Environmental applications of photocatalysis

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Focus and restrictions – Environmental applications of photocatalysis, considering three main areas: air purification, water purification and self cleaning surfaces. An in depth explanation of the mechanism of photocatalysis is beyond the scope of this paper, as is an analysis between different types of purifiers which use the mechanism of photocatalysis.

Abstract –This paper presents a literature review on destroying harmful contaminants in the environment by using photocatalytic oxidation (PCO) or photocatalysis. First, some rudimental information about the mechanism of PCO is given, after which three main areas in which PCO can be applied are studied. These areas are (indoor) air purification, water purification and self-cleaning surfaces. PCO is found a useful technique for purification. It is a cheap and environmentally friendly technique. However, attention has to be given to the design of the purifier: the ability of UV light to reach the catalytic surface, the surface area, and the amount of contaminant to be destructed determine the effectivity of PCO. There are some situations in which PCO doesn't seem a suitable purification technique, for example the purification of outdoor air. These applications require further research.

Key words – photocatalysis, environmental applications, photocatalytic oxidation

1 Introduction

The industrialized world faces a broad range of environmental problems related to contamination of the environment. Purification of the environment and cleaning up of these contaminants is a high national and international priority (Hoffmann, Martin, Choi, & Bahnemann, 1995).

An environmentally friendly procedure to clean up these contaminants has to be found. This literature review examines the possibility of using photocatalytic oxidation, (PCO) for this and the applications of PCO in building technology.

After studying the mechanism behind PCO, different areas are discussed in which it can be a useful technique. After researching these areas, the possibilities for using PCO in building technology are highlighted.

2 Methodology

First, understanding of the photocatalysis process is necessary. Second, the applications of photocatalysis are researched in multiple steps: first papers which discuss a broad range of applications are read to gain understanding, after which conclusions are reached about the main applications. After this papers which deal with one specific solution are studied. The literature is organised by themes: the papers with a broad overview are grouped together, after which the papers which deal with one specific application (air, water) are organised together.

A literature search in Sciencedirect, Google Scholar and Scopus is carried out. Keywords used for the literature search are ''photocatalysis'', ''photocatalysis fundamentals'', ''environmental applications photocatalysis'', ''photocatalytic oxidation indoor air purification'' and ''photocatalytic purification air water''. These keywords have been compared to other keywords and found to yield the most suitable results.
Articles were excluded for the following reason: the studies performed were about a very specific detailed part of photocatalysis and therefore too specialistic.

If multiple different studies find the same result, it is assumed the results are valid. Two other indicators the quality of the literature is sufficient are: if the paper is published by a reputable publisher and if the paper is cited by other reliable sources. Consequently, 10 studies have been compared for this paper.

3 Principle of photocatalysis

Photocatalysis is a chemical process in which the absorption of light by a semiconductor surface, which acts as a catalyst, results in a photochemical process where the TiO_2 molecules are temporarily altered and an indirect reaction with the pollutant occurs which breaks down the pollutant in harmless molecules (Agrios & Pichat, 2005). The photocatalytic surface is not used up during this process. In figure 1 this process is explained.

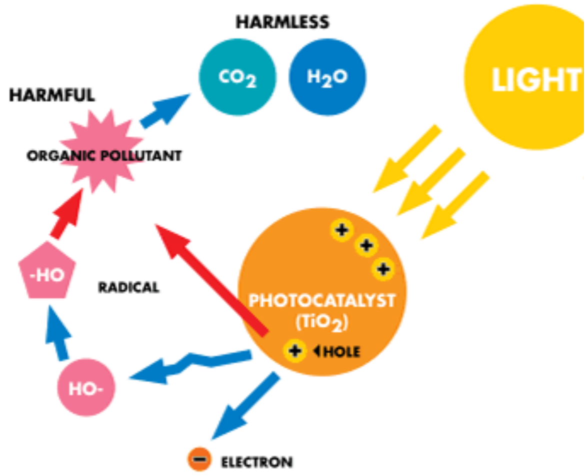

Figure 1: The photocatalysis process
Source: Air Revolution
http://www.airrevolution.co.za/research.html

Multiple studies have found that TiO_2 is a superior material to use as the catalyst. The material has been proven safe for man and environment because it has been in use since ancient times (Hashimoto, Irie, & Fujishima, 2005). Next to this, the material is cheap, it has high photocatalytic efficiency, it works at room temperature and it can completely degrade many organic and inorganic pollutants (Zhao & Yang, 2003). The material is also stable and will last for years, without being used up during the photocatalytic process (Hoffmann et al., 1995). These reasons are an important part of the environmental friendliness of PCO.

4 Applications of TiO2 photocatalysis

4.1 Water purification

A wide range of organic pollutants can be cleaned from water. For example, herbicides and pesticides can be cleaned from water. These are pollutants which occur in the agricultural section. Not only can organic pollutants be cleaned from water, so can inorganic, poisonous pollutants like cyanide (Herrmann, 1999).
Hoffmann et al (1995) agree photocatalysis is capable of purifying organic and inorganic pollutants, in for example drinking water. It has been demonstrated that two of the most common contaminants in drinking water in the United States can be dehalogenated using photocatalysis (Ollis, 2000).

However, there is a sidenote given by Hashimoto et al. (2005) on the purification of water by TiO_2 photocatalysis. Even though photocatalysis has been used since 1970 for pollution clean-up, there are a few problems. The purification of three-dimensional spaces (like a body of water) is quite difficult when compared to the purification of a two-dimensional surface. There are two reasons for this. The first is that photocatalysis is a surface reaction, which means the pollutants have to be captured by the surface first. The second is that in general there are more pollutants in three-dimensional spaces than on a surface, which means more energy is necessary for the purification of these three dimensional spaces.
Despite these problems a water purification system was constructed based on TiO_2 photocatalysis for wastewater from agriculture and soil polluted by volatile organic compounds (VOCs). Not only was this a possible application, a purification system for rice hulls, which is wastewater highly contaminated with agricultural chemicals, was also designed. If this water is not purified, the wastewater simply gets poured on the ground, which causes damage to the soil. Another design in which photocatalysis could be used was the design of a hydroponic tomato culture system in which the wastewater from the system is recirculated and purified by photocatalysis. Figure 2 explains this system.

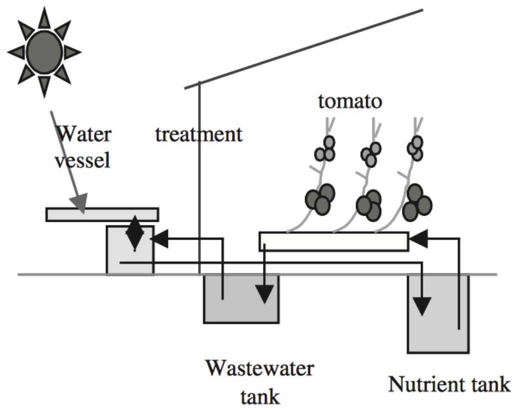

Figure 2: Water recycling system based on photocatalysis of a hydroponic culture
Source: (Hashimoto et al., 2005)

Agrios & Pichat (2005) give another critical sidenote on the purification of water by photocatalysis. The applications are determined by the quality and quantity (and flow rate) of the water to be treated and the requirements for the treated water. Because of the low photocatalytic rates of degradation and mineralization of pollutants and the difficulties in increasing these rates (the chemical reaction takes a certain amount of time), the water purification is limited to niches. Figure 3 shows these niches.

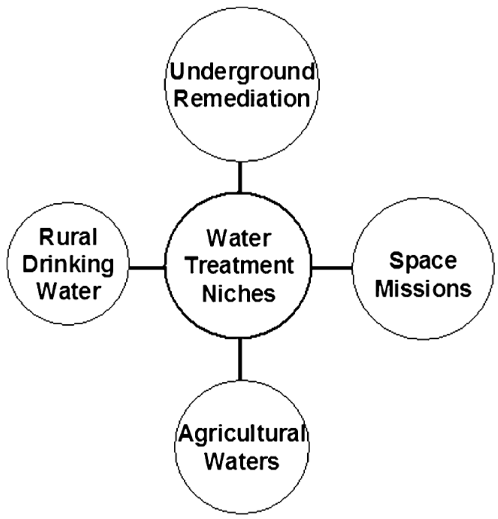

Figure 3: Niches in which photocatalytic water purification can be useful
Source: (Agrios & Pichat, 2005)

Some studies state photocatalysis can break down almost any pollutant. As we have seen, other studies are more critical and not only research the possibilities, but also mention the limitations. The studies which state PCO can be used on a wide range of pollutants are not wrong (as the possibilities of PCO in the field of agriculture and drinkwater are highlighted, which are niche applications), but different papers have a different focus: possibilities versus limitations.

4.2 Air purification

Multiple studies agree on the use of air purification by TiO_2 photocatalysis. This has been tested by installing a PCO filter in a commercially available air cleaner for indoor use to investigate the efficiency. The results have been compared to using the PCO in combination with an activated carbon filter, which absorbs the pollutants to increase the pollutant concentration and therefore the rate of photocatalysis. A pollutant removal of 83% was found by the TiO_2 filter and 97% by the TiO_2/activated carbon filter (Ao & Lee, 2005). As pointed out before, the amount of pollutant is critical for the efficiency of the purifier. This seems to relate to the fact that adding an absorber makes the air purifier more efficient.

Research focusing on techniques of quantifying the effect of PCO has been carried out. Objective measurement techniques are compared to subjective sensory techniques, where participants are asked if they noticed the air quality got better. The different measuring techniques all found the air quality got better, but the subjective method yielded much better results (Kolarik, Wargocki, Skorek-Osikowska, & Wisthaler, 2010). This is important to stress because the other studies only focused on the results and not on researching whether or not the measurement techniques were the best methods available.

Which design of purifier is best has also been researched. There are many different types of reactors, and the design determines the efficiency. Not every design can be used for every application. Zhao & Yang (2003) give a critical sidenote: the efficiency is also determined by other factors, like the contaminant concentration and intermediate substances produced during the process. These intermediate substances occupy the surface area of the catalyst and slow down the chemical process (Zhao & Yang, 2003). Some other factors found are the amount of TiO_2 used and the necessarity for some pollutants to pass through the purifier multiple times. There are a few contaminants which are difficult to remove (CO and CH4) (Agrios & Pichat, 2005).

Agrios & Pichat (2005) mention outdoor air: it is not possible to clean pollutants outdoors, because PCO is restricted to pollutants that are absorbed. Only a very small amount can be absorbed in open spaces, as the contaminants are less concentrated than indoors.

As with water purification, air purification is possible with photocatalysis. Some studies only focus on the possibilities, but others are more critical and give circumstances under which purification by PCO can work. However, there is no contradiction between the literature: some highlight the possibilities, and others give a framework under which these possibilities can be applied.

4.3 Self cleaning function

TiO_2 materials have been found to be self-cleaning. Under influence of UV-light the material becomes hydrophilic, which means stains do not attach to the surface (Hashimoto et al., 2005). This also means the surface does not fog because water droplets cannot form on the surface (Portela & Hernández-Alonso, 2013). It has been proposed to use this property of the material to cool buildings: by covering buildings with TiO_2 coated materials and pouring water down the façades the building can be cooled (Agrios & Pichat, 2005).

However, because this hydrophilic property appears under influence of UV-light, it can't be utilized indoors efficiently (Hashimoto et al., 2005). The self-cleaning function is therefore promising, but can only be utilized outdoors.

5 Discussion

Different environmental applications for PCO can be thought of. As we've seen, the technique itself is environmentally friendly (Zhao & Yang, 2003), (Hashimoto et al., 2005), (Hoffmann et al., 1995). Other techniques for cleaning up pollution are less environmentally friendly, like absorbing the pollutants and then incinerating it at a high temperature (Hoffmann et al., 1995). It is safe to say it is the most environmentally friendly technique to clean up pollutants.

The found literature agrees on the usefulness of PCO for the purification of indoor air and water, but there are factors which determine the efficiency. A specific design for different situations is necessary (Zhao & Yang, 2003). Other parameters like surface area, concentration of contaminants an type of contaminants in the air and water and ability of UV-light to reach the surface influence the efficiency of the designed purifier. (Agrios & Pichat, 2005). One study claims outdoor air can't be purified by PCO. As multiple studies which confirm this statement can't be found, more research is necessary before concluding this definitely.

Different applications in building technology can be thought of. Indoor air could be purified with a PCO system attached to the inside wall, combined with ventilation. The UV-light would be able to reach the material, and as it's combined with ventilation, the air with contaminants would pass through the filter.

As the literature has pointed out, the purification of black water is possible with PCO. Therefore, a system could be designed where blackwater from buildings pass through a PCO filter. However, time is important: the chemical process takes a while. The design must take this circulation time into account.

The self-cleaning function is the application which attracts the attention of construction industries the most (Portela & Hernández-Alonso, 2013). Not without reason, as this is useful for façade elements. Other solutions might be for mirrors (Portela & Hernández-Alonso, 2013) which don't fog or to cool buildings (Agrios & Pichat, 2005). However, cooling buildings by pouring water down the façades seems like a wasteful technique. It might be more environmentally friendly technique to passively cool buildings (Santamouris & Kolokotsa, 2013).

6 Conclusions

Photocatalytic oxidation (PCO) is a useful, environmentally friendly and cheap process for cleaning up contaminants in the environment. Applications like indoor air purification and purification of different wastewaters (industrial, organic black water) has been researched extensively and proven. However, there are a few characteristics which might make a purifier less efficient. Attention has to be given to the design of the purifier, as different applications ask for a different design. Important design aspects are the surface area of TiO2, the amount of UV-light which can reach the surface area, the type and amount of contaminants and the forming of intermediates on the TiO_2 surface.

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