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Looking at Pollution Control in a New Light

Photochemistry for a Cleaner Environment

Researchers from the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories are shedding light on one of our most pressing societal problems: environmental pollution. Recognized nationally as a leader in environmental photochemistry, the NREL/Sandia team has developed a pollution control technique—photocatalytic oxidation, or PCO—that uses the energy in light to destroy environmental contaminants. Applicable as both a waste clean-up and a pollution control technique, PCO could help thousands of businesses comply with today's—and tomorrow's—environmental regulations.

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Photocatalytic Oxidation: Cleansing Air and Water with Light Energy

Photons—the packets of energy that make up light—are abundant and can be precisely controlled. The photocatalytic oxidation (PCO) process harnesses photon energy to destroy many toxic organic compounds that are hazardous to human health and the environment.

Photochemistry is the Game

The researchers at NREL and Sandia have unparalleled expertise in basic and applied photochemistry. The NREL/Sandia team, which comprises the resources of two national laboratories and more than 30 scientists and engineers, is the nation's preeminent photo-chemistry/photocatalytic research organization. Through the innovative use of photochemistry, photocatalysis, and solar energy, this team is helping American industry solve critical environmental problems. The team has a number of dedicated photochemistry laboratory facilities—both indoor and outdoor.

NREL and Sandia work collaboratively with industrial and government partners, including environmental and solar firms, technology end users, and trade organizations. The team offers partners a range of capabilities, from basic research in chemical and kinetic fundamentals to treatability analyses and pilot testing. Partnerships between outside parties and the NREL/Sandia team come in a

The key to PCO is the photocatalyst, a chemical compound that becomes highly reactive when exposed to various wavelengths of light. In the presence of organic pollutants—such as solvents, alcohols, dyes, and fuel oils—the activated photocatalyst attacks the pollutants' chemical bonds, converting the toxic compounds into benign constituents such as water and carbon dioxide.

Warren Greitz, NREL

A Versatile and Economic Technique

PCO is a technique for both pollution control and environmental remediation. NREL has successfully decontaminated polluted groundwater at a number of test sites including the Lawrence Livermore Superfund site in California where the groundwater contained 200 parts per billion (ppb) trichloroethylene (TCE), a solvent that has become one of the most common groundwater contaminants in the United States. PCO reduced TCE levels to below 5 ppb—well within the drinking water standard set by the Environmental Protection Agency (EPA).

A number of organizations including SEMATECH, the research consortium of integrated circuit manufacturers, are testing PCO on organic-compound-containing air streams produced during manufacturing processes. Other industries are applying PCO as a method to maintain indoor air quality and to disinfect drinking water. The U.S. Department of Defense is experimenting with PCO technology in two different projects: one is evaluating the technique's ability to decontaminate pinkwater, that is, water containing traces of the

variety of forms, including cooperative research and development agreements (CRADAs), cost-shared subcontracts, and other collaborative arrangements. The work accomplished through these partnerships is given the highest level of proprietary protection.

Warren Greitz, NREL

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The Photocatalytic Oxidation (PCO) Process

This laboratory-scale reactor is used by researchers at the National Renewable Energy Laboratory in their gas-phase PCO investigations. Artist's rendering of the process.

CD-SS25-B001801

Warren Greitz, NREL

explosive TNT; the other is examining PCO to treat a variety of hazardous wastes and process pollution associated with military operations.

PCO's versatility stems from its flexible operating characteristics. PCO is most effective on low-concentration and low-flow-rate waste streams, and it normally operates at—though is not limited to—ambient temperatures and pressures. Common chlorinated and oxygenated organic pollutants are highly susceptible to PCO and are destroyed without producing any NO_x emissions. PCO systems are modular, portable, and ideally suited to the on-site waste treatment requirements of many small and mid-size businesses.

PCO is cost competitive with traditional techniques for treating air emissions contaminated by organic compounds (see graph below). The technique is particularly cost effective for low-flow-rate streams that many newly regulated industries, such as dry cleaners, surface coating shops, photo processors, and other manufacturers, are now required to treat.

CD-SS25-B001802

Cost of air pollution control technology versus flow rate. Values are based on 500 ppm of a hydrocarbon pollutant. (From: Turchi, C.S.; Wolfrum, E.; Miller, R. *Gas-Phase Photocatalytic Oxidation: Cost Comparison with Other Air Pollution Control Technologies*, NREL/TP-471-7014, National Renewable Energy Laboratory, Golden, Colorado, 1994.)

Hit List

The NREL/Sandia research team has shown that the photocatalytic oxidation (PCO) process can destroy the following compounds (the complete list of compounds susceptible to PCO is much more extensive):

- Chlorinated solvents—trichloroethylene, perchloroethylene
- Alcohols—ethanol, methanol
- Ketones—acetone, methylethylketone
- Aromatics—BTEX (benzene, toluene, ethylbenzene, xylenes)
- Hydrocarbons—octane

of photochemistry-based technology—and its extensive laboratory capabilities—places it in the vanguard of photochemical environmental R&D. The team is uniquely qualified to solve real-world environmental problems with both basic and applied scientific and engineering studies and to assist companies in bringing new technologies to the market place.

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Research for Industry and the Nation

The photochemistry research ongoing at NREL and Sandia is funded primarily by the U.S. Department of Energy's Office of Industrial Technologies (OIT). OIT is dedicated to increasing energy efficiency, preventing pollution, and improving productivity in American industry.

OIT's Industries of the Future program promises to be an avenue by which PCO and other photochemical processes will penetrate the market. Industries of the Future brings together OIT and key materials and process industries to strengthen the position of these industries—economically and environmentally—in the global market in the coming decades. The following list presents examples of the role PCO could play in this program.

- Petroleum refineries. PCO can destroy the BTEX contamination associated with petroleum operations such as pipelines, underground storage tanks, tank vents, refineries, and gas stations.
- Chemicals. PCO will be tested on volatile organic compounds (VOC) emissions from curing operations on adhesives and polymers.
- Forest products. PCO can be applied to emissions from green wood and particle board drying, pulp mill odors, plywood and pressboard manufacturing, and unit operations in pulp and bleach mills.
- Foundries. Recent legislation requires this industry to reduce aromatic compound emissions, such as toluene and xylene, and the organic binders vaporized in the molding process; PCO may be an effective treatment for these emissions.
- Aluminum. PCO may be effective in eliminating toxic components of the off-gas from dry scrubbing systems.
- Steel. PCO could reduce lubricant contamination from cooling and wash water and may control VOC emissions from painting and melting processes.

12/10-30-95 JSC①

National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, CO 80401-3393

The National Renewable Energy Laboratory is a DOE national laboratory.

DOE/GO-10095-215
DE95013117
NREL/SP-471-8185
September 1995

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 20% postconsumer waste

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Left: International Technologies Corporation's gas-phase lamp PCO test reactor. Right: closeup of the reaction chamber.

The Market

The Supply Side

The NREL/Sandia photochemistry research team is working with a diverse group of environmental remediation companies and potential users of PCO. International Technologies Corporation (IT), one of the nation's leading firms for developing and marketing new pollution control technologies, is working with NREL under a cooperative research and development agreement (CRADA) to develop commercial gas-phase PCO systems. IT anticipates having the first systems available commercially in early 1996 through NEPCCO, an IT subsidiary.

NREL and Sandia have numerous cost-shared research and development (R&D) agreements with other environmental remediation and waste management firms, chemical engineering companies, and pollution control equipment manufacturers.

The Demand Side

The NREL/Sandia team is also working closely with a number of industries for whom PCO may be the most cost-effective method for complying with recent or pending EPA regulations. The International Fabricare Institute—the industry association representing dry cleaners—is working with NREL to

determine if PCO can treat perchloroethylene or "perc," the primary solvent used in the dry cleaning process. The EPA has recently enacted strict perc emission standards, and laboratory tests have shown that PCO destroys perc with an extremely high level of efficiency.

Other industries, such as baking and brewing industries that are

The Industry Connection

The following are just a few of the numerous industrial companies and organizations—both technology suppliers and end users—that are actively involved in the NREL/Sandia photochemistry research:

- *IT Corporation*, Knoxville, Tennessee—Commercial gas-phase reactors, environmental applications
- *Solarchem Environmental Systems*, Markham, Ontario, Canada—Homogeneous photocatalysis
- *International Fabricare Institute*, Silver Spring, Maryland—PCO for dry cleaning applications
- *DuPont*—Kinetic modeling of photochemical reactions
- *Solar Kinetics, Inc.*, Dallas, Texas—Solar aqueous-phase PCO demonstration
- *SAIC*, Golden, Colorado—Photolytic contaminant destruction

facing new standards limiting ethanol emissions, are also looking at PCO to treat their emission streams. The potential applicability for PCO is enormous; many businesses and manufacturers that produce waste streams containing organic compounds are potential beneficiaries of PCO.

And PCO Is Just the Beginning...

NREL—in concert with industry and academia—is investigating a number of other technologies for managing or remediating environmental pollution. A solar-based process, in which intensely concentrated sunlight is used to combust pollutants extracted from contaminated soil, is currently being tested at the Sierra Army Depot in California. The team is also investigating a process that uses molten carbonate salts as a reactive medium for destroying

Warren Greitz, NREL

Aqueous-phase PCO reactors—similar to the two laboratory designs shown here—are being field tested on contaminated groundwater and process water. Researchers are investigating this technology as a low-cost method for disinfecting drinking water.

Close Ties to the Academic Research Community

Researchers in academia are a crucial component of the photochemistry program at NREL and Sandia. The following list is a sample of the academic research funded by the PCO research program through subcontracts and research grants.

- Arizona State University—Guidelines for improved titanium dioxide gas-phase photocatalysts
- Colorado School of Mines—Gas-phase kinetics
- North Carolina State University—Halide-enhanced photocatalytic oxidation
- University of Colorado at Boulder—Transient studies of gas-phase photocatalytic oxidation; catalyst characterization and improvement
- University of Idaho—Combined photochemical and biological treatment of pinkwater
- University of New Mexico—Analytical method development for organometallics
- University of Texas at Arlington—Photocatalytic disinfection of water
- University of Texas at Austin—Improved photocatalysts for water treatment

organic compounds containing halides, nitrogen, sulfur, and phosphorus.

In work derived from fundamental PCO studies, researchers are investigating disinfecting drinking water with an aqueous, solar-driven PCO system. Just as PCO destroys organic pollutants, it also attacks the organic exterior of the microbes and bacteria that contaminate water, effectively killing the organism. A large market exists for this potentially cost-effective disinfection method in developing countries around the globe. Researchers are also investigating a bio-aerosol technique for destroying airborne pathogens in hospitals or other indoor environments and a solar-driven process for recovering dissolved metals.

The NREL/Sandia team's in-depth work with both suppliers and users