NREL/TP-471-7262 • UC Category: 1303 • DE95000264

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A national laboratory of the U.S. Department of Energy
Managed by the Midwest Research Institute
for the U.S. Department of Energy
under Contract No. DE-AC36-83CH10093

October 1994

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OVERVIEW OF SOLAR DETOXIFICATION ACTIVITIES IN THE UNITED STATES

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ABSTRACT

The U.S. Department of Energy, through the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories, has been investigating a process that uses solar energy to destroy hazardous wastes in air and water. The process, photocatalytic oxidation, uses ultraviolet light in conjunction with the semiconductor titanium dioxide to generate highly reactive hydroxyl radicals. Early research and development activities have demonstrated that photocatalysis may be cost effective for some applications. The Department of Energy is currently working to establish a commercial industry that uses solar energy to destroy hazardous wastes in air, water, and soil. To achieve this objective, NREL and Sandia are bringing together environmental firms, solar manufacturers, and organizations that have waste or remediation problems.

KEYWORDS

Pollution Control, Remediation, Photocatalysis, Solar Energy

1.0 INTRODUCTION

There is an urgent need for new environmental technologies in the United States. Years of neglect have led to substantial degradation of the nation's groundwater, drinking water, and air. During the past two decades, Congress has passed several laws that have had a profound effect on U.S. industry. In 1980, the U.S. Congress enacted the Comprehensive Environmental, Response, Compensation, and Liability Act, usually referred to as "CERCLA" or "Superfund." CERCLA funds and enforces the cleanup of thousands of hazardous waste sites in the United States. As a result of the high cost of cleanup and the lack of technologies currently able to meet regulatory standards for waste cleanup, many sites are still in need of remediation. In 1990, Congress greatly expanded the 1970 Clean Air Act. The purpose of the Act was to prevent or control volatile organic compound (VOC) emissions throughout the United States. Very few, if any, sectors of U.S. industry remain unaffected by these and other federal laws designed to control or reduce pollution.

Conventional technologies for treating hazardous organic compounds in water include carbon adsorption and packed column air stripping. Carbon adsorption is also widely used for treating air emissions. These technologies have been applied to a wide range of organic compounds with varying degrees of effectiveness. A drawback of these technologies is that they do not destroy hazardous compounds—they simply transfer them to another medium. For carbon adsorption, the organic compounds are transferred to a carbon canister that must be transported for disposal or regeneration. Air strippers without secondary treatment systems emit the organic compounds stripped from the water directly into the atmosphere. Because of the increased costs of transporting and regenerating carbon and tighter restrictions on emissions from air strippers, a need has arisen for technologies that are more cost-effective than the conventional technologies used in the past.

A new class of technologies is emerging that destroys hazardous organic compounds rather than transferring them to other media. Such advanced oxidation processes, commonly referred to as AOPs, are increasingly being considered as alternatives to more conventional technologies because of their potential for lower cost and greater effectiveness. AOPs are generally characterized by their ability to generate hydroxyl radicals, strong oxidizing species capable of reacting with most organic compounds. Examples of AOPs include UV/hydrogen peroxide, UV/ozone, and UV photocatalytic oxidation (PCO). The first two processes require short wavelength ultraviolet light ($\lambda < 280$ nm) provided by medium-pressure mercury lamps. PCO processes use a semiconductor catalyst, titanium dioxide (TiO_2), which absorbs the longer wavelength UV light ($\lambda < 385$ nm) available in sunlight or provided by low-pressure mercury lamps.

Photocatalytic processes offer several advantages over other AOPs. Because low-pressure lamps are less expensive and easier to maintain than their medium-pressure counterparts, capital and operating costs can be substantially reduced. Whereas processes using ozone or hydrogen peroxide are generally applied only in the liquid phase, PCO can be operated in the liquid phase or gas phase. This makes the process useful not only for treating hazardous organic compounds in water but also in air. In fact, substantial improvements in performance have been observed when treating organic compounds in air rather than water.

Figure 1 shows that PCO is well suited to low concentration (1000 ppm or less) waste streams. This is partially a result of the strong dependence of PCO cost on VOC concentration and partially a result of the suitability of product recovery technologies (such as condensation) to high-concentration waste streams. As a modular technology, PCO offers the advantage of system flexibility. However, this same attribute prevents PCO from benefitting from economies of scale like most of the other air pollution control technologies. Thus, while PCO costs remain relatively constant as flow rate increases, the normalized costs for many competing technologies drop. Conversely, the modular nature of PCO is a key advantage when treating smaller flow rate streams. Therefore, the advantages of PCO over conventional treatment technologies are most apparent on low- to moderate-volume streams. Given that surveyed users expect 80% of their expenditures for VOC control systems to be for low-flow-rate streams (< 5000 cfm) [1], PCO systems could make significant inroads into this market.

3.0 DOE COMMERCIALIZATION STRATEGY

PCO has matured to the point that several companies are interested in commercializing the process as a remediation and pollution control technology. To successfully commercialize the technology, DOE will pull together environmental firms with end-users interested in applying the technology to solve their waste problems and state and federal agencies responsible for permitting and enforcing environmental regulations.

3.1 Environmental Firms

NREL is working with several companies to commercialize PCO technologies for treating hazardous organic compounds in air and water. In FY94, NREL completed negotiations and signed a Cooperative Research and Development Agreement (CRADA) with International Technology Corporation (IT), a major U.S. environmental firm, to jointly pursue the development of the gas-phase photocatalytic technology. Under the CRADA, NREL is responsible for bench-scale testing to identify reaction intermediates, investigating catalyst deactivation/reactivation mechanisms, and improving the performance of the gas-phase photocatalytic process. Using these results, IT plans to scale-up the process for field demonstrations in early FY95.

NREL is working with two companies interested in commercializing the aqueous-phase photocatalytic process: ClearFlow, Inc., and Solar Kinetics, Inc. (SKI). DOE is sharing the cost of designing, building, and operating two solar-driven water detoxification systems. SKI has selected Kelly Air Force Base in San Antonio, Texas as the site for their cost-shared demonstration project. The system at Kelly Air Force Base will treat groundwater contaminated with solvents such as trichloroethylene (TCE), a common groundwater pollutant found throughout the United States. Researchers from SKI and NREL are beginning laboratory-scale treatability and catalyst optimization studies using the site-specific

Because the wavelengths required to drive the process are available in sunlight, solar energy can be used as the UV source. This may be an advantage for PCO techniques requiring large amounts of UV light, which would be too expensive to produce using electric-powered UV lamps. Also, a solar-driven process would be well suited to locations where solar energy is abundant, such as the southwestern United States. For this reason, the National Renewable Energy Laboratory (NREL), DOE's primary laboratory for alternative energy research, and Sandia National Laboratories are working to demonstrate the technology and to promote its commercialization.

2.0 MARKET FOR PHOTOCATALYTIC OXIDATION

Figure 1 shows the range of applicability for four VOC treatment technologies—carbon adsorption, thermal and catalytic oxidation, and condensation—widely in use throughout the United States [1]. The ranges represent current industry practice for control of air emissions. Also shown in the figure is the predicted range of application for PCO. This range is based on laboratory data, pilot-scale tests, and engineering assumptions [2]. Although the predicted range of application for PCO is less accurate than the information from commercially operating systems, it is sufficient to identify potential markets for commercialization of photocatalysis.

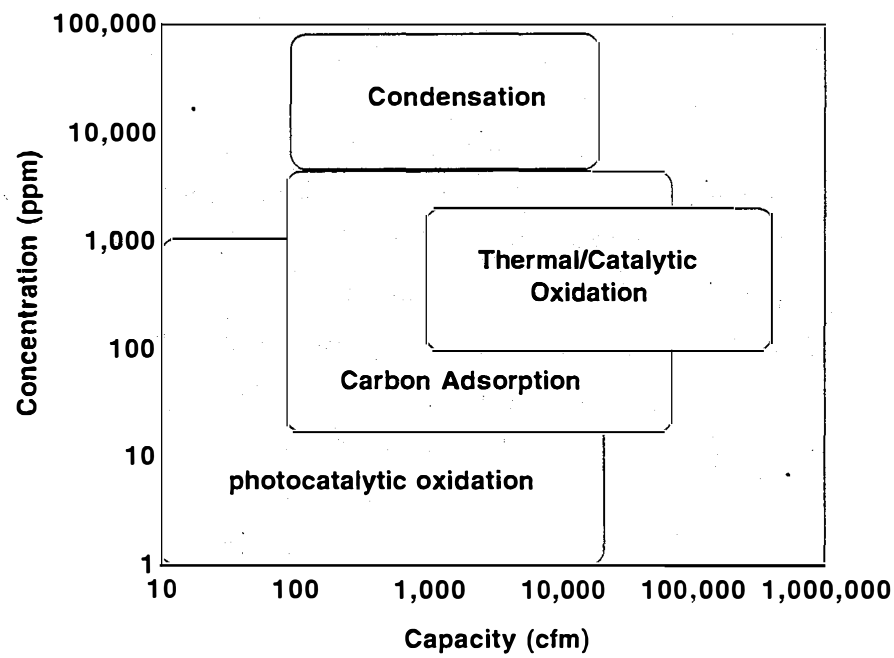

Figure 1 Range of application for conventional technologies compared to photocatalytic oxidation

contaminants.

In addition, NREL is working with Solarchem Environmental Systems, based in Ontario, Canada, to investigate a unique homogeneous iron-based photocatalyst for use in destroying hazardous wastes in water. This catalyst uses longer wavelength light ($\lambda < 450$ nm) than the TiO_2 typically used, thus making better use of the solar spectrum. NREL is funding Solarchem to develop, optimize, and test this potentially low-cost process. Solarchem has selected a site in northern California for treatability testing. The site is contaminated with BTEX compounds (benzene, xylene, ethyl benzene, and toluene). Remediation of BTEX-contaminated water represents a large market in the United States. If treatability tests are successful, Solarchem will design and construct a pilot-scale demonstration at the California site in mid-FY95.

3.2 End-Users

With environmental firms in place to commercialize photocatalysis within the United States, NREL and its industrial partners are seeking relationships with end-users interested in the application of photocatalysis to solve their waste problems. NREL recently signed a 1-year CRADA with SEMATECH to determine if gas-phase PCO can be used to clean exhaust streams produced during microelectronics manufacturing. SEMATECH is a consortium of U.S. semiconductor manufacturing industries and represents a large and growing U.S. market for environmental control technologies. Under the CRADA, NREL will be responsible for performing bench-scale treatability studies and process optimization, designing and operating a small field test at an industrial site, and estimating the cost of a gas-phase PCO system for the site. If successful, the CRADA will open the door for IT Corporation to work directly with SEMATECH and the semiconductor industry to commercialize the PCO technology for semiconductor applications.

In a related application, Sandia National Laboratories is working with Intel, a U.S. semiconductor manufacturer, to jointly conduct a treatability study to determine if aqueous-phase photocatalysis can successfully pretreat waste water produced during the fabrication of microelectronics. The 3-month study is being conducted at Sandia on actual waste water samples from an Intel plant. If the results of the treatability tests are encouraging, project researchers believe a demonstration project involving Clearflow or SKI would likely follow.

NREL is actively pursing other applications where photocatalytic technologies may fit the needs of U.S. industry. One example includes surface coating operations, a significant source of VOC emissions in the United States. The annual emissions from surface coating facilities are estimated to be nearly one million tons [4]. Of this, over 500,000 tons can be classified as toxic air emissions. Because organic emissions from coating operations can contribute to urban smog and urban ozone formation, regulatory agencies are limiting emissions and requiring businesses in the coming years. Several companies have expressed interest in the use of PCO to control their emissions because PCO may provide an easier, cheaper solution than technologies currently in use.

3.3 Regulatory Agencies

Testing and implementation of new commercial environmental technologies requires collaboration with a new stakeholder: government regulatory agencies. Early and active collaboration with local, state, regional, and federal agency personnel provides many benefits and reduces the time required by the government to approve the new pollution control technology.

Many types of environmental legislation and regulation are technology specific. If regulators are not familiar with a new control or pollution prevention technology, it may be excluded from regulations and laws as an approved strategy. If agency personnel are involved from the early stages of technology field testing and commercialization, an interactive relationship can develop that assists both regulators and engineers. The regulators learn about the developing technology and become familiar with its applications and advantages. Regulators are also often familiar with the regulated community, and can provide advice to researchers on how to develop the technology to be most effective with its projected application. Regulators may also provide a forum for contacting new potential end users, and can provide information about other applicable technologies.

Experienced staff members at regulatory agencies often have extensive technical knowledge about industrial processes and emissions. They can provide practical advice about real-world applications for new environmental technologies. For new regulations and control measures under development, interaction with regulatory agencies is critical. Regulators need to know what kind of control technology is available, and researchers need to be informed of regulatory developments that may affect commercialization and use of their new technology. Working together, regulators and researchers can develop regulations that take advantage of new technology and that effectively protect human health and the environment.

4.0 SUMMARY

The U.S. Department of Energy, through the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories, has been investigating photocatalysis as a means for destroying hazardous wastes in air and water. PCO appears to be best suited for low-concentration (1000 ppm or less) waste streams and low flow rates. While research is still needed to optimize the process, photocatalysis has progressed to the point that several environmental firms are interested in commercializing the technology. DOE's challenge is to unite these environmental firms with end-users, manufacturers, and regulators with the hope that the technology can gain widespread use throughout the United States.

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