J. Viet. Env. **2018**, 10(2):66-71
DOI: 10.13141/jve.vol10.no2.pp66-71

RESEARCH ARTICLE

Indoor air quality and health risk assessment for workers in packaging production factory, Can Tho city, Viet Nam

Đánh giá chất lượng không khí và rủi ro sức khỏe cho công nhân nhà máy sản xuất bao bì ở Cần Thơ, Việt Nam

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The production of packaging goods for cement is one of the most important industries, contributing to income of many workers. Production activities, however, cause air pollution and health risk. The study was conducted to assess air quality and health risks of workers through air quality data and interviewing employees from 2016-2017 at a packaging production factory, Can Tho city, Vietnam. The findings indicated that temperature and noise exceeded the national technical regulations (QCVN 22-26: 2016/TT-BYT) while the humidity, wind speed, light, respirable particles, toxic gases (benzene, toluene, methyl ethyl ketone (MEK)) were in accordance with the national standards for occupational health and safety (Decision 3733/2002/QĐ-BYT). However, health risk assessment showed that long-term exposure in this factory would result in severe impact on health of workers due to indoor air pollution. The non-cancer risk caused by benzene, toluene and MEK for workers in the working sections such as printing, film coating, weaving, spinning and pasting was expected to cause serious impact on workers' health. The cancer risk (benzene) index was in the range of 1.3×10^{-5} to 7.7×10^{-4} and averaged at 3.3×10^{-4}. The study clearly showed that benzene greatly contributes to serious workers' health effects. Appropriate protection measures such as treatment of air pollutants, regular health check, wearing protective clothes should be implemented to mitigate impact of indoor air pollution at the factory. More importantly, it is necessary to reconsider the standard values of benzene, toluene, methyl ethyl ketone to ensure health of workers.

Công nghiệp sản xuất bao bì xi măng thuộc lĩnh vực ngành xây dựng là một trong những ngành công nghiệp quan trọng, đã góp phần mang lại nguồn thu nhập cho nhiều người lao động. Tuy nhiên hoạt động sản xuất cũng gây ra những vấn đề về ô nhiễm môi trường không khí và rủi ro sức khỏe. Nghiên cứu được thực hiện nhằm đánh giá mức độ ô nhiễm môi trường không khí và đánh giá rủi ro sức khỏe của công nhân thông qua số liệu chất lượng môi trường không khí và phỏng vấn trực tiếp người lao động trong khoảng thời gian từ 2016 - 2017. Kết quả nghiên cứu cho thấy nhiệt độ, tiếng ồn vượt qui chuẩn cho phép (QCVN 22-26:2016/TT-BYT) trong khi độ ẩm, tốc độ gió, ánh sáng, bụi hô hấp, hơi khí độc (Benzen, toluen, methyl ethyl ketone) đạt chuẩn cho phép theo tiêu chuẩn vệ sinh an toàn lao động (QĐ 3733/2002/QĐ-BYT). Tuy nhiên, kết quả đánh giá rủi ro sức khỏe cho thấy công nhân làm việc lâu dài sẽ bị ảnh hưởng nghiêm trọng đến sức khỏe do ô nhiễm không khí. Rủi ro không gây ung thư do benzene, toluene và MEK gây ra đối với công nhân ở từng khu vực có thể gây ảnh hưởng nghiêm trọng đến sức khỏe công nhân làm việc ở các khu vực sản xuất như in, tráng màng, dệt, kéo sợi và dán. Benzene gây rủi ro ung thư với xác suất từ 1 đến 7 người trong 10.000 người trong quá trình làm việc lâu dài tại nhà máy. Nghiên cứu cho thấy benzene đóng góp rất lớn vào khả năng gây ảnh hưởng nghiêm trọng đến sức khỏe công nhân. Môi trường không khí bên trong nhà máy cần được cải thiện hơn nữa đồng thời tuyên truyền nâng cao ý thức công nhân thực hiện nghiêm túc bảo hộ lao động, tổ chức khám sức khỏe định kỳ cho công nhân. Quan trọng hơn là cần điều chỉnh lại các giá trị qui chuẩn để đảm bảo an toàn sức khỏe cho công nhân đang làm việc tại những nơi có sự hiện diện của khí độc như benzene, toluen, methyl ethyl ketone.

Keywords: cancer risk, benzene, health risk assessment, methyl ethyl ketone, toluene, workers

1. Introduction

The development of the packaging industry has brought tremendous economic benefits for society. However, this sector also produces many pollutants, especially benzene, toluene, methyl ethyl ketone (MEK) (Chinh and Van, 2014). Benzene is widely used in industries (Yardley-Jones et al., 1991) and is a carcinogenic compound for humans and animals (Rana and Verma, 2005). Toluene ($C_6H_5CH_3$) is a benzene derivative, less volatile than benzene, soluble in many substances, used as solvent (Yardley-Jones et al., 1991). Commercial toluene has high content of benzene ranging from 10 to 20% (Donald et al., 1991). Methyl ethyl ketone

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http://dx.doi.org/10.13141/JVE
ISSN 2193-6471

(C_4H_8O) is volatile, flammable and explosive. It is used as a solvent in paint, varnish, rubber, dyes and synthetic leather. Exposure to high concentrations of methyl ethyl ketone causes several health problems (Trung, 2002). Scientists have shown that indoor air pollution can be more serious than outdoor air, especially in industrial areas (Wallace et al., 1985). Recent report from the World Health Organization (WHO, 2018) shows that indoor air quality worldwide is declining dramatically. It is estimated that one billion people, mostly children and women, are breathing in indoor air containing the concentration of pollutants higher than 100 times compared to permissible level regulated by WHO. Indoor air pollution can lead to many health problems including cancer (Guo et al., 2004). Health impact mitigation from chemical exposure using health risk assessment was proposed by many researchers (Chaiklieng et al., 2015; Ounsaneha et al., 2017). At present, study on the effects of indoor air pollution is still limited in Vietnam. This study aims to assess indoor air quality and health risk associated with indoor air pollutants at the packaging factory in Can Tho city, Vietnam. The results of this study could contribute to better management of health and air quality in this workplace.

2. Materials and methods

2.1 Measurement of indoor air pollutants

The company mainly produces packaging goods, generating jobs for 269 workers and 65 administration staff. The factory has five production areas including fabrication, weaving, film coating, printing and pasting. At each production area, six parameters comprising temperature, humidity, wind speed, light, noise, respirable particles, and toxic gases (benzene, toluene, and methyl ethyl ketone) were measured at different positions in the factory to represent for the air quality in the workplace. Each measurement was repeated three times to increase accuracy of the air quality data. The air quality parameters were measured in December, 2016, January and February 2017 and the reported data were the average of eight hours. The measured air quality parameters were compared with the standard values regulated in the Decision No. 3733/2002/QĐ-BYT and the national technical regulations no. 22, 24, 26: 2016/TT-BYT. The air quality parameters were measured using equipment listed in Table 1.

Table 1. Measurement of air quality in working environment

No.	Equipment	Parameters
1	Testo 480 (USA)	Temperature, humidity, wind speed
2	Testo 540 (USA)	Light
3	Rion NL-42 (China)	Noise
4	Sampler Perion, balance	Respirable particles
5	SKC, Kimoto, Helios (USA)	Benzene, toluene, methyl ethyl ketone

2.2 Health risk assessment

2.2.1 In case of non-carcinogens

For non-carcinogenic risk assessment, hazard index (HI) is used. Hazard index was calculated using equation (1).

$$\mathrm{HI} = \frac{\mathrm{C}}{\mathrm{RfC}} \qquad (1)$$

Where C is the concentration of the pollutants in air (mg/m^3) and RfC is the reference concentration (mg/m^3) obtained from the United States Environmental Protection Agency's risk assessment website (USEPA). HI is used as an indicator of risk. If HI> 1, that means the risk has a serious impact on health. If HI <1, no significant health effect was predicted. If there are several pollutants causing non-carcinogenic risk, HI is calculated for each of individual pollutant and then summed up.

2.2.2 In case of carcinogens

In this study, benzene is a carcinogen that could be uptaken into the body mainly through inhalation. The chronic daily intake due to inhalation could be calculated using equation (2) that is obtained from the previous study (Chaiklieng et al., 2015).

$$\mathrm{CDI} = \frac{\mathrm{C \times IR \times EF \times ED}}{\mathrm{BW \times AT}} \qquad (2)$$

Where CDI is chronic daily intake (mg/kgBW-day); C is the concentration of benzene (mg/m^3) which was measured; IR is intake rate (m^3/day), obtained from IRIS EPA; EF is exposure frequency (days/year), obtained from interviewing workers; ED is exposure duration (years), for life time cancer risk, ED is 70 years; BW is body weight (kg), obtained from interviewing workers; and AT is averaging time (25555 days = 70 years x 365 days/year). Cancer risk was calculated by using equation 3:

$$\text{Life time risk} = \mathrm{CDI} \times \mathrm{SF} \qquad (3)$$

Where, SF is slope factor. The slope factor and references concentration of benzene, toluene, and methyl ethyl obtained from IRIS EPA are presented in Table 2.

Table 2. The slope factor and reference concentrations for calculating risk

Pollutants	Critical endpoint	RfC (mg/m^3)	SF $(mg/kg/day)^{-1}$	Sources
Benzene	Carcinogenic/non-carcinogenic	0.03	0.035	US.EPA
Toluene	Non-carcinogenic	4	-	US.EPA
MEK	Non-carcinogenic	5	-	US.EPA

2.3 Data analysis

The air quality parameters were presented as mean ± standard deviation (SD). The variation in air quality parameters at the sampling sites was analysed by one-way ANOVA using IBM SPSS statistics for Windows, Version 20.0 (IBM Corp., Armonk, NY, USA); Duncan test was applied to compare the difference in air quality parameters at a significance level of 5% ($p < 0.05$). The mean values of air quality parameters were compared those regulated in Decision No. 3733/2002/QĐ-BYT and the Vietnam National Technical Regulation No. 22, 24, 26: 2016/BYT.

3. Results and discussion

3.1 Indoor air quality

The results showed that the average temperature in the film coating area was the highest (32.6 ± 0.5°C), followed by the fabrication area (32.4 ± 0.5°C) and both slightly exceeded the permitted standard (QCVN 26: 2016/ BYT); air temperature in the printing area (31.9 ± 0.3°C), weaving area (31.8 ± 0.6°C) and pasting area (31.7 ± 0.4°C) were in accordance with the allowable standards. As reported in Table 3, the mean values of humidity and wind speed in the manufacturing areas were in line with the permitted standards, however, the differences in the mean values of humidity and wind speed in the different areas were also statistically significant ($p < 0.05$).

Table 3. Temperature, humidity and wind speed in the production areas

Sampling areas	Temperature (°C)	Humidity (%)	Wind speed (m/s)
Fabrication	32.4 ± 0.5^{bc}	55.3 ± 0.5^{a}	0.24 ± 0.02^{a}
Weaving	31.8 ± 0.6^{ab}	62.2 ± 2.1^{b}	0.27 ± 0.03^{a}
Film coating	32.6 ± 0.5^{c}	64.6 ± 0.8^{bc}	0.25 ± 0.01^{a}
Printing	31.9 ± 0.3^{ab}	68.9 ± 0.8^{d}	0.26 ± 0.01^{a}
Pasting	31.7 ± 0.4^{a}	66.8 ± 1.1^{cd}	0.31 ± 0.03^{b}
Mean	32.1 ± 0.5	63.6 ± 1.1	0.27 ± 0.02
Ambient air	33.4 ± 0.6^{d}	52.8 ± 1.9^{a}	0.37 ± 0.07^{c}
QCVN 26:2016/TT-BYT	16 - 32	40 - 80	0.2 - 1.5

Note: Different letters in the same column indicate statistically significant at α = 5%.

The mean values of light intensity in various production areas were significantly different ($p<0.05$) and these values were in accordance with the allowable standard (QCVN 22: 2016/ BYT). The average concentrations of respirable particles in the working areas were not exceeding the permitted standards regulated in the Decision No. 3733/2002/QD-BYT. The difference in respiratory particles in the production areas was statistically significant ($p <0.05$) in which the highest concentration (0.422 ± 0.019 mg/m^3) was found in the weaving area while the lowest (0.076 ± 0.018 mg/m^3) was found in the fabricating zone. The average noise level at all locations exceeded the national technical regulation on noise level (QCVN 24: 2016/ BYT). The highest noise was at the weaving area (97.0 ± 2.9 dBA) since this area is characterized by several adjacent machines and synchronous operation. The mean noise levels at different production areas were statistically significant ($p < 0.05$). The results indicated that noise pollution is a serious health problem for workers. In practice, there are 2% of workers have been deaf as a consequence of high noise level.

Table 4. Light, respirable particles and noise in the production areas

Sampling areas	Light (lux)	Respirable particles (mg/m^3)	Noise (dBA)
Fabrication	301 ± 38^{bc}	0.076 ± 0.018^{a}	91.6 ± 1.9^{b}
Weaving	274 ± 21^{b}	0.422 ± 0.019^{d}	97.0 ± 2.9^{c}
Film coating	245 ± 5^{a}	0.104 ± 0.012^{b}	88.8 ± 1.3^{a}
Printing	312 ± 12^{c}	0.122 ± 0.014^{b}	89.1 ± 1.2^{a}
Pasting	329 ± 35^{c}	0.144 ± 0.009^{c}	87.5 ± 1.1^{a}
Mean	292 ± 20	0.174 ± 0.014	90.8 ± 1.7
Regulation standards	$150 - 10.000^{a}$	$\leq 2^{b}$	$\leq 85^{c}$

Notes: Different letters in the same column indicate statistically significant at α = 5%. [a]QCVN 22: 2016/ BYT National technical regulation on lighting - permitted level of workplace lighting. [b]Decision No. 3733/2002/QDD-BYT Decision on promulgation of 21 safety and *hygienic standards, 5 principles and 7 safety and hygienic standards.* [c]*QCVN 24: 2016/ BYT National regulation on noises – allowable exposure levels at the workplace*

The concentrations of benzene, toluene and methyl ethyl ketone were highest in the printing area and lowest in the pasting area. The concentrations of these chemicals in various production areas were statistically significant ($p<0.05$) (Table 5). However, the concentrations of benzene, toluene, methyl ethyl ketone were all in the permitted level regulating in the Decision No. 3733/2002/QĐ-BYT.

Table 5. Toxic air pollutants in the production areas

Sampling areas	Benzene (mg/m^3)	Toluene (mg/m^3)	Methyl Ethyl Ketone (mg/m^3)
Fabrication	0.34 ± 0.14^{a}	3.27 ± 0.33^{b}	10.38 ± 1.06^{b}
Weaving	0.82 ± 0.19^{b}	4.03 ± 0.09^{bc}	13.74 ± 0.49^{c}
Film coating	1.10 ± 0.09^{b}	5.18 ± 0.12^{c}	15.17 ± 0.60^{cd}
Printing	2.01 ± 0.08^{c}	25.56 ± 1.24^{d}	$17.08 \pm 0.90d^{d}$
Pasting	0.04 ± 0.02^{a}	0.10 ± 0.01^{a}	0.06 ± 0.02^{a}
Decision No. 3733/2002/QĐ-BYT)	≤ 5	≤ 100	≤ 150

Note: Different letters in the same column indicates statistically significant at α = 5%

The overall results showed that temperature and noise in the factory exceeded the allowed standards. These factors can significantly affect workers' health. Appropriate measures are necessary to limit noise and temperature to reduce occupational deafness and other health problems for the employees. The other air quality indicators such as dust, benzene, toluene, methyl ethyl ketone were not exceeded the currently regulating standards, however, they potentially cause certain risks to human health through long-term exposure.

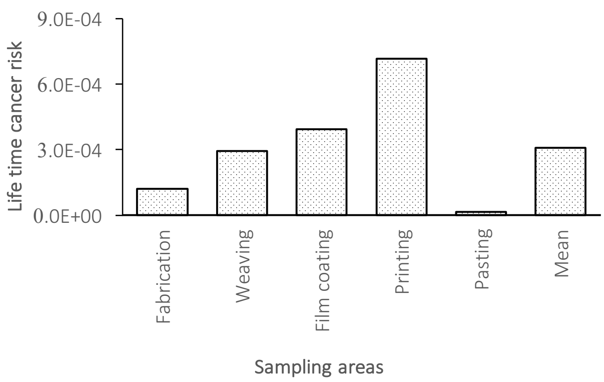

Figure 1. Life time cancer risk due to exposure to benzene in different working areas

3.2 Health risk assessment

3.2.1 In case of carcinogenic risk (benzene)

To calculate risk of benzene inhalation at various working areas, the following conditions were obtained from directly interviewed workers: Body weight of the workers was estimated to be 65.7 kg in average. Exposure time was five days per week, 50 weeks per year for 16.43 years (in average years based on interviewing 30 workers). The worker deeply inhales two hours (1.5 m^3 air per hour) and in other 6 hours the worker breathes only 1m^3 per hour. Total intake rate (IR) was 9m^3 of air per day (Jafari and Ebrahimi, 2007).

The calculated risk of cancer resulted from exposure to benzene was in the range of 1.3×10^{-5} to 7.7×10^{-4} and averaged at 3.3×10^{-4} (Figure 1). This cancer risk exceeded EPA value (10^{-6}) by 13 to 770 times and 330 times in average. However, the total amount of cancer risk posed by benzene in the manufacturing areas was 2×10^{-3} meaning that there are likely two individuals at risk of cancer in 1,000. This finding shows that benzene potentially adversely affects workers' health in the factory. Former study also found that benzene is a common and harmful health hazard in a number of working environments (Guo et al., 2004).

3.2.2 In case of non-carcinogenic risk

Benzene is also considered as a non-carcinogenic (i.e. chronic effects) (US. EPA). Based on the results, the benzene has exceeded the reference concentration (RfC) from 1.3 to 67 times (averaged at 28.7 ± 25.4 times). The benzene concentration exceeded the highest reference concentration at the printing, film coating and weaving areas whereas it was lowest at the pasting area (Figure 2). This result shows that benzene could seriously damage health of workers if they are not equipped with good labor protection. For toluene, the hazard indexes at all sampling sites were less than 1, excepted for the printing area (HI = 5.11) (Figure 2). As a result, health risk result from toluene was not as high as from benzene. Previous research revealed that exposure to toluene through the respiratory system causes irritation of the eyes and respiratory systems, causing headaches, affecting the central nervous system, brain damage, and death. Repeated exposure to toluene can cause permanent damage to the heart, kidneys, liver, and lungs (Mckeown et al., 2011). For MEK, the results indicated that MEK could pose a high health risk for workers working in fabrication, weaving, film coating, and printing areas with the risk indexes of 2.08, 2.75, 3.03, and 3.42, respectively.

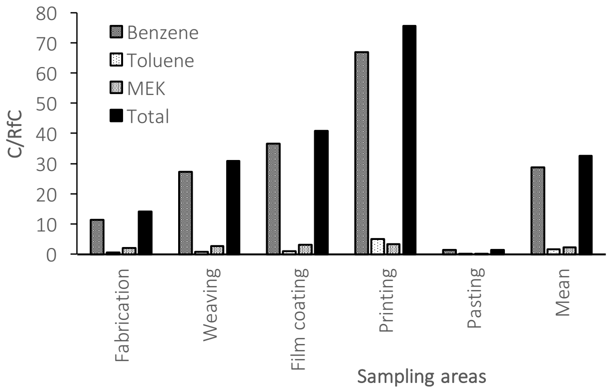

Figure 2. Hazard indexes of toxic air pollutants

There was no risk of health due to exposure to MEK found in pasting area (Figure 2). MEK could cause headache, dizziness, liver and kidney damage (Trung, 2002). Total risk was defined as the sum of risk results from different pollutants at the same production area. The findings revealed that the total risk of benzene, toluene and MEK in the manufacturing sector such as printing, film coating, weaving, fabricating, and pasting were 75.5, 40.74, 30.9, 14.1 and 1.37, respectively (Figure 2). The results clearly indicated that workers have been working in very hazardous environments.

This study pointed out that long-term exposure to benzene, toluene, MEK resulted in serious human health damages, especially pregnant women, elder workers al-though the concentrations of the air pollutants were complied with the national technical regulations (Decision No. 3733/2002/QĐ-BYT). Therefore, performance of health risk assessment is very important in supporting the current regulations on occupational safety and health.

4. Conclusions

The current status of the air quality at the packaging factory showed that the temperature and noise exceeded the permitted standards issued by Vietnam's Ministry of Health. The other parameters such as humidity, wind speed, light, respiratory particles, toxic gases (benzene, toluene, methyl ethyl ketone) were still in the allowable standards. However, health risk still exists. The non-cancer risk for benzene, toluene and MEK for workers in each production area could seriously affect the workers' health working in production areas such as printing, film coating, weaving, fabricating and pasting. The cancer risk assessment indicated that benzene could pose risk of cancer for workers with a probability of 3.3×10^{-4}. Thus, the health risk for workers exposed to toxic gases in the indoor environment in this study is considered to be very serious. It is worth noting that benzene greatly contributes to the potential for serious human health effects. An effective ventilation system is needed to reduce air pollution in the workplace areas. It is necessary to regularly provide periodical medical examination and treatment for workers. Collaborating with related departments to closely monitor the operation of the company and comply with the current standards on air quality and occupational health.

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