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Review article

Health effect from Volatile Organic Compounds and Useful Tools for Future Prevention: A Review

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Abstract

Health effects to industrial workers are more severe whilst high exposure and time exposed to contaminants at workplace. Objective of this paper are to investigate health effect to contaminant and using a tools in prediction to control exposure levels. Literature review on health effect on workers how exposure to contaminant and a tool in prediction best control using Computerized Fluid Dynamic (CFD) in prevention method. Action taken in control from the hierarchy is eliminate, substitute, isolate, engineering control, administration control the hazard and lastly provide PPE. But in prediction the hazard is the best recommendation before the work was carrying out or fabrication the system.

Keywords: Computerized Fluid Dynamic (CFD), Green Technology, Local Exhaust Ventilation (LEV), Occupational Safety and Health (OSH), Volatile Organic Compounds (VOCs)

Introduction

Occupational Safety and Health Act (Act 514) enforced by the Department of Occupational Safety and Health Malaysia since 1994. In the act, it required the employers to ensure workers' safety, health and welfare. Furthermore, it avoids workers from exposing themselves to any risk of accident. In current work, a mechanism to

control hazardous to workers health is proposed to design and implementations a good ventilation system. Industrial ventilation is a system of controlling airborne toxic chemicals or flammable vapors by exhausting contaminated air away from the work area and replacing it with clean air. It is one alternative to control employee exposure to air contaminants in the workplace. Other alternatives include process changes, work practice changes, substitution with less toxic chemicals, or elimination of the use of toxic chemicals. Industrial ventilation is typically used to remove welding fumes, solvent vapors, oil mists or dusts from a work location and exhaust these contaminants outdoors.

The objective of a local exhaust ventilation system is to remove the contaminant as it is generated at a source. Controlling the air in which they are contained controls gases and vapors and exist. Special procedures are required to control large particles that are generated at the source. These particles are controlled for other than health purposes. Industrial which involved and used with ventilation systems are required to comply with Malaysian Legislation such as Occupational Safety and Health Act 1994, Use of Standard Exposure Chemical Hazardous to Health Regulation and Factory and Machinery Act 1967 and Regulations under this Act. Objective of this paper are to investigate health effect to contaminant and using a tools in prediction to control exposure levels.

Health effect from Volatile Organic Compounds (VOCs)

Common exposures of VOCs involved workers at industries for example spray painting industry. Currently it is become an issues to the workers are involve in this activities. Although painting also used in others activity such as wood based, metals and others. This activity will be effects to the workers health when long term exposed. Organic pollutants are one of the main causes of indoor air pollution problems. Indoor levels of about a dozen common organic pollutants were found to be two to five times higher than outdoor levels [1]. VOCs form a subgroup of organic pollutants. VOCs are carbon-based organic chemicals that are present as vapors at room temperature. Hundreds of VOCs present indoors comprise a wide variety of hydrocarbons and hydrocarbon derivatives, including aliphatics, aromatics, alkylbenzenes, ketones, and chlorinated and polycyclic hydrocarbons. Based on sampling methods, VOCs are defined as organic compounds that have a lower boiling point limit between 50^{o}C and 100^{o}C and upper boiling limit between 240^{o}C and 260^{o}C. Organic compounds with boiling points above 400^{o}C are solids and compounds with the boiling points in the intermediate range are semi-VOCs. The semi-VOCs are presented indoor both in particles and in the gaseous phase. Spray paint activity emissions VOCs. Even though, there are a lot of study in VOC emissions, effects, and purposed to control to the workers. The impacts of VOCs are discussed below:

VOCs Exposure

Sources of contaminants are emission from the process from many sources. The investigation by Chun [2] found that workers are to high volatile exposure. Workers from constructions industry especially interior workers and office workers are exposed to very high VOCs concentration in their work environment. Furthermore in constructions industry, exposed to contaminants not only harmful to interior workers but also to others will involve methods of painting activity and related with exposure. Qian [3] conducted investigation on the relationship between air concentrations of VOCs during bridge painting and potential influencing factors. Method application are spraying, rolling, and brushing, paint coating type (primer, intermediate, and finish coatings), and meteorological conditions (temperature, humidity, and wind speed) through multivariate regression models. As a result Qian concluded that regression models then could be used to predict solvent exposure during bridge painting.

Ongwandee [4] also conducted investigation of VOCs. Chemical involved named hexane, benzene, toluene, ethylbenzene, m,p-xylene, o-xylene, styrene, tetrachloro-ethylene (PCE), trichloroethylene (TCE), 1,2-dichloroethane (EDC), 1,2-dichloropropane (DCP), chloroform, and limonene. Objectives of study are to quantify levels and source strengths, and determining indoor/outdoor relationships. And the results demonstrated that many air-conditioned office buildings in Bangkok have very low ventilation rates, which could be due to energy conservation measures enacted in Thailand. To quantify exposures to hexane, acetone, and toluene during typical vehicle repair tasks worker exposure to VOCs in the vehicle repair industry study by Wilson [5]. There is a characteristic pattern of aerosol solvent use that is largely independent of the task type, shop, or individual. As a consequence, there is a correlation between the task-based solvent emission rate (g/min) and the breathing zone VOCs exposure concentration (mg/m^3)(R^2 = 0.45).

Other chemical emission from spray both is benzene. Health affects exposed are drowsiness, dizziness, headache, nausea, and loss of coordination, confusion and unconsciousness. Liu [6] conducted a review online and manual searching, as well as expert discussions aimed at providing insight into factors affecting benzene exposure levels in paint/coatings industries from 1956 to 2005 and found mean benzene exposure was significantly lower for paint manufacturing than paint spraying. No significant difference was found among paint types and benzene exposure for paint application. Benzene exposure was significantly higher in workplaces judged to have poor ventilation. No significant differences were found in benzene exposure as a function of industry type and recent benzene exposure measurements suggested.

VOCs effect to the workers

Workers mostly involve in spray paint as example are exposed to inhale the chemical at workplace. Studies conducted that workers who involve in this activity and exposed to chemical directly effect to occupational health. Enander [7] conducted a survey of pollution prevention, environmental control, and occupational health and safety practices found that nearly all of the shops reported that they use spray-painting booths, only 38 % own booths of the more effective downdraft design. Spray paint activity workers are affected while working. In the Rhode Island automotive refinishing industry sector and found that nearly one-half of the shops employ three or fewer people, and in many cases, spray painters double as body repair technicians thereby increasing their potential exposure to workplace contaminants. Meanwhile other study in Australia conducted and found that solvent exposure are relate with Spray Painters in Automotive Body Repair Workshop by Winder & Turner [8]. They interviewed to 50 apprentices and 14 experienced spray painter at breathing-zone samples. They found that solvent exposure was highest when spraying acrylic paint in the open workshop and lowest when spraying two pack paint in a spray booth.

Inhalation study and dermal exposure to hexamethylene diisocyanate (HDI) and its oligomers as well as personal protection equipment (PPE) use during task performance in conjunction with urinary hexamethylene diamine (HDA) in car body repair shop workers and industrial spray painters conducted by Pronk et al [9]. The result shows inhalation exposure was strongly associated with tasks during which aerosolisation occurs. Dermal exposure occurred during tasks that involve direct handling of paint. In conclusion, workers who involve in spray paint activity are closely exposed to chemical hazards emission. Workers are exposed to chemical can cause harm. There are the available evidence indicates that VOCs can cause adverse health effects to the building occupants and may contribute to symptoms of Sick Building Syndrome investigated by Yu & Crump [10]. The results are Polymeric materials important sources of VOC emissions in buildings and secondary products from the reactions of some monomers, solvents or plasticizers and some are the plasticizers used in the production of the material.

The effects on asthmatics of exposure to a conventional water-based and a VOCs-free paint study by Beach [11]. Respiratory symptoms, lung function, and air- way responsiveness were measured. A significant in reported "wheeze" and "breathlessness" was detected during use of conventional paint. In contrast, lung function measurements showed a small but significant increase during the use of both paints. There was no significant change in airway responsiveness after use of either paint. Not reflected in measurements of lung function or airway responsiveness. Some exposure required to analyses the effect of VOCs. Analyzing the effect of elevated temperatures on the emission of formaldehyde and VOCs from laminate flooring is investigated by Wiglusz [12] and a result found that at 23^{o}C and 29^{o}C the measurements did not show any emissions of formaldehyde and very low emissions of VOCs. Wiglusz claims that some laminate flooring may affect the chemical contamination of indoor air with the use of floor heating. Others part such as tropical country possible shown different findings in another study. Analyses the findings of VOCs levels found in two tropical offices by Zuraimi [13]. They found majority of the VOCs rose in concentrations after the ventilation system has shut down with exceptions for benzene, benzaldehyde and tridecane that are attributable to outdoor and occupant related activities.

VOCs control

In order to control to exposure of VOCs, a practical method will discuss in control the VOCs. Benzene emission from spray paint activity is difficult to remove from a site 100 %. A study by Jafari [14] in Iran was conducted investigation on successful design and implementations of several exhaust ventilation systems in a paint-manufacturing factory. They are used references based on ACGIH, ASHREA, USEPA and USNFPA to design and analyzing using OSHA method 12, therefore the results are reducing of benzene, toluene and xylene and also difficulty to remove 100 % benzene. The method to control emission is especially to reduce VOCs while detected. Pollutant concentration of emission are high and Darvin [15] used a method multiple sampling systems to investigate dispel safety concerns regarding the use of recirculation. The results show that pollutant concentration within each booth not significantly increased, the cost be reduced, and reductions of exhaust flow rates of up to 90 %. To minimize contaminant exposed to workers, proper design of spray paint system, operation include the local exhaust ventilation and cost consideration should took in place before execute the project.

Others chemical hazardous to health are also take part in a few study. Kim [16] investigated ventilation characteristics of toluene have been analyzed in a room of a small-scale process with various exit location and with different suction velocities at exit and found that the concentration of toluene depends on the specified exit velocities and the position of the exit and recommended good exhaust efficiency of contaminant materials could be acquired.Exposure to workers can control by using filters. Filter media play important roles in early prevention. Sidheswaran [17] used Activated Carbon Filter (ACF) to investigate potential environment and energy benefits as air cleaning in Heating Ventilation Air Con (HVAC) and ACF not perform well which removal 25-30 % with heated for Formaldehyde and concluded not necessarily include a heating phase on every cycle for optimal usage of ACF. Meanwhile study activated carbon fiber materials by Navarri [18] to evaluating their performances in terms of VOC adsorption capacity, and looking at the influence of specific area, number of layers, and gas type, velocity and concentration on this parameter. The results shows as 40 %, confirming carbon fiber materials are suitable for VOC removal applications. To support above statement in using activated carbon, Shareefdeen [19] claims that in the adsorption process, pollutants are adsorbed onto adsorbents (i.e., activated carbon). This process is effective when the concentration in the airstreams is low. Regeneration of the adsorbents is done using steam or hot air.

Computerized Fluid Dynamic (CFD) on prevention method

For control the VOCs exposure to the workers, LEV systems are design and fabricate to remove contaminants. CFD is the solution on preventive method in designing LEV system and before the LEV systems are fabricate. In the spray paint is using compressed air, the activity is carrying out in spray paint booth to avoid any spray mist emission scattered. Flynn [20] presents a mathematical model to predict breathing-zone concentrations of airborne contaminants generated during compressed air spray painting in cross flow-ventilated booths in his study and the result indicate that a dimensionless breathing zone concentration is a nonlinear function of the ratio of momentum flux of air from the spray gun to the momentum flux of air passing through the projected area of the workers body.

Flynn & Sills [21] conducted study to simulate breathing-zone concentration for a simple representation of spray-painting a flat plate. The results demonstrate the capability of CFD to track correctly changes in breathing-zone concentration associated with work practices shown previously to be significant in determining exposure. CFD is the way to determine the efficiency of ventilation systems. Kassomenos [22] use CFD model PHOENICS to investigate VCM concentration at workplaces. The results showed that the use of a CFD is a promising technique to study the occupational exposure in the known carcinogen VCM and to design the proper ventilation system to reduce the consequences of an accidental release of VCM in a workplace. Measurement also made and found that the computational results are realistic and in good agreement with the experimental measurements.

More efficient in remove contaminant from workplace is using push pull method. A study in Occupational Exposure to VOCs and Mitigation by Push-Pull Local Exhaust Ventilation in Printing Plants conducted by Leung [23]. Evaluate the Occupational VOC exposure, quantitatively, by detailed field measurement and parametric analysis on a proposed mitigation measure; push pull local exhaust ventilation (LEV) was conducted. None was found close to individual 8-h time weighted average (TWA) and push-pull effective identified by CFD. In determining of LEV System Performance, Vittorio [24] investigate performance of a flange freestanding slot opening with 6:1 aspect ratio using commercial CFD code FLUENT 5.5 and GAMBIT for modeling. Result of the study shows simulation almost similar with experiments for validation.

Kyoungbin L & Changhee L [25] using FLUENT V.6 in order to investigate flow characteristic of kitchen hood system with using 3D numerical analysis method and improving the system to expel pollutes more efficiently. The work are divided to 4 different types of separation plates (Case 1, Case 2, Case 3 and Case 4) were modeled using Gambit Ver. 2.1.X and Case 3 showed the lowest value of the temperature and CO2 concentration distribution. CFD simulation is using as study of the effectiveness of mechanical ventilation systems of a hawker center in Singapore using conducted by Wong [26]. The objective is to investigate the effectiveness of the different types of mechanical ventilation systems to alleviate the thermal discomfort in a hawker center using Phoenics v3.5. The result found that installation of fans should help hot air flow out of building and most effective fan is exhaust fan because it can improve stack ventilation in the building.

In wood processing industry, workers are commonly exposed to mechanical hazard. Inthavong [27] conducted study of effect of ventilation design on remove of particles in woodturning workstations. Using five different ventilation designs were considered with the aim of reducing the particle suspension within the breathing zone. The result stated that ventilation R3, where the local outlet emanated from the roof and had an angled outlet, provided greatest total particle clearance and low particles in the breathing plane. Model in CFD is used by Anastasios [28] in evaluation of thermal comfort in Galatsi Arena of the “Athens 2004”. Air temperatures, air velocities and mean radiant temperatures were determined from the CFD calculations, while the air humidity was taken equal to 50%. CFD

calculations in the Galatsi Arena demonstrated that the variable air volume conditioning system serving the Galatsi Arena is capable to ensure satisfactory thermal conditions for the spectators.

Aircraft cabin as a confined area and required good ventilation systems. An experimental and CFD study of unsteady airborne pollutant transport within an aircraft cabin mock was conducted to study the global transport process of contaminated air within the cabin using tracer gas experiments. Experimental and simulated results were compared and discussed to develop a relationship between concentration and airflow pattern, source location, transport direction, and ventilation rate found by Wei Y [29] a concluded that longitudinal airflow was observed in the experiment. This may be due to the complex geometry, furniture, and passengers. This longitudinal airflow contributes to the pollutant transport in a longitudinal direction. Transient simulations with computational fluid dynamics (CFD), based on the finite element method (FEM) were performed to investigate the efficiency of the existing heating, ventilation and air-conditioning (HVAC) plant with a variable air volume (VAV) primary air system conducted by Carla Balocco [30]. Current study highlights the fact that the CFD-FEM application is useful for understanding the efficiency, adequacy and reliability of the ventilation system, but also provides important suggestions for controlling air quality, patients' comfort and energy consumption in a hospital.

Conclusion

Workers in constructions industry including office staff are highly exposed to high VOCs concentrations as reported by Chun and supported by Qian. Furthermore Qian in their study to investigate the exposures involve method of painting activity. As a suggestion to protect and prevent workers method proposed are to install LEV system and used the regression models for prediction exposure respectively. Others study in VOCs exposure conducted in Bangkok and Thailand. Building industry either constructions or current building there are an issues in exposure to hazardous such as VOCs and harmful to workers health.

Surveys conducted by Enander and Winder & Turner in workers effect and recommended method of communication should apply. Chemical exposed affected to occupational health, studied by Chuck & Crump showed that, the symptom of Sick Building Syndromes as an indicator. Others sources of VOCs are from laminated floor found by Wiglusz. In tropical country, the case by Zuraimi recommended utilizing the ventilation-resolved mass balanced model method to evaluate contributions of sources from outdoors, building materials, occupants, their activities and ventilation systems have yielded relatively good and accurate results. Further survey required for tropical country due to temperature and humidity related and affected to the systems. Medical screening and workers health baseline should provide at early stage before start a new job. Exposures to latest concentration are proposed to measure and compare with previous study done by Jafari. The LEV systems are suggested designing over by 20 % to ensure the contaminants removed by 100 percent. The contaminant exposure from the material and hazardous to workers health can protect by implementing filter. Sidheswaran used activated carbon filter (ACF) in their study to get clean air. Navarri and Zarook also using the activated carbon material in their investigation to remove contaminant.

Flynn and Kassomenos also recommended CFD model are very useful tools for evaluation and analysis of existing ventilation equipment. CFD is a tool for Occupational hygienists in expose control. Flynn, Kassomenos, Leung, Vittorio, Kyoungbin, Wong, Inthavong, Anastasios, Wei and Carla used a CFD solution to solve, compare with experimental work in LEV systems. Even though, the CFD software make useful for preventive and prediction of LEV system on VOCs exposure, the estimated of boundary in a system should take full considerations for better design. Workers and building occupier are most exposed to high contaminant produced from the process and materials. The effects to the worker detect after long time exposed without any protection or prevention taken and it

known as an Occupational Health and Symptoms Sick Building Syndrome. CFD is one of potential tools in prediction of engineering control to remove contaminants.

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