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PHOTOCATALYTIC Oxidation of Volatile Organic Compounds (Voc) for Improving Indoor Air Quality: An Overview

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ABSTRACT

Volatile organic compounds (VOC) are the major pollutants in indoor air, which significantly impact indoor air quality and thus influencing human health. A long-term exposure to VOC will be detrimental to human health causing sick building syndrome. Different methods are used for improving the air quality and photocatalysis as an advanced oxidizing process, could be a promising solution. Pollutants, like volatile organic compounds were successfully degraded by photocatalyic oxidation. This paper presents a literature review of using photocatalytic oxidation (PCO) to destruct volatile organic compounds (VOC) from indoor air, its basic requirements to recent development, its current state of the art and potential future developments in the application of engineering and technology is also presented

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INTRODUCTION

Most of the people living in urban areas spend between 80 and 90% of their time indoors (Juan, 2003). The concentrations of pollutants, such as a variety of volatile organic compounds (VOC) and microorganisms, tobacco smoke, or even asbestos, found in indoor environments are often higher than those found in outdoor air (Chapuis, 2002). Consequently, many nations have adopted VOC exposure standards for non industrial workplace areas (Herrmann, 2005).

Common methods of controlling indoor air pollution include controlling pollution sources, increasing the air exchange rate and using air purifiers. Traditional air purifiers use filters to remove particulate matters or use sorption materials (e.g., granular activated carbon) to adsorb gases or odors (Cao, 2000). However, these techniques only transfer the contaminants to another phase rather than eliminating them and additional disposal or handling steps are subsequently required (Jo, 2004).

Photocatalytic oxidation (PCO) of volatile organic compounds (VOC) is a highly attractive alternative technology for purification and deodorization of indoor air (Ao, 2005). It is characterized by a surface reaction assisted by light radiation inducing the formation of superoxide, hydroperoxide anions, or hydroxyl radicals, which are powerful oxidants (Nath, 2012). Operating at low or room temperature, the PCO can degrade a broad range of contaminants into innocuous final products such as CO_2 and H_2O without significant energy input (Ching, 2004).

Voc and its hazardous effect:

Indoor VOC come from varieties of sources like adhesives, building materials, consumer commercial products and Furnishings and clothing. These compounds are widely used in indoor environment because they exhibit the desirable characteristics of good insulation properties, economy, fire resistance, and case of installation (Hoffmann, 2008; Nath, 2013).

The concentration of VOC in indoor environment depends on many factors such as location, building age and indoor activities. VOC concentration is much higher in newly constructed buildings (Ibram Ganesh, 2011).

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Australian Journal of Basic and Applied Sciences, 8(19) Special 2014, Pages: 351-355

VOC are the most extensively investigated indoor air pollutant because of its adverse acute and chronic health impact. At evaluated concentrations, VOC are potent narcotics and depressed the central nervous system. Some VOC at high concentration may impair neurobehavioral function. Obee *et al*. (1995) showed that individual reported symptoms of headache, drowsiness, fatigue and confusion under the exposure of 22 VOC at a concentration of 6.3 ppb. At an even higher concentration (12.8ppb), toluene may cause symptoms of lethargy, dizziness and confusion. These may progress to coma, convulsions, and possibly death at levels in excess of 8750ppb (Nath, 2012). The chronic effect of VOC is the increase in cancer risk. Chloroform, benzene, tetrachloroethylene, toluene, styrene and xylene are suspected to be toxic or carcinogenic (Stock, 2011; Hunger, 2010).

Theoretical approach:

In the PCO reaction, pure or doped metal oxide semiconductors are commonly used as the photocatalysts. A few examples include WO_3 (Eg=2:80eV), TiO_2(Eg=3:20eV), $LiNbO_3$(Eg=3:78eV), SnO_2(Eg=3:90eV), ZnS(Eg=3:70eV), ZnO(Eg=3:20eV) and CdS(Eg=2:50eV) (Nath, 2013; nojosa, 2012; Folli, 2009; Stock, 2011).

An important step of photoreaction is the formation of hole–electron pairs which need energy to overcome the band gap between valence band (VB) and conduction band (CB). When the energy provided (photon) is larger than the band gap, the pairs of electron-holes are created in the semiconductor, and the charge will transfer between electron–hole pairs and adsorbed species (reactants) on the semiconductor surface, then photo-oxidation happens (Peter, 1996). FIGURE 1 shows the schematic of the PCO process using TiO_2 as the catalyst.

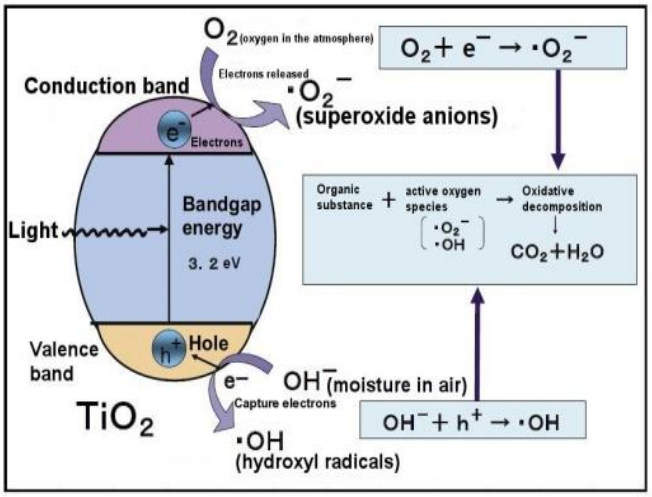

Fig. 1: The schematic of TiO_2 UV photo-excitation process.

The oxidative and reductive reactions are expressed as

Oxidative reaction:

$OH^- + h^+ \rightarrow OH.$ (1)

Reductive reaction:

$O_2ads + e^- \rightarrow O^-_2ads$ (2)

For a complete PCO reaction, the final products are CO_2 and H_2O.

$OH* + pollutant + O_2 \rightarrow products\ (CO_2, H_2O, etc.)$ (3)

Factors affecting this process:

1. ***Effect of UV-light intensity:***

Semiconductors absorb the light with a threshold wave length that is enough to provide the energy used to overcome the band gap between valence bands and conduction bands (Harhira, 2007). For TiO_2, the UV-light with between 300 and 365 nm wave length can provide enough energy to overcome the band gap (3.2 eV). The energy is provided by photons, more photons are produced when UV-light intensity becomes stronger (Stokke, 2008).

2. ***Effect of Humidity:***

The dependencies of humidity on the oxidation rates are explained as being the results of competitive adsorption on available hydroxyl adsorption sites and of changes in hydroxyl radical population levels. Cao *et al* [4] also investigated the effect of humility on activity of TiO_2 and SnO_2 in 1-butene photooxidation and reported that the oxidation rate on SnO_2 drops dramatically with increasing moisture in the feed steam (Demeestere,

Australian Journal of Basic and Applied Sciences, 8(19) Special 2014, Pages: 351-355

2008). However, Jo and Park (Jo, 2004) found that the humidity had little effect on photocatalytic oxidation of benzene, ethyl benzene, and o-, m-, p-xylenes, trichloroethylene, and perchloroethylene.

The PCO destruction efficiencies were close to 100% for four different RH ranges from 18 to 78% (Sleiman, 2009).

Recent Studies in the Photocatalytic Oxidation of Vocs Using Photocatalyst:

We mention general studies about photocatalysis and applications in air depollution from publications covering last years. J.M. Herrmann (Herrmann, 2005) realized a study about fundamentals and misconceptions regarding photocatalysis.

The development of photocatalytic oxidation processes offers a significant number of perspectives especially in gaseous phase depollution (Donya, 2014). It is proved that the photo-oxidizing properties of photocatalyst (TiO_2) activated by UV plays an important role in the degradation of volatile organic compounds (VOC) (Husken, 2009; Akly, 2010).

The application of photocatalytic concrete containing TiO_2 in urban streets is a method to improve the air quality in highly polluted areas. By using this technology it is possible to degrade a wide range of air contaminants, like nitric oxide (NO) and nitrogen dioxide (NO_2), mainly emitted by automobiles. Photocatalysis of gas-phase toluene using TiO_2/SiO_2 composites was studied by James (James, 2005). The performances provided by this novel catalyst are suitable for large-scale applications.

A. Strini and L. Schiavi (Strini, 2005) studied toluene degradation in air using a cementitious material with photocatalytic properties, in low irradiance UV. They successfully performed degradation of 2- butanone and methyl-ethyl-ketone (MEK), two VOC which could cause olfactory discomfort. Acetaldehyde results as by-product in both cases.

Removal of VOC by photocatalysis process using adsorption enhanced by TiO_2 -SiO_2 catalyst. VOC exist in both the indoor and outdoor environment. Some of them are toxic and carcinogenic to human health. In the experiment toluene was used like VOC indicator (Harhira, 2007). The catalyst was synthesized using a sol-gel technique. Toluene was successfully removed from air but there were detected some suspected intermediates or aliphatic hydrocarbons and CO too.

Obee and Brown (Obee, 1995) first reported an investigation of photocatalytic oxidation of VOC using TiO_2 for indoor air. In the investigation, they used the Degussa P25 TiO_2 as catalyst and focused the study on the effects of humidity on the oxidation rates of formaldehyde, toluene, and 1,3-butadiene. An important finding was that competitive adsorption between water and trace contaminants of VOC has a significant effect on the oxidation rate (Poon, 2007; Kang, 2010).

A TiO_2-coated fibre glass mesh composed of anatase TiO_2 and SiO_2 was first employed for photocatalytic oxidation of benzene, toluene and xylenes in indoor air (Pichat, 2000). The average concentrations of benzene, toluene and xylenes were indeed reduced by a factor of 2–3 in an ordinary non-airtight room (FIGURE 2). O_3 addition in O_2 markedly increases the mineralisation percentage of n-octane, under otherwise identical conditions, in the laboratory photoreactor without photoexcitation of O_3.

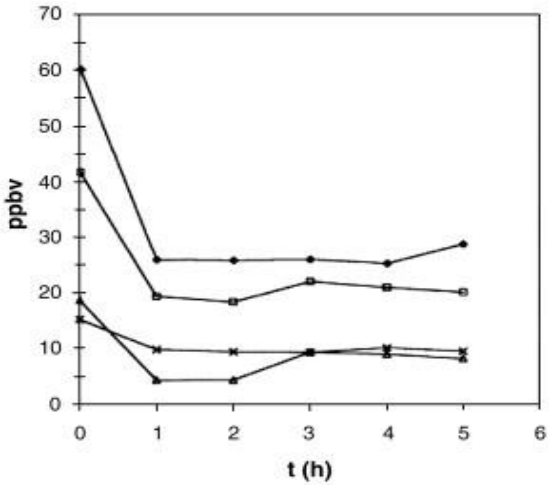

Fig. 2: Decreases in the concentrations of benzene (crosses), toluene (diamonds), *o*-xylene (triangles) and both *m*- and*p*-xylene (squares) in a non-air tight room caused by the prototype air purifier; *t* = o refers to the concentrations before the purifier UV lamps were switched on (Pichat, 2000).

Jo *et al*. (Jo, 2004) evaluated the application of P25 TiO_2 photocatalysis for the removal of five target VOC, benzene, ethyl benzene, and o-, m-, p-xylenes in-vehicle air.

All above investigations with artificial UV-light has been demonstrated. The application has the potential to be made more economical if the artificial UV is replaced by solar UV. However, such a research is limited in the literature. Solar photocatalytic degradation of formaldehyde in the gaseous phase has been investigated by Ching *et al*. (Ching, 2004). It is found that the sol–gel TiO_2 thin film has a lower apparent photonic efficiency of solar photocatalysis than a Degussa P25 TiO_2 coating. However, for the photonic efficiency taking into account the absorbed and scattered photons only and, in other words, excluding the transmitted photons, the thin film has a higher value.

Conclusion:

Removal of VOC from indoor air can be achieved using photocatalytic oxidation, which is efficient and cost-effective. Due to low concentration of pollutants, incorporating TiO_2 catalyst with adsorbent will be beneficial to the adsorption of pollutants and significantly improve the oxidation efficiency and using $LiNbO_3$ as a photocatalyst can creates artificial photosynthesis in concrete construction. In recent years, mesoporous materials have been developed and exhibit higher adsorption capacity than microporous activated carbon. However, little work has been done employing mesoporous adsorbents as supports for photocatalysts and investigations should be conducted towards this direction. More research should be directed in the catalyst development effective under visible or solar light irradiation and also testing in indoor air pollution levels.

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Conflict of interests:

The authors declare that there is no conflict of interests regarding the publication of this paper.

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