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Health Risk Assessment of Volatile Organic Compounds Emitted from Wastewater Treatment Plants in Tapioca Industry

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Tapioca starch production is one of an important agro-industry in Thailand. Wastewater generating from starch processes can emit large amount of air pollutants. In order to evaluate human effects of air pollutants emit from tapioca wastewater treatment plant, health risk assessment was performed in this study. Twenty-one VOC species were found in air samples collected by the closed chamber experimental study and analyzed for their speciation using GC/MS analysis. Four dominant VOCs were partly odorous compounds. After that 9 VOCs categorized as carcinogenic and non-carcinogenic substances by the IARC were selected for the health risk analysis. The total non-carcinogenic risk was approximately 0.151, 0.005 for workers and general public, the value is lower than one which no poses a threat to human health. The carcinogenic risk of benzene for workers and general public were 2.84 x 10-7 and 1.17 x 10-10 respectively. These values were much lower than an acceptance level. It is estimated to pose no health hazard. As a result, it can be concluded that there are some odor nuisance problem caused by air pollutants released from wastewater treatment system of the tapioca starch production factory. This finding determines the necessity in improving and managing of existing wastewater treatment system in order to minimize nuisance problems.

Keywords: Health risk assessment, Wastewater treatment plants, Volatile organic compounds, Carcinogenic, Tapioca industry

I. INTRODUCTION

Tapioca starch production is recognized as one of the most important agro-industries to the Thai economy. Tapioca is the third most important agricultural crop in Thailand after rice and sugarcane. The starch production facilities expect a number of environmental problems such as the consumption of large volumes of water and energy, and the generation of high organic-loaded wastewater and solid waste (Chavalparit & Ongwandee, 2009). Wastewater treatment plants (WWTPs) are considered important sources of gaseous

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emissions, including greenhouse gases (GHGs) and odorants. The malodorous emissions associated with treatment processes are measured one of the major concerns of exposed population living in surrounding areas of WWTPs (Shaw & Koh, 2013; Alfonsin *et al.*, 2015). Most of air emissions are volatile organic compounds (VOCs) also form during the phases of degradation (Ramos *et al.*, 2002). Some of compounds have odor cause nuisance problem. Unpleasant odors from wastewater treatment plants may cause acute social and economic conflicts due to poor quality of life and economic depreciation of the neighboring real estate (Stellacci *et al.*, 2010). Gas chromatography (GC) is the technique most commonly applied to separate and identify volatile and gaseous samples (Stuetz & Nicola, 2001). Modeling air pollution is an important tool to devise strategies to manage pollution. AERMOD, the regularly recommended model by the U.S. EPA, has been used to predict concentration of various air pollutants including chemical compounds, based on measurements (Olafsdottir *et al.*, 2014). Consequently, it was found that many volatile compounds presented in wastewater can volatilize to the ambient air and cause physical and mental harm to nearby people. Long-term exposure to these compounds will affect the central nervous system of human beings and cause a series of adverse reactions in the human body (Niu *et al.*, 2014). In this study, the air samples from experimental study were collected and analyzed to measure concentration. These data were calculated for their emission rates and were used as input data for air dispersion model. The predicted ambient concentrations were estimated. According to the analysis results and combined with the exposure and toxicity of their parameters, the health risk assessment of compounds through the inhalation route was applied to evaluate the potential health effect of odor on the people from tapioca wastewater treatment plant.

II. MATERIALS AND METHODS

A. Sampling Area

The study was conducted at one of the largest tapioca factories located in Chanthaburi Province, in the eastern region of Thailand (Figure 1). The total capacity of the starch plant is 400 tons per day. Approximately 3,000 m^3 per day of wastewater with high organic content produced from starch production are treated by wastewater treatment plant in this factory.

Figure 1. Location of study site

B. Sampling and Analytical Method

On-site chamber experiment was conducted in this study as shown in Figure 2. Duplicate air samplings were conducted for each sampling batch. All of air samples were analyzed with gas chromatography/mass spectrometer (Agilent Technologies Model 7890B GC). Air samples were simultaneously collected for 3 hours using 6-liter evacuated canisters (0.05 mmHg) and analyzed in accordance with U.S. EPA TO-15 method for the determination of toxic organic compounds. When the canisters were opened to the atmosphere, the VOCs sample was introduced into the canisters by the differential pressure between atmospheric pressure and vacuum pressure inside each canister. With a flow controller, the sub-atmospheric sampling system maintained a constant flow rate from full vacuum to within about 7 kPa (1.0 psi) or less below ambient pressure. The sample canisters were then pressurized by humidified nitrogen to about 20 psi in order to prevent the contamination entering the sample canister (Thepanondh *et al.*, 2011).

Figure 2. On-site chamber experimental study

C. Prediction of Ambient Concentrations

In order to estimate the concentration of chemical compounds, numerical simulations were performed to obtain the most reliable model via a Gaussian-based dispersion model, AERMOD (U.S.EPA 2004). The U.S. EPA approved AERMOD model (version 9.1) was used for concentrations estimation in this study. AERMOD model was run for predicting average concentrations of chemical compounds emitted from the WWTP for use to calculate health risk.

D. AEROMOD Model Configuration

The meteorological parameters data input was prepared over one year (1^{st} January 2015 to 31^{th} December 2015). Data used in this study were generated by Mesoscale Meteorological Model (MM5). Data were then pre-processed using AERMET processor. The gridded data needed by AERMAP was selected from Digital Elevation Model (DEM) data and collected during the Shuttle Radar Topography Mission (SRTM3). In this study, the model was simulated over the area of 6 × 6 km^2 centered at the wastewater treatment plant to predict ambient concentrations. The Cartesian receptor grid has a uniform spacing of 50 m.

E. Health Risk Assessment

For evaluated effect of airborne VOCs released from the WWTPs, inhalation was considered as the main exposure route. A standard health risk assessment method recommended by the U.S. EPA was applied in this study. Various factors were considered in this evaluation such as exposure concentration (EC), the daily exposure time (ET), the frequency (EF) and duration (ED) of exposure (U.S.EPA 2009). The EC equation is presented as follows:

$$EC = (CA \times ET \times EF \times ED)/AT \qquad (1)$$

where CA is the contaminant concentration (micrograms per cubic meter (μg/m^3)); ET is the daily exposure time (hours per day (h/d)); EF is the exposure frequency (days per year (d/y)); ED is the exposure duration (years (y)) and AT is the averaging time (ED×365 d/y×24 h/d, hours).

The risk characterization for the non-carcinogenic compounds is expressed as the Hazard Quotient (HQ):

$$HQ = EC/RfC \qquad (2)$$

where RfC (short for reference concentration) is an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups), which is likely to be without an appreciable risk of deleterious effects during a lifetime (U.S.EPA, 2013a). For non-carcinogenic compounds, it is common to consider the risk to be negligible if the HQ is less than or equal to 1.0, while the HQ higher than 1.0 signifies an appreciable risk of health effects.

The risk characterization for the carcinogenic compounds is expressed as:

$$Risk = EC \times IUR \qquad (3)$$

where IUR is the inhalation unit risk (cubic meters per microgram), which is the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 μg/L in water or 1 μg/m^3 in air (U.S.EPA, 2013b). For risk predicted to be ≤ 1.0×10^{-6} is usually considered negligible, whereas risk predicted to be ≥ 1.0×10^{-3} was defined as a significant risk.

III. RESULTS AND DISCUSSIONS

A. VOC Concentration

Twenty-one compounds of VOCs were found from the wastewater treatment plant air samples (Table 1).

As seen in Table 1, four dominant compounds emitted from WWTP air samples are acetaldehyde, acetone, isopropyl alcohol and 2-butanone. Especially, acetaldehyde and 2-butanone had low their odor threshold. These compounds are odorous compounds which may cause mainly nuisance problem not harm to human health. Vietnam, Indonesia as the world tapioca starch suffered with that serious air pollution problem similar in Thailand. Anaerobic pond released the air pollution and the obnoxious smell. The nuisance problem also particularly originates from chemical

Table 1. Types and concentrations of 21 measured VOCs ($\mu g/m^3$) in air samples of the WWTP

Compounds	Concentration Mean+S.D. ($\mu g/m^3$)	Compounds	Concentration Mean+S.D. ($\mu g/m^3$)
1. Acetaldehyde	257.50±233.26	12. Isobutane	0.100±0.06
2. Acetone	288.78±144.65	13. Isoprene	0.076±0.03
3. Acrylonitrile	0.070±0.03	14. Isopropyl alcohol	10.75±5.99
4. Benzene	0.012±0.05	15. Methacrolein	0.316±0.32
5. Carbon disulfide	0.133±0.05	16. Pentane	0.101±0.07
6. Carbon tetrachloride	0.018±0.00	17. Propene	0.215±0.19
7. Chloroform	0.081±0.06	18. Toluene	0.125±0.06
8. Chloromethane	0.106±0.02	19. 1,2-Dichloroethane	0.676±0.65
9. Cyclohexane	0.018±0.00	20. 2-Butanone	22.22±13.27
10. Dichloromethane	0.301±0.17	21. 3-Pentanone	0.488±0.67
11. Hexane	0.018±0.00		

compounds during wastewater treatment process (Huynh, 2006; Setyawaty *et al.*, 2011). Thus, environmental management through wastewater management should be given emphasis.

Only VOC compounds which potentially affect to human health were considered for further analysis in this study. These target compounds were categorized following The International Agency for Research on Cancer (IARC) consistent with their carcinogenic properties. There were nine compounds classified according to their carcinogenicity. From categorization, the risk characterization for the carcinogenic compounds was focused on benzene which may cause carcinogen in humans.

B. Predicted Concentrations

AERMOD was simulated over the center of the wastewater treatment plant area. The predicted average concentration of compounds at the receptor site was designated to calculate in health risk evaluation.

C. Health Risk Assessment

Potential health risk to workers and general public were evaluated separately. The major reasons for the separated analysis were due to the differences in daily exposure time and exposure duration of population in the determination of exposure concentrations (EC). Values of the other parameters were selected according to the values of general staff recommended by the U.S. EPA.

1. Non-Carcinogenic Health Risk Assessment

The hazard quotient of compounds was calculated as shown in Table 2. The total non-carcinogenic risk was approximately 0.151, 0.005 for workers and general public. The estimated hazard quotients of chemical compounds were lower than the upper confidence limit (1.0), which could no pose a threat to human health. The non-carcinogenic risk of benzene for workers and general public were 1.44 x 10^{-5}, 5.04 x 10^{-7} respectively.

Table 2. Non-carcinogenic risk (HQ) of 9 VOC compounds in workers and general public

Compounds	Workers	General public
Acetaldehyde	0.15122	0.00529
Acrylonitrile	0.00010	3.62x10^{-6}
Benzene	1.44x10^{-5}	5.04x10^{-7}
Carbon tetrachloride	5.02x10^{-7}	1.76x10^{-8}
Chloroform	3.43x10^{-6}	1.20x10^{-7}
Chloromethane	3.87x10^{-6}	1.36x10^{-7}
Dichloromethane	1.82x10^{-6}	6.39x10^{-8}
Isopropyl alcohol	0.00017	6.29x10^{-6}
Toluene	9.31x10^{-8}	3.26x10^{-9}
Sum	**0.15152**	**0.00531**

2. *Carcinogenic Health Risk Assessment*

According to the IARC's weight-of-evidence classification system for carcinogenicity, benzene is classified as Group 1 (Carcinogenic to humans). Consequently, benzene was considered only in this study when calculating carcinogenicity risk. The carcinogenic risk of benzene for workers and general public were 2.84 x 10^{-7} and 1.17 x 10^{-10}, which were within the acceptable level (1 x 10^{-6}). Therefore, the carcinogenic risk for benzene is negligible, and it's estimated to pose no health hazard to workers and general public around the wastewater treatment plant area.

IV. SUMMARY

This study aimed to estimate the potential health risk of major compounds emitted from the tapioca WWTPs on the workers and general public and conclusions were drawn from this research. Firstly, the air sampling analysis indicates that major VOC emissions were contributed by acetaldehyde, acetone, isopropyl alcohol and 2-butanone. These compounds were considered as odorous compounds which will cause only odor nuisance problem. Second, by considering IARC carcinogenicity, the adverse health risk of nine compounds had been evaluated in this study. The calculated total non-carcinogenic risk was approximately 0.151, 0.005 for workers and general public. The carcinogenic risk of benzene for workers and general public were 2.84 x 10^{-7} and 1.17 x 10^{-10}, the carcinogenic risk for benzene is negligible. It's estimated to pose no health hazard to workers and general public. Consequently, air pollutants emitted from the WWTP of tapioca factory are generally from VOCs that causes odor nuisance problem

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