture manufacturing industry has been counted as one of the fastest growing industries in Indonesia, Vietnam, Malaysia and Thailand (Ratnasinngam *et al.*, 2012). This industry has played an important role on Thailand's economy. Wood furniture industry brings in remarkable income from oversea to Thailand. The wood furniture is made both in large scale factory with high technology machines and in household business level. Past research showed that, in the wood furniture manufacturing workplace, testing result of dust and some hazardous chemicals in the atmosphere exceeded the occupational health standard (Yang *et al.*, 2012). One of the chemicals of concerns in the workplace atmosphere is toluene. In the past, toluene was used as a safe replacement for benzene in industrial solvents (Fishbein, 1985). Toluene is a volatile aromatic hydrocarbon that is principally used as a solvent in manufacturing process. The worker exposure mainly occurs by inhalation, particularly in occupational settings that use toluene (Clough, 2014). Toluene exposure leads to various negative health effects. Breathing high concentration of toluene for short periods of time can have negative effects on nervous system, kidneys, liver and heart. Chronic contact with toluene liquid or vapor can cause irritation or burn. These effects are not likely to occur at normal levels of toluene in daily life. However, repeatedly breathing toluene in occupational environment can cause permanent brain damage. Other problems with speech, hearing, and vision could be possible (Office of pollution prevention and toxics, 1994). Recently, a scientific report showed that inhaled toluene can modulate the effects of anesthetics on the middle ear acoustic reflex (Campo *et al.*, 2013).

There are many household businesses that manufacture wood furniture in small scale at Nakhon Ratchasima, a province in Northeastern part of Thailand. These household industries make various kinds of wood furniture such as shelves, cabinets, tables and chairs. The processes are generally simple e.g. cutting, polishing and assembling. Volatile organic solvent is also used in the processes for cleaning and polishing purposes. Worker exposure to toluene might be possible in this occupational environment. Moreover, the lack of safety regulation in such a small scale workplace can lead to high risk. Therefore, this research focused on the investigation of toluene concentration in wood furniture manufacturing atmosphere. Another research objective was to study the adverse health effects related to toluene exposure by measuring the frequency of symptoms.

Materials and Methods

This survey research was consisted of air sample collection and analysis. The toluene concentrations of the samples were analyzed using gas chromatography while the workers' health status was assessed in terms of frequency of the toluene exposure related symptoms. The research was conducted at a furniture factory in Rangkayai area, Phimai district, Nakhon Ratchasima, Thailand. The samples were chosen by purposive sampling method from an overall of 27 workers. These workers were responsible for the processes in which solvents are used, *i.e.*, polishing (1), painting, (1), spray painting (2), coating (1), and assembling (3). The control group was set up by selecting the most identical population with no occupational risk of toluene exposure. Then, the 8 samples and the control group were asked to complete the questionnaire.

Air sampling and analytical method

Air samples were collected *in situ* in activated charcoal tubes using a universal pump (SKC PCXR4). NIOSH procedure 1501 was used as the sampling method. Blanks were performed together with the collected sample. Then the contaminated activated charcoal in both front and back sides of the adsorption tube was eluted with CS₂. The solutions were kept in tightly sealed vials. The analysis of the toluene concentration in the solution was carried out in the laboratory using gas chromatography (Agilent model 6890GC) with FID detector. The toluene standards were also prepared to create the calibration curve. The toluene concentrations were calculated using Eq. [1]

$$C = \left(\frac{W_f + W_b - B_f - B_b}{V} \right) \quad [1]$$

where

C	=	toluene concentration (mg m ⁻³)
W_f	=	mass of toluene found in sample front (μg)
W_b	=	mass of toluene found in sample back (μg)
B_f	=	mass of toluene found in media blank front (μg)
B_b	=	mass of toluene found in media blank back (μg)
V	=	volume of air sample (L)

The Assessment of worker health status

The investigation of the health status of worker was carried out using a questionnaire survey. The symptoms related to toluene exposure were reviewed and gathered in the questionnaire. These negative health effects were divided into 4 systems, *i.e.* dermal, muscle, respiratory and nervous systems. The frequency for each of the symptom was also inquired. The content validity of the questionnaire was tested by using Index of Congruence (IOC). Then it was tested for the reliability before distribution. The Frequency of Health Problems Score is the summation of score obtained from each question. The scoring criteria were:

The symptom occurs every day	=	3
The symptom occurs several day a week	=	2
The symptom occurs several day a month	=	1
The symptom never occurs	=	0

Results and Discussion

Basic information of the furniture factory

The case study was set in a small furniture factory (operated Monday to Friday, eight hours a day, having 11 departments and 27 workers in total). The factory building has one floor with large opening area in the middle. There were separated rooms for spray painting and coating processes. Only general ventilation was provided inside the spray painting room. The processes of furniture manufacture were shown in **Figure 1**.

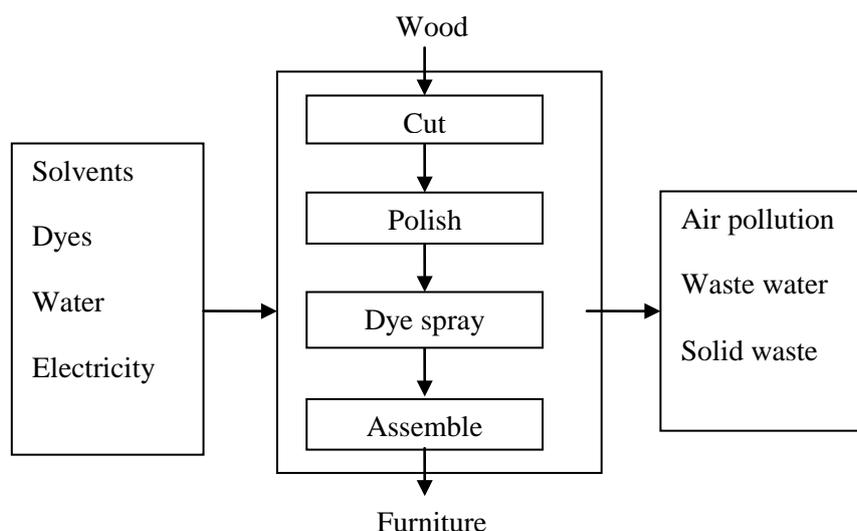


Figure 1: Furniture manufacturing Process

Toluene exposure concentration in working atmosphere

The triplicate sampling was performed using personal sampling method. Eight workers from painting (1), polishing (1), spray painting (2), coating (1), and assembling (3) department were requested to attach the sampling equipment to their belts. The air samples were collected for 8 hours during working period. The air samples collected in activated charcoal tubes were taken to the laboratory in order to evaluate the toluene exposure concentration. It was found that the average toluene exposure concentration was 1.13 ppm (S.D. = 1.48 ppm, maximum concentration = 3.66 ppm, minimum concentration = 0.01 ppm). The results were shown in **Table 1**.

Table 1: Toluene Exposure Concentrations

Department (sample number)	Concentration (ppm) Avg ± S.D.	Min-Max (ppm)
Assembling (1)	0.1325 ± 0.0248	0.1097 - 0.1589
Assembling (2)	0.0068 ± 0.0009	0.0058 - 0.0075
Assembling (3)	0.5485 ± 0.3831	0.2532 - 0.9814
Painting	3.6556 ± 0.7243	3.1581 - 4.4866
Coating	3.0914 ± 0.3193	2.8003 - 3.4329
Spray painting (1)	0.0212 ± 0.0200	0.0080 - 0.0443
Spray painting (1)	0.0654 ± 0.0383	0.0404 - 0.1095
Polishing	1.4983 ± 0.0932	1.4168 - 1.5999

Health status and the frequency of the health problems

Basic information of sample and control group

Sample group was consisted of the 8 workers who had the high risk of toluene exposure. A most identical group of 8 workers who have no risk of toluene exposure in occupational environment was selected as the control group. The average age of sample and control groups were 44.25±7.21 and 44.13±7.12 years, respectively. Basic information acquired from questionnaires was shown in **Table 2**.

Table 2: Basic information of sample and control group

Data	Sample (%)	Control (%)
<i>Sex</i>		
Male	4(50.00)	4(50.00)
Female	4(50.00)	4(50.00)
<i>Age (years)</i>		
33-39	2(25.00)	2(25.00)
40-46	3(37.50)	3(37.50)
47-53	2(25.00)	2(25.00)
54-60	1(12.50)	1(12.50)
Average age ± S.D.	44.25 ± 7.21	44.13± 7.12
<i>Former job</i>		
Employee	2(25.00)	4(50.00)
Trader	1(12.50)	0(0.00)
Self-employed	3(37.50)	1(12.50)
Farmer	2(25.00)	2(25.00)
Construction worker	0(0.00)	1(12.50)
<i>Period of former job employment (years)</i>		
<1	0(0.00)	0(0.00)
1-8	6(75.00)	4(50.00)
9-17	0(0.00)	2(25.00)
18-26	1(12.50)	2(25.00)
27-35	1(12.50)	0(0.00)
<i>Period of present job employment (years)</i>		
<1	0(0.00)	0(0.00)
1-5	3(37.50)	4(50.00)
6-10	3(37.50)	3(37.50)
>10	2(25.00)	1(12.50)

Health problems of sample and control groups in the past twelve months

Health problems of sample and control showing up during the past year of working were investigated. In sample group, workers' health problems were found mostly in the respiratory system, followed by dermal and nervous system. The obvious symptoms were eczema (dermal system), muscle pain (muscle system), nasal and throat irritation/burn (respiratory system), nausea and vomit (nervous system). The frequency of health problem of sample was shown in **Table 3**.

Table 3: Frequency of toluene-exposed worker's (sample) health problems

Symptoms	Frequency (percentage)			
	Never	Several days a month	Several days a week	Every day
1. Dermal system				
1.1 dry skin, inflammatory	6(75.00)	1(12.50)	1(12.50)	0(0.00)
1.2 eczema	4(50.00)	3(37.50)	1(12.50)	0(0.00)
1.3 skin numbness	7(87.50)	0(0.00)	1(12.50)	0(0.00)
2. Muscle system				
2.1 muscle weakness	7(87.50)	1(12.50)	0(0.00)	0(0.00)
2.2 muscle pain	3(37.50)	1(12.50)	3(37.50)	1(12.50)
2.3 stagger	7(87.50)	1(12.50)	0(0.00)	0(0.00)
2.4 imbalance	7(87.50)	0(0.00)	1(12.50)	0(0.00)
2.5 convulse	8(100.00)	0(0.00)	0(0.00)	0(0.00)
2.6 uncontrollable	7(87.50)	1(12.50)	0(0.00)	0(0.00)
2.7 irregular heartbeat	7(87.50)	1(12.50)	0(0.00)	0(0.00)
3. Respiratory system				
3.1 nasal irritation	3(37.50)	0(0.00)	3(37.50)	2(25.00)
3.2 nose numbness	8(100.00)	0(0.00)	0(0.00)	0(0.00)
3.3 nasal and throat burn	0(0.00)	0(0.00)	6(75.00)	2(25.00)
3.4 chest pain	7(87.50)	0(0.00)	1(12.50)	0(0.00)
3.5 productivity cough	6(75.00)	1(12.50)	1(12.50)	0(0.00)
4. Nervous system				
4.1 polyuria	8(100.00)	0(0.00)	0(0.00)	0(0.00)
4.2 abnormal urine color	8(100.00)	0(0.00)	0(0.00)	0(0.00)
4.3 nausea or vomit	7(87.50)	1(12.50)	0(0.00)	0(0.00)
4.4 loss of appetite	8(100.00)	0(0.00)	0(0.00)	0(0.00)
4.5 auditory hallucination	7(87.50)	1(12.50)	0(0.00)	0(0.00)
4.6 dysarthria	8(100.00)	0(0.00)	0(0.00)	0(0.00)

Workers in the control group which had no risk of occupational toluene exposure, had less health problem than those in the sample workers. The frequency of the health problems of control group was shown in **Table 4**. The FH Scores of sample and control groups were calculated and statistically tested for the independence between two groups.

Table 4: Frequency of the health problems of control group

Symptoms	Frequency (percentage)			
	Never	Several days a month	Several days a week	Every day
1. Dermal system				
1.1 dry skin, inflammatory	8(100.00)	0(0.00)	0(0.00)	0(0.00)
1.2 eczema	7(87.50)	1(12.50)	0(0.00)	0(0.00)
1.3 skin numbness	8(100.00)	0(0.00)	0(0.00)	0(0.00)
2. Muscle system				
2.1 muscle weakness	6(75.00)	2(25.00)	0(0.00)	0(0.00)
2.2 muscle pain	2(25.00)	4(50.00)	2(25.00)	0(0.00)
2.3 stagger	8(100.00)	0(0.00)	0(0.00)	0(0.00)
2.4 imbalance	8(100.00)	0(0.00)	0(0.00)	0(0.00)
2.5 convulse	8(100.00)	0(0.00)	0(0.00)	0(0.00)
2.6 uncontrollable	8(100.00)	0(0.00)	0(0.00)	0(0.00)
2.7 irregular heartbeat	7(87.50)	1(12.50)	0(0.00)	0(0.00)
3. Respiratory system				
3.1 nasal irritation	6(75.00)	0(0.00)	2(25.00)	0(0.00)
3.2 nose numbness	8(100.00)	0(0.00)	0(0.00)	0(0.00)
3.3 nasal and throat burn	8(100.00)	0(0.00)	0(0.00)	0(0.00)
3.4 chest pain	8(100.00)	0(0.00)	0(0.00)	0(0.00)
3.5 productivity <i>cough</i>	7(87.50)	1(12.50)	0(0.00)	0(0.00)
4. Nervous system				
4.1 polyuria	6(75.00)	2(25.00)	0(0.00)	0(0.00)
4.2 abnormal urine color	8(100.00)	0(0.00)	0(0.00)	0(0.00)
4.3 nausea or vomit	6(75.00)	2(25.00)	0(0.00)	0(0.00)
4.4 loss of appetite	7(87.50)	1(12.50)	0(0.00)	0(0.00)
4.5 auditory hallucination	0(0.00)	0(0.00)	0(0.00)	0(0.00)
4.6 <u>dysarthria</u>	0(0.00)	0(0.00)	0(0.00)	0(0.00)

Some symptoms occur mainly during working period and are relieved after a long break. The chart below illustrated the symptoms that were suspected to be a consequence of occupational toluene exposure. Moreover, the sample workers were asked if they agree that the symptoms were work-related. The results were shown in **Figure 2**. Due to small sample size, non-parametric tests were used for data analysis. The *Spearman rank test* was used to test the association between toluene concentration and the FH Score of the samples. It was found that the association was not statistically insignificant ($p = 0.949$). The *Mann–Whitney U-test* was

used to test the differences of FH Score acquired from sample and control groups. Statistically significant differences ($p = 0.004$) in FH Score were found between these two groups.

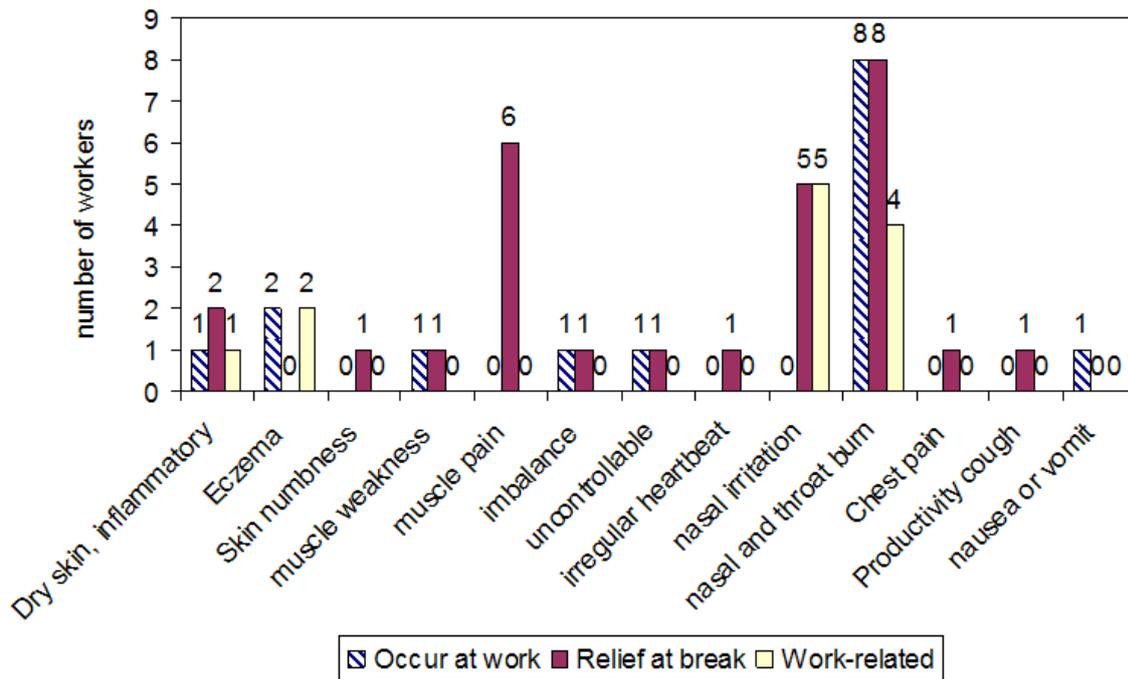


Figure 2: Symptoms that always occur during working period, relieved after work and workers agree that it was work-related health problem

Nasal and throat burn were problems that found mostly among sample workers, followed by nasal irritation. These symptoms were relieved after a long break. Muscle pain was one of the furniture manufacturing workers' health problems but, from **Figure 2**, the workers did not agree that it relates to their job. In workers' point of view, there were 4 work-related symptoms, i.e. dry skin/inflammatory, eczema, nasal irritation and nasal/throat burn.

Working area that had high level of toluene exposure concentration was the coating department. The low air movement in the factory building and by having the process of solvent mixing in opened drums causing the solvents to be evaporated and accumulated in the working atmosphere. The assembling department had low toluene exposure concentration compared to painting and coating. Solvent based glue was used in the assembling steps but the long, small tip of the glue bottle decreased the risk of solvent evaporation. The lowest toluene exposure concentration was found in spray.

The highest toluene exposure concentration in the furniture factory was found at the painting department. The maximum toluene exposure concentration was 4.49 ppm. This number was lower than the exposure limit (TLV-TWA) proposed by ACGIH and other recommendations (**Table 5**). Although, the number did not exceed the threshold limit or recommendations, worker health status was significantly different from that of control group (no occupational toluene exposure). Besides, the chronic exposure of toluene may lead to various negative health effects. The control procedures should be applied to some extent to prevent the workers from occupational exposure.

Table 5: Table of Exposure Limits and Recommendations (OSHA, 2014)

Exposure Limit	Limit Values	Health Factors and Target Organs
OSHA Permissible Exposure Limit (PEL) - General Industry	200 ppm TWA	- Central nervous system depression, causing fatigue, headache, confusion, paresthesia, dizziness, and muscular incoordination
	300 ppm Ceiling 500 ppm Peak (10 minutes)	
National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limit (REL)	100 ppm (375 mg/m ³) TWA	- Fatigue, weakness, confusion, headache, dizziness, drowsiness
	150 ppm (560 mg/m ³) STEL	
American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) (2007)	20 ppm (75 mg/m ³) TWA	- Female reproductive system damage and pregnancy loss - Central nervous system impairment and visual impairment
	A4; BEI	

Past researches also reported the VOCs in occupational environments. The study in Argentina (Colman Lerner *et al.*, 2012) showed that many types of VOCs, including toluene, were found in both indoor and surrounding environment of small enterprises. The VOCs, especially toluene, were studied in the application of water-based paints (Sweden) (Norbäck *et al.*, 1995), in the solid waste management plants (Finland) (Lehtinen *et al.*, 2013), in office buildings (Thailand) (Ongwandee *et al.*, 2011), and in residence area (USA) (Jia *et al.*, 2008).

After all, we recommend further study on the influence of working procedures or worker behaviors on occupational VOCs exposure. As we can see from this research that opened drum mixing contributed to a high toluene exposure concentration whereas the small tip glue bottle helped decrease the risk. The lack of safety regulations or safety department in the organization, especially in small scale business should be reviewed.

Conclusion

In this research, the toluene exposure concentrations acquired from a small wood furniture industry was found to be lower than the threshold limit value (TLV-TWA). Various toluene related symptoms occurred among the workers with risk of occupational toluene exposure. The frequency of health problem of these workers was significantly different from the control group. Comparison of toluene concentrations from each working department revealed that, not only the air ventilation but the working procedure, worker behavior, and material/equipment selection also contribute to the high risk of toluene exposure.

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