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Research Article
Assessment of Exposure to Indoor Air Pollutants at the Transformer Manufacturing Plant in Selangor, Malaysia

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Abstract

Background and Objective: The concern on indoor air in the industries arises due to the various indoor air pollutants emitted in the air from the chemicals used. Therefore, this study was done to assess the air quality status in the production area of a transformer manufacturing plant in Selangor, Malaysia. **Materials and Methods:** Several indoor air quality parameters were selected, which include temperature (T), relative humidity (RH), air movement, carbon monoxide (CO), carbon dioxide (CO_2), respirable particulate (PM_{10}) and total volatile organic compounds (TVOCs). All parameters were measured by using real-time reading measurement over an 8 h Time Weighted Average (TWA) at 8 sampling points in the production area. The sampling was conducted during an 8 h work shift from 08:00-16:00. **Results:** The results showed that all parameters were within the acceptable limit set by Industry Code of Practice on Indoor Air Quality (ICOP-IAQ), 2010 except the temperature, TVOCs concentration and air movement. The reading of temperature taken was ranged from 32.48±1.103 to 33.17±1.169°C and the TVOCs concentration recorded was ranged from 2.83±0.539 to 5.55±0.207 ppm. Meanwhile, the air movement in the production area was below the acceptable limit (<0.15 m sec^{-1}) at certain sampling points ranging from 0.09±0.044 to 0.30±0.058 m sec^{-1}. **Conclusion:** Several parameters (temperature, TVOCs and AV) measured were not within the acceptable limit based on ICOP. Thus, safety measures and engineering control should be imposed to encounter those exceeded air contaminants for the sake of employee health and well-being.

Key words: Air pollutants, indoor air, transformer, industry, ventilation system, total volatile organic compounds

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

In Malaysia, electronic industry has been a significant contributor to the Malaysia's economy as this industry got 84.5% of all investment from overseas and has been identified as one of the catalytic sector[1] in 2017. This statement proved that electronic industries are growing fast in Malaysia and many workers work in those industries. In concerning the worker's health, only few studies related to indoor air quality have been conducted in this industry in Malaysia although indoor air pollutants in the workplace have become a concern since past decades. Exposure towards indoor air pollutants can be considered as one of the most dangerous health hazards in the electronic industry. This is because indoor air pollutants can cause many adverse health effects[2] and sick building syndrome[3].

Electronic industries are engaged in different production process. For example, process of making transformer require six main process which are preparing, winding, wiring, coring, impregnation and finishing. Some of the processes, such as; impregnation process requires the use of many chemicals. Workers involved in the impregnation area are potentially exposed directly to organic solvents such as isonel varnish. These chemicals can evaporate to the surrounding air and to the breathing zone of the workers in higher concentration. Previous studies found that concentration of indoor air pollutants are ranging 2-5 times higher and difficult to dilute compared to outdoor air pollutants[4-6]. Therefore, this study was carried out to determine the concentration of selected indoor air pollutants at the transformer manufacturing plant in Shah Alam, Selangor in order to improve the Indoor Air Quality (IAQ) in the manufacturing plant and raise awareness to the workers on the risk of poor Indoor Air Quality (IAQ) in the workplace.

MATERIALS AND METHODS

A cross-sectional study was conducted in the production area of transformer manufacturing plant located in Shah Alam, Selangor. This research was conducted from July-September, 2019. Before collecting the data, a walk-through survey was done in the production site to determine the targeted population and the possible source of indoor air pollutants. After that, the IAQ questionnaire which was adopted from the ICOP-IAQ 2010 guidelines published by Malaysia Department of Occupational Safety and Health[7] was distributed to the workers in the production area. The questionnaire was needed to obtain the demographic information and sick building symptoms that may experience by workers. The total number of workers in the production area was 80 and only workers from production area participated in this study.

The sampling was conducted at 8 sampling points in the production area, based on the main work stations of the workers which include impregnation (S1-near varnish tank, S2-near oven), finishing (S3 and S4-large and domestic transformers, respectively), small transformer production (S5), coring and winding for domestic transformer (S6), winding of large transformer (S7) and preparing station (S8). As for the crucial work stations which were using chemicals such as; impregnation and finishing had 2 sampling points each. The instruments used in this study were TSI Quest EVM-7 (PM_{10}) and TSI 9565 meter (TSI Incorporated, Minnesota, USA) with TSI 966 articulate probe (temperature, relative humidity, air movement) and also Aeroqual series 500 (TVOCs) (Aeroqual Limited, Auckland, New Zealand). The assessment was carried out during an 8 h normal work shift from 8:00-16:00 in strict conformance to Industry Code of Practice on Indoor Air Quality[7]. All the instruments have been calibrated before sampling. The collected data was analyzed using the Statistical Package for Social Sciences (SPSS) software version 25.

RESULTS AND DISCUSSION

Respondent characteristics: A total of 80 respondents were given the questionnaire, however only 90% of the respondents answered the given questionnaire form. The results of the questionnaire survey have been done descriptively. About 33% of the workers are female and another 67% are male. The age of the respondents ranged between 22-57 years old. The mean age of respondents is 43.61 years. Regarding the smoking status among workers in the production area, only 8% of the respondents are smoker and the rest are non-smoker. The mean number of hours per week respondents spent for working in the manufacturing plant was 35.67 h.

Sick Building Syndrome (SBS) occurrence: The results of percentage prevalence of sick building symptoms experienced by respondents are presented in Table 1. Based on the Table 1, hoarse and dry throat has the largest percentage prevalence (16.7%) indicating that the respondents frequently felt disturbed or affected with these symptoms. The other higher percentages of symptoms followed were drowsiness, skin rash/itchiness and headache.

The least symptom was nausea/vomiting, which were experienced by only 2.8% respondents. However, according to the International Labour Organisation (ILO)[8], sick building syndrome can be considered occurs if 20% of the respondents have the associated symptoms with their workplace and air quality.

Indoor air assessment: The results on the assessment of the selected indoor air pollutants were presented in Table 2. Based on the results, the indoor air assessment measurement illustrated low levels of indoor air pollutants in the production area of transformer manufacturing plant. Most of the selected indoor air pollutants were meet the acceptable limit set by Malaysia Department of Safety and Health, Malaysia in Industry Code of Practice[7], except temperature, air movement and total volatile organic compounds.

In order to determine the air quality of the transformer manufacturing plant, selected indoor air pollutants were measured from 8 sampling points in the production area. The air temperature was recorded with higher reading and exceeded the acceptable limit set by ICOP[7] which is between 23-26°C at all sampling points. The air temperature reading ranged between 32.48-33.17°C. It is due to the usage of the machine generating heat such oven in impregnation work station which released the heat to the surrounding, leading to increase the temperature at the study area. This situation still happens although the production area is not an enclosed area, where the outside air can go inside and vice versa. Moreover, the production area in this plant is not using the air conditioning system.

As for the relative humidity, station 3 showed the highest level which was 64.21% compared to other station, but, all stations were within the acceptable limit when comparing to ICOP[7] which is below 70%. The results of air temperature and relative humidity in this study were in agreement with the study by Arundel *et al.*[9] that stated the air temperature is inversely proportional to relative humidity. This is important in order to feel comfortable, the humidity in a space must not be too little or too much[10].

The level of air movement must be in a range of 0.15- 0.50 m sec^{-1} in order to be comfortable[7]. The level of air movement in the indoor environment of production area at the transformer manufacturing plant was in the range of 0.09-0.30 m sec^{-1}. In this study, there were three stations (S1, S3 and S7) recorded the air movement reading below the acceptable limit 0.09, 0.12 and 0.12 m sec^{-1}, respectively. However, the level of air movement can be influenced by many factors. In the studied area, several workers bring their own fan which may affect the reading and some work stations have huge pillar in between, thus preventing the air movement efficiently.

The concentration of CO and CO_2 at the transformer manufacturing plant were in the range between 1.12-1.88 ppm and 387-420 ppm each. Both results met the acceptable limit by ICOP[7] and also the regulatory limit by OSHA[11] for industry which are 10 and 50 ppm for CO, and 1000 and 5000 ppm for CO_2 over 8h working period a day, respectively. Previous study by Ahmad and Hassim[12] stated location of the building which are located near the road and in the industrial area can affect the reading of CO and CO_2 in the indoor environment. However, it was different in this study which probably due to the huge space in the production area and this manufacturing plant located at hilly area although surrounded with other industries.

Table 1: Percentage prevalence of SBS symptom experienced by workers in the production area

Sick building symptoms	Percentage
Headache	12.5
Feeling heavy-headed	10.9
Fatigue	09.7
Drowsiness	15.3
Dizziness	09.7
Nausea/vomiting	02.8
Cough	04.2
Irritated, stuffy nose	04.2
Hoarse, dry throat	16.7
Skin rash/itchiness	15.3
Irritation of the eye	09.7
Scaling/itching scalp or ears	06.9

Table 2: Descriptive summary of selected IAQ parameters in the production area

Parameters	Malaysian standard*	Mean of the IAQ parameters							
		S1	S2	S3	S4	S5	S6	S7	S8
T (°C)	23-26	33.13	33.17	32.48	32.58	32.58	32.89	32.58	32.66
RH (%)	40-70	61.71	61.68	64.21	63.74	63.57	62.76	63.91	63.32
Air movement (m sec^{-1})	0.15-0.50	0.09	0.15	0.12	0.30	0.17	0.24	0.12	0.26
CO (ppm)	10	1.88	1.61	1.40	1.22	1.12	1.17	1.20	1.44
CO_2 (ppm)	1000	405	406	417	409	407	409	420	387
PM_{10} (mg m^{-3})	0.15	0.043	0.050	0.044	0.047	0.048	0.059	0.058	0.057
TVOCs (ppm)	3	5.55	4.60	4.57	4.92	4.11	5.43	3.62	2.83

*Malaysian standard refers to the acceptable limit set by ICOP[7]

Respirable particulate or PM_{10} at all stations also were within the acceptable limit 0.043-0.059 mg m^{-3}. The highest concentration of PM_{10} was in station 6 with 0.059 mg m^{-3} which was located in the winding work station. In that work station, the particulates from machines and the work activity itself may contribute to the PM_{10} concentration. This transformer manufacturing plant keeps their working area clean and tidy. Other than that, some process that producing particulate matter such as grinding was put in isolated room and located near the door of the manufacturing plant. Furthermore, the production area is tidy and clean as the workers keeps the cleanliness in their work station accordingly.

According the ICOP[7], the acceptable limit of TVOCs concentration must be below 3 ppm, but all stations in the production area recorded higher than 3 ppm in a range between 3.62-5.55 ppm, except station 8 where the TVOCs concentration was 2.83 ppm. The TVOCs concentration is higher due to the usage of chemical solvent which is isonel varnish for impregnation. Impregnation is a process of insulating liquid which hardens after filling in order to protect the wire from any mechanical damage[13]. Takeuchi and Ozaki[14] evaluated the volatile organic compounds (VOCs) emission from transformer and found the transformers that have been insulated emitted many VOCs at the beginning then gradually decrease to the air by evaporation. This condition also assisted by fan to circulate the air inside the production area which supposedly to decrease the air temperature.

Furthermore, there are also other factors that may contribute to the higher TVOCs concentration in the production area such as penetration of VOCs into the building through the crack on window, wall or directly through the door. Since the TVOCs concentration in the production area are higher, this may expose greater health risk to the workers. Studies found that the effects of VOCs exposure are related to asthma[15,16]. Other exposure such as; acute exposure of VOCs can cause nausea, headaches, allergic skin irritation and irritation of the nose, throat and eyes[17]. Meanwhile, chronic exposures to VOCs varies depending on which VOCs the workers are exposed to. For example, chronic exposure of toluene can cause dementia[18]. In this study, all workers in the production area were exposed to the indoor air pollutants. This is due to the open space area in the production area whereby the pollutants may distributed evenly.

CONCLUSION

All the selected IAQ parameters measured in the transformer manufacturing plant were within the acceptable limit of ICOP except air temperature (>26°C), air movement (<0.15 m sec^{-1}) for certain sampling points and TVOCs concentration (>3 ppm). Hence, action should be taken by the management to overcome the problem in order to create a good and safe workplace for workers. Other than that, it is suggested to conduct personal air sampling to measure the individual exposure among the workers to the specific volatile organic compounds in the studied location.

SIGNIFICANCE STATEMENT

This study discovered that several indoor air pollutants in the transformer manufacturing plant exceeded the acceptable limit which may affect the health of the workers. This study has discovered the main indoor air pollutant that existed in the transformer manufacturing plant, which is the organic solvent used during impregnation process. Thus, further study to determine the workers exposure to organic solvents in breathing zone can be assessed.

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