Environmental Pollution 233 (2018) 501–509

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Direct and potential risk assessment of exposure to volatile organic compounds for primary receptor associated with solvent consumption

Di Wang [a], Han Yu [a], Xia Shao [b], Hongbing Yu [a, *], Lei Nie [b, **]

[a] College of Environmental Science and Engineering, Nankai University, Tianjin 300350, China
[b] National Engineering Research Center of Urban Environmental Pollution Control, Beijing Municipal Research Institute of Environment Protection, Beijing 100037, China

ARTICLE INFO

Article history:
Received 4 June 2017
Received in revised form
12 September 2017
Accepted 4 October 2017

Keywords:
Risk assessment
Primary receptor
Personal protective equipment
Potential health risk
Water-based paints
Solvent-based paints

ABSTRACT

Rapid development of industrial production has stimulated the growth of consumption of raw and auxiliary materials including organic paints, among which volatile organic compounds (VOCs) are proved harmful to the population who inhale the polluted air based on epidemiologic studies. Therefore, new types of environment-friendly paints were developed to replace solvent-based paints (SBPs). Nevertheless, new types of paints containing VOCs failed to replace SBPs entirely due to certain disadvantages. Hence, five kinds of paints were employed in simulation experiments to assess the health risk of primary receptor including three kinds of water-based paints (WBPs) and two kinds of SBPs. Conclusions showed that mean TVOC concentration in breathing zone of primary receptor ranged from 9.5 to 13.6 mg/m^3 and 3.4×10^3 to 1.4×10^4 mg/m^3 for WBPs and SBPs, respectively. Assessments of non-cancer risk concluded that nearly one third quantified compounds exceeded corresponding thresholds for WBPs, and the maximum risk value was 101.33; for SBPs, the maximum risk value reached 50760.20, and twenty-two compounds exceeded the reference limits. The calculation of cancer risk values showed that seventeen compounds were higher than acceptable limit amongst which 1,2-dibromoethane had maximum values of 1.27×10^{-2} to 3.24×10^{-2} for WBPs; for SBPs, all quantified compounds exceeded the acceptable limit, and 82.61% VOCs were distributed in a scope larger than 1×10^{-3}. Additionally, a removal efficiency of 60% was considered for primary receptor with personal protective equipment, and subsequent results confirmed its inability of lowering the risk resulted from hazardous VOCs. The calculated potential health risk could be applied to estimate the total health risk for both primary and secondary receptor based on consumed materials. The finding suggested that WBPs could improve VOCs exposure condition and reduce the direct and potential health risk significantly for primary receptor, although they might dissatisfy acceptable limit.

1. Introduction

The advancement in industrial products leads to more raw and auxiliary material consumption, and paints serving protective purposes are crucial. According to a market research, the paint market will reach 143.9 billion dollars in 2019 (SpecialChem, 2015). Although water-based paints (WBPs) are riding the trend and occupy 40% of the total paint market in 2012, recent researches have revealed that newly developed paints still contained volatile organic compounds (VOCs) provided a considerable reduction compared with solvent-based paints (SBPs), namely traditional paints (Chang et al., 1999; Kim et al., 2012; Yu and Crump, 2000). VOCs derived from paints consumption normally consist of aromatics, ketones, esters, alkanes and alkenes, among which toluene, benzene and other aromatics contributed approximately 67% of the total VOCs emission and were recognized as carcinogenic or neurotoxic and reproductive toxicity (Zbigniew et al., 2002; H. L. Chen et al., 2012; Yuan et al., 2010; Rumchev et al., 2007; Venn et al., 2003; Gerasimov et al., 2003). Through combining with epidemiologic studies of individual compound, researchers have

Abbreviations: WBPs, water-based paints; SBPs, solvent-based paints; HQ, hazard quotient; RfC, reference concentration; UR, unit risk; PHR, potential health risk; CV, coefficient of variation; PPE, personal protective equipment; APR, air-purifying respirator; ASP, atmosphere-supplying respirator; REL, ratio of exceeding limit.

* Corresponding author. College of Environmental Science and Engineering, Nankai University, No. 38, Tongyan Road, Jinnan District, Tianjin, China.
** Corresponding author.
E-mail address: hongbingyu1130@sina.com (H. Yu).

https://doi.org/10.1016/j.envpol.2017.10.009
0269-7491/

focused on the adverse health effects caused by various emission sources (Colman Lerner et al., 2014; Ramirez et al., 2012; Parra et al., 2008; Delgado-Saborit et al., 2009, 2011; Park and Jo, 2004). The group affected by hazardous VOCs is considered as the VOCs receptor because of its direct or indirect contact with solvents. Therefore, three categories of receptors are defined according to the sequential occurrence of exposure: 1) initial receptor, commonly as producer of paints; 2) primary receptor, namely occupational painters; 3) secondary receptor, involving all affected public (non-occupational). Statistically, corresponding population of three receptors increases successively from the initial receptor to the secondary receptor by an unknown ratio, while the VOCs exposure levels decline gradually since the accessible quantity of solvents decrease at stages.

Due to the tremendous influence, the secondary receptor has been emphasized with extensive studies. Recent renovation involving painting procedure had been proved to be crucial factor of influencing household microenvironment which resulted in elevated indoor VOCs. Consequent cancer risk assessment showed that main VOCs exceeded acceptable risk level proposed by U.S. Environment Protection Agency (U.S. EPA), and the condition would maintain for 1–5 years (Dai et al., 2017; Lee et al., 2002; Wheeler et al., 2013; Park and Ikeda, 2006; Liu et al., 2013; Jarnstrom et al., 2008). Walser et al. (2014) recently demonstrated that exposure in production, retail and use in households accounted for significant contribution (44%) of the total life cycle.

Compared with secondary receptor, the VOCs exposure posed a higher threat to primary receptor due to a closer proximity with various solvents. Vincent et al. (1994) measured methylene chloride and phenol in aeronautical workshop, and concluded that exposure concentration of the former elevated from 86 mg/m^3 to 1239.5 mg/m^3 during paint stripping operations in working atmospheres which was extremely higher than it to the secondary receptor (Sarigiannis et al., 2011; Khanchi et al., 2015). Moro et al. (2012) showed that industrial painters were suffering hepatic damage and genotoxicity caused by toluene exposure. Tse et al. (2011) confirmed a significantly increased lung cancer risk to both spray and non-spray painting workers (nonsmoking), and moreover a positive gradient of all lung cancers and adenocarcinoma was simultaneously observed with the duration of employment for painters. Furthermore, the adverse effect of high VOCs level exposure may have surpassed primary receptor itself. Metayer et al. (2016) assessed the correlation between the parental occupational exposure to organic solvents and childhood leukemia based on job modules, and the conclusion showed that childhood acute lymphoblastic leukemia could be associated with parental exposure to any organic solvents for Latino fathers. Additionally, prenatal VOCs exposure had been confirmed to be associated with incremental risk of respiratory diseases in early childhood as well (Franck et al., 2014). Therefore, International Agency for Research on Cancer (IARC) has identified occupational exposure to paints as carcinogenic (WHO, 2012), meanwhile toluene was normally taken as emission marker of painting industry.

However, as well as the relevant health risk assessment, the actual inhalation VOCs levels of primary receptor are rarely monitored. Malherbe and Mandin (2007) evaluated the quantity of emitted VOCs in building and repair shipyards, and assessed the exposure and resulting health risk for surrounding populations. Colman Lerner et al. (2012) analyzed several occupational environments and indicated that the highest levels of VOCs, lifetime cancer risk (LCR) and hazard quotient (HQ) were all found in car painting centers. However, the impact of occupational exposure was supposed to be even larger, as this study regarded the indoor VOCs concentration as exposure concentrations for convenience omitting the source proximity effect which caused the concentration of pollutants in receptor's breathing zone to accumulate to nine times greater than the indoor airflow (Rim and Novoselac, 2010). More studies are in need to assess the health risk of primary receptor based on actual exposure concentrations with taking different types of emission sources into consideration. Additionally, occupational printers and other relating workers who face organic solvents under normal operating condition need to be categorized to the primary receptor undoubtedly.

The aim of this study is to quantify the actual and potential impacts to primary receptor caused by paints consumption with a particular focus on the different types of indoor emission sources covering WBPs and SBPs. Moreover, correlations between the sources and receptor will be analyzed to compose a comprehensive method to estimate the potential health impact for primary receptor concisely.

2. Methods

2.1. Exposure profile

In previous research, we have concluded that average breathing zone concentration (BZC) of primary receptor is merely dependent on types of consumed paints with no correlation with activity pattern of receptor, meanwhile indoor VOCs concentration is failing in representing BZC (Wang et al., 2017). Therefore, in this study, two occupational painters were recruited as representatives of primary receptor, and the sampling points were mainly set in breathing zone for monitoring concentration and component of exposure accurately.

For studying actual exposure level, two recruited painters were required to simulate process of spraying paints according to normal operating condition. A complete experiment cycle included: injected paints into tank which was connected with high-pressure airless spray machine (TP-496, Tugpt) and spray gun (Silver, Graco); performed activity of spraying paints near the substrate (channel iron, length of 2 m, thickness of 5 mm); finished spraying the substrate and turned on exhaust system for 2 h to discharge the polluted indoor air. The spray gun used herein operated with a maximum pressure of 34.5 MPa, and the high-pressure airless spray machine could provide a maximum pressure of 23 MPa. During spraying paints, the painters carried a bag equipped with two-stage sorbent tubes and low flow rate pump (Model QC-2B, Beijing Municipal Institute of Labour Protection Air sampler) with a pre-set flow rate of 300 ml/min, and the first stage of which was stainless steel tube filled with Carboxen 100 (50 mg, 45/60 mesh, Markes), Carbopack B (100 mg, 40/60 mesh, Markes) and Carbopack C (50 mg, 40/60 mesh, Markes) with a length of 13 mm, 25 mm and 13 mm, respectively; the second stage was fully filled with Tenax TA (200 mg, 60/80 mesh, Camsco); both of the sorbent tubes were designed to operate with inner diameter of 6 mm. Two-stage sorbent tubes could ensure complete adsorption of VOCs, and guard against the problem of penetration initiated by single-stage tube simultaneously. The inlet of sorbent tubes was installed in painters' breathing zone. All lines used for guiding gas were Teflon lines which were flushed with background air before experiment, and then replaced by new lines after one experiment cycle. Furthermore, the low flow rate pump was calibrated five times by soap-film flowmeter for confirming the error ranges were below 1%, and the sorbent tubes were aged for 20 min at 350 °C with a flow rate of 40 ml/min by thermal desorber (TD-100, Makers). Samples of sorbent tubes were preserved in ice bags at about 4 °C, and then transported to laboratory for analysis on the night. All experiments were conducted in a large and controllable chamber during June and July with temperature of 29 ± 3 °C and relative humidity of 50 ± 3% which was maintained by humidifiers (PH03LA, Parkoo) (Supplementary Fig. 1).