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Review article

The destruction of organic pollutants under mild reaction conditions: A review

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Abstract

A survey of the literature covering the destruction of organic pollutants accomplished under mild reaction conditions is presented. Technologies presented are segregated according to two main reaction pathways; oxidation and reduction. Sub-topics discussed are representative of the main component of the degradation system, including the following; electrochemical reactors, hydrogen as a reducing agent, zero-valent metals, biological based systems, photolytic processes, Fenton reaction, and a recently discovered process that is a form of room temperature and pressure oxygen activation.

Keywords: Environmental remediation; Oxidation; Reduction; Halocarbons; Review

Contents

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1. Introduction

There is much interest in developing technologies that are efficient at pollution prevention and degradation using green chemistry practices. Green chemistry makes use of environmentally conscience manufacturing and production procedures [1–3]. The importance of green chemistry practices is becoming apparent to world governing bodies. In the mid 1990s, under the United Nations Environment Programme (UNEP), several countries throughout the world came to a consensus on the prohibition, restriction, and reduction on the production, use, and release of persistent organic pollutants (POPs) [4]. The UNEP agreement includes a list of 12 priority pollutants that are to be phased out by international law established by the Stockholm Convention [5]. This list includes the following compounds and classes of compounds: Aldrin, DDT, Dieldrin, Endrin, Chlordane, Heptachlor, Hexachlorobenzene, Mirex, Toxaphene, PCBs (polychlorinated biphenyls), PCDDs (polychlorinated dibenzo-dioxins), and PCDFs (polychlorinated dibenzo-furans) [6].

These 12 compounds and compound classes consist mostly of pesticides, the rest being industrial chemicals and industrial by-products. All of these compounds were selected based on their negative impact to humans, animals, and the environment. There are many other POPs outside of the UNEP list, some of which are now being considered for addition to the original 12. These compounds are generally halogenated, lipophilic, semi-volatile organic compounds that have potential for global distribution.

Different strategies for organic pollutant destruction are under investigation. The feasibility of a particular waste destruction technology depends on the condition of the waste. In general there are three types of waste that require different destruction strategies. These are point source, bulk and dispersed. Point source waste destruction involves the destruction of waste at the point of production or contamination. An example of point source waste is a discharge or spill [7]. A point source waste destruction technology needs to be transportable to be applied to the point of contamination or production. Bulk pollutants are those that are stockpiled in large quantities. A bulk pollutant destruction technology must be highly efficient and can withstand large quantities of waste. Lastly, there are dispersed pollutants such as contaminated soils. An appropriate technology used for dispersed pollutant abatement would need to address the degree of dispersal and influence on the local environment. In general, an effective technology for the destruction of organic pollutants should have several qualities.

- The method should have high destruction efficiency (DE). DE is defined as the fraction of pollutant or waste destroyed. DE is calculated by taking the weight of sample input and subtracting off the sum of the sample weight in all products, by-products, and releases divided by the sample input [8].
- The method should release non-toxic, environmentally benign substances and should contain any leftover waste or keep any hazardous by-products from escaping to the environment.
- Processes at room temperature and atmospheric pressure are preferred. This obviates the need for the design of specialized reactors, and lowers energy consumption. This also increases the prospects for the transportation of the process to point sources.
- Any reagents or starting materials should also be non-toxic and environmentally benign. In addition, the reagents should be inexpensive, have a long shelf life, easy storage requirements, and as much as possible avoid specialized catalysts.

These points taken together form the basis for the destruction of POPs using green chemistry practices.

The following discussion is a brief literature survey of organic pollutant degradation technologies that meet some or all of the criteria of pollutant destruction based on green chemistry practices. This review focuses on methods of destruction that require mild reaction conditions, i.e. room temperature and pressure conditions (RTP). The discussion is organized according to the mechanism of action, namely oxidation or reduction. It should be noted that this is a brief review and that the literature regarding emerging technologies for the destruction of hazardous wastes is vast.

2. Methods and technologies—incineration

Although this review consists of degradation technologies under mild reaction conditions, it is first important to review incineration as it is the principle method of organic pollutant degradation. There are many problems associated with incineration that an alternative processes under milder reaction conditions may possibly obviate. Incineration is a technique that is placed in a larger class of thermal methods that have been developed and studied for pollutant degradation. Thermal methods include the following; rotary kiln incineration, liquid injection incineration, fluidized-bed incineration, high temperature fluid wall destruction-advanced electric reactor (AER), infrared incineration, plasma arc pyrolysis, supercritical water oxidation, and in situ vitrification [9].

The basic chemistry involved with incineration is the oxidation of organic compounds by oxygen at high temperatures (>800 °C) ideally forming CO_2 and H_2O as shown below.

$$R\text{–}H + O_2 + \Delta \rightarrow CO_2 + H_2O \quad (1)$$

$$R\text{–}Cl + O_2 + \Delta \rightarrow CO_2 + H_2O + HCl \quad (2)$$

However, many side reactions can take place which produce by-products that are of much concern. Incinerators themselves can be a significant source of dioxin releases [9–13]. When polychlorinated biphenyls (PCB's) or other chlorinated organics are the target pollutant for incineration, polychlorinated dibenzodioxins and furans (PCDD/F's) can be formed as follows in Reaction 3 [10,14–17]. PCDD/F formation occurs when oxygen is not provided in excess