NREL/TP-473-20300 • UC Category: 1600 • DE95013148

Bibliography of Work on the Heterogeneous Photocatalytic Removal of Hazardous Compounds from Water and Air Update Number 1 To June, 1995

Daniel M. Blake

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

November 1995

Available to DOE and DOE contractors from:
Office of Scientific and Technical Information (OSTI)
P.O. Box 62
Oak Ridge, TN 37831
Prices available by calling (615) 576-8401

Available to the public from:
National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

Printed on paper containing at least 50% wastepaper, including 10% postconsumer waste

Summary

The Solar Industrial Program, funded by the United States Department of Energy, is carrying out research and development on processes for the destruction or removal of hazardous substances from water and air. The work is being done at the National Renewable Energy Laboratory in Golden, CO, and Sandia National Laboratory in Albuquerque, NM, and by their subcontractors. The processes of interest in this report are based on the application of heterogeneous photocatalysts. The current state of the art in catalysts are forms of titanium dioxide or modifications thereof but work on other heterogeneous catalysts is included in this compilation.

This report is an update of a bibliography of work done on the photocatalytic oxidation of organic or inorganic compounds in air or water and on the photocatalytic reduction of metal containing ions in water that was published in May, 1994. The previous report included 663 citations obtained through the middle of 1993 and some selected references from the balance of that year. This update contains an additional 574 references. These were published during the period from January 1993 to June 1995, or are references from prior years that were not included in the initial report The general focus of the work is removing hazardous contaminants from air or water to meet environmental or health regulations. This report follows the same organization as the previous publication. The first part provides citations for work done in a few broad categories that are generic to the process. Three tables provide references to work on specific substances. The first table covers organic compounds that are included in various lists of hazardous substances identified by the United States Environmental Protection Agency (EPA). The second table lists compounds not included in those categories, but which have been treated in aphotocatalytic process. The third table covers inorganic compounds that are on EPA lists of hazardous materials or that have been treated by a photocatalytic process. A new section has been added which gives information about companies that are active in providing products based on photocatalytic processes or that can provide pilot, demonstration, or commercial-scale water- or air-treatment systems. Key words, assigned by the author of this report, have been included with the citations in the listing of the bibliography.

Table of Contents

Page

1.0 Introduction

This update in combination with the previous report[1] provides a comprehensive bibliography of work available in the open literature for scientists and engineers interested in the use of heterogeneous photocatalytic oxidation or reduction processes in environmental remediation, process emission control, indoor air quality, or other applications. The combined bibliographies include more than 1200 citations to work published between 1970 and the middle of 1995. The literature cited includes United States and foreign patents. Information was compiled by manually scanning the literature and searching commercial databases. This update includes about 100 citations to work done prior to 1993 that were not included in the initial report. Some citations have doubtless been missed and topics covered in certain papers may not have been identified and covered in every appropriate category. The limitation to heterogeneous processes means that work on homogeneous photocatalytic processes is not included. Examples of these are the recently patented process based on the iron(III)-oxalate-hydrogen peroxide system[2] and the systems based on soluble polyoxometalates.[3] The author invites readers to send references to relevant work that appeared before 1995 that has been missed to the mail or e:mail address included in Section 5.3 of this report.

The photocatalytic oxidation of organic compounds in water is the subject of a large body of research that has been performed in laboratories all over the world. A lesser but rapidly increasing amount of work has been devoted to the oxidation of volatile organic or inorganic compounds in the gas phase. Photocatalytic reduction of both organic compounds and metal-containing ions is also receiving increasing attention. Representative reactions are shown below:

---

[1]Blake, Daniel M. (1994). *Bibliography of Work on the Photocatalytic Removal of Hazardous Compoundsfrom Water and Air.* NREL/TP-430-6084. Golden, CO: National Renewable Energy Laboratory. 75 pp. [DE94006906] Available from the National Technical Information Service, Springfield, VA 22161.

[2]Safarzedeh-Amiri, Ali, inventor. "Photocatalytic Method for Treatment of Contaminated Water." Cryptonics Corporation, assignee. United States Patent, 5,266,214. November 30, 1993.

[3]Hill, C. L. and C. M. Prosser-McCartha. "Photocatalytic and Photoredox Properties of Polyoxometalate Systems." *Photosensitization and Photocatalysis Using Inorganic and Organometallic Compounds,* eds. K. Kalyanasunderam and M. Gratzel, 307-30, Dordrecht: Kluwer Academic Publishers, 1993.

$$C_6H_5OH_{(aq)} + 7\ O_{2(aq)} \xrightarrow[hv]{semiconductor} 6\ CO, + 3\ H_2O \quad (1)$$

$$C_2HCl_{3(g)} + 3/2\ O_{2(g)} + H_2O_{(g)} \xrightarrow[\text{'}hv]{semiconductor} 2\ CO_{2(g)} + 3HCl_{(g)} \quad (2)$$

$$2\ CrO^{-2}_{4(aq)} + CH_3OH_{(aq)} + 4\ H + \xrightarrow[hv]{semiconductor} 2\ Cr(OH)_{3(s)} + co, + H_2O \quad (3)$$

Reactions are shown in the idealized case of complete oxidation or reduction. It is widely observed that intermediates and by-products are often formed that persist in the treated stream. These can include a variety of acids, oxygenated compounds, and carbon monoxide.

The net process involves oxidizing the organic compound to an intermediate stage of oxygen content or to carbon dioxide, water, and a mineral acid (if a heteroatom such as nitrogen or chlorine is present). Other oxidizing agents may be substituted for oxygen. Modifying or removing certain metal ions from water can be accomplished when the ions replace oxygen as the electron acceptor in the process and sacrificial electron donor compounds are provided.

A survey of the literature collected reveals that about 20% of the new citations are for work in which the target compound is carried in the gas phase rather than in water. Twenty-four citations cover work on disinfection of water or air or to potential medical applications. Control of odor compounds or application to removal of volatile organic compounds specifically for indoor air purification was the subject of nine papers. Use of the sun as the light source was identifiable in more than 80 papers. Engineering issues were addressed in more than 70 papers. Of the 46 patents that are included in the new list, 35 have assignees in Japan.

Reference to test work on more than 150 compounds is included in the Tables in Section 3. The most-studied compounds are phenol derivatives, BTEX (benzene, toluene, ethyl benzene, and xylene) components found in fuel spills, and chlorinated solvents such as trichloroethylene and chloroform. A significant number of pesticides, dye compounds, and surfactants have been shown to be mineralized and a variety of bacteria and virus have been found to be killed by irradiation with near-ultraviolet light in the presence of titanium dioxide. The breadth of work attests to the very wide range of applications that are being evaluated for the technology.

A new section has been added which lists the names and addresses of companies that offer products or services based on a heterogeneous photocatalytic process. These are mainly in the United States and Canada but a few are from Europe and Japan. The author has attempted to obtain information directly from the company or used information from the open literature in the preparation of the entries which identify the product or service. Companies not listed are invited to send information, to the address in Section 5.3, that can be included in the next update of the bibliography.

The following sections cover reviews written on various aspects of the technology, work in developing and testing photocatalysts and oxidants, engineering issues, other topics, patents, and companies active in bringing photocatalytic processes or devices to the marketplace. These sections, which include information that can apply to a range of applications, are followed by tables listing references to work performed on specific substances. Documents referring to work on systems in which the compound to be treated is carried in the gas phase are indicated by the prefix "g" in the citation number.

2.0 Generic Information

This section refers to work that cuts across the field of photocatalytic processes.

2.1 Review Articles

Many new reviews have been written that cover various aspects of photocatalytic chemistry and technology. This section also includes reviews written in the years prior to 1993 that were not cited in the first report. Reviews covering the broad topics given can be found in the following references:

methodology for comparing reaction systems - 21,350, and 428; mechanisms/activity - 27, 50, 63, 133, 205, 258, 290, 325, 338, 425, 426, 427, 429, 535, 537, 546, 549, 550, 561, and 569; ultra small particles - 28,206, 326, and 547; photoelectrochemical systems - 32 and 33; solar facilities - 36; photocatalysis - 45, 116, 124, 309, 366, 543, 549, 564, 568, and 570; solar processes - 51, 509, 53 1, and 574; companies active in the field - 69; adsorption - 90, 91, and 537; metallized photocatalysts - 145; disinfection - 150 and 319; indoor air quality - 150,319, and 565; oil spills - 150; surfactant degradation - 159 and 360; environmental applications - 171, 266, 286, 300, 316, 342, 343, 358, 381, 421, 422, 424, 425, 429, 517, 556, 558, 559, 560, 562, 565, and 571; production and applications of ultra-fine TiO_2 - 201; preparation and applications of semiconductor thin films - 204; microfabrication and integrated chemical systems - 226; overview of Department of Energy R&D in photocatalysis - 289; Degussa P25 properties - 321; new photocatalytic processes - 338; titanium dioxide pigments and the control of photodegradation of polymers - 339; comparison of advanced oxidation processes - 340 and 557; issues and questions in application of photocatalysis - 341; solar production of fuels and chemicals - 381; and photochemical reactors - 390.

2.2 Photocatalysts

The nature of the photocatalyst determines the rate and efficiency of the process. The anatase form of titanium dioxide has the desirable properties of being chemically stable, readily available, and active as a catalyst for oxidation processes. On the negative side, its 3.2 eV band gap results in only a small overlap of its action spectrum with the solar spectrum. Also, the efficiency for converting photons absorbed to hazardous molecules destroyed is generally low, particularly for the aqueous phase processes. In order to identify ways to increase process efficiency and to improve the overlap of the absorption spectrum of the photocatalyst with the solar spectrum, a great deal of work has been done on modifying TiO_2 and testing other semiconductors. This work is broken down into a few broad categories and covered in the references cited.

2.2.1 Modified Titanium Dioxide

Titanium dioxide and modified forms, including different commercially available forms, heat treated materials, and materials prepared by a range of techniques:

sol-gel - 11, 167, 211, 212, 355, 376, 520, and 523; rutile - 12, 46, 48, 160, 167, 219, 220, 292, and 389; heat treatment - 22, 49, 78, 167, 303, 337, 352, 353, 406, 520, and 526; colloidal or quantized particles - 28, 67, 81, 114, 115, 136, 170, 200, 241, 254, 277, 278, 279, 389, 510, 511, 519, and 548; modified - 29; xerogel/aerogel - 94, 95, 96, 97, 230, 413, and 466; flame synthesis - 119 and 376; or catalysts from different vendors - 405.

2.2.2 Hydrophobic Surface Treatment

Titanium dioxide has been modified to make the surface hydrophobic to alter the interaction with organic compounds in water. This work is covered in the following: silica - 94.

2.2.3 Dye Sensitized Titanium Dioxide

Dye sensitizers have been used in conjunction with titanium dioxide to improve the response to visible light:

ruthenium complex - 38, 200, and 460; eosin - 151; cobalt tetraphenylphorphine - 187; cobalt tetrasulfophthalocyanine - 235; organic dyes - 209 and 393; polyviologen - 397; $[Mo_2S_4(S_2C_2H_4)](-2)$ - 254; iron-porphyrin - g368; coupled semiconductors - 423; or Ni-phthalocyanines - 499.

2.2.4 Metal Ion Doping of Titanium Dioxide

Other metal ions have been introduced into the titanium dioxide lattice to modify the properties. They are covered in the following:

Si - 323; Al - 82 and 323; V - 40, 81, 82, and 279; Fe - 28, 40, 47, 49, 81, 82, 259, 278, 311, and 348; Co - 40 and 82; Zr - 230; Ni - 474; Nb - 89,223, and 230; Mo - 81, 82, 242, 352, 353, and 380; W - 104,105, 269, 270, 352, 353, and 380; Re - 81 and 82; Ru - 81 and 82; Rh - 81 and 82; or Os - 81.

2.2.5 Metaiiized Titanium Dioxide

Noble metals have been deposited on the titanium dioxide surface to enhance catalytic activity:

Cu - 311,504, and 515; Ru - 203; **Os** - 203; Rh - 203; Ir - 203; Pd **- 151, 203, 269, 270, 333,** and 335; Ag **- 243, 269, 270, 311, 337,** and 459; Au **- 31, 244, 269, 270,** and 337; or Pt **- 23, 24, 87, 88, 146, 147, 160, 164, 191, 203, 269, 270, 273, 317, 327, 337, 370, 401, 413, 467,** and486.

2.2.6 Other Semiconductors

A wide range of other semiconductors have been tested for photocatalytic activity. In general they have been found to be less active than titanium dioxide. Relevant work is cited in the following:

Al_2O_3 - 148 and g436; Sr - or **$BaTiO_3$** - 219 and 220; **V_2O_5** - g14 and g367; **Fe_2O_3 - 28, 87, 106, 114, 148, 184, 259, 356, 364, 423, 461, 541,** and 542; **FeO(OH)** - 135,354, and 524; **$CaFe_2O_4$** - 282; **ZnO - 9, 23, 28, 30, 106, 157, 160, 204, 217, 261, 278, 292, 337, 356, 357, 364,** g367, **385, 386, 388,** 423, **g436, 461, g487, 499, 545, 566,** and 573; **Zn**- or **CdS - 106, 112, 143, 301, 337, 423, 433,** 519,539, and 540; **ZrO_2** - 87 and g367; **$ZrPO_4$** - 313; **MoO_3** - g14; **MoS_2 - 160; SnO_2 - 9, 38, 87, 204, 356,** g367, 482, and 484; **Sb_2O_4** - g367; **CeO_2** - g367; WO, **- 9, 39, 106, 160, 204, 337, 356,** g367, 499,541, and 542; **SiO_2** - 148, ; **SiC** - 221; **Nb_2O_5** - 17; **RuS_2** - 18; fly ash - 148 and 555; polyaniline - 296; or natural minerals - g192 and 354.

2.2.7 immobilized Photocatalysts

Most experimental work on aqueous systems has been performed using the photocatalyst in the form of **fine** particles suspended in the liquid phase. In a waste treatment application it would be simpler if the catalyst were immobilized in the photoreactor so the material would not have to be separated from the treated fluid in a subsequent process step. For the treatment of gases most work has involved immobilized catalyst. Titanium dioxide has been affixed to a variety of surfaces:

glass (including fibers) **- g14, 42,** 152, 153, 172, 173, 174, **194, 212, 265, 280, 281, 304, 314, 315,** 320,345, **g440, 481, 484, 485, 552, 553, 554,** and 572; silica - 186 and 532; metal - 178 and 446; **ceramic-2, 10, g16, 168,** 403, **g407;** clays - 260,449, and g452; polymer -1, **12, 40, 41, 60,** 70, 145, **149, 296, 345, 401,** and 474; thin films **- 26, 38, 83, 84, 144, 210, 223, 334, 398, 406,** and 523; zeolite **- 14, 35,** 120, 143,260, and 402; alumina - 143; carbon **- 179, 184, 185, 231, 312,** g453, and 473; Ambersorb - 327; or **β** -cyclodextrin - 5 10.

2.3 Hydrogen Peroxide and Other Oxidants

Oxygen has been the oxidant of choice in most studies, but hydrogen peroxide has been found to improve the rates of reaction with a variety of organic substrates under some conditions. This work is covered in the following:

hydrogen peroxide - 13, 22, 40, 62, 92, 102, 110, 126, 137, 170, 173, 251, 310, 330, 394, and 399; persulfate - 130; or ozone - 17 and g436.

2.4 Engineering Issues

In recent years the success of laboratory work has led to interest in applying the technology to environmental remediation and treatment of process waste streams. Work has appeared in the literature addressing issues related to the scale-up of the process and resolution of engineering problems. Progress has been significant and many companies are now providing turn-key systems for treating contaminated water and air (see Section 2.7).

2.4.1 Reactor and System Design

A number of papers have addressed topics relevant to the design of reactors for photocatalytic processes:

photochemical reactors - 390; photoelectrochemical system - 10; non-concentrating reactor - 137, 138, 330, 347, 421, 471, 513, 514, and 532; shallow ponds/tanks - 37, 85, and 512; parabolic trough - 52, 53, 71, 72, 134, 288, 306, and 346; kinetic modelling - 68, 214, 215, 276, 298, 301, 302, and 572; recirculating reactor - 80 and 456; fixed bed - 88, 110, 369, 415, and 530; filtration - 110; hybrid lamp/solar system - 111; equipment requirements - 197 and 421; ultrasonic reactor - 199; batch-type reactors - 228 and 229; optimization of air purification systems - 363; controlled periodic illumination - 418,419, and 420; or falling film reactor - 521.

2.4.2 Systems Analysis

As the technology for the photocatalytic treatment of contaminated air or water has progressed, a few studies have compared the costs of sunlight and electric lamps as photon sources; others have compared the photocatalytic processes with conventional treatment methods, such as carbon adsorption or W-peroxide oxidation:

process waste water - 53, 394, and 442; photocatalysis process cost - 56, 110, **251, 364, 421, 43** 1, g472, and 557; or photon costs from lamps and sunlight - 4 11 and 47 1.

2.5 Miscellaneous Topics

This category includes papers of interest that do not fall into the preceding headings: adsorption - 382 and 528; combined photocatalytic and biological treatment **-152, 227, 267, 268, 310, 412,** 434,435, and 476; non-aqueous solvent systems - 488 and 49 1; or electron microscopy of TiO_2 phases - 493.

2.6 Patents

The number of patents that cover aspects of photocatalytic technology has increased rapidly in the last decade. They cover a range of aqueous and gas-phase applications. The general topic of the patents are included in the following:

catalyst formulation - 1, 149, 193, 224, 225, 280, 281, 312, 345, 400, 404, 502, and 518; photoelectrochemical system - 10 and 344; spent plating bath - 24; point-of-use water treatment system - 65; water treatment system - 85 and 456; regeneration of adsorbents - 87; metals removal from water - 118 and 28 1; magnetic catalyst particle - 128; oil spill treatment - 152; catalyst on inorganic fibers - 168; photocatalysis with 185 nm light for air treatment - 169; removal of chlorinated compounds from vent gas (includes scrubber) - 183; removal of air pollutants (catalyst on exterior walls of buildings) - 185 and 335; additive to enhance degradation of plastics in the environment - 190 and 291; deodorizing agents **-202, 404, 502, 503** and 518; removal of nitrogen compounds from water - 222; regenerable deodorant - 231; combined biological and photocatalytic treatment of wastewater - 267 and 268; process for killing cells or disinfection - 283,391, and 503; photocatalyst plate material - 285; total organic carbon analyzer - 287; nitrogen and phosphorus analyzer - 451; purification of waste gases - 331; disinfecting construction materials - 333; methanol synthesis - 334 and 345; fluid purification - 391; method for preparing dialkyldipyridinium salts - 395; semiconductor modified with insoluble polyviologen derivatives - 396; moisture-resistant catalyst for ethylene oxidation - 400; or optical fiber as light source - 489.

2.7. Companies Active in the Field

The following is a list of companies that have products or services based on heterogeneous photocatalysis. The list is compiled from the best information available to the author from personal contacts and material published in the open literature.

American Energy Technologies, Inc.
Mr. Greg Peebles
P.O. Box 1865
Green Cove Springs, FL 32043
Telephone: 904-284-0552 Fax: 904-284-0006
Product(s): Stable W-transmissive polymers and glass for photoreactor construction and development and fabrication of photoreactors.

Degussa Corporation
Ms. Maria Nargiello
3500 Embassy Parkway, Suite 100
Akron, OH 44333
Telephone: 2 16-668-2235 Fax: 216-668-3846
Product(s): **Photocatalysts,** fumed titanium dioxide, P25 and high surface area P25.

Industrial Solar Technology
Mr. Ken May
4420 McIntyre Street
Golden, CO 80403
Telephone: 303-279-8 108 Fax: 303-279-8107
-Product(s): Compound parabolic concentrators, parabolic concentrators, and glass and polymer tubes for solar reactors.

Ishihara Sangyo Kaishi, Ltd.
l-3-11, Edohori, Nishi-ku
Osaka City 550, JAPAN
Telephone: **+81-6-444-5812** Fax: **+81-6-444-5878**
Product(s): Photocatalytic paints and papers.

IT Corporation
Mr. Richard Miller
3 12 Directors Drive
Knoxville, TN 37923
Telephone: 423-690-3211 Fax: 423-694-9573
Product(s): Provides technology based solutions to environmental problems, reactor design and process engineering for treatment systems, and manufactures treatment systems through its NEPCCO Equipment Division.

Kato Manufacturing Company, Ltd.
400, Iwasaki, Komaki City
Aichi Pref. 485, JAPAN
Telephone: +81-568-72-8280 Fax: +81-568-75-1385
Product(s): Glassware with photocatalytic titanium dioxide coatings.

KSE, Inc.
Dr. Charles Quinlan
P.O. Box 368
Amherst, MA 01004
Telephone: 413-549-5506 Fax: 413-549-5788
Product(s): Development and manufacturing of air emission control equipment for environmental remediation, industrial emissions, and indoor air quality applications.

LightStream Photocatalytic LLC
(A Division of E. Heller & Company)
Ephraim Heller
13 11 Harbor Bay Parkway
Suite 1000
Alameda, CA 94502
Telephone: 5 10-748-690 1 Fax: 5 10-748-6902
Product(s): Photocatalytic indoor air purification systems and photocatalytic paints and coatings.

Matrix Photocatalytic, Inc.
Mr. Bob Henderson
22 Pegler Street
London, Ontario
CANADA N5Z 2B5
Telephone: 5 19-660-8669 Fax: 5 19-660-8525
Product(s): Develop and supply photocatalytic treatment systems for aqueous and gas phase environmental remediation and control of process emissions.

NEPCCO
Mr. John S. "Sandy" Reese
2140-100 N.E. 36th Avenue
Ocala, FL 34470
Telephone: 904-867-7482 Fax: 904-867- 1320
Product(s): Provides photocatalytic oxidation treatment systems as stand alone units or integrated into existing treatment or manufacturing processes.

Photo-Catalytics, Inc.
Mr. Gerald Cooper
755 S. 42nd Street
Boulder, CO 80303
Telephone: 303-494-7623 Fax: 303-494-7623

Photox
Dr. Elliot Berman
P.O. Box 15717
Kenmore Station
Boston, MA 02215
Telephone: 617-353-6407 Fax: 617-353-6466
Product(s): Development of photocatalysts and coatings for indoor air purification and residential water treatment.

Purifics Environmental Technologies, Inc.
Mr. Brian Butters
161 Mallard Road
London, Ontario
CANADA NOM 1Z0
Telephone: 519-473-5788 Fax: 519-473-0934
Product(s): Sell or lease turn-key TiO_2 photocatalytic systems for treatment of ground water, process, and ultra pure water, perform laboratory and on-site treatability tests, and perform design work to integrate units into existing treatment systems.

Sachtleben Chemie
Z. Hd. Bernhard Becker/NPP
Dr.-Rudolf-Sachtleben - Str. 4
D-47198 Duisburg, GERMANY
Telephone: 02066-22-o Fax: 02066-2222-00
Product(s): Photocatalysts, sulfate process titanium dioxide, Hombikat UV 100

Science Applications International
Mr. Kelly Beninga
15000 West 6th Avenue
Suite 202
Golden, CO 80401
Telephone: 303-279-5677 Fax: 303-384-0320
Product(s): Develop and fabricate low-cost photochemical reactors.

Solar Kinetics, Inc.
Mr. Bennett Howell
P.O. Box 540636
Dallas, TX 75354
Telephone: 2 14-556-2376 Fax: 214-869-4158
Product(s): Develop and demonstrate solar photocatalytic systems for water treatment.

Trojan Technologies
Dr. William Cairns or Mr. Rory Murphy
3020 Gore Road
London, Ontario
CANADA N5V 4T7
Telephone: 5 19-457-3400 Fax: 519-457-3030
Product(s): Cooperative and in-house research and development of commercial photocatalytic systems.

United Technologies Research Center
Dr. James Freihaut
411 Silver Lane, MS 129-24
East Hartford, CT 06108
Telephone: 203-727-7328 Fax: 203-727-2 15 1
Product(s): Research and development services for photocatalytic systems.

3.0 Compounds Studied

The tables in this section have the same format as in the first report. No compounds have been removed from the tables but new compounds have been added to the second and third tables to incorporate the expanded work. The list of the compounds included in various lists of priority pollutants, air toxics, and the toxic release inventory compiled by the EPA[4] provides a convenient frame of reference for citing the application of photocatalysis to compound oxidation. Table 1 lists compounds in the EPA categories; Table 2 lists organic compounds that are not in EPA lists; and Table 3 covers inorganic compounds in EPA lists or that have been treated by a photocatalytic process. The inorganic compounds are arranged by element unless a significant number of citations referred to work on a specific ion or compound. Formulas of compounds, when given, are not in the standard format because the software used to prepare the tables does not support subscripts. A few broad categories are included in Table 2 that reflect new applications: bacteria, algae, and virus; coal or carbon; adsorbable organic halides (AOX); color or chemical oxygen demand (COD); and oil or petroleum. Again, the citation prefix "g" indicates a gas-phase study. The treatability of compounds not demonstrated can in many cases be inferred from results for related compounds in the tables.

[4]"Notice of the Second Priority List of Hazardous Substances Commonly Found at Superfund Sites," *Environmental Reporter,* October 28, 1988, 1255-1260.

Table 1. Organic Compounds in EPA Lists of Priority Pollutants, Air Toxics, or Toxic Release Inventory

Substance	Formula	Halo-gen	Het. Atom	Reference
1,1,1-Trichloroethane	CHCl2CH2Cl	Cl		;43,232,275
1,1,2,2-Tetrachloroethane	CHCl2CHCl2	Cl		;43,275
1,1,2-Trichloroethane	CHCl2CH2Cl	Cl		:75,g384
1,1,2-Trichloro-1,2,2-trifluoroethane	CCl2FCClF2	Cl,F		
1,1-Dichloroethane	CH3CHCl2	Cl		:75
1,1-Dimethyl hydrazine	(CH3)2NNH2		N	
1,2,3-Trichloropropane	CH2ClCHClCH2Cl	Cl		
1,2,4-Trichlorobenzene	C6H3Cl3	cl		159,474
1,2,4-Trimethylbenzene	C6H3(CH3)3			
1,2-Butylene oxide	H2COCHCH2CH3			
1,2-Dibromoethane	BrCH2CH2Br	Br		
1,2-Dibromo-3-chloropropane (DBCP)	CH2BrCHBrCH2Cl	Br,Cl		
1,2-Dichlorobenzene	C6H4Cl2	Cl		
1,2-Dichloroethane	ClCH2CH2Cl	Cl		'6,232,275
1,2-Dichloroethylene	ClHC:CHCl	Cl		
1,2-Dichloropropane	CH3CHClCH2Cl	c1		:32
1,2-Dinitrotoluene	C6H3CH3(NO2)2		N	
1,2-Diphenylhydrazine	C12H12N2		N	
1,2-Trans-dichloroethene	C2H2Cl2	Cl		
1,3,5-Trinitrobenzene	C6H3(NO2)3		N	
1,3-Butadiene	H2C:CHHC:CH2			
1,3-Dichlorobenzene	C6H4Cl	Cl		
1,3-Dichloropropene	CHCl:CHCH2Cl	Cl		232
1,4-Dichlorobenzene	C6H4Cl2	Cl		38,89,104,242,243,244,380
1,4-Dioxane	OCH2CH2OCH2CH2			
1-Amino-2-methylanthrquinone	C6H4[C(O)]2C6H2NH2CH3			
1-Bromo-4-phenyoxybenzene	p-BrC6H4OC6H5	Br		
2,2,4-Trimethylpentane	(CH3)3C5H9			
2,3,7,8-Tetrachlorodibenzo-p-dioxin	C12H4Cl4O2	Cl		
2,4,5-Trichlorophenoxyacetic acid	C6H2Cl3OCH2CO2H	Cl		
2,4,5-TP acid (silvex)	Cl3C6H2OCH(CH3)COOH	Cl		
2,4,5-Trichlorophenol	C6H2Cl3OH	Cl		
2,4,6-Trichlorophenol	C6H2Cl3OH	Cl		457
2,4,6-Trinitrotoluene	CH3C6H2(NO2)3			412,500
2,4 Diaminoanisole	(NH2)2C6H3OCH3		N	
2,4-Dichlorophenoxyacetic acid (24-D)	Cl2C6H3OCH2COOH	Cl		380,467
2,4-Diaminoanisole sulfate	(NH2)2C6H3OCH3.H2SO4		N	
2,4-Dichlorophenol	Cl2C6H3OH	Cl		5,430,448,467,468
2,4-Dimethylphenol	(CH3)2C6H3OH			

Substance	Formula	Halo-gen	Het. Atom	Reference
2,4-Dinitrophenol	C6H3OH(NO2)2		N	
2,4-Dinitrotoluene	C6H3CH3(NO2)2			
2,4-Toluene diamine	CH3(NH2)2C6H3		N	
2,6-Dinitrotoluene	C6H3CH3(NO2)2		N	
2,6-Xylidine	(CH3)2C6H3NH2		N	
2-Acetylaminofluorene	, CH3C(O)NHC6H3CH2C6H4	F	N	
2-Aminoanthraquinone	C6H4(CO)2C6H3NH2		N	
2-Butanone	CH3COCH2CH3			
2-Chloroacetophenone	C6H5COCH2Cl	Cl		
2-Chloroethyl vinyl ether	CH2ClCH2OCHCH2	Cl		
2-Chlorophenol	C6H4OHCl	Cl		91,107,175,175,176,296,423,497
2-Ethoxyethanol	H3CCH2OCH2CH2CH2OH			
2-Methoxyethanol	MeOCH2CH2OH			
2-Methylnaphthalene	C10H7CH3			
2-Nitrophenol	NO2C6H4OH		N	
2-Nitropropane	CH3CHNO2CH3		N	
2-Pentanone, 4-Methyl	CH3(CH2)2COCH3			
2-Phenylphenol	C6H5C6H4OH			
3,3'-Dichlorobenzidine	C6H3ClNH2C6H3ClNH2	Cl	N	
3,3'-Dimethoxybenzidine	[C6H3(OCH3)NH2]2		N	
3,3'-Dimethylbenzidine (o-Tolidine)	[C6H3(CH3)NH2]2		N	
4,4'-Dichlorodiphenyldichloroethylene	(ClC6H4)2CCCl2	Cl		
4,4'-Diaminodiphenyl ether	NH29C6H4)2NH2		N	
4,4'-Isopropylidenediphenol	(CH3)2C(C6H4OH)2			
4,4'-Methylenebis(N,N-dimethyl) benzenamine	C17H22N2		N	
4,4'-Methylenedianiline	H2NC6H4CH2C6H4NH2		N	
4,4'-Methylene-bis-(2-chloroaniline)	CH2(C6H4ClNH2)2	Cl	N	
4,4'-Thiodianiline	C12H12N2S		S,N	
4,6-Dinitro-o-cresol	CH3C6H2(NO2)2OH		N	
4,6-Dinitro-2-methylphenol	C7H6N2O5		N	
4-Aminoazobenzene	C6H5NNC6H4NH2		N	
4-Aminobiphenyl	C6H5C6H4NH2		N	
4-Chloroaniline	ClC6H4NH2	Cl		
4-Chlorophenyl phenyl ether	p-ClC6H4OC6H5	Cl		
4-Dimethylaminoazobenzene	(CH3)2C6H3NH2		N	
4-Methylphenol	p-CH3C6H4OH			328
4-Nitrobiphenyl	C6H5C6H4NO2		N	
4-Nitrophenol	NO2C6H4OH		N	140,348
5-Nitro-o-anisidine	NO2C6H3(NH2)(OCH3)		N	
Acenaphthene	C10H6(CH2)2			
Acenaphthylene	C12H8			
Acetaldehyde	CH3CHO			g404,g440

Substance	Formula	Halo-gen	Het. Atom	Reference
Acetamide	CH3CNOH2		N	194,
Acetone	CH3COCH3			g43.g253.g383.g384.g407. g450
Acetonitrile	CH3CN		N	g43,g252,g253
Acetophenone	CH3C(O)C6H5			477
Acrolein	CH2CHCHO			
Acrylamide	CH2CHCONH2		N	
Acrylic acid	H2C:CHCOOH			
Acrylonitrile	H2C:CHCN		N	
Aldrin	C12H8Cl6	Cl		
Ally1 chloride	H2C=CHCH2Cl	Cl		
Aniline	C6H5NH2		N	374
Anthracene	C6H4(CH)2C6H4			98.188
Aramite	(CH3)3CC6H4OCH2CH(CH3)-SO3C2H4Cl	c l	S	
Atrazine	C18H14ClN5	Cl	N	80,296,355,356.357.447,527
Benzal chloride	C6H5CHCl2	Cl		
Benzamide	C6H5CONH2		N	271.272
Benzene	C6H6			g43,110,137.138,154,g169.200, 269,322,330,g384,414,470, 488,530
Benzidine	NH2(C6H4)2NH2		N	
Benzoic acid	C6H5COOH			91,135
Benzoic tnchloride	C6H5CCl3	Cl		
Benzoyl chloride	C6H5COCl	Cl		
Benzoyl peroxide	(C6H5CO)2O2			
Benzo(a)anthracene	C22H14			188
Benzo(a)pyrene	C20H12			188
Benzo(b)fluoranthene	C20H 12			
Benzo(g,h.i) perylene	C22H12			
Benzyl alcohol	C6H5CH2OH			91.120
Benzyl chloride	C6H5CH2Cl	Cl		
BHC (Benzenehexachloride)	C6H6Cl6	Cl		
Biphenyl	C6H5C6H5			
bis(2-Chloroethoxy)methane	CH2(2-ClC2H5O)2	Cl		
Bis(2-chloroethyl) ether	ClCH2CH2OCH2CH2Cl	Cl		
Bis(2-chloro- 1 -methylethyl) ether	[ClCH2(CH3)CH]2O	Cl		
Bis(2-ethylhexyl) adipate	(C7H13)2C4H8(CO2)2			
Bis(2-ethylhexyl)phthalate	(C4H9CH(CH2))2OOC			
Bis(chloromethyl)ether	(CH2Cl)O(CH2Cl)	Cl		
Bromochloromethane	BrCH2Cl	Br,Cl		
Bromodichloromethane	CHCl2Br	Cl.Br		
Bromoethane	C2H5Br	Br		

Substance	Formula	Halo-gen	Het. Atom	Reference
Bromoform (Tribromomethane)	CHBr3	Br		235
Bromomethane (Methyl bromide)	CH3Br	Br		
Butyl acrylate	CH2:CHCOOC4H9			
Butylbenzyl phthalate	C4H9OOCC6H4COOC7H7			
Butyraldehyde	CH3(CH2)2CHO			
Calcium cyanamide	NCNCa		N	
Caprolactam	CH2(CH2)4NHCO		N	
Captan (N-Trichloromethylmercapto-tetrahydrophthalimide)	C9H8C13NO2S	Cl	N,S	
Carbaryl [1 -Naphthalenol, methylcarbamate]	C 10H7OOCNHCH3		N	362
Carbon disulfide	cs2		S	
Carbon tetrachloride	CCl4	Cl		g43,81,82,88,164,g169,277
Carbonyl sulfide	cos			
Catechol	C6H4(OH)2			
Chloramben (Benzoic acid, 3-amino-2, 5-dichloro-)	C6H(CO2H)(NH2)Cl2	Cl	N	
Chlordane	c 10H6C18	Cl		
Chloroacetic acid	CH2ClCOOH	Cl		40,275
Chlorobenzene	C6H5Cl	Cl		g102,322,336
Chlorobenzilnte (Benzeneacetic acid, 4-chloro-alpha-(4-chlorophenyl)-)	(C6H4Cl)2C(OH)COOC2H5	Cl		
Chlorodibentodioxins, various	c 12O2H8-xClx	Cl		
Chlorodibenzofurans	c 12OH8-xClx	Cl		
Chlorodibromomethane	ClBr2CH	Br,Cl		
Chlorodifluoromethane	CHClF2	Cl,F		
Chloroethane	C2H5Cl	Cl		
Chloroform	CHCl3	Cl		g43,73,81,129,219,220,232,g253, 277,278,314,315,327,364
Chloromethane	CH3Cl	Cl		g263
Chloromethyl methyl ether	C2H5ClO	Cl		
Chloroprene	H2C:CHCCl:CH2	Cl		
Chlorothalonil (1,3-Benzendedicarbonitrile, 2,4,5,6-tetrachloro-)	C6Cl4(CN)2		N	
Chrysene	C18H12			
cis-1,2-Dichloroethylene	ClHC:CHCl	Cl		
cis-1,3-Dichloropropene	CHCl:CHCH2Cl	Cl		
o-,m-.p-Cresols	CH3C6H4OH			60,6 1,429
Cumene	C6H5CH(CH3)2			
Cumene hydroperoxide	C6H5C(CH3)2OOH			
Cupferron (Benzeneamine, N-hydroxy-N-nitrose. ammonium salt)	C6H5N(NO)ONH4		N	
Cyclohexane	C6H12			

Substance	Formula	Halo- gen	Het. Atom	Reference
Cyclohexanone	C6H10O			
Cyclonite (RDX)	(CH2)4(NNO2)4		N	
Decabromodiphenyl oxide	(C6Br5)2O	Br		
Dialate [Carbamothioic acid. bis (1-methylethyl)-, S-(2,3-dichloro-2-propenyl) ester]	[(CH3)2CH]2NCOSCH2CClCHCl	Cl	N,S	
Diaminotoluene (mixed isomers)	CH3C6H3(NH2)2		N	
Diazomethane	CH2N2		N	
Dibenzofuran	C12H8O			
Dibenzo(a.h)anthracene	C22H14			
Dibromochloropropane	CH2BrCHBrCH2Cl	Br,Cl		
Dibutyl phthalate	C6H4(COOC4H9)2			
Dichlorobenzene (mixed isomers)	C6H4Cl2	Cl		
Dichlorobromomethane	CHBrCl2	Cl,Br		
Dichlorodifluoromethane	CCl2F2	Cl,F		
Dichlorvos (Phosphoric acid. 2 dichloroethenyl dimethyl ester)	(CH3O)2P(O)OCH:CCl2	Cl	P	265
Dicofol ,4.4'-Dichloro-alpha-trichloro-methylbenzhydroi	C14H9Cl5O	Cl		
Dieldrin/aldrin	C12H10OPCl6	Cl	P	
Diepoxybutane	C4H6O2			
Diethanolamine	(HOCH2CH2)2NH		N	
Diethyl phthalate	C6H4(CO2C2H5)2			
Diethyl sulfate	(C2H5)2SO4		S	
Dimethyl aminoazobenzene	C6H5NNC6H4N(CH3)2		N	
Dimethyl formamide (DMF)	HCON(CH3)2		N	
Dimethyl phthalate	C6H4(COOCH3)2			
Dimethyl sulfate	(CH3)2SO4		S	
Dimethylcarbamyl chloride	(CH3)2NCOCl	Cl	N	
Disulfoton	(C2H5O)2P(S)SCH2CH2SCH2CH3		P,S	
Di-n-butyl phthalate	C6H4(COOC4H9)2			
Di-n-octyl phthalate	C6H4(CO2)(n-C8H17)2			
Di-(2-ethylhexy) phthalate (DEHP)	C6H4[COOCH2CH(C2H5)C4H9]2			
Endosulfan	C9H6Cl6O3S	Cl		
Endrin aldehyde/ endrin	(C12H8OCl6)	Cl		
Epichlorohydrin	CH2OCHCH2Cl	Cl		
Ethyl acrylate	CH2:CHCOOC2H5			
Ethyl chloroformate	ClCOOC2H5	Cl		
Ethylbenzene	C6H5C2H5			35,137,138,330,477,530
Ethylene	H2C:CH2			g169,g400,g405,g518
Ethylene glycol	CH2OHCH2OH			31
Ethylene oxide	CH2CH2O			g169
Ethylene thiourea	NHCH2CH2NHCS		N,S	

Substance	Formula	Halogen	Het. Atom	Reference
Ethyleneimme (Aziridine)	CH2NHCH2		N	
Fluometuron [Urea. N.N-dimethyl-N'-[3-(trifluoromethyl)phenyl]-]	C10H11F3N2O	F	N	
Fluoranthene	C16H10			
Fluorene	C6H4CH2C6H4			98
Fluorotrichloromethane	CCl3F	Cl,F		
Formaldehyde	HCHO			g329,354
Heptachlor/heptachlor epoxide	C 10H7Cl7	Cl		
Heptane	CH3(CH2)5CH3			g368
Hexachlorobenzene	C6Cl6	Cl		234
Hexachlorobutadiene	Cl2C:CClCCl:CCl2	Cl		
Hexachlorocyclopentadiene	C5Cl6	Cl		
Hexachloroethane	Cl3CCCl3	Cl		
Hexachloronaphthalene	C 10H2Cl6	Cl		
Hexamethylphosphoramide	[(N(CH3)2]3PO		P,N	
Hexamethylene- 1,6-diisocyanate	OCN(CH2)6NCO		N	
Hexane	CH3(CH2)4CH3			g43
Hydroqunone	C6H4(OH)2			467521
Indeno(1,2,3-cd)pyrene	C22H12			
Isophorone	C(O)CHC(CH3)CH2C(CH3)2CH2			
Isopropyl alcohol	(CH3)2CHOH			28,g46,115,143,203,235,386
Lindane (gamma-Benzenehexachloride)	C6H6Cl6	Cl		
Malachite Green	C23H25ClN2	Cl	N	
Malathion	(CH3O)2P(S)SCH(CO2C2H5)-CH2CO2C2H5		P,S	131,177
Maleic anhydride	HC:CHC(O)OC(O)			30
Maneb (Carbamodithioic acid, 1,2-ethanediylbis-,manganese complex)	(SSCNCH2CH2NHCSS)Mn		N,S	
Mechlorethamine	CH3N(CH2CH2Cl)2	Cl	N	
Melamine	H2NCNC(NH2)NC(NH2)N		N	
Methanol	CH3OH			g43,53,203,g252,g253,293,364,373,g486,498
Methoxychlor	Cl3CCH(C6H4OCH3)2	Cl		
Methyl acrylate	CH2:CHCOOCH3			
Methyl butyl ketone	CH3COC4H9			
Methyl ethyl ketone	CH3COCH2CH3			88,448
Methyl iodide	CH3I	I		
Methyl isobutyl ketone	(CH3)2CHCOCH3			
Methyl isocyanate	CH3NCO		N	
Methyl methacrylate	CH2:C(CH3)COOCH3			
Methyl ten-butyl ether	(CH3)3COCH			34,g383,g384
Methylene bromide	CH2Br2	Br		
Methylene chloride	CH2Cl2	Cl		40,g43,232,g253

Substance	Formula	Halo-gen	Het. Atom	Reference
Methylenebis(phenylisocyanate) (MBI)	CH2(C6H4NCO)2		N	
Methylhydrazine	CH3NHNH2		N	
Michler's ketone	CO[C6H4N(CH3)2]2		N	
Mirex	C10Cl12	Cl		
Mustard gas	S(CH3CH2Cl)2	Cl	S	121
m-Nitroaniline	NO2C6H4NH2		N	
N,N-Dimethylaniline	C6H5N(CH3)2		N	
Naphthalene	C10H8			98
Naphthylamine (alpha-, beta-)	C10H7NH2		N	148
Nitrilotriacetic acid	N(CH2COOH)3		N	
Nitrobenzene	C6H5NO2		N	272,307,336,357,373
Nitrofen [Benzene, 2,4-dichloro-1-(4-nitrophenoxy)-]	C12H7Cl2NO3	Cl	N	
Nitrogen mustard (2-Chloro-N-(2-chloroethyl)-N-methylethanamine)	(ClCH2CH2)2NCH3	Cl	N	
Nitroglycerin	CH2NO3CHNO3CH2NO3		N	317,g318,g450
Nitrophenol	NO2C6H4OH		N	19,307
n-Butyl alcohol	CH3(CH2)2CH2OH			
n-Dioctyl phthalate	(C8H17OOC)2C6H4			
N-Nitrosodiethylamine	C4H10N20		N	
N-Nitrosodimethylamine	(CH3)2N2O		N	
N-Nitrosodiphenylamine	(C6H5)2NNO		N	
N-Nitrosodi-n-butylamine	ONN(n-C4H9)2		N	
N-Nitrosodi-n-propylamine	ONN(n-C3H7)2		N	
N-Nitrosomethylvinylamine	ONN(CH3)(C2H3)		N	
N-Niuosomorpholine	ONNC4H8O		N	
N-Nitrosonomicotine			N	
N-Niuosopiperidine	C5H10NHNO		N	
N-Niuoso-N-ethylurea	C(O)(NH2)N(NO)C2H5		N	
N-Nitroso-N-methylurea	C(O)(NH2)N(NO)(CH3)		N	
n-Pentane	CH3(CH2)3CH3			
Octachloronaphthalene	C10Cl8	Cl		
Octane	CH3(CH2)6CH3			
Oxirane	H2COCH2			
o-Anisidine	CH3OC6H4NH2		N	
o-Anisidine hydrochloride	CH3OC6H4NH2.HCl	Cl	N	
o-Nitroaniline	NO2C6H4NH2		N	
o-Toluidine	CH3C6H4NH2		N	
o-Toluidine hydrochloride	CH3C6H4NH2.HCl	Cl		
Parathion (DNTP)	(C2H5O)2P(S)OC6H4NO2		P,S	
PCBs (Aroclor 1260,1254,1248, and1242)	C12ClxH10-x	Cl		88,359,529 536
Pentachlorobenzene	C6Cl5H	Cl		
Pentachlorophenol	C6Cl5OH	Cl		5,52,130,277,305,306,423

Substance	Formula	Halo-gen	Het. Atom	Reference
Peracetic acid	:H3COOOH			
Phenanthrene	:4H10			
Phenol	:6H5OH			2.47.53,119.136,224,272-328. 36.g349,355,364.373,387, 15,423,429,g441,442,468, 69.566
Phenol,'-methyl	:H3C6H4OH			
Phosgene	:OCl2	Cl		
Phthalic anhydride	:6H4(CO)2O			·0
Picric acid	:6H2(NO2)3OH		N	
Polybrominatedbiphenyls	:12BrxH10-x	Br,Cl		
Propane sultone	:3H6SO2		S	
Propionaldehyde	:2H5CHO			45,246,g522
Propiolactone, beta-	)CH2CH2CO			
Propoxur [Phenol, 2-(1-methylethoxy)-methylcarbamate]	:11H15NO3		N	96
Propylene oxide	:H2OCHCH3			
Propylene (Propene)	:H3CH:CH2			367
Propyleneimine	:H3HCNHCH2		N	
Pyrene	:16H10			
p-Anisidine	CH3OC6H4NH2		N	
p-Chloro-m-cresol	C6H3CH3OHCl	Cl		
p-Cresidine	CH3C6H3(NH2)OCH3		N	
p-Nitrosodiphenylamine	(C6H5)2NNO		N	
p-Phenylenediamine	:6H4(NH2)2		N	
Quinoline	:9H7N		N	
Quinone	:6H4O2			
Quintozene (Pentachloronitrobenzene)	:6Cl5NO2	Cl	N	
Safrole	:3H5C6H3O2CH2			
sec-Butyl alcohol	:H3CH2CHOHCH3			
Sevin (carbaryl)	2 10H7OOCNHCH3			
Sodium Alizarinsulfonate	SO3C6H3(CO)2C6H2(OH)2Na		N,S	
Styrene	:6H5CH:CH2			·76
Styrene oxide	:6H5CHOCH2			
Terephthalic acid	C6H4(COOH)2			
tert-Butyl alcohol	(CH3)3COH			34
tert-Butylformate	(CH3)3COC(O)H			34,
Tetrachloroethylene	Cl2C:CCl2	Cl		g4,88,g183,g195,217,232,g253
Tetrachlorvinphos	C 1 0H0Cl4O4P	Cl	P	
Tetrahydrofuran	CH2CH2CH2CH2O			73
Thioacetamide	CH3CSNH2		S,N	
Thiourea	(NH2)2CS		S,N	

Substance	Formula	Halogen	Het. Atom	Reference
Tol uene	C6H5CH3			g16,g43,66,110,137,138,g169, g195,269,270,g329,330,336, g403,448,470,530
Toluene diisocyanate	CH3C6H3(NCO)2		N	
Total xylenes	C6H4(CH3)2			
Toxaphene	C10H10Cl8	Cl		
Triaziquone	C12H13N3O2		N	
Trichlorfon	(CH3O)2P(O)CH(OH)CCl3	Cl	P	
Trichloroethylene	CHCl:CCl2	Cl		g4,g11,40,g43,167,g174,g183, g195,g196,g198,217,232,239, 240,g252,g253,269,270,288, 327,346,g384,g445,448,g494, g485,g496,523,532
Triethylamine	N(C2H5)3		N	
Trifluralin	F3C(NO2)2C6H2N(C3H7)2	F	N	
Tnnitrophenylmethylnitramine	(NO2)3C6H2N(NO2)CH3		N	
Tris(2,3-dibromopropyl) phosphate	(CH2BrCHBrCH2O)3PO	Br	P	
Urethane (ethyl carbamate)	CO(NH2)OC2H5		N	
Vinyl acetate	CH3COOCH:CH2			
Vinyl bromide	CH2CHBr	Br		
Vinyl chloride	CH2:CHCl	Cl		g43
Vinylidene chloride	CH2:CCl2	Cl		
Xylene (mixed isomers)	C6H4(CH3)2			110,137,138,269,313,330,g403, 470,530
Zineb	Zn(CS2NHCH2)2		S,N	

Table 2. Other Organic Compounds Treated by a Photocatalytic Process

Substance	Formula	Halo-gen	Het. Atom	Reference
1,1,1,2-Tetrachloroethane	Cl3CCH2Cl	Cl		275
1, 1.1 -Trifluoro-2.2.2-trichloroethane	F3CCCL3	F,Cl		
1,1,1-Trifluorobromochloroethane	C2HF3ClBr	F		
1, I -Difluoro- I ,2,2-trichloroethane	ClF2CCHCl2	F.Cl		
1, I -Difluoro-1,2-dichloroethane	FClCCClH2	F,Cl		
1, 1 -Difluoroethylene	CH2CF2	F		
1,2-Dimethoxybenzene	(CH3O)2C6H4			272
1,2-Bis(2-chloroethoxy)ethane	(ClC2H4)2C2H4	Cl		506
I ,2,4,5-Tetramethylbenzene	(CH3)4C6H2			113
1,3-Diphenylisobenzofuran	(C6H5)2C6H2OC6H4			
I-Benzylnicotinamide	(C6H5)CH2(C5H3N)C(O)NH2		N	433
1-Bromodecane	BrC10H21	Br		
1-Bromododecane	BrC12H25	Br		
1-Butanol	CH3(CH2)3OH			
1 -Dodecanol	CH3(CH2) 1 1OH			
1-Hexene	C6H12			
1-(Methoxyphenyl)-2-propanol	(CH3OC6H4)(CH3)CHOH			25
1 -Propanol	n-C3H7OH			245,246,247
2,3- , 2,4- or 3,4-Difluorophenol	F2C6H3OH	F		429
Tris-(2,4-dichlorophenoxy)ethylphosphite	C2H5P[OC6H3Cl2]3	Cl	P	
2,6-Dichlorophenol	C6H3Cl2OH	Cl		
2,7-Dichlorodibenzo-p-dioxin	Cl2C12H6O2	Cl		
2-, 3-, 4-Fluorophenol	FC6H4OH	F		129
2-Chlorodibenzo-p-dioxin	ClC12H7O2	Cl		
2-Chloroethylmethylsulfide	ClCH2CH2SCH3	Cl	S	
2,3-Benzofuran	C8H6O			
2,3- and 2,5-Dichlorophenol	Cl2C6H3OH	Cl		
2,5-Dinitrophenol	(NO2)2C6H3OH	Cl	N	
2,6-Dichloroindophenol	C8H2N(OH)Cl2			
2,5-Furandimethanol	C4H2O(CH2OH)2			388
2-Chloroaniline	ClC6H4NH2	Cl	N	525
2-Coumaranone	C8H6O2			
2-Furoic Acid	(CH2)3CHOCO2H			
2-Hydroxypyridine	HOC5H4N		N	271
2-Hydroxytetrahydropyran	HOC5H9O			59
2-Naphthol	C10H7OH			
3,3,3-Trifluoropropene	CH2CHCF3			
3,3'-Dichlorobiphenyl	(ClC6H4)2	Cl		

Substance	Formula	Halo-gen	Het. Atom	Reference
3,4-Chlorophenol	3,4-Cl2C6H3OH	Cl		
3-Chlorophenol	m-ClC6H4OH	Cl		175,296,497
3-Chlorosalicylic acid	C7H5ClO3	Cl		
4-Bromophenol	BrC6H4OH	Br		328
4-t-Butyltoluene	p-(t-C4H9)C6H4CH3			
4-Chloro-3-nitro-benzotrifluoride	C6HCl(NO2)F3	F,Cl	N	
4-Chlorophenol	ClC6H4OH	Cl		108,140,141,142,172,173,175,277, 279,296,298,303,328,394, 443,g444,481,484,485,497, 512,513,514,521
4-Chlorophenylisocyanate	ClC6H4NCO	Cl	N	375
4-Fluorophenol	FC6H4OH	F		328
4-Hydroxyacetophenone	HOC6H4C(O)CH3			328
4-Hydroxybenzyl Alcohol	p-HO(C6H4)CH2OH			386
4-Iodophenol	IC6H4OH	I		328
4-Methoxyphenol	CH3C6H4OH			328
4-Nitroaniline	NO2C6H4NH2		N	442
4-Nitrocatechol	(NO2)C6H3(OH)2		N	
4-Niuophenylethylphosphinate	(NO2)C6H4(C2H5)PO2		N,P	
4-Nitrophenylisopropylphosphinate			N,P	
4-nitrophenyldiethylphosphate			N,P	
4-Thiophenyl- 1 -butanol	C6H5S(CH2)4OH		S	
4-Trifluoromethylphenol	CF3C6H4OH	F		328
5-Fluorouracil	FC4H(NH)2(O)2	F		12
5-Hydroxypentanoic acid	HO(CH2)4CO2H			
12-phenyldodecanesulfonate, Sodium Salt	C6H5(CH2)12SO3H			
Acenapthane	C10H16(CH2)2			98,188
Acetic Acid	CH3CO2H			52,203,210,212,275,354,g416, g417
Acetophenone	CH3COC6H5			
Acetylene	C2H2			236,254
Acid orange 7	Na,O3SC6H4N2C10H6OH		N,S	480,482,483
Adipic acid	C5H11CO2H			147
Aldicarb	CH3SC(CH3)2CHN(O)C(O)NHCH3		N,S	5
p-alkylphenol (various)	R(C6H4)OH			
Allyl alcohol	C3H5OH			
Alochlor				
p-Aminophenol	NH2(C6H4)OH		N	74,79,101
Anthraquinone-2-sulfonic acid	HO3SC14H7O2		S	227
AOX or Haloform Precursors				248,249,434,435
Asulam				
Azobenzenes (various)	XC6H4NNC6H4X		N	103
Azobisformamidoaceuc acid			N	490

Substance	Formula	Halo-gen	Het. Atom	Reference
Bacteria/Algae/Virus				15,55,123,124,125,126,g139,189, 216,283,284,333,365,391,401, 437,503,505,507
Benzaldehyde	C6H5C(O)H			476
Benzophenone	(C6H5)2CO			323
Benzoquinone	C6H4O2			272,385,387
Benzyldodecyldimethylarnonium chloride	(C6H5CH2)(C12H25)(CH3)2N,Cl	Cl	N	161,533
Benzyltetradecyldimethylamonium chloride	(C6H5CH2)(C14H27)(CH3)2N,Cl	Cl	N	158,160
Biomass				187
Biphthalate	(C6H4)(CO2H)CO2)(-1)			
Bromobentene	BrC6H5	Br		336
Butane	C4H10			
But-2-ene, trans	CH3CHCHCH3			g181
Butyl alcohol	n-C4H7OH			53
Butylamine	n-C4H7NH2		N	75
t-Butylazine			N	296,393
Butadiene	CH2CHCHCH2			g329
Butyric acid	C3H7CO2H			135,354
Carbetamide			N	54
Carbon dioxide (reduction)	202			166,186,191,282,334,438,460
Carbon monoxide	30			g264,g405,g452
Carbon tetrabromide	CBr4	Br		
Catechol	C6H4(OH)2			521
Cetyldimethylbenzylamonium chloride	CH3(CH2)15(CH3)2(C6H5CH2)N,Cl		N	200,370
Cetylpyridinium chloride	N-[CH3(CH2)15](C5H5N),Cl		N	370
Chloroacetaldehyde	CH2ClC(O)H	Cl		275
Chlorobenzoic acids, o-, m-, or p-	Cl(C6H4)CO2H	Cl		93
Chlorofluorocarbons, various		F,C		
Chloral hydrate	Cl3CO(OH)2	cl		275.534
Chloranil, o- and p-	C6Cl4O2	Cl		
Chloroethylammonium chloride	ClH3N,Cl	Cl	N	
Chlorpyrifos		Cl	S,N	127
Ciba Orange RI				528
Coal or Carbon				567
Color and/or COD (in wastewater)				13,100,103,251,332,434,435, 159.465
Congo Red	C32H22O6N6S2Na2			
Cresol violet	C16H8NO(NH2),Cl		N	
Creosote phenolics				464
Cyanuric acid	C3N3(OH)3		N	
Cyclododecanol	C12H23OH			120
Cyclohexane	C6H12			g368,g508
Cyclohexanedicarboxylic Acids	C6H10(CO2H)2			

Substance	Formula	Halo-gen	Her. Atom	Reference
Cyclohexanol	C6H11OH			120.442
Cyclohexene	C6H10			
Cyclohexene oxide	C6H10O			
Cyclophosphamide	OPONHC3H6[N(C2H4Cl)2]		P,N	
Cynnamyl alcohol	C6H4C2H2OH			
DDT	(ClC6H4)2CHCCl3	Cl		
Decalin	C10H18			
Decamethylteuasiloxane	(CH3)10Si4O3		Si	g361
Decanoic acid	C9H19CO2H			
Decanol	HOC10H21			
Desipramine	(C6H4)2(CH2)2N(CH2)3NHCH3			
Dibenzo-p-dioxines, various		Cl		536,555
Dibromomethane	CH2Br2	Br		
Dichloroacetic acid	Cl2CHCO2H	Cl		40,52,167,256,275,277,392
Dichloroacetyl Chloride	Cl2CHCOCl	Cl		g239,g240
Dimethylamme	(CH3)2NH		N	364
Dimethylsulfide	(CH3)2S		S	g361,g363
Dimethyl-2,2-dichlorovinyl phosphate	(CH3)2(Cl2CCH)PO4	Cl	P	177
Diphenylmethane	(C6H5)2CH2			
Diphenylsulfide	(C6H5)2S		S	
Direct blue 1	[(Na,O3S)C16H6(NH2)(OH)-(OCH3)N2]2		N,S	480
Dodecane	C12H26			
Dodecyl sulfate	(C12H25)2SO4			
Dodecylbenzenesulfonate	(C12H25)C6H4SO3)(-1)		S	160,161,533
Dodecyldecaoxyethylenephosphates			P	162
Dodecylpyridinium chloride	(C12H25)C5H5NH,Cl	Cl	N	23,156,158
Doxycycline				
Eosin				
Ethambutol			N	261
Ethane	C2H6			g487,488
Ethanol	C2H5OH			28,g43,122,194,203,g450,454
Ethylacetate	CH3CO2C2H5			
Ethylenediaminetetraacetic acid	(O2CCH2)4N2C2H4		N	259,373
2-, 3-, or 4-Ethylphenol	(C2H5)C6H4OH			177
Feniuothion	C9H12NO5PS		NSP	
Fluorescein	C20H 1205			
Folicur			N	491
Formic Acid	HCO2H			2,80,117,135,223,233,275,354,373,418,419,420
Fullerenes	C60, C70, and C84			207,208,408
Fulvic acid				177,573

Substance	Formula	Halo-gen	Het. Atom	Reference
Glycerol	C3H5(OH)3			
HCFC or HFC		Cl,F		g455
Heparin				54
Hexafluorobenzene	C6F6	F		308
Hexafluoropropene	CF2CFCF3	F		113
Hexanol	C6H13OH			120
Humic Acids				132,170,250,332,479
Hydroxybenzoic acid (various)	HOC6H4(OH)CO2H			
Hydroxycarboxylic acids, alpha	RCH(OH)CO2H			
Hydroxyethylcellulose				
Indole	C8H6NH		N	g361
Isobutane	C4H10			86
Isobutanol	CH3CH(CH3)CH2OH			
Isobutene	C4H8			
Isobutyric Acid	CH3CH(CH3)CO2H			
Isoprene	CH2C(CH3)CHCH2			g192
Isorsorbide dinitrate	C6O2H8(ONO2)2		N	
Iso-octane	(CH3)2CH(CH2)4CH3			g43,g253
L-Lysine	NH2(CH2)4CH(NH2)CO2H			
Lactic acid	C3H6O3			163
Kraft lignin				187,337,434,435
Maleic acid	HO2CCHCHCO2H			135
Malonic acid	CH2(CO2H)2			135,147,259
Methane	CH4			g487,488
Methanethiol	CH3SH			g504
Methylcyclohexane	CH3C6H11			g368
Methyl orange	Na,O3SC6H4N2C6H4N(CH3)2		N,S	77,78,301
Methyl viologen	(CH3C5H4N)2,Cl2	Cl	N	260,301,501
Methylene blue	(CH3)2NC6H3NSC6H3N(CH3)2,Cl	Cl	N,S	17,39,324,463,475
Methylvinylketone	CH3COC2H3			
Monuron	ClC6H4NHCON(CH3)2	Cl	N	20,375
m-Phenoxytoluene	m-C6H5O-C6H4CH3			
N,N,N',N'-Tetraethyloxonine			N	179
Naphthol	C10H7OH			
Nile Blue A	C16NO(NH2)N(C2H5)2,SO4		N,S	179
Nitrocellulose			N	12
p-Nitrotoluenesulfonic acid	(CH3)(NO2)C6H3SO3H		N,S	310
Nitrotoluene, various	NO2C6H4CH3		N	
Nonylphenolethoxylate	C9H17C6H4OC2H5			
Oil/Petroleum				44,152,153,200,320
Oxalic acid	C2O4H2			135,147,259,273,275,354
Pendimethalin				351
Pentafluorophenol	C6F5OH			308

Substance	Formula	Halo-gen	Het. Atom	Reference
n-Pentyl amine	n-C5H11 NH2		N	
Permethrin				161
Phenosafranin	C6H5N2C12H4(NH2(CH3)2		N	39
Picoline	CH3C5H4N		N	
Piperidene	C5H1 ONH		N	75
Polyethoxylene Alkyl Ethers	R2(OC2H4)n			156,432
Polyethylene	(CH2CH2)n			291
Polypropylene	[(CH3)CHCH2]n			291
Polyvinylalcohol	(C2H3OH)n			213,292
Proline	C4H8NCO2H		N	
Prometon				
Prometryn				
Propane	C3H8			g487
Propionic acid	C2H5CO2H			
Propylene glycol dinitrate	CH3CH(NO3)CH2(NO3)		N	257
Propyne	CH3CCH			
Propyzarnide			N	473
Pyridine	C5H5N		N	75.g195.27 1,g402
Pyrocatechol	o-C6H4(OH)2			
Pyrrole	C4H5N		N	g361
Reactive Dyes				299
Red Dye 79			N,S	
Resorcinol	C6H6O2			101
Rhodamine B	CH3OC(O)(C6H4)C13H6O(NH2)2		N	
Rhodamine 6G	C2H5OC(O)C6H4C13H4(CH3)2-[N(C2H5)]2,Cl	Cl	N	297
Rhodamine 6ZH				237
Rose Bengal	Na2,O2CC6Cl4C13H2OI4O2	Cl,I		393
S-Dodecyl thioether carboxylates			S	157
S-Ethyl-N,N-dipropyl thiocarbamate (EPTC)	(C2H5)SC(O)N(C3H7)2		N,S	478
S-Ethyl-N.N-diisopropylthiocarbamate (Butylate)	(C2H5)SC(O)N(i-C3H7)2		N,S	478
S-Ethyl-4-hexahydro-1-H-azepine-1-carbothionate (molinate)			N,S	478
S-Propyl-N-cyclohexyl thiocarbamate (cycloate)	(C3H7)SC(O)NH(C6H11)		N,S	478
S-Propyl-N,N-dipropyl thiocarbamate (vemolate)	(C3H7)SC(O)(NC3H7)2		N,S	478
Salicylic acid	C7H6O3			7,92,95,97,99,221,302,373,376,448,454,466,52 1,524
Simazine	(C2H5)Cl(NHC2H5)C3N3			
Sodium chloroacetate	CH3CO2Na	Cl		

Substance	Formula	Halo-gen	Het. Atom	Reference
Sodium dodecylbenzene sulfonate	ͻ12H25C6H4SO3Na		S	
Stilbene	ͻ6H5CHCHC6H5			
Succinic acid	⊣O2CCH2CH2CO2H			35,147,163
Sucrose	ͻ12H22O11			
Sulfones	ʀS(O)2R'		S	ı39
Tetrachlorvinphos	ͻHClCH(2,4,5-Cl3C6H2)(CH3)PO4	Cl	P	²18
Tetrafluoroethylene	ͻ2F4	F		
Tetralin	ͻ10H12			
Tetramethylenediamine	ɴH2(CH2)4NH2		N	
Tetrabutylammonium phosphate	[(n-C4H9)4N]4.PO4		P	
Theophylline	C7H8N4O2.H2O		N	
Thioethers	RSR'		S	121
Thiobencarb				322.336
Thymine	ͻ5H6N2O2		N	
Thionine	3 12NS(NH2),O2CCH3		S,N	19
p-Toluenesulfonic acid	ͻH3(C6H4)SO3H		S	ͻ0,62
s-Triazines			N	²74
Trichloroacetic acid	Cl3CCO2H	Cl		10.275
Trietazine			ɴ	
Triethanolamine	N(CH2CH2OH)3		ɴ	433
Trifluoroacetic acid	CF3CO2H	F		238
Trihydrazmotriazine			N	490
Trihydroxybenzene	(HO)3C6H3			
Trimethylamine	(CH3)3N		ɴ	
·Trinitrophenol	(NO2)3C6H2OH			
Triphenylacetic acid	(C6H5)3CCO2H			
Umbelliferone	C9H6O3			

Table 3. Inorganic Substances Included in EPA Lists of Hazardous Substances and/or Treated by a Photocatalytic Process

Substance/Element	Formula/Symbol	Reference
Actinides	Th,Pa,U,Np,Pu	
Aluminum (fume or dust)	Al	
Aluminum oxide	A1203	
Ammonia	NH3	364,492,g5 18
Ammonium nitrate (soln)	NH4NO3	58
Ammonium sulfate (soln)	(NH4)2SO4	
Antimony	Sb	
Arsenic	As	
Asbestos	Mg,Si	
Azide ion	N3(-)	
Barium	Ba	
Beryllium	Be	
Bismuth	Bi	
Boron	B	
Cadmium	Cd	221,371,372,373
Chlorine	Cl	
Chlorine dioxide	C102	
Chromium	Cr	71,72,106,134,255,371,372,373
Cobalt	co	
Copper	cu	109,117,165,166,221,371,372,373, 498
Cyanide and Complexes	CN(-1) and M(CN)x	3,9,106,178,262,377,378,379,540,545,571
Cyanite ion	CNO(-1)	57
Gold	Au	57,115,373
Halide ion	X(1-), X = F, Cl, Br, or I	292,398,542
Hydrazine	H2NNH2 .	
Hydrogen sulfide	H2S	538,539,562,570
Hypophosphorus acid	H2PO2	24,163,282
Iron	Fe	154
Lead	Pb	272
Manganese	Mn	
Mercury	Hg	3,22 1.37 1,373,377,379, 162,499
Molybdenum	Mo	
Nickel	Ni	109.37 1,372,373
Nitrates/nitrites	NO3(-1),NO2(-1)	294,295

Substance/Element	Formula/Symbol	Reference
Nitrogen oxides	NOX	g179,g180,g181,g182,g409, g410,g453
Nitrogen	N2	461
Oxalate ion	C2O4(2-)	
Oxygen	02	
Ozone	03	g436
Palladium	Pd	
Phosphorus		
Platinum	Pt	37 1,372,373
Radium	Ra	
Radon	Rn	
Rhodium	Rh	
Selenium	Se	
Silicon	Si	
Silver	Ag	25,78,92,155,--"1,--294,37 1,373
Strontium	Sr	
Sulfate radical	SO4(1-)	
Sulfite		114,294,54 1
Sulfur		
Sulfur dioxide	so2	
Sulfuric acid	H2SO4	
Thallium	Tl	
Thiocyanate	SCN(1-)	59,540
Thiosulfate	S2O3(2-)	
Thorium	rh	
Tin	Sn	
Tritium	H,(T)	
Tungsten	W	
Vanadium	V	
Zinc	zn	

4.0 Conclusions

The level of activity in this field continues to grow at a rapid rate. The potential to develop new methods for solving environmental problems is the primary driving force for the R&D activity. However, the patents that have been awarded and the increase in research activity in areas such as water and air disinfection, odor control, indoor air quality, and consumer products indicate that the technology has a broader commercial potential. Recent work reflects the increased interest in applying photocatalytic processes to the treatment of contaminated gas streams. More attention is also being paid to the detection and identification of intermediates and by-products that can be formed during the photocatalytic process, both in aqueous and gas phase systems. This can be an aid in developing an understanding of the chemical mechanisms of the processes and is necessary to insure that potentially harmful substances are not left in the processed stream. Still, relatively few studies include mass balances for the reactions. Kinetic models that can be used to size treatment systems are also relatively rare. As systems are deployed in the field, it is increasingly important that the issues of catalyst lifetime and regeneration be addressed. Related to this is the need to identify those components of an air or water stream that can inhibit or kill activity. All of these are important to the design of efficient and economical treatment systems. The high level of activity in this field is likely to continue -- it remains to be seen how widespread the applications may be.

5.0 Bibliography

1. Abe, Takeaki, inventor. "Photocatalyst." Fuji **Chitan** Kogyo **Kk,** assignee. Japan Patent, 05096181 **A2. 20** April 1993. ***CA119(14):147490u.***
modified TiO_2, other semiconductor, immobilized TiO_2.

2. Aguado, M. A., M. A. Anderson, and C. G. Hill Jr. "Influence of Light Intensity and Membrane Properties on the Photocatalytic Degradation of Formic Acid Over TiO_2 Ceramic Membranes." *J. Mol. **Catal.*** **89(1-2)** (1994): 165-78.
immobilized TiO_2, process efficiency, aqueous phase.

3. Aguado, M. A., S. **Cervera-March,** and J. Gimenez. "Continuous Photocatalytic Treatment of **Mercury(II)** on Titania Powders. Kinetics and **Catalyst** Activity." *Chem. Eng. **Sci.** 50,* no. 10 (1995): 1561-9.
TiO_2, oxidant, **reductant,** aqueous phase, application, mechanism, modeling, metal removal.

4. AI-Ekabi, Hussain, Brian Butters, Dale Delany, Wendy **Holden,** Tony Powell, and Joan Story. "The Photocatalytic Destruction of Gaseous **Trichloroethylene** and **Tetrachloroethylene** Over Immobilized Titanium Dioxide." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. **Ollis** and Hussain AI-Ekabi, 719-25, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, gas phase, immobilized TiO_2.

5. Al-Ekabi, Hussain, **Ali** Safarzadeh-Amiri, Wendy **Sifton,** and Joan Story. "Advanced Technology for Water Purification by Heterogeneous Photocatalysis." ***Int.** J. Environ. **Pollut.*** 1, no. l-2 (199 1): 125-36.
TiO_2, reactor, aqueous phase, process efficiency, immobilized TiO_2.

6. **Alarcon,** R. Parreno, and A. Morales-Rubio. "**Online** Catalytic Photodegradation of Aldicarb." *J. Flow Injection Anal.* 11, no. 1 (1994): 79-93.
TiO_2, reactor, pesticide, aqueous phase, process **efficiency.**

7. **Amalric,** Laurence, **Chantal Guillard,** and Pierre **Pichat.** "The Photodegradation of **2,3-Benzofuran** and Its Intermediates, **2-Coumaranone** and **Salicylaldehyde,** in TiO_2 Aqueous Suspensions." ***J. Photochem.*** *Photobiol., A 85,* no. 3 (1995): 257-62.
TiO_2, aqueous phase, application, mechanism, process efficiency.

8. **Ameta,** Surech C., Mukesh Mehta, Bhoopendra Sharma, and Manju Dak. "Photocatalyzed Reaction in Sodium Nitroprusside-Thiocyanate System." ***Izv.*** *Vyssh. Uchebn. **Zaved.,** Khim. Khim. **Tekhnol.** 37,* no. 2 (1994): 43-7.
TiO_2, other semiconductor, aqueous phase, process efficiency, metal removal.

9. **Ameta,** Suresh C., Manju Bala, Jatinder Kaur, and Sapna Sahasi. "**Photocatalytic** Reactions of Sodium Nitroprusside." *Arabian **J. Sci.** Eng.* 19, no. 1 (1994): 71-5.
TiO_2, other semiconductor, aqueous phase, application, mechanism, metal removal.

10. Anderson, Marc A., inventor. "Reactor Process Using Metal Oxide Ceramic Membranes." Wisconsin Alumini Research Foundation, assignee. United States Patent, 5308454.3 May 1994. *CA121:94509.*
TiO_2, other semiconductor, engineering, reactor, modified TiO_2, immobilized TiO_2, catalyst reactivation.

11. Anderson, Marc A., Suzuko Yamazaki-Nishida, and Salvador Cervera-March. "Photodegradation of Trichloroethylene in the Gas Phase Using Titanium Dioxide Porous Ceramic Membrane." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 405-20, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, reactor, gas phase, modified TiO_2, immobilized TiO_2.

12. Ando, Hiromi, Akiyoshi Yamaoka, Jun Yamauchi, and Masami Sugita. "Influence of Titanium Pigments on Lightfastness of Nitrocellulose (NC) Film." *Hikaku Kagaku 40,* no. 2 (1994): 103-10.
TiO_2, application, mechanism, immobilized TiO_2, polymer stabilization.

13. Anheden, Marie, D. Yogi Goswami, and G. Svedberg. "Photocatalytic Treatment of Wastewater From 5-Fluorouracil Manufacturing." *Solar Engineering* 1995, eds. William B. Stine, Tadayoshi Tanaka' and David E. Claridge, 439-8, New York, NY: ASME, 1995.
TiO_2, oxidant' aqueous phase, application.

14. Anpo, M. "Photocatalysis and Photoinduced Reactions on Well-Defined Supported Metal Oxides - Molecular Scale Reaction Mechanisms." *Photochemical Conversion and Storage of Solar Energy, Proceedings of the 8th International Conference on Photochemical Conversion and Storage of Solar Energy,* eds. E. Pelizzetti and M. Schiavello, 307-2 1, Dordrecht: Kluwer Academic Publishers, 199 1.
TiO_2, other semiconductor, modeling, gas phase, modified TiO_2, mechanism, immobilized TiO_2, adsorption.

15. Araz, Klodya Vert, and Miray Bekbolet. "Photochemical Sterilization of E. Coli in Drinking Water." *Kim. Kim Muhendisligi Semp.,* Volume 4,255-K Edited by: Aydin, Adnan. Marmara Univ. Fac. Sci. Lett.: Istan, 1992.
TiO_2, disinfection, aqueous phase.

16. Artem'ev, Yu. M., N. N. Nikolaeva, and M. A. Artem'eva "Some Features of the Photocatalytic Destruction of Air Pollutants - Toluene on Titanium Dioxide." *Vestn. S.-Peterb. Univ., Ser. 4: Fiz., Khim.* (1) (1994): 95-9.
TiO_2, gas phase, oxidant, immobilized TiO_2.

17. Artemjeva, M. A., and Yu. M. Artemjev. "Photostimulated Degradation of Methylene Blue in Ozonated Water Suspensions of TiO_2 and Nb2O5." *Vestn. S.-Peterb. Univ., Ser. 4: Fit., Khim.,* no. 4 (1993): 90-2.
TiO_2, other semiconductor, oxidant' aqueous phase.

18. Ashokkumar, M., A. Kudo, N. Saito, and T. Sakata. "Semiconductor Sensitization by RuS_2 Colloids on TiO_2 Electrodes." *Chem. Phys. Let. 229* (1994): 383-K
TiO_2, other semiconductor, modified TiO_2.

19. Augugliaro, V., M. J. Lopez-Munoz, L. Palmisano, and J. Soria "Influence of **pH** on the Degradation Kinetics of Nitrophenol Isomers in a Heterogeneous Photocatalytic System." ***Appl. Catal.***, *A* 101, no. 1 (1993): 7-13.
TiO_2, aqueous phase.

20. Augugliaro, V., G. **Marci,** L. Palmisano, E. Pramauro, and A. Bianco-Prevot. "Kinetics of Heterogeneous Photocatalytic Decomposition of Monuron Over Anatase Titanium Dioxide Powder." *Res.* ***Chem. Intermed.*** 19, no. 9 (1993): 839-53.
TiO_2, pesticide, aqueous phase.

21. Augugliaro, V., M. **Schiavello,** and L. Palmisano. "Rate of Photoabsorption and Turnover Number: Two Parameters for the Comparison of Heterogeneous Photocatalytic Systems in a Quantitative Way." *Coord.* ***Chem.*** *Rev.* 125, no. 1-2 (1993): 173-81.
TiO_2, other semiconductor, engineering, modeling, aqueous phase, process efficiency.

22. Augugliaro, Vincenzo, Vittorio **Loddo,** Leonardo **Palmisano,** and Mario Schiavello. "Performance of Heterogeneous **Photocatalytic** Systems: Influence of Operational Variables on Photoactivity of Aqueous Suspension." *J.* ***Catal.*** 153, no. 1 (1995): 3240.
TiO_2, modeling, oxidant, aqueous phase, modified TiO_2, process efficiency, mechanism, anion inhibition.

23. Avranas, A., I. Poulios, C. Kypri, D. Jannakoudakis, and G. Kyriakou. "Heterogeneous Photocatalytic Degradation of the **Cationic** Surfactant Dodecylpyridinum Chloride." ***Appl. Catal., B*** *2,* no. 4 (1993): 289-302.
TiO_2, other semiconductor, **metallized** TiO_2, aqueous phase.

24. **Azuma,** Kunihiko, and Kenji **Ootsuka,** inventors. "Treatment of Aging Effluents From Plating Containing Hypophosphorous Acid Ion." Japan Tokyo Prefecture, assignee. Japan Patent' 06136549 A2. 17 June 1994. ***CA121:116805.***
TiO_2, reductant, oxidant, **metallized** TiO_2, aqueous phase, modified TiO_2, application, engineering.

25. Baciocchi, Enrico, Cesare Rol, Giovanni V. Sebastiani, and **Luca** Taglieri. "Structural Effects in the **TiO_2-Photocatalyzed** Oxidation of Alkylaromatic Compounds in Acetonitrile in the Presence of Ag_2SO_4." *J. Org.* ***Chem.*** *59,* no. 18 (1994): 5272-6.
TiO_2, oxidant, **metallized** TiO_2, nonaqueous, metal removal.

26. Bahador, **Sardar** Khan. "Semiconducting **Metal** Oxide Photoelectrodes: Their Probed Characteristics and Implications. (Pt. 3). **Interfacial** Photodynamics." *Front. Sci. Ser.* 7 (New Energy Systems and Conversions) (1993): **715-20.**
TiO_2, aqueous phase, mechanism.

27. Bahnemann, D. W. "Mechanism of Organic Transformations on Semiconductor Particles." *Photochemical Conversion and Storage of Solar Energy, Proceedings of the 8th International Conference on Photochemical Conversion and Storage of Solar Energy,* eds. E. Pelizzetti and M. Schiavello, 251-76, Dordrecht: **Kluwer** Academic Publishers, 199 1.
TiO_2, other semiconductor, oxidant, aqueous phase, modified TiO_2, process efficiency, **mechanism.**

28. Bahnemann, Detlef. "**Ultrasmall Metal** Oxide Particles: Preparation, Photophysical Characterization, and Photocatalytic Properties." *Isr. J.* ***Chem.*** *33,* no. 1 (1993): 115-36.
TiO_2, other semiconductor, oxidant, reductant, aqueous phase, modified TiO_2, mechanism.

29. Bai, Chuansheng. "Preparation and Characterization of the Phases Formed by the Reactions of Transition Metal Precursors With **MgO, Al_2O_3**, and **$MgAl_2O_4$**, and Preparation and Characterization of Titanium(N) Oxide Photocatalysts." Ph.D. diss., Brown Univ., Providence, RI, USA, 1993.
TiO_2, modified **TiO_2**.

30. **Bajt,** O., B. Sket, and J. Faganeli. "The Effect of Semiconductor Oxides on the Photochemical Degradation of **Phthalic** and **Maleic** Anhydrides in Aqueous Media." *Toxicol. Environ. Chem. 40,* no. 1-4 (1993): 267-73.
TiO_2, other semiconductor, aqueous phase.

31. Bamwenda, G. R., S. **Tsubota,** T. Kobayashi, and M. Haruta "Photoinduced Hydrogen Production From an Aqueous Solution of Ethylene Glycol Over **Ultrafine** Gold Supported on **TiO_2**." *J. Photochem. Photobiol. A: Chem. 77* (1994): 59-67.
TiO_2, reductant, metallized **TiO_2**, aqueous phase, modified **TiO_2**.

32. Bard, Allen J. "Photoelectrochemistry and Heterogeneous Photocatalysis at Semiconductors." *J. Photochem.* 10 (1979): 59-75.
TiO_2, other semiconductor, reactor, modeling, solar, metallized **TiO_2**, aqueous phase, modified **TiO_2**, application, process efficiency, mechanism.

33. Bard, Allen J. "Semiconductor Particles and Arrays for the Photoelectrochemical Utilization of Solar Energy." *Ber. Bunsenges. Phys. Chem. 92* (1988): 1187-94.
TiO_2, other semiconductor, solar, aqueous phase, application, mechanism.

34. Barreto, **Reynaldo** D., Kimberly A. Gray, and Krista Anders. "Photocatalytic Degradation of Methyl-Tert-Butyl Ether *in* **TiO_2** Slurries: a Proposed Reaction Scheme." *Water Res. 29,* no. 5 (1995): 1243-8.
TiO_2, aqueous phase, application, mechanism.

35. Beaune, O., A. Finiels, P. Geneste, P. **Graffin,** A. **Guida,** J. L. Olive, and A. Saeedan. "Selective Photocatalytic Oxidation of Hydrocarbon Compounds Over **Zeolites.**" *Stud. Surf. Sci. Catal. 78,* Heterogeneous Catalysis and Fine Chemicals III (1993): 401-8.
TiO_2, modified **TiO_2**, gas phase, immobilized **TiO_2**, adsorbent.

36. Becker, M., B. **Gupta,** W. Meineke, and M. Bohn. *Solar Energy Concentrating Systems.* Heidelberg: C. F. Muller Verlag, 1995.
engineering, solar, reactor.

37. Bedford, J., James F. **Klausner,** D. Yogi **Goswami,** and Kirk S. Schanze. "Performance of Nonconcentrating Solar Photocatalytic Reactors: Part I - Shallow Pond Configuration." *Solar Engineering 1993,* eds. **Allan** Kirkpatrick, and William Worek, 3542, New York, NY: **ASME,** 1993.
aqueous phase, engineering, solar, **TiO_2**.

38. Bedja, Idriss, Surat Hotchandani, and Prashant K. Kamat. "Preparation and Photoelectrochemical Characterization of Thin Sn02 **Nanocrystalline** Semiconductor Films and Their Sensitization With **Bis(2,2'-Bipyridine-4,4'-Dicarboxylic Acid)Ruthenium(II)** Complex." *J. Phys. Chem.* 98, no. 15 (1994): 4133-O.
other semiconductor.

39. **Bedja,** Idriss, Surat Hotchandani, and Prashant V. **Kamat.** "Photoelectrochemistry of Quantized WO_3 Colloids. Electron Storage, Electrochromic, and Photoelectrochromic Effects." *J. Phys. Chem. 97,* no. 42 (1993): 11064-70.
other semiconductor, **reductant,** aqueous phase, mechanism.

40. Bellobono, Ignazio R., Carrara Anna, Barbara Bami, and Aleardo Gazzotti. "**Laboratory-** and Pilot-Plant-Scale Photodegradation of Chloroaliphatics in Aqueous Solution by Photocatalytic Membranes Immobilizing Titanium Dioxide." ***J.*** *Photochem.* ***Photobiol*** *A: Chem. 84* (1994): **83-90.**
TiO_2, other semiconductor, engineering, modeling, aqueous phase, modified TiO_2, immobilized TiO_2.

41. Bellobono, Ignazio **Renato,** and Anna Carrara "Laboratory and Pilot Reactor Experience for Photochemical Degradation of Organic Contaminants in Wastewaters by Photocatalytic Membranes Immobilizing Titanium Dioxide." ***BHR*** *Group* ***Conf.*** *Ser.* ***Publ.*** 3, Effective Membrane Processes-New Perspectives (1993): 257-74.
aqueous phase, immobilized TiO_2.

42. Bennett, P. A., and S. Beadles. "Photocatalytic Oxidation: a Safe and Clean Alternative in TOC Analysis." ***Am. Lab.*** 26, no. 15 (1994): 29-32.
TiO_2, aqueous phase, application, immobilized TiO_2.

43. Berman, Elliot, and Junchang **Dong.** "Photocatalytic Decomposition of Organic Pollutants *in Gas Streams."* ***Chem. Oxid.*** Volume Date 1993, no. 3 (1994): 183-9.
TiO_2, gas phase, modified TiO_2, application, process efficiency, immobilized TiO_2, solar.

44. Berry, R. James, and Michael R. Mueller. "Photocatalytic Decomposition of Crude Oil Slicks Using TiO_2 on a Floating Substrate." ***Microchem.*** *J. 50,* no. 1 (1994): 28-32.
TiO_2, solar, aqueous phase, modified TiO_2, immobilized TiO_2, adsorption.

45. Bickley, R. I. "Heterogeneous Photo-Catalysis.", 308-2. Catalysis, A Specialist Periodical Report, eds. G. C. Bond, and G. Webb, 5. London: The Chemical Society, 1982.
TiO_2, other semiconductor, solar, gas phase, aqueous phase.

46. Bickley, R. I., G. **Munuera,** and F. S. Stone. "Photoadsorption and **Photocatalysis** At Rutile Surfaces. II. **Photocatalytic** Oxidation of Isopropanol." *J.* ***Catal.*** (1973): **398-407.**
gas phase, modified TiO_2, TiO_2.

47. Bickley, R. I., L. Palmisano, M. Schiavello, and A. Sclafani. "Heterogeneous Photocatalysis: Mechanistic Considerations of Photocatalytic Reductions and Photocatalytic Oxidations on Semiconductor Oxide Surfaces." *Stud.* ***Surf.*** Sci. ***Catal.*** 75, New Frontiers in Catalysis, Pt. C (1993): 2151-4.
TiO_2, aqueous phase, modified TiO_2.

48. Bickley, R. I., and F. S. Stone. "Photoadsorption and Photocatalysis At Rutile Surfaces. I. Photoadsorption of Oxygen." *J.* ***Catal.*** *3* 1 (1973): 389-97.
adsorption, gas phase, TiO_2, oxidant.

49. Bickley, Roger I., Teresita Gonzalez-Carreno, Agustin R. Gonzalez-Elipe, Guillermo Munuera, and Leonardo Palmisano. "Characterization of **Iron,Titanium** Oxide Photocatalysts. Part 2. Surface Studies." ***J. Chem. Soc.,*** *Faraday Trans.* 90, no. 15 (1994): 2257-64, 1 plate.
TiO_2, modified TiO_2.

50. Bideau, M., B. Claudel, L. Faure, and H. Kazouan. "Metallic Complexes As Intermediates in Homogeneously and Heterogeneously Photocatalysed Reactions." *J. Photochem. Photobiol. A: Chem.* 84 (1994): 57-67.
TiO_2, other semiconductor, modeling, aqueous phase, mechanism.

51. Blake, Daniel M. "Solar Processes for the Destruction of Hazardous Chemicals." *Alternative Fuels and the Environment,* ed. Francis S. Sterrett, 175-86. Boca Raton, FL: Lewis Publishers, 1994.
TiO_2, engineering, solar, gas phase, aqueous phase, application.

52. Blanco, Julian, and Sixto Malato. "Wastewater Decontamination by Solar Photocatalysis." *Ing. Quim.* 25, no. 286 (1993): 129-37.
TiO_2, engineering, reactor, solar, aqueous phase, application, adsorbent.

53. Blanco, Julian, and Sixto Malato. "Solar Photocatalytic Mineralization of Real Hazardous Waste Water At Pre-Industrial Level."*Solar Engineering 1994,* eds. David E. Klett, Roy E. Hogan, and Tadayoshi Tanaka' 103-9, 1994.
TiO_2, engineering, reactor, solar, oxidant' aqueous phase, application, cost.

54. Blazkova, A., V. Brezova, Z. Soldanova, A. Stasko, M. Soldan, and M. Ceppan. "Photocatalytic Degradation of Heparin Over Titanium Dioxide." *J. Mater. Sci.* 30, no. 3 (1995): 729-33. .
TiO_2, aqueous phase, application, mechanism.

55. Block, Seymour S., and D. Yogi Goswami. "Chemically Enhanced Sunlight for Killing Bacteria." *Solar Engineering 1995,* eds. William B. Stine, Tadayoshi Tanaka' and David E. Claridge, 431-7, New York, NY: ASME, 1995.
TiO_2, solar, disinfection, aqueous phase.

56. Bolton, J. R., A. Safarzadeh-Amiri, and S. R. Cater. "The Detoxification of Waste Water Streams Using Solar and Artificial Light Sources." *Alternative Fuels and the Environment,* ed. Francis S. Sterrett, 187-92. Boca Raton, FL: Lewis Publishers, 1995.
aqueous phase, cost, process efficiency, TiO_2, solar.

57. Bravo, Agustin, Josep Garcia' Xavier Domenech, and Jose Peral. "Some Observations About the Photocatalytic Oxidation of Cyanate to Nitrate Over TiO_2." *Electrochim. Acta 39,* no. 16 (1994): 2461-3.
TiO_2, aqueous phase, mechanism.

58. Bravo, Agustin, Josep Garcia' Xavier Domenech, and Jose Peral. "Some Aspects of the Photocatalytic Oxidation of Ammonium Ion by Titanium Dioxide." *J. Chem. Res., Synop.,* no. 9 (1993): 376-7.
TiO_2, aqueous phase, adsorption.

59. Brezova, V., M. Breza, and M. Ceppan. "The Photocatalytic Degradation of Cyclic Acetals in Aqueous Titanium Dioxide Suspension." *Chem. Pap.* 46, no. 6 (1992): 359-63.
TiO_2, aqueous phase, mechanism.

60. Brezova, V., M. Jankovicova, M. Soldan, A. Blazkova, M. Rehakova, I. Surina, M. Ceppan, and B. Havlinova. "Photocatalytic Degradation of P-Toluenesulfonic Acid in Aqueous Systems Containing Powdered and Immobilized Titanium Dioxide." *J. Photochem. Photobiol., A* 83, no. 1 (1994): 69-75.
TiO_2, oxidant, aqueous phase, modified TiO_2, immobilized TiO_2.

61. Brezova, V., and A. Stasko. "Spin Trap Study of Hydroxyl Radicals Formed in the Photocatalytic System TiO_2-Water-p-Cresol-Oxygen." *J. Catal.* 147, no. 1 (1994): 156-62.
TiO_2, modeling, aqueous phase, process efficiency, mechanism, adsorption.

62. Brezova, V., A. Stasko, A. Blazkova, and B. Havlinova "Kinetics of Hydroxyl Radical Spin Trapping in Photoactivated Homogeneous (H_2O_2) and Heterogeneous (TiO_2) Aqueous Systems." *J. Phys. Chem.* 98, no. 36 (1994): 8977-4.
TiO_2, aqueous phase, mechanism, adsorption.

63. Brezova, V., A. Stasko, M. Ceppan, M. Mikula, J. Blecha, M. Vesely, A. Blazkova, J. Panak, and L. Lapcik. "Photocatalytic Activity of Titanium Dioxide and the Formation of Radical Intermediates." *Photocatalytic Purification and Treatment of Water and Air, eds.* David F. Ollis and Hussain Al-Ekabi, 659-4, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, mechanism.

64. Brun, H., J. P. Percherancier, and B. Pouyet. "Study of Optimal Experimental Conditions in the Photocatalytic Degradation of an Herbicide." *Environ. Technol.* 16, no. 4 (1995): 395-400.
TiO_2, pesticide, aqueous phase, process efficiency.

65. Brym, Stanley J., inventor. "Water Purification System." Conventure Corp, assignee. United States patent, 5227053. 13 July 1993. *CA119(22):233639f.*
TiO_2, other semiconductor, reactor, disinfection, aqueous phase, application, immobilized TiO_2, adsorbent.

66. Butler, Elizabeth C., and Allen P. Davis. "Photocatalytic Oxidation in Aqueous Titanium Dioxide Suspensions: the Influence of Dissolved Transition Metals." *J. Photochem. Photobiol., A 70,* no. 3 (1993): 273-83.
TiO_2, oxidant, aqueous phase, mechanism.

67. Caballero, A., A. R. Gonzalez-Elipe, A. Fernandez, J.-M. Herrmann, H. Dexpert, and F. Villain. "Experimental Set-Up for in-Situ X-Ray Absorption Spectroscopy Analysis of Photochemical Reactions: the Photocatalytic Reduction of Gold on Titania." *J. Photochem. Photobiol., A 78,* no. 2 (1994): 169-72.
TiO_2, oxidant, metallized TiO_2.

68. Cabrera, Maria I., Orlando M. Alfano, and Alberto E. Cassano. "Novel Reactor for Photocatalytic Kinetic Studies." *Ind. Eng. Chem. Res. 33,* no. 12 (1994): 3031-42.
TiO_2, reactor, modeling, aqueous phase, process efficiency.

69. Caruana, Claudia M. "Photocatalysts Aim to Make Light Work of Pollution Cleanup." *Chem. Eng. Prog.* 91, no. 2 (1995): 11-20.
TiO_2, engineering, gas phase, aqueous phase, application, process efficiency.

70. Catilaz, L., and J. P. Fouassier. "Role of Pigments in Polymerization Under UV-Visible Light." *Angew. Makromol. Chem.* 218 (1994): 81-109.

71. Cervera-March, S., J. Gimenez-Farreras, M. A. Aguado, L. Borrell, D. Curco, and M. A. Queral. "Kinetic and Radiation Studies for the Photoreactor Design in Photocatalytic Detoxification Processes Using Titanium Dioxide." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 633-8, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, modeling, aqueous phase, process efficiency, metal removal.

72. Cervera, S., J. Gimenez, and D. Curco. "Reaction Rate and Radiation Absorption in Photocatalysis." *Proc. - Electrochem. Soc.* 94-19(Water Purification by Photocatalytic Photoelectrochemical, and Electrochemical Processes) (1994): 255-66.
TiO_2, modeling, solar, reactor, oxidant, aqueous phase, process efficiency, metal removal.

73. Chant, Eileen E., Carmen A. Ortiz-Aponte, and Maribel Navarro-Ortiz. "Photocatalytic Detoxification of Tetrahydrofuran and Chloroform in Dilute Aqueous Solutions. " *Solar Engineering 1995,* eds. William B. Stine, Tadayoshi Tanaka, and David E. Claridge, 475-84, New York, NY: ASME, 1995.
TiO_2, oxidant, aqueous phase, application.

74. Chen, Ci-Ping, Xin-Min Ren, Dao-Hui Lu, and Guang-Zhi Xu. "Study on Free Radicals Produced During the Photolysis of p-Aminophenol in Aqueous TiO_2 Suspension." *Chin. Sci. Bull. 39,* no. 1 (1994): 41-6.
aqueous phase, TiO_2, mechanism.

75. Chen, Ciping, Daohui Lu, and Guangzhi Xu. "Free Radicals Generated in Photocatalytic Oxidation of Some Organic Compounds Containing Nitrogen Atoms." *J. Environ. Sci 5,* no. 4 (1993): 464-9.
TiO_2, aqueous phase, mechanism.

76. Chen, H. Y., 0. Zahraa, M. Bouchy, F. Thomas, and J. Y. Bottero. "Adsorption Properties of TiO_2 Related to the Photocatalytic Degradation of Organic Contaminants in Water." *J. Photochem. Photobiol., A 85,* no. l-2 (1995): 179-86.
TiO_2, modeling, aqueous phase, adsorption.

77. Chen, Lung Chyuan, and Tse-Chuan Chou. "Photobleaching of Methyl Orange in Titanium Dioxide Suspended in Aqueous Solution." *J. Mol. Catal. 85,* no. 2 (1993): 201-14.
TiO_2, aqueous phase, process efficiency.

78. Chen, Lung-Chyuan, and Tse-Chuan Chou. "Photodecolorization of Methyl Orange Using Silver Ion Modified TiO_2 As Photocatalyst." *Ind. Eng. Chem. Res. 33,* no. 6 (1994): 143643.
TiO_2, oxidant, aqueous phase, process efficiency, adsorption.

79. Chen, Paris Honglay, and Christina H. Jeng. "Kinetic Study of Photocatalytic Oxidation With TiO_2 to Remove DOC *in &inking* Water." *Zhongguo Huanjing Gongcheng Xuekun 4,* no. 2 (1994): 79-87.
TiO_2, aqueous phase, application, adsorption, modeling.

80. Chester, Cordon, Marc A. Anderson, Harry Read, and Santiago Esplugas. "A Jacketed Annular Membrane Photocatalytic Reactor for Wastewater Treatment: Degradation of Formic Acid and Atrazine." *J. Photochem. Photobiol., A 71,* no. 3 (1993): 291-7.
TiO_2, aqueous phase, modified TiO_2, immobilized TiO_2, modeling, process efficiency.

81. Choi, Wonyong, Andreas Termin, and Michael R. Hoffmann. "Effect of Doped Metal Ions on the Photocatalytic Reactivity of TiO_2 Quantum Particles." Angew. *Chem.* 106, no. 10 (1994): 1148-9.
TiO_2, aqueous phase, modified TiO_2.

82. Choi, Wonyong, Andreas Termin, and Michael R. Hoffmann. "The Role of Metal Ion Dopants in Quantum-Sized TiO_2: Correlation Between Photoreactivity and Charge Carrier Recombination Dynamics." *J. Phys. Chem.* 98, no. 51 (1994): 13669-79.
TiO_2, modeling, aqueous phase, modified TiO_2, process efficiency, mechanism.

83. Christensen, P. A., A. Hamnett, R. He, C. R. Howarth, and K. E. Shaw. "Fundamental Photocatalytic Studies on Immobilized Films of Titanium Dioxide." *Photocatalytic Purification and Treatment of* Water and Air, eds. David F. Ollis and Hussain Al-Ekabi, 765-70, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, immobilized TiO_2, gas phase.

84. Christensen, P. A., A. Hamnett, R. He, C. R. Howarth, and K. E. Shaw. "Photocatalytic Detoxification of Water." *Spec. Publ. - R Soc. Chem.* 146 (Electrochemistry and Clean Energy) (1994): 64-86.
TiO_2, mechanism, aqueous phase, immobilized TiO_2.

85. Cooper, Gerald, and Matthew A. Ratcliff, inventors. "Method of Decontaminating a Contaminated Fluid by Using Photocatalytic Particles." Photocatalytics, Inc. assignee. United States Patent, 52943 15.15 March 1994.
TiO_2, other semiconductor, engineering, reactor, gas phase, aqueous phase, application, adsorption.

86. Courbon, H., Marc Formenti, and Pierre Pichat. "Study of Oxygen Isotopic Exchange Over Ultraviolet Irradiated Anatase Samples and Comparison with the Photooxidation of Isobutane to Acetone." *J. Phys. Chem.* 81, no. 6 (1977): 550-4.
TiO_2, gas phase, mechanism.

87. Crittenden, John C., Sawang Notthakun, David W. Hand, and David L. Perram, inventors. "Regeneration of Adsorbents Using Advanced Oxidation." Michigan Technological University, assignee. United States Patent, 5182030.26 January 1993. *CA119(6):52272k.*
TiO_2, other semiconductor, reactor, metallized TiO_2, aqueous phase, modified TiO_2, application, immobilized TiO_2, adsorbent.

88. Crittenden, John C., Yin Zhang, David W. Hand, and David L. Perram. 'Destruction of Organic Compounds in Water Using Fixed-Bed Photocatalysts." *Solar Engineering 1995,* eds. William B. Stine, Tadayoshi Tanaka, and David E. Claridge, 449-57, New York, NY: ASME, 1995.
TiO_2, solar, modeling, metallized TiO_2, aqueous phase, modified TiO_2, application, process efficiency, immobilized TiO_2, adsorption.

89. Cui, H., K. Dwight, S. Soled, and A. Wold. "Surface Acidity and Photocatalytic Activity of Nb_2O_5,TiO_2 Photocatalysts." *J. Solid State Chem.* 115, no. 1 (1995): 187-91.
TiO_2, aqueous phase, modified TiO_2, adsorption.

90. Cunningham, J. "Radiation and Photoeffects At Gas,Solid Interfaces." *Simple Processes At the **Gas-Solid Interface***, 291-427. Comprehensive Chemical Kinetics, eds. C. H. Bamford, C. F. H. Tipper, and R. G. Compton, 19. New York: Elsevier,' 1984.
TiO_2, other semiconductor, modeling, metallized **TiO_2**, gas phase, mechanism, adsorbent, adsorption.

91. Cunningham, Joseph, and Petr Sedlak. "Initial Rates of Titanium Dioxide-Photocatalyzed Degradations of Water Pollutants: Influences of Adsorption, **pH** and Photon-Flux." *Photocatalytic **Purification** and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 67-8 1, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, modeling, aqueous phase, mechanism, adsorption.

92. Cunningham, Joseph, and **Petr** Sedlak. "Interactive Adsorption and Charge-Transfer Processes in UV-Illuminated Aqueous **Pollutant,TiO_2** Slurries." ***Proc.** - Electrochem. **Soc.*** **94-19(Water** Purification by Photocatalytic Photoelectrochemical, and Electrochemical Processes) (1994): 267-77.
TiO_2, modeling, oxidant, aqueous phase, mechanism, adsorption.

93. **D'Oliveira,** J. C., W. D. W. Jayatilake, K. **Tennakone,** J. M. Herrmann, and P. **Pichat.** "Heterogeneous Photocatalysis As a Method of Water Decontamination: Degradation of **2-, 3-,** and **4-Chlorobenzoic** Acids Over Illuminated Titania At Room Temperature." *Stud. **Surf.** Sci. **Catal.** 75,* no. New Frontiers in Catalysis, Pt. C (1993): 2167-7 1.
TiO_2, aqueous phase, mechanism.

94. Dagan, Geula, **Srinivasan Sampath,** and Ovadia Lev. "Preparation and Utilization of Organically Modified Silica-Titania Photocatalysts for Decontamination of Aquatic Environments." *Chem. Mater. 7,* no. 3 (1995): 446-53.
TiO_2, aqueous phase, modified **TiO_2**, application, mechanism.

95. Dagan, Geula, and Micha Tomkiewicz. 'Preparation and Characterization of **TiO_2** Aerogels for Use As Photocatalysts." *J. Non-Cryst. Solids* 175, no. **2,3** (1994): 294-302.
TiO_2, aqueous phase, modified **TiO_2**, adsorption.

96. Dagan, Geula, and Micha Tomkiewicz. "Preparation and Utilization of Porous Titanium Dioxide for Photocatalysis in Aquatic Environments." ***Proc.** - Electrochem. **Soc.*** 93-18, Proceedings of the Symposium on Environmental Aspects of Electrochemistry and Photochemistry (1993): 137-46.
TiO_2, aqueous phase, modified **TiO_2**, immobilized **TiO_2**.

97. Dagan, Geula, and Micha Tomkiewicz. "Titanium Dioxide Aerogels for Photocatalytic Decontamination of Aquatic Environments." *J. Phys. **Chem.** 97,* no. 49 (1993): 1265 l-5.
TiO_2, aqueous phase, modified **TiO_2**, immobilized **TiO_2**.

98. Das, S., M. Muneer, and K. R. Gopidas. "Photocatalytic Degradation of Wastewater Pollutants. Titanium Dioxide-Mediated Oxidation of Polynuclear Aromatic Hydrocarbons." *J. Photochem. Photobiol., A 77,* no. 1 (1994): 83-8.
TiO_2, solar, oxidant, mechanism.

99. Datye, Abhaya K., Georg Riegel, James R. **Bolton,** Min Huang, and Michael R. Prairie. "Microstructural Characterization of a Fumed Titanium Dioxide Photocatalyst." *J. Solid **State** Chem.* 115, no. 1 (1995): 236-9.
TiO_2, aqueous phase, catalyst characterization.

100. Davis, Robert J., John L. Gainer, Gilbert O'Neal, and I Wen Wu. "Photocatalytic Decolorization of Wastewater Dyes." *Water Environ. Res. 66,* no. 1 (1994): 50-3.
TiO_2, aqueous phase, application.

101. de la Guardia' Miguel, Karim D. Khalaf, Berween A. Hasan, Angel Morales-Rubio, and Vicente Carbonell. "In-Line, Titanium Dioxide-Catalyzed, Ultraviolet Mineralization of Toxic Aromatic Compounds in the Waste Stream From a Flow-Injection-Based Resorcinol Analyzer." *Analyst* 120, no. 2 (1995): 23 l-5.
TiO_2, aqueous phase, application.

102. Dellinger, Barry, John L. Graham, Joel M. Berman, and Zhen Jiang. "Photocatalytically Enhanced Oxidation of Chlorinated Hydrocarbons." *Combust. Fundam. Appl., Jt. Tech. Meet., Cent. East. States Sect. Combust. Inst.,* 448-52, Combustion Inst. 1993.
TiO_2, solar, gas phase, mechanism, immobilized TiO_2.

103. Dieckmann, Melissa S., Kimberly A. Gray, and Richard G. Zepp. "The Sensitized Photocatalysis of Azo Dyes in a Solid System: a Feasibility Study." *Chemosphere 28,* no. 5 (1994): 1021-34.
Dyes, TiO_2, other semiconductor, application, immobilized TiO_2, adsorption.

104. Do, Y. R, W. Lee, K. Dwight' and A. Wold. "The Effect of WO_3 on the Photocatalytic Activity of TiO_2." *J. Solid State Chem.* 108, no. 1 (1994): 198-201.
TiO_2, aqueous phase, modified TiO_2, mechanism.

105. Do, Youngrag. "The Crystal Growth and Characterization of I-III-VI2-Doped II-VI Chalcogenides and the Effect of WO, on the Photocatalytic Activity of TiO_2." Ph.D. diss., Brown Univ., USA, 1994.
TiO_2, modified TiO_2, catalyst characterization.

106. Domenech, X. "Photocatalysis for Aqueous Phase Decontamination: Is Titanium Dioxide the Better Choice?" *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 337-51, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, other semiconductor, aqueous phase, metal removal.

107. Dong, C. D., and C. P. Huang. "A Comparative Study on the Direct Photolysis and Titanium Dioxide-Mediated Photodegradation of 2-Chlorophenol in Aqueous Solutions." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 701-6, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, aqueous phase, mechanism.

108. Dong, Chengdi, and Chin-Pao Huang. "Photocatalytic Degradation of 4-Chlorophenol in TiO_2 Aqueous Suspensions." *Adv. Chem. Ser.* 244(Aquatic Chemistry) (1995): 291-3 13.
TiO_2, aqueous phase, mechanism.

109. Dong, Jim J., and Ronald J. Enzweiler. "Reductive Photocatalysis: A New Separation Technology for Heavy Metals." *Adv. Filtr. Sep. Technol. 8* (1994): 283-6.
TiO_2, oxidant, metal removal.

110. Enzweiler, Ron J., Debby L. Mowery, Larry M. Wagg, and Jim J. Dong. "A Pilot Scale Investigation of Photocatalytic Detoxification of BETX *in* Water." *Solar Engineering* 1994, eds. David E. Klett, Roy E. Hogan, and Tadayoshi Tanaka' 155-62, 1994.
TiO_2, engineering, reactor, solar, oxidant, aqueous phase, application, immobilized TiO_2, cost.

111. Enzweiler, Ron, Wagg, Larry, and Dong, Jim. "Requirement, Design and Field Test of State of-the-Art Industrial Wastewater Recycling System." Presented at AIChE Summer Meeting, Seattle, WA, 17 August 1993, 28 pp.

112. Evans, J. E., K. W. Springer, and J. Z. Zhang. "Femtosecond Studies of Interparticle Electron Transfer in a Coupled CdS-TiO_2 Colloidal System." *J. Chem. Phys.* 101, no. 7 (1994): 6222-5.
TiO_2, other semiconductor, mechanism, process efficiency.

113. Fan, Jingfu, and John T. Yates Jr. "Infrared Study of the Oxidation of Hexafluoropropene on TiO_2." *J. Phys. Chem. 98* (1994): 10621-7.
TiO_2, gas phase, mechanism, thermal catalysis.

114. Faust, Bruce C., Michael R. Hoffmann, and Detlef W. Bahnemann. "Photocatalytic Oxidation of Sulfur Dioxide in Aqueous Suspensions of Alpha-Fe_20_3." *J. Phys. Chem. 93,* no. 17 (1989): 6371-81.
other semiconductor, aqueous phase, process efficiency.

115. Femandez, A., A. Caballero, A. R. Gonzalez-Elipe, J.-M. Herrmann, H. Dexpert, and F. Villain. "In Situ EXAFS Study of the Photocatalytic Reduction and Deposition of Gold on Colloidal Titania." *J. Phys. Chem. 99,* no. 10 (1995): 3303-9.
TiO_2, reductant, metallized TiO_2, aqueous phase, mechanism, metal removal.

116. Formenti, M., and S. J. Teichner. "Heterogeneous Photo-Catalysis." 87-106. Catalysis, A Specialist Periodical Report, eds. C. Kemball and D. A. Dowden, 2. London: The Chemical Society, 1978.
TiO_2, other semiconductor, solar, gas phase, aqueous phase.

117. Foster, Nancy S., Garrett N. Brown, Richard D. Noble, and Carl A. Koval. "Use of Titanium Dioxide Photocatalysis in the Treatment of Spent Electroless Copper Plating Baths." *Photocatalytic Purification and Treatment of Water and Air, eds.* David F. Ollis and Hussain Al-Ekabi, 365-73, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, engineering, aqueous phase, metal removal.

118. Foster, Nancy S., Carl A. Koval, and Richard D. Noble, inventors. "Reversible Photodeposition and Dissolution of Metal Ions." USA University of Colorado, assignee. United States Patent, 5332508.26 July 1994. *CA121:140869.*
TiO_2, other semiconductor, aqueous phase, application, metal removal.

119. Fotou, George P., Srinivas Vemury, and Sotiris E. Pratsinis. "Synthesis and Evaluation of Titania Powders for Photodestruction of Phenol." *Chem. Eng. Sci 49,* no. 24B (1994): 4939-8.
TiO_2, aqueous phase, modified TiO_2.

120. Fox, Marye Anne, Kate E. Doan, and Maria T. Dulay. "The Effect of the "Inert" Support on Relative Photocatalytic Activity in the Oxidative Decomposition of Alcohols on Irradiated Titanium Dioxide Composites." *Res. Chem. Intermed. 20,* no. 7 (1994): 71 l-22.
nonaqueous, TiO_2, modified TiO_2, process efficiency, immobilized TiO_2, adsorbent.

121. Fox, **Marye** Anne, R. Barton Draper, Maria Dulay, and Kevin O'Shea. "Control of Photocatalytic Oxidative Selectivity on Irradiated **TiO_2** Powders: Diffuse Reflectance Kinetic Study." *Photochemical Conversion and Storage of Solar **Energy,** Proceedings of the 8th International Conference on Photochemical Conversion and Storage of Solar Energy,* eds. E. Pelizzetti, and M. Schiavello, 323-5, Dordrecht: Kluwer Academic Publishers, 199 1.
nonaqueous, **TiO_2**, mechanism.

122. Fox, **Marye** Anne, Shiyamalie Ruberu, Andrew Hadd, and Young Soo Kim. "Competitive Photooxidative Degradation of **Amines** and Alcohols on Heterogeneously Suspended Titanium Dioxide Particles." ***Proc.*** *- Electrochem.* ***Soc.*** 93-18, no. Proceedings of the Symposium on Environmental Aspects of Electrochemistry and Photoelectrochemistry (1993): 104-l.
nonaqueous, **TiO_2**, mechanism, adsorption.

123. Fujishima, A., R. Cai, K. Hashimoto, H. Sakai, and Y. Kubota. "Biochemical Application of Titanium Dioxide Photocatalysts." *Photocatalytic* ***Purification*** *and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 193-205, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, disinfection, aqueous phase, application.

124. Fujishima, Akira "Applications of Semiconductor Photocatalysts." ***Kikan Kagaku*** *Sosetsu* 23 (1994): 129-38.
TiO_2, disinfection, application.

125. Fujishima, Akira "Highly Effective Photocatalytic Reactions using **TiO_2** Surface." Presented at 17th U.S.-Japan Cooperative Seminar on Photoconversion and Photosynthesis Research, La Jolla, CA, 12-14 March **1995, 3** pp.

126. Fujishima, Akira, Ru Xiong Cai, Hideki Sakai, Ryo Baba, Kazuhito Hashimoto, and Yoshinobu Kubota. "Detection of Intermediates Formed At the Surface of Photo-Excited Titanium Dioxide and Biological Application of Titanium Dioxide Photocatalysts." ***Proc.*** *- Electrochem.* ***Soc.*** 93-1 1, no. Proceedings of the Fifth International Symposium on **Redox** Mechanisms and Interfaces (1993): 363-72.
TiO_2, disinfection, aqueous phase, mechanism, application.

127. **Fujita,** Jinji, Masahiro Kubo, **Emi Fumrukawa,** Makiko Higashikawa, and Keizou Nakano. "Photocatalytic Decomposition of Chlorpyrifos in the Presence of Titanium Dioxide." *Kugawa-Ken Kankyo Kenkyu* ***Senta*** *Shoho* 18 (1994): 31-4.
TiO_2, pesticide, mechanism.

128. Fukui, Hiroshi, Yukiko Hashimoto, Michihiro Yamaguchi, and Shoichi **Anho,** inventors. "Magnetic Photocatalysts." Japan Shiseido Co Ltd, assignee. Japan Patent, 06154620 A2.3 June 1994. ***CA121:219967.***
TiO_2, other semiconductor, engineering, modified **TiO_2**, application.

129. Funayama, Hitoshi, and Takuo **Sugawara.** "Photocatalytic Decomposition Rate of Chloroform in Dilute Aqueous Solution in a Titanium Dioxide Suspension." ***Kagaku Kogaku*** *Ronbunshu* 19, no. 2 (1993): 272-8.
TiO_2, aqueous phase.

130. Galvez, Julian **Blanco,** and **Sixto Malato** Rodriguez. "Influence of Solar Irradiation Over Pentachlorophenol Solar Photocatalytic Decomposition." *Photocutulytic **Purification** and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 63944, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, oxidant, aqueous phase, process efficiency.

131. Gao, Cuiqin, Yulin Dong, and Qinhua Dong. "Study on the Decomposition of Organophosphorous Insecticide in Water by Using Solar Energy." *Wuhan **Daxue** Xuebao, **Ziran** Kexuebun,* no. 3 (1992): 73-7.
TiO_2, solar, pesticide, aqueous phase.

132. Gao, Cuiqin, Jianzhen Shi, Qinghua Dong, and Yu Guo. "Photocatalytic Decomposition of **Humic** Acid in Water in the Presence of Semiconductor Suspension." ***Huaxue** Shijie 34,* no. 8 (1993): 390-3.
TiO_2, solar, aqueous phase.

133. Gerischer, H. "Conditions for an Efficient Photocatalytic Activity of Titanium Dioxide Particles." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 1-17, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, modeling, aqueous phase, process efficiency, mechanism.

134. Gimeniz-Farreras, Jaime, M. A. Aguado, S. Cervera, L. Borrell, D. **Curco,** and M. A. Queral. "Photoreactor Design for Photocatalytical Detoxification: Kinetic and Radiation Studies. " *Solar Engineering 1994,* eds. David E. **Klett,** Roy E. Hogan, and Tadayoshi Tanaka, 139-45, 1994.
TiO_2, engineering, reactor, modeling, solar, oxidant, aqueous phase, metal removal.

135. Goldberg, Marvin C., **Kirkwood** M. Cunningham, and Eugene R. Weiner. "Aquatic Photolysis: Photolytic **Redox** Reactions Between Geothite and Adsorbed Organic Acids in Aqueous Solutions." *J. Photochem. Photobiol. A: Chem. 73* (1993): 105-20.
other semiconductor, solar, **reductant,** aqueous phase, mechanism.

136. Goldstein, Sara' Gidon Czapski, and Joseph Rabani. "Oxidation of Phenol by Radiolytically Generated OH Radical and Chemically Generated **SO_4(-1)** Radical. A Distinction Between OH Transfer and Hole Oxidation in the Photolysis of **TiO_2** Colloid Solution." *J. Phys. Chem. 98,* no. 26 (1994): 6586-9 1.
TiO_2, oxidant, aqueous phase, mechanism, metal removal.

137. **Goswami,** D. Y., J. **Klausner,** G. D. Mathur, A. Martin, K. Schanze, and P. Wyness. *Solar Photocatalytic Treatment of Groundwater At Tyndall AFB: Field Test Results,* University of Florida, Gainesville, FL, 1993.
engineering, aqueous phase, oxidant, solar, **TiO_2.**

138. **Goswami,** D. Yogi, J. Klausner, G. D. Mathur, A. Martin, K. Schanze, P. Wyness, Craig T. Turchi, and E. Marchand. "Solar Photocatalytic Treatment of Groundwater At Tyndall AFB: Field Test Results." ***Solarl** 993. Proceedings of the American Solar Energy Society Annual Conference, 235-9,* Boulder, CO: ASES, 1993.
aqueous phase, engineering, process efficiency, oxidant' adsorbent, **TiO_2.**

139. **Goswami,** D. Yogi, Dhara M. Trivedi, and Seymour S. Block "Photocatalytic Disinfection of Indoor Air." *Solar Engineering* 1995, eds. William B. Stine, Tadayoshi Tanaka' and David E. Claridge, *421-7, New* York, NY: **ASME,** 1995.
TiO_2, reactor, disinfection, gas phase, application, IAQ, immobilized TiO_2.

140. Gray, K. A., U. Stafford, M. S. **Dieckmann,** and P. **Kamat.** "Mechanistic Studies in Titanium Dioxide Systems: Photocatalytic Degradation of Chloro- and Nitrophenols." *Photocatalytic Purification and Treatment of Water* and *Air,* eds. David F. **Ollis** and **Hussain** Al-Ekabi, 455-72, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, aqueous phase, mechanism, immobilized TiO_2, adsorption.

141. Gray, Kimberly A., and Ulick Stafford. "Probing Photocatalytic Reactions in Semiconductor Systems: Study of the Chemical Intermediates in **4-Chlorophenol** Degradation by a Variety of Methods." *Res. **Chem. Intermed.** 20,* no. 8 (1994): 835-53.
TiO_2, aqueous phase, mechanism.

142. Gray, Kimberly A., and Ulick Stafford. "Probing Photocatalytic Reactions in Semiconductor Systems: Study of the Chemical Intermediates in **4-Chlorophenol** Degredation by a Variety of Methods." *Res. Chem **Intermed.** 20,* no. 8 (1994): 835-53.
TiO_2, aqueous phase, modified TiO_2, mechanism, immobilized TiO_2, adsorbent.

143. Green, Kevin J., and Robert Rudham. "Photocatalytic Oxidation of **Propan-2-ol** by Semiconductor-Zeolite Composites." *J. Chem. **Soc.**, Faraday Trans. 89,* no. 11 (1993): 1867-70.
nonaqueous, TiO_2, other semiconductor, modified TiO_2, mechanism, immobilized TiO_2.

144. **Hagfeldt,** Anders, Henrik Lindstrom, Sven Sodergren, and Sten-Eric Lindquist. "**Photoelectochemical** Studies of Colloidal TiO_2 Films: The Effect of Oxygen Studied by Photocurrent Transients." *J. Electroanalytical **Chem.*** 381 (1995): 39-46.
TiO_2, oxidant, aqueous phase, process efficiency, mechanism, immobilized TiO_2.

145. **Hamid,** S. H., M. B. **Amin,** A. G. Maadhah, and A. M. Al-Jarallah. "Polymer Lifetime Studies in Hostile Environments." ***J.** Vinyl Technol.* 14, no. 4 (1992): 182-6.
plastics, TiO_2, solar, application, mechanism.

146. Harada, Hisashi. "Photocatalysis by Semiconductors Loaded With Metal." *Kikan **Kagaku** Sosetsu 23* (1994): **69-77.**
TiO_2, metallized TiO_2, aqueous phase, modified TiO_2, mechanism.

147. **Harada,** Hisashi. "Photocatalytic Reactions for Aliphatic **Dicarboxylic** Acids Using **Metal-**Loaded Titanium Oxide." *Res. Bull. **Meisei** Univ., Phys. Sci Eng. 29* (1993): 27-36.
TiO_2, metallized TiO_2, aqueous phase, nonaqueous, mechanism.

148. **Hasegawa,** Kiyoshi, Masanori Murase, Masao **Kuboshita,** Hidetaka **Saida,** Misao Shinoda, Masatoshi Miyamoto, Choichiro Shimasaki, Toshiaki **Yoshimura,** Eiichi Tsukurimichi, and Shigeya Takeuchi. "Photooxidation of Naphthalenamines Adsorbed on Particles Under Simulated Atmospheric Conditions." *Environ. Sci. Technol. 27,* no. 9 (1993): 1819-25.
TiO_2, other **semiconductor,** reactor, solar, gas phase.

149. Hasegawa, Shigeo, Hiroyuki Ozora, Kazuto Kobayashi, and Yoshimasa Fujimoto, inventors. "Photocatalyst Composite." Ltd Mitsubishi Heavy Industries, assignee. Japan Patent, 04334552 A2. 20 November 1992. *CA118(14): 133096n.*
TiO_2, other semiconductor, modified TiO_2, immobilized TiO_2.

150. Hashimoto, Kazuhito, and Akira **Fujishima.** "Removal of Environmental Pollutants Using Photocatalytic Reactions." *Kagaku Sochi 36,* no. 4 (1994): 77-8 1.
TiO_2, gas phase, aqueous phase, application, immobilized TiO_2.

151. **Heleg,** Vered, and **Itamar** Willner. "Photocatalyzed CO,-Fixation to **Formate** and H_2 Evolution by Eosin-Modified **Pd-**TiO_2 Powders." *J. Chem. Soc., Chem. Commun.* (1994): 2113-4.
TiO_2, solar, **reductant,** metallized TiO_2, aqueous phase, modified TiO_2.

152. Heller, Adam, and James R. Brock, inventors. "Materials and Methods for Enhanced Photocatalysis of Organic Compounds in Oil Spill Treatment." University of Texas System, assignee. World Patent, 9317971 Al. 16 September 1993. *CA120(2):14565w.*
TiO_2, other semiconductor, engineering, solar, gas phase, aqueous phase, application, immobilized TiO_2, adsorbent, biotreatment.

153. Heller, Adam, Maya **Nair,** Lois Davidson, Zhenghao Luo, Jorg Schwitzgebel, Jeffery Norrell, James R. Brock, Sten Eric Lindquist, and John G. **Ekerdt.** "Photoassisted Oxidation of Oil and Organic Spills on Water." *Photocatalytic **Purification** and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 139-53, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, solar, aqueous phase, modified TiO_2, application, process efficiency, immobilized TiO_2, adsorbent.

154. Heller, Adam, **Joerg** Schwitzgebel, Michael V. Pishko, and **J.** G. Ekerdt. "Environmental Photoelectrochemistry." ***Proc. - Electrochem. Soc.*** 94-19 (Water Purification by Photocatalytic Photoelectrochemical, and Electrochemical Processes) (1994): 1-9.
TiO_2, oxidant, aqueous phase, modified TiO_2, process efficiency, mechanism, immobilized TiO_2.

155. Herrmann, Jean-Marie, Jean Disdier, and Pierre **Pichat.** "Photocatalytic Deposition of Silver on Powder Titania: Consequences for the Recovery of Silver." ***J. Catal.*** 113 (1988): 72-81.
TiO_2, oxidant, metallized TiO_2, aqueous phase, application, process efficiency, metal removal.

156. Hidaka, H., J. **Zhao,** K. Nohara, K. **Kitamura,** Y. **Satoh,** E. Pelizzetti, and N. Serpone. "Photocatalyzed Mineralization of Non-Ionic, Cationic, and Anionic **Surfactants** At Titanium **Dioxide,Water Interfaces."** *Photocatalytic Purification and Treatment of* Water and Air, eds. David F. Ollis and Hussain Al-Ekabi, 251-9, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, aqueous phase.

157. **Hidaka,** Hisao, Kayo Nohara, **Kazuhiko** Ooishi, Jincai **Zhao,** Nick Serpone, and Ezio Pelizzetti. "Photodegradation of Surfactants. XV: Formation of **SO42-** Ions in the Photooxidation of Sulfur-Containing Surfactants." *Chemosphere 29,* no. 12 (1994): 26194.
TiO_2, aqueous phase, other semiconductor, application.

158. Hidaka, Hisao, Kayo Nohara, Jincai **Zhao,** Keiko **Takashima,** Ezio Pelizzetti, and Nick Serpone. "Photodegradation of Surfactants. XIII. Photocatalytic Mineralization of Nitrogen-Containing Surfactants At the TiO_2,**Water** Interface." New J. ***Chem.*** 18, no. 4 (1994): 541-5.
TiO_2, aqueous phase.

159. Hidaka, Hisao, and Jincai **Zhao.** "Photodegradation of Surfactants Catalyzed by a Titania Semiconductor." ***Colloids Surf.*** *67* (1992): 165-82.
TiO_2, aqueous phase.

160. Hidaka, Hisao, Jincai **Zhao,** Satoshi Horikoshi, Nick Serpone, and Ezio Pelizzetti. "The Photodegradation of Surfactants. XVI. Photocatalytic Effect of Various Semiconductors on the Photooxidation of Surfactants." ***Yukagaku*** *44,* no. 2 (1995): 121-5.
TiO_2, other semiconductor, metallized TiO_2, aqueous phase, modified TiO_2.

161. Hidaka, Hisao, Jincai Zhao, and Kayo Nohara. "Photodegradation of Surfactants Using Titanium Dioxide." *Yosui to Haisui 36,* no. 10 (1994): 863-70.
TiO_2, aqueous phase, pesticide.

162. **Hidaka,** Hisao, Jincai **Zhao,** Yasuhito **Satoh,** Kayo Nohara, Ezio Pelizzetti, and Nick Serpone. "Photodegradation of Surfactants. Part XII: Photocatalyzed Mineralization of Phosphorus-Containing Surfactants At TiO_2,H_2O Interfaces." *J. Mol.* ***Catal.*** *88,* no. 2 (1994): 239-48.
TiO_2, aqueous phase.

163. Higashi, Kunihiko, and Kenji **Otsuka.** "Treatment of Hypophosphite **Ion** in Waste Electroless Nickel Plating Solution by Photocatalysis." Kogyo *Yosui* 415 (1993): 34-9.
TiO_2, reductant, aqueous phase, application, metal removal.

164. Hilgendorff, M., M. Hilgendorff, and D. W. Bahnemann. "Photocatalytic Reduction of Perhalogenated Hydrocarbons on Platinized Titanium Dioxide in Aqueous Solution." *J.* ***Inf.*** *Rec. Mater.* 21, no. 5-6 (1994): 697-8.
TiO_2, metallized TiO_2, aqueous phase, reductant.

165. Hirano, Katsuhiko, Kazuhisa Funaki, and Akio Hoshino. "Electron Transfer to Metal Particles From Photoilluminated **N-Titania** Electrode. Detection of the Electron-Loaded Particles by **RRDE.**" *Denki Kagaku Oyobi Kogyo Butsuri Kagaku* 61, no. 4 (1993): 446-7.
TiO_2, reductant, metallized TiO_2, aqueous phase, process efficiency, mechanism, metal removal.

166. Hirano, Katsuhiko, Kohei Inoue, and **Tomomi** Yatsu. "Photocatalyzed Reduction of CO, in Aqueous TiO_2 Suspension Mixed With Copper Powder." *J. Photo&em. and* ***Photobiol.*** *A: Chem. 64* (1992): 255-8.
TiO_2, reductant, aqueous phase.

167. **Hisanaga, Teruaki,** and Keiichi Tanaka. "Effect of the Crystal Type of Titanium Dioxide on Photocatalytic Degradation of Organohalogen Compounds." ***Mizu*** *Shori* ***Gijutsu*** *34,* no. 1 (1993): 13-18.
TiO_2, aqueous phase, modified TiO_2, mechanism.

168. **Hisanaga,** Teruaki, and Keiichi Tanaka, inventors. "Manufacture of Fixed Photocatalysts." Kogyo Gijutsuin, assignee. Japan Patent, 05096180 A2. 20 April 1993. ***CA119(10):102684u.***
TiO_2, other semiconductor, aqueous phase, modified TiO_2, application, immobilized TiO_2.

169. **Hisanaga, Teruaki,** and Keiichi Tanaka. "Photocatalytic Degradation of Harmful Compounds in Gas Phase by the Illumination With Short Wavelength **UV."** *Denki **Kagaku** Oyobi Kogyo Butsuri Kagaku 63,* no. 3 (1995): 212-16.
TiO_2, gas phase.

170. Hoffman, A. J. "Photocatalytic Reactions on Quantum-Sized Semiconductor Colloids: Photoinitiated Polymerization of Vinylic Monomers, Formation of Hydrogen Peroxide and Organic Peroxides, Oxidation of Carboxylic Acids, and Synthesis of Humic-Like Material." Ph.D. diss., California Institute of Technology, 1993.
aqueous phase, modified TiO_2, other semiconductor, oxidant.

171. Hoffmann, Michael R., Scot T. Martin, Wonyong Choi, and **Detlef** W. **Bahnemann.** "Environmental Applications of Semiconductor Photocatalysis." ***Chem.** Rev. 95,* no. 1 (1995): 69-96.
TiO_2, other semiconductor, engineering, reactor, modeling, **metallized** TiO_2, gas phase, aqueous phase, modified TiO_2, application, process efficiency, mechanism, metal removal.

172. Hofstadler, K., Rupert Bauer, S. Novalic, and G. Heisler. "New Reactor Design for Photocatalytic Wastewater Treatment With TiO_2 Immobilized on Fused-Silica Glass Fibers: Photomineralization of **4-Chlorophenol."** *Environ. Sci. Technol. 28,* no. 4 (1994): **670-4.**
TiO_2, engineering, aqueous phase, modified TiO_2, application, immobilized TiO_2.

173. Hofstadler, K., G. Ruppert, R. Bauer, G. Heisler, and S. Novalic. "Photocatalyzed Treatment of **4-Chlorophenol** With Immobilized Titanium Dioxide." *Photocatalytic Purification and Treatment of Water and Air,* **eds.** David F. Ollis and Hussain Al-Ekabi, 777-82, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, oxidant, aqueous phase, immobilized TiO_2.

174. **Holden,** Wendy, **Angelica** Marcellino, Damir **Valic,** and Alan C. **Weedon.** "Titanium Dioxide Mediated Photochemical Destruction of Trichloroethylene Vapors in Air. ***" Photocatalytic*** *Purification and Treatment of Water and Air,* eds. David F. Ollis and **Hussain** Al-Ekabi, 393404, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, gas phase, immobilized TiO_2.

175. Hsieh, **Yung-Hsu,** Kuo-Shu Huang, and Kuo-Hua Wang. "Study on the Photocatalytic Degradation of Monochlorophenol Pollutants by Titanium Dioxide in Aqueous Solutions." *Organohalogen Compd.* 19, Dioxin '94 (1994): 503-7.
TiO_2, aqueous phase, application, mechanism.

176. Hsieh, Yung Hsu, and Kuo Hua Wang. "Photocatalytic Decomposition of 2-Chlorophenol Over Titanium Dioxide." ***Xingda** Gongcheng Xuebao 4* (1993): 85-93.
TiO_2, aqueous phase, mechanism.

177. Hung, Sze To, and Mark K. S. Mak. "Titanium Dioxide Photocatalyzed Degradation of Organophosphate in a System Simulating the Natural Aquatic Environment" *Environ. Technol.* 14, no. 3 (1993): 265-9.
aqueous phase, application, photocatalysis, TiO_2, Malathion, DDVP, **fulvic** acid, pesticide.

178. Hwang, Bing Joe, and Shyh Song Jeng. "Photoelectrochemical Study for Destruction of Cyanide Waste With Modified TiO_2 Electrodes." *J. Chin. Inst. **Chem.** Eng. 24,* no. 6 (1993): 401-6.
TiO_2, metallized TiO_2, aqueous phase, modified TiO_2, application, process efficiency, immobilized TiO_2.

179. Ibusuki, Takashi. "Nitrogen Oxides Reducing Technology by Photocatalysts." *Kogyo Zairyo* 41, no. 13 (1993): 59-64.
TiO_2, gas phase, modified TiO_2, application, immobilized TiO_2, adsorbent.

180. Ibusuki, Takashi. "Nitrogen Oxides Removal by Photocatalytic Oxidation." *PPM 24,* no. 10 (1993): 66-72.
TiO_2, solar, engineering, gas phase, aqueous phase, modified TiO_2, application, immobilized TiO_2, catalyst reactivation.

181. Ibusuki, Takashi, and Takeuchi Koji. "Photocatalytic Effect of Titanium Dioxide in Trans-2-C_4H_8/O_2 and Trans-2-C_4H_8/NO_2, Air Reaction Systems." *Tatki Osen Gakkaishi 20,* no. 2 (1985): 82-8.
TiO_2, reactor, oxidant, gas phase.

182. Ibusuki, Takashi, Shuzo Kutsuna, Koji Takeuchi, Kazuteru Shinkai, Toshiharu Sasamoto, and Masahiro Miyamoto. "Removal of Low Concentration Air Pollutants Through Photoassisted Heterogeneous Catalysis. " *Photocatalytic Purification and Treatment of Water and Air, eds.* David F. Ollis and Hussain Al-Ekabi, 375-86, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, gas phase, modified TiO_2, application, immobilized TiO_2, adsorbent, catalyst reactivation.

183. Ibusuki, Takashi, Keigo Nakamura, and Schuzou Kutsuna, inventors. "Method for Photochemical Decomposition of Volatile Organic Chlorine Compound in Vent Gas." Agency of Industrial Science and Technology, assignee. Japan Patent, 4966665.30 October 1990.
gas phase, immobilized TiO_2, TiO_2.

184. Ibusuki, Takashi, and Koji Takeuchi. "Removal of Low Concentration Nitrogen Oxides Through Photoassisted Heterogeneous Catalysis." *J. Mol. Catal. 88,* no. 1 (1994): 93-102.
TiO_2, engineering, gas phase, modified TiO_2, application, immobilized TiO_2, adsorbent, catalyst reactivation.

185. lbusuki, Takashi, Koji Takeuchi, Kazuteru Shinkai, Satoshi Nishikata, Masahiro Miyamoto, Yukihiro Noguchi, and Takeo Takahashi, inventors. "Photocatalyst for Removing Pollutants From Air." Ltd. Japan Fuji Electric Co., and Agency of Industrial Sciences and Technology, assignees. Europe Patent, 614682 Al. 14 September 1994. *CA121:237630.*
TiO_2, engineering, reactor, solar, gas phase, modified TiO_2, application, immobilized TiO_2, adsorbent, catalyst reactivation.

186. Inoue, Hiroshi, Takehiko Matsuyama, Bi Jin Liu, Takao Sakata, Hirotaro Mori, and Hiroshi Yoneyama "Photocatalytic Activities of TiO_2 Microcrystals Prepared in Si02 Matrixes Using a Sol-Gel Method for Carbon Dioxide Reduction." *Chem. Lett.*, no. 3 (1994): 653-6.
TiO_2, reductant, gas phase, aqueous phase, modified TiO_2, immobilized TiO_2.

187. Ion, Rodica Mariana, and Viorel Gazdaru. "New Efficient Metalloporphyrin Photocatalysts for Kraft Lignin Photodegradation." *Prog. Catal.* 1, no. 2 (1992): 21-7.
Lignin, TiO_2, aqueous phase, modified TiO_2, application.

188. Ireland, John C., Brunilda Davila, Hector Moreno, Shannon K. Fink, and Stephanie Tassos. "Heterogeneous Photocatalytic Decomposition of Polyaromatic Hydrocarbons Over Titanium Dioxide." *Chemosphere 30,* no. 5 (1995): 965-84.
TiO_2, aqueous phase, application.

189. Ireland, John C., Petra Klostermann, Eugene W. Rice, and Robert M. Clark "Inactivation of Escherichia Coli by Titanium Dioxide Photocatalytic Oxidation." *Appl. Environ. Microbiol. 59,* no. 5 (1993): 1668-70.
TiO_2, disinfection, aqueous phase.

190. Irick, Gether Jr, inventor. "Photoactive Catalyst of Barium Phosphate or Calcium Phosphate Supported on Anatase Titanium Dioxide." Eastman Kodak Co, assignee. United States Patent, 5242880 A. 7 September 1993. *CA120(6):55977a.*
Plastics Manufacture and Processing, TiO_2, aqueous phase, modified TiO_2, application.

191. Ishitani, Osamu, Chieko Inoue, Yuji Suzuki, and Takashi Ibusuki. "Photocatalytic Reduction of Carbon Dioxide to Methane and Acetic Acid by an Aqueous Suspension of Metal-Deposited Titania." *J. Photochem. Photobiol., A 72,* no. 3 (1993): 269-7 1.
TiO_2, reductant, metallized TiO_2, aqueous phase.

192. Isidorov, V. A. "Non-Methane Hydrocarbons in the Atmosphere of Boreal Forests: Composition, Emission Rates, Estimation of Regional Emission and Photocatalytic Transformation." *Ecol. Bull. 42,* Trace Gas Exchange in a Global Perspective (1992): 71-76.
other semiconductor, modeling, solar, gas phase.

193. Ito, Takehiko, inventor. "Iron Oxide Photocatalyst." Japan Mitsubishi Heavy Ind Ltd, assignee. Japan Patent' 06039285 A2.15 February 1994. *CA121:46470.*
TiO_2, other semiconductor, aqueous phase, modified TiO_2, application.

194. Jackson, N. B., C. M. Wang, Z. Luo, J. Schwitzgebel, J. Norrell, J. R. Brock, and A. Heller. "Attachment of TiO_2 Powders to Hollow Glass Microbeads: Activity of the TiO_2 Coated Beads to the Photoassisted Oxidation of Ethanol to Acetaldehyde." *J. Electrochem. Soc.* 138 (199 1): 3660-4.
TiO_2, aqueous phase, immobilization TiO_2.

195. Jacoby, William A., Daniel M. Blake, LeAnn M. Vargo, John A. Fennell, Marya C. George, Suzanne K. Dolberg, and James E. Boulter. "Heterogeneous Photocatalysis for Control of Volatile Organic Compounds and Bioaerosols in Indoor Air." Presented at Engineering Solutions to Indoor Air Quality Problems, Research Triangle Park, NC, 24-26 July 1995, 28 pp.

196. Jacoby, William A., Mark R. Nimlos, Daniel M. Blake, Richard D. Noble, and Carl A. Koval. "Products, Intermediates, Mass Balances, and Reaction Pathways for the Oxidation of Trichloroethylene in Air Via Heterogeneous Photocatalysis." *Environ. Sci. Technol. 28,* no. 9 (1994): 1661-68.
TiO_2, gas phase, process efficiency, mechanism, immobilized TiO_2.

197. Jakob, Laurent, Esther Oliveros, Omar Legrini, and Andre M. Braun. "Titanium Dioxide Photocatalytic Treatment of Water. Reactor Design and Optimization Experiments. " *Photocatalytic Purification and Treatment of Water and Air, eds.* David F. Ollis and Hussain Al-Ekabi, 5 1 l-32, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, reactor, modeling, aqueous phase, application, engineering.

198. **Jardim,** Wilson F., Rosana M. Alberici, Marcia M. K. **Takiyama,** and C. P. Huang. "Gas-Phase Photocatalytic Destruction of Trichloroethylene **(TCE)** Using **UV,TiO_2."** *Hazard. Ind. Wastes* 26 (1994): 230-8.
TiO_2, engineering, reactor, gas phase, immobilized **TiO_2.**

199. Johnston, A. J., and P. Hocking. "Ultrasonically Accelerated Photocatalytic Waste Treatment." *ACS Symp. Ser.* 518, Emerging Technologies in Hazardous Waste Management III (1993): 106-8.
TiO_2, engineering, reactor, aqueous phase, application, process efficiency, sonication.

200. Joselevich, Emesto, and Itamar Willner. "Photosensitization of Quantum-Sized **TiO_2** Particles in Water-in-Oil Microemulsions." *J. Phys. Chem. 98,* no. 31 (1994): 7628-35.
TiO_2, aqueous phase, microemulsion.

201. Judin, Vesa P. S. "The Lighter Side of **TiO_2."** ***Chem. Brit.*** June (1993): 503-5.
TiO_2, modified **TiO_2.**

202. Kadowaki, Satoru, Makoto Suzuki, Kunio Okamoto, and Yoshimasa **Kodama,** inventors. "Deodorizing Agents." Japan Nippon **Denso** Co, and Nippon **Soken,** assignees. Japan Patent' 07024256 A2.27 January 1995. ***CA122:247162.***
TiO_2, other semiconductor, engineering, gas phase, application, immobilized **TiO_2,** adsorbent.

203. Kaise, Masahiro, Hidekazu Nagai, Kazuaki Tokuhashi, Shigeo Kondo, Shigeaki **Nimura,** and Osamu Kikuchi. "Electron Spin Resonance Studies of Photocatalytic Interface Reactions of Suspended **M/TiO_2** (M = Pt, Pd, Ir, Rh, Os, or Ru) With Alcohol and Acetic Acid in Aqueous Media" ***Langmuir*** 10, no. 5 (1994): 1345-7.
TiO_2, metallized **TiO_2,** mechanism.

204. Kamat, Prashant K. **"Nanocrystalline** Semiconductor Thin Films for Microelectronic and Optoelectronic Applications." *Mat. Tech. 9* (1994): 147-9.
TiO_2, other semiconductor, application.

205. **Kamat, Prashant** V. **"Interfacial** Charge Transfer Processes in Colloidal Semiconductor Systems." ***Prog.*** *Reaction Kinetics* 19 (1994): 277-3 16.
TiO_2, other semiconductor, modeling, oxidant, **reductant,** aqueous phase, modified **TiO_2,** mechanism.

206. Kamat, Prashant V. "What Makes Semiconductor Colloids Unique As Photocatalysts?" *The Spectrum 6* (1993): 14-20.
TiO_2, other semiconductor, aqueous phase, mechanism.

207. Kamat, Prashant V., Idris Bedja, and Surat Hotchandani. "Photoinduced Charge Transfer Between Carbon and Semiconductor Clusters. One-Electron Reduction of **C_60** in Colloidal **TiO_2** Semiconductor Suspensions." *J. Phys. Chem. 98,* no. 37 (1994): 913742.
TiO_2, nonaqueous, modified **TiO_2,** process efficiency, application.

208. **Kamat,** Prashant V., Idriss Bedja, and Surat Hotchandani. "Photoinduced Charge Transfer Between Fullerenes and **TiO_2** Semiconductor Colloids." ***Proc. -*** *Electrochem.* ***Soc.*** **94-24(Recent** Advances in the Chemistry and Physics of Fullerenes and Related Materials) (1994): 964-75.
nonaqueous, **TiO_2.**

209. Kamat, Prashant V., and K. **Vinodgopal.** "Titanium Dioxide Mediated Photocatalysis Using Visible Light: Photosensitization Approach. " *Photocatalytic* ***Purification*** *and Treatment of Water and Air, eds.* David F. Ollis and Hussain Al-Ekabi, 83-94, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, modeling, aqueous phase, modified **TiO_2**, application.

210. Kato, K., A. Tsuzuki, H. Taoda, Y. **Torii,** T. Kato, and Y. Butsugan. "Crystal Structures of **TiO_2** Thin Coatings Prepared From the Alkoxide Solution Via the Dip-Coating Technique Affecting the Photocatalytic Decomposition of Aqueous Acetic Acid." *J. Mater. Sci 29,* no. 22 (1994): 591 l-15.
TiO_2, aqueous phase, modified **TiO_2**, immobilized **TiO_2**.

211. Kato, Kazumi. "Synthesis of Titanium Dioxide Photocatalysts With High Activity by the Alkoxide Method." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 809-13, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, aqueous phase, application, modified **TiO_2**.

212. Kato, Kazumi, Akihiro Tsuzuki, Yasuyoshi **Torii,** Hiroshi Taoda, Tamihiko Kato, and Yasuo Butsugan. "Preparation of Titanium Dioxide Thin Coatings As Photocatalyst With High Activity by Sol-Gel Method." *Nagoya Kogyo* ***Gijutsu Kenkyusho Hokoku*** *42,* no. 12 (1994): 346-53.
TiO_2, aqueous phase, modified **TiO_2**.

213. Kato, Tamihiko, Yasuo Butsugan, Kazumi **Kato,** Boon **Hian** Loo, and Akira Fuishima. "Decomposition of Aqueous **Poly(Vinyl** Alcohol) on Photoexcited Titanium Dioxide." *Denki Kagaku* ***Oyobi*** *Kogyo Butsuri* ***Kagaku*** 61, no. 7 (1993): 876-7.
Polymers, **TiO_2**, aqueous phase, application.

214. Kawaguchi, Hideki. "Dependence of Photocatalytic Reaction Rate on Titanium Dioxide Concentration in Aqueous Suspensions." *Environ. Technol.* 15, no. 2 (1994): 183-8.
TiO_2, modeling, aqueous phase.

215. Kawaguchi, Hideki. "Dependence of Photocatalytic Reaction Rate on Photocatalyst Concentration in Aqueous Suspensions." *Photocatalytic Purification and Treatment of* Water and Air, eds. David F. Ollis and Hussain Al-Ekabi, 665-82, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, modeling, process efficiency.

216. **Kawashima, Shinya,** and Seigo Nagame. "Inhibition of Streptococcus **Mutans** Adherence to Pit and Fissure Sealants Containing Powdered Semiconductor **TiO_2**." *Shika Igaku 57,* no. 2 (1994): 129-40.
TiO_2, disinfection, aqueous phase, application, immobilized **TiO_2**.

217. Kenneke, John F., John L. Ferry, and William H. Glaze. "The Titanium Dioxide-Mediated Photocatalytic Degradation of Chloroalkenes *in* Water." *Photocatalytic* ***Purification*** *and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 179-9 1, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, modeling, aqueous phase, mechanism.

218. **Kerzhentsev,** M., **C.** Guillard, J. M. Herrmann, and P. **Pichat.** "Titanium Dioxide-Photosensitized Degradation of the Insecticide Tetrachlorvinphos **((z)-2-Chloro-1-(2,4,5-** Trichlorophenyl)Ethenyl **Dimethyl** Phosphate)." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and **Hussain** Al-Ekabi, **601-,** Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, aqueous phase, pesticide.

219. Kesselman, Janet M., **Amit** Kumar, and Nathan S. Lewis. "Fundamental Photoelectrochemistry of Titanium Dioxide and $SrTiO_3$ Applied to Environmental Problems." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 19-37, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, other semiconductor, aqueous phase, process efficiency, mechanism.

220. Kesselman, Janet M., Gary A. Shreve, Michael R. Hoffmann, and Nathan S. Lewis. "Flux-Matching Conditions At TiO_2 Photoelectrodes: Is Interfacial Electron Transfer to O_2 Rate-Limiting in the **TiO_2-Catalyzed** Photochemical Degradation of **Organics?"** *J. Phys. Chem. 98,* no. 50 (1994): 13385-95.
TiO_2, oxidant, aqueous phase, process efficiency, mechanism, immobilized TiO_2.

221. Khan, **Shahed** U. M., and Bradley D. Craig. "A Model of a Dual Semiconductor Photocatalyst System for the Detoxification of Polluted Water." ***Proc.** - Electrochem. **Soc.*** **94-19(Water** Purification by Photocatalytic Photoelectrochemical, and Electrochemical Processes) (1994): 352-64.
TiO_2, other semiconductor, modeling, oxidant, **reductant,** metallized TiO_2, aqueous phase, process efficiency, metal removal.

222. Kidoguchi, Akira, Toshiharu **Inaba,** and Hidenobu **Ito,** inventors. "Oxidation of Nitrogen-Containing Compounds." Japan Mitsui Shipbuilding Eng, assignee. Japan Patent' 06339682 A2. 13 December 1994. ***CA122:141533.***
TiO_2, other semiconductor, aqueous phase, application.

223. Kim, Dong Hyun, and Marc A. Anderson. "Performance of Nb-Doped TiO_2 Thin Films in Photocatalytic and Photoelectrocatalytic Degradation of Formic Acid." ***Proc.** - Electrochem. **Soc.*** **94-19(Water** Purification by Photocatalytic Photoelectrochemical, and Electrochemical Processes) (1994): 342-51.
TiO_2, aqueous phase, modified TiO_2, process efficiency.

224. Kitamura, Masaki, inventor. "Manufacture of Photocatalyst." Japan Storage Battery Co Ltd, assignee. Japan Patent, 06246165 A2.6 September 1994. ***CA122:42586.***
TiO_2, other semiconductor, gas phase, aqueous phase, modified TiO_2, application, immobilized TiO_2.

225. Kitamura, **Masaki,** and Juko Fujita, inventors. "Photocatalyst." Japan Storage Battery Co Ltd, assignee. Japan Patent, 05309267 A2.22 November 1993. ***CA120(22):281538q.***
TiO_2, other semiconductor, engineering, modified TiO_2, gas phase, aqueous phase, immobilized TiO_2.

226. **Kitamura,** Noboru, Tatsuya Uchida, Hiroyuki Sugimura, and Hiroshi Masuhara. "Microfabrication and Modification for Integrated Chemical Systems." ***Proc.** - Electrochem. **Soc.*** **93-12(Electrochemical** Processing of Tailored Materials) (1993): 187-200.
TiO_2, metallized TiO_2, application, immobilized TiO_2.

227. Kiwi, J. Pulgarin C., P. Peringer, and M. Graetzel. "Beneficial Effects of Heterogeneous Photocatalysis on the Biodegradation of Anthraquinone Sulfonate Observed in Water Treatment." New *J. Chem.* 17, no. 7 (1993): 487-94.
TiO_2, aqueous phase, application, solar, biotreatment.

228. Klausner, J. F., A. R. Martin, D. Y. Goswami, and K. S. Schanze. "On the Accurate Determination of Reaction Rate Constants in Batch-Type Solar Photocatalytic Oxidation Facilities." *J. Sol. Energy Eng.* 116, no. 1 (1994): 19-24.
TiO_2, engineering, reactor.

229. Klausner, James F., Andrew R. Martin, and D. Yogi Goswami. "On the Accurate Determination of Reaction Rate Constants in Batch Type Solar Photocatalytic Oxidation Facilities." *Solar Engineering* 1993, eds. Allan Kirkpatrick and William Worek, l-8, New York, NY: ASME, 1993.
aqueous phase, engineering, solar, TiO_2.

230. Ko, Edmond I. "Aerogels As Catalysts and Catalyst Supports." ***Chemtech*** April (1993): 3 l-6.
TiO_2, other semiconductor, modified TiO_2, immobilized TiO_2.

231. Kosaka, Atsushi, Yoshimasa Kodama, and Satoru Kadowaki, inventors. "Manufacture of Regenerable Deodorants." Japan Nippon Soken, and Nippon Denso Co., assignees. Japan Patent, 06170220 A2. 21 June 1994. *CA122:137318.*
TiO_2, other semiconductor, gas phase, aqueous phase, modified TiO_2, immobilized TiO_2, adsorbent.

232. Koster, T. P. M., J. W. Assink, J. M. Slaager, and C. van der Veen. "Photocatalytic Oxidation of Multi-Component Organochlorine Mixtures in Water." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 613-18, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, aqueous phase, modeling.

233. **Koval,** Carl A., Foster, Nancy S., Norrof, Karen, Sczechowski, Jeffery G., and Noble, Richard D. "Effects of Controlled Periodic Illumination on the Photoeffrciency of the Photocatalytic Oxidation of Organic Compounds at Titanium Dioxide." Presented at 17th U. S.-Japan Cooperative Seminar on Photoconversion and Photosynthesis Research, La Jolla' CA, 12-14 March 1995, 4 pp.

234. **Kuchmy,** S. Ya, A. V. Korzhak, S. V. Kulik, A. I. Belous, and A. I. Kryukov. "Photoreductive Dehalogenation of Polychlorobenzenes by Ethanol." *Teor.* ***Eksp.*** *Khim. 30,* no. 1 (1994): 34-8.
nonaqueous, TiO_2, mechanism.

235. Kuhler, Ronald J., Gregory A. Santo, Thomas R. Caudill, Eric A. Betterton, and Robert G. Arnold. "Photoreductive Dehalogenation of Bromoform With Titanium Dioxide-Cobalt Macrocycle Hybrid Catalysts." *Environ. Sci. Technol.* 27, no. 10 (1993): 2104-11.
TiO_2, solar, reductant, aqueous phase, modified TiO_2, mechanism.

236. Kuntz, Robert R. "Photocatalytic Reduction of Acetylene by $[MoOCl(Dppe)_2]^+Cl^-$ on TiO_2." *J. Photo&m. Photobiol., A 84,* no. 1 (1994): 75-82.
TiO_2, aqueous phase, modified TiO_2.

237. **Kuznetsova,** N. A., and 0. L. **Kaliya.** "Photoinduced Oxidation of Rhodamine 6Zh in Titanium Dioxide Aqueous Suspension." Zh. *Fit Khim. 67,* no. 7 (1993): 1492-5.
TiO_2, aqueous phase, dye.

238. Lai, Cuiwei, and Thomas E. Mallouk. "A New Approach to the Photochemical Trifluoromethylation of Aromatic Compounds." *J. Chem. Soc., Chem. Commun.,* no. 17 (1993): 1359-61.
Benzene and Its Derivatives, TiO_2, nonaqueous, application.

239. Larson, Sheldon A., and John L. Falconer. "Characterization of TiO_2 Photocatalysts Used in Trichloroethene Oxidation." *Appl. Catal., B 4,* no. 4 (1994): 325-42.
TiO_2, gas phase, aqueous phase, mechanism, catalyst reactivation, catalyst characterization.

240. Larson, Sheldon A., and John L. Falconer. "Characterization of Titanium Dioxide Used in Liquid-Phase and Gas-Phase Photooxidation of Trichloroethylene." *Photocatalytic Purification and Treatment of Water and Air, eds.* David F. **Ollis** and **Hussain** Al-Ekabi, 473-9, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, gas phase, aqueous phase, process efficiency, mechanism, adsorption, catalyst reactivation.

241. Lawless, Darren F. "Photophysical Studies on Ultra-Small Semiconductor Particles: **CdS** Quantum Dots, Doped and Undoped TiO_2, and Silver Halides." Ph.D. diss., Corcordia Univ., Can., 1993.
TiO_2, other semiconductor, modified TiO_2, mechanism.

242. Lee, W., Y. R. Do, K. Dwight, and A. Wold. "Enhancement of Photocatalytic Activity of Titanium(N) Oxide With **Molybdenum(VI)** Oxide." *Mater. Res. Bull.* 28, no. 11 (1993): 1127-34.
TiO_2, aqueous phase, modified TiO_2.

243. Lee, W., H. S. Shen, K. Dwight' and A. Wold. "Effect of Silver on the Photocatalytic Activity of **Titania."** *J. Solid State Chem.* 106, no. 2 (1993): 288-94.
TiO_2, metallized TiO_2, aqueous phase, modified TiO_2, metal removal.

244. Lee, Wan In. "Study of the Photocatalytic Property of Titanium (IV) Oxide (Gold, Ultrasonic Nebulization, Flame Hydrolysis)." Ph.D. diss., Brown Univ., Providence, RI, USA, 1993.
TiO_2, metallized TiO_2, modified TiO_2, catalyst characterization.

245. Lepore, Giuseppe P., Cooper H. Langford, **Jana Vichova,** and **Antonin** Jr. Vlcek. "Photochemistry and Picosecond Absorption Spectra of Aqueous Suspensions of a **Polycrystalline** Titanium Dioxide Optically Transparent in the Visible Spectrum." *J. Photochem. Photobiol., A 75,* no. 1 (1993): 67-75.
TiO_2, aqueous phase, modified TiO_2, process efficiency, mechanism.

246. Lepore, Giuseppe P., Bhuvan C. Pant' and Cooper H. Langford. "Limiting Quantum Yield Measurements for the Disappearance of 1-Propanol and Propanal: an Oxidative Reaction Study Employing a TiO_2-**Based** Photoreactor." *Can. J. Chem.* 71, no. 12 (1993): 2051-g.
TiO_2, reactor, aqueous phase, modified TiO_2, process efficiency, mechanism, immobilized TiO_2, adsorption.

247. Lepore, Giuseppe P., Antonin Jr. Vlcek, and Cooper H. Langford. "The Photocatalytic Oxidation of Propanol by Titanium Dioxide." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 95-109, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, aqueous phase, modified TiO_2, process efficiency, mechanism, adsorption.

248. Li, Tian, and Xushi Yan. "Photocatalytic Oxidation for Drinking Water Purification." *Water Treat. 9,* no. 2 (1994): 119-26.
TiO_2, aqueous phase, application.

249. Li, Tian, and Xushi Yan. "Study on Removing Organochlorine Compounds in Water by Photocatalytic Oxidation Method." *Shanghai Huanjing Kexue* 11, no. 12 (1992): 1 1-14,7.
TiO_2, aqueous phase, application, catalyst reactivation.

250. Li, Tian, Xushi Yan, and Weiyi Xu. "Photocatalytic Oxidation of Humic Acid in Aqueous Solution." *Shuichuli Jishu 20,* no. 1 (1994): 51-5.
TiO_2, aqueous phase, application.

251. Lichtin, Norman N., and M. Avudaithai. "Application of Photocatalytic Oxidative Degradation to Industrial Waste Streams." *Photochem. Photoelectrochem. Convers. Storage Sol. Energy, Proc. Znt. Conf., 9th,* ed. Zhao Wu Tian, 97-112, Beijing, Peop. Rep. China: Int. Acad. Publ., 1993.
TiO_2, oxidant, aqueous phase, application, process efficiency, cost.

252. Lichtin, Norman N., Musuthami Avudaithai, and Elliot Berman. "Relative Reactivity of Aqueous and Vaporized VOCs to Photocatalytic Oxidative Mineralization Over TiO_2." *Proc.-Electrochem. Soc.* 94-19(Water Purification by Photocatalytic, Photoelectrochemical, and Electrochemical Processes) (1994): 320- 1.
TiO_2, reactor, gas phase, aqueous phase, mechanism, modeling, adsorption.

253. Lichtin, Norman N., Muthusami Avudaithai, Elliot Berman, and Junchang Dong. "Photocatalytic Oxidative Degradation of Vapors of Some Organic Compounds Over TiO_2." *Res. Chem. Intermed. 20,* no. 7 (1994): 755-8 1.
TiO_2, gas phase, modified TiO_2, process efficiency.

254. Lin, Lufei, and Robert R. Kuntz. "Competative Photocatalytic Reduction of H+ and C2H2 by Mo2S4(S2C2H4)2(2-) on Colloidal TiO_2." *J. Photochem. Photobiol. A: Chem. 66* (1992): 245-5 1.
TiO_2, reductant, aqueous phase, modified TiO_2, process efficiency.

255. Lin, Wen Yuan, Chang Wei, and Krishnan Rajeshwar. "Photocatalytic Reduction and Immobilization of Hexavalent Chromium At Titanium Dioxide in Aqueous Basic Media." *J. Electrochem. Soc.* 140, no. 9 (1993): 2477-82.
TiO_2, oxidant, aqueous phase, application, metal removal.

256. Liidner, Martin, Detlef W. Bahnemann, Bemd Hirthe, and Wolf-D. Griebler. "Solar Water Detoxification: Novel TiO_2 Powders As Highly Active Photocatalysts. " *Solar Engineering 1995,* eds. William B. Stine, Tadayoshi Tanaka' and David E. Claridge, 399-408, New York, NY: ASME, 1995.
TiO_2, modeling, aqueous phase, modified TiO_2, process efficiency, mechanism, catalyst reactivation, anion inhibition.

257. Linkous, Clovis A., Nazim Z. Muradov, and Ali T-Raissi. "A Perspective on Photo- and Electrochemical Detoxification of Aqueous Nitrate Esters." *Proc.- Electrochem. Soc.* 94-19(Water purification by Photocatalytic Photoelectrochemical, and Electrochemical Processes) (1994): 309-19.
TiO_2, aqueous phase, application, process efficiency, immobilized TiO_2.

258. Lmsebigler, Amy L., Guangquan Lu, and John T. Yates Jr. "Photocatalysis on TiO_2 Surfaces: Principles, Mechanisms, and Selected Results." *Chem. Rev. 95,* no. 3 (1995): 735-58.
TiO_2, gas phase, aqueous phase, modified TiO_2, process efficiency, mechanism, immobilized TiO_2, metal removal, catalyst characterization.

259. Litter, Marta I., and Jose A. Navio. "Comparison of the Photocatalytic Efficiency of TiO_2, Iron Oxides and Mixed Ti(IV)-Fe(III) Oxides: Photodegradation of Oligocarboxylic Acids." *J. Photochem. Photobiol., A 84,* no. 2 (1994): 183-93.
TiO_2, other semiconductor, modified TiO_2, aqueous phase.

260. Liu, Xinsheng, Kai Kong Iu, and J. Kerry Thomas. "Preparation, Characterization and Photoreactivity of Titanium(IV) Oxide Encapsulated in Zeolites." *J. Chem. Soc., Faraday Trans. 89,* no. 11 (1993): 1861-5.
TiO_2, aqueous phase, modified TiO_2, immobilized TiO_2, adsorbent.

261. Lodha, Anita' Jatinder Kaur, Pinki B. Punjabi, and Suresh C. Ameta. "Photocatalytic Reaction of Ethambutol on Zinc Oxide Powder." *Rev. Roum. Chim. 39,* no. 5 (1994): 583-6.
other semiconductor, oxidant' aqueous phase, mechanism.

262. Love, Jonathan G., A. James McQuillan, and David A. Buckingham. "In-Situ IR Reflection Absorption Spectroscopy (IRRAS) During W-Irradiation of Ferrocyanide Adsorbed on TiO_2." *Bull. Electrochem. 9,* no. 5-7 (1993): 277-9.
TiO_2, aqueous phase, modified TiO_2, mechanism, immobilized TiO_2, metal removal.

263. Lu, G., A. Linsebigler, and J. T.Yates Jr. "Photooxidation of CH_3Cl on TiO_2(110): A Mechanism Not Involving H_2O." *J. Phys. Chem. 99,* no. 19 (1995): 7626-3 1.
TiO_2, gas phase, mechanism, adsorption, catalyst characterization.

264. Lu, Guangquan, Amy Lmsebigler, and John T. Yates Jr. "The Photochemical Identification of Two Chemisorption States for Molecular Oxygen on TiO_2(1 10)." *J. Chem. Phys.* 102, no. 7 (1995): 3005-8.
TiO_2, gas phase, mechanism, immobilized TiO_2, adsorption.

265. Lu, Ming-Chun, Gwo-Dong Roam, Jong-Nan Chen, and C. P. Huang. "Factors Affecting the Photocatalytic Degradation of Dichlorvos Over Titanium Dioxide Supported on Glass." *J. Photochem. Photobiol., A 76,* no. 1-2 (1993): 103-10.
Agrochemical, TiO_2, pesticide, aqueous phase, application.

266. Lyons, Carol, Craig S. Turchi, and David Gratson. *Solving Widespread Low-Concentration VOC Air Pollution Problems: Gas-Phase Photocatalytic Oxidation Answers the Needs of Many Small Businesses,* NREL,TP-473-7569. National Renewable Energy Laboratory, Golden, CO, 1995. DE95004059.
TiO_2, gas phase, application, cost.

267. Maeda, Yukitoshi, Susumu Kato, and Atsushi Matsushita' inventors. "Pretreatment With Photocatalyst for Biological Treating Wastewaters." Japan Maeda Kosen Kk, assignee. Japan Patent, 06182363 A2.5 July 1994. *CA121:237788.*
TiO_2, engineering, reactor, solar, oxidant' aqueous phase, modified TiO_2, application, immobilized TiO_2, biotreatment.

268. Maeda, Yukitoshi, Susumu Kato, and Atsushi Matsushita' inventors. "Treatment of Wastewater by Biological Treatment Using Photocatalysts for Pretreatment." Japan Maeda Kosen Kk, assignee. Japan Patent, 07060269 A2.7 March 1995. *CA122:273233.*
TiO_2, other semiconductor, engineering, reactor, aqueous phase, application, immobilized TiO_2, biotreatment.

269. Magrini, K. A., R. M. Goggin, A. S. Watt' A. M. Taylor, and A. L. Baker. "Improving Catalyst Performance for Solar-Based Photocatalytic Oxidation of Organics." *Solar Engineering 1994,* eds. David E. Klett, Roy E. Hogan, and Tadayoshi Tanaka' 163-9, 1994.
TiO_2, metallized TiO_2, aqueous phase, modified TiO_2.

270. Magrini, Kimberly A., A. Watt' and B. Rinehart. "Photocatalyst Evaluation for Solar Based Aqueous Organic Oxidation." *Solar Engineering 1995,* eds. William B. Stine, Tadayoshi Tanaka, and David E. Claridge, 415-20, New York, NY: ASME, 1995.
TiO_2, metallized TiO_2, aqueous phase, modified TiO_2, ferrioxalate.

271. Maillard-Dupuy, Catherine, Chantal Guillard, Henri Courbon, and Pierre Pichat. "Kinetics and Products of the TiO_2 Photocatalytic Degradation of Pyridine in Water." *Environ. Sci. Technol. 28,* no. 12 (1994): 2176-83.
TiO_2, pesticide, aqueous phase, application, mechanism.

272. Maillard-Dupuy, Catherine, Chantal Guillard, and Pierre Pichat. "The Degradation of Nitrobenzene in Water by Photocatalysis Over TiO_2: Kinetics and Products; Simultaneous Elimination of Benzamide or Phenol or Pb2+ Cations." *New J. Chem.* 18, no. 8-9 (1994): 941-8.
TiO_2, oxidant, aqueous phase, process efficiency, metal removal, adsorption.

273. Malinka, E. A., and G. L. Kamolov. "Photocatalytic Hydrogen Evolution From Aqueous Pt/TiO_2 Suspension in the Presence of Oxalic Acid." *React. Kinet. Catal. Lett. 52,* no. 1 (1994): 13-8.
TiO_2, reductant, metallized TiO_2, aqueous phase, mechanism.

274. Mansour, M., and E. A. Feicht. "Transformation of Chemical Contaminants by Biotic and Abiotic Processes in Water and Soil." *Chemosphere 28,* no. 2 (1994): 323-32.
TiO_2, solar, pesticide, aqueous phase.

275. Mao, Y., C. Schoeneich, and K. D. Asmus. "Radical Mediated Degradation Mechanisms of Halogenated Organic Compounds As Studied by Photocatalysis At Titanium Dioxide and by Radiation Chemistry." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 49-66, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, modeling, oxidant, aqueous phase, process efficiency, mechanism.

276. Martin, Carlos A., Miguel A. Baltanas, and Alberto E. Cassano. "Photocatalytic Reactors. I. Optical Behavior of Titanium Oxide Particulate Suspensions." *J. Photochem. Photobiol., A 76,* no. 3 (1993): 199-208.
TiO_2, reactor, modeling.

277. Martin, Scot T., H. Herrmann, W. Choi, and Michael R. **Hoffmann.** "Photochemical Destruction of Chemical Contaminants on Quantum-Sized Semiconductor Particles. " *Solar Engineering* 1995, eds. William B. Stine, Tadayoshi Tanaka, and David E. Claridge, 409-13, New York, NY: **ASME,** 1995.
TiO_2, other semiconductor, solar, oxidant, reductant, aqueous phase, modified **TiO_2**, process efficiency, mechanism, immobilized **TiO_2**, metal removal.

278. Martin, Scot T., Hartmut Herrmann, Wonyong Choi, and Michael R. Hoffmann. "Time-Resolved Microwave Conductivity. Part 1. **TiO_2** Photoreactivity and Size Quantization." *J. Chem. Soc., Faraday Trans. 90,* no. 21 (1994): 3315-22.
TiO_2, other semiconductor, aqueous phase, modified **TiO_2**, process efficiency, mechanism.

279. Martin, Scot T., **Colin** L. Morrison, and Michael R. Hoffmann. "Photochemical Mechanism of Size-Quantized Vanadium-Doped **TiO_2** Particles." ***J.** Phys. Chem. 98,* no. 5 1 (1994): 13695-704.
TiO_2, aqueous phase, modified **TiO_2**, mechanism, process efficiency.

280. Masuda, Ryuji, Koichi Kawashima, Wataru Takahashi, Masayuki Murabayashi, and Kiminori **Ito,** inventors. "Photocatalysts for Treatment of Harmful Substances and Its Apparatus." Japan Nippon Muki Kk, assignee. Japan Patent, 06320010 A2.22 November 1994. ***CA122:118763.***
TiO_2, immobilized **TiO_2**, modified **TiO_2**.

281. Masuda, Ryuji, Koichi Kawashima, Wataru Takahashi, Masayuki Murabayashi, and Kiminori **Ito,** inventors. "Photocatalysts and Apparatus for Heavy Metal Ion Removal From Solutions." Japan Nippon Muki Kk, assignee. Japan Patent, 06320011 A2.22 November 1994. ***CA122:114046.***
TiO_2, immobilized **TiO_2**, metal removal, aqueous phase

282. Matsumoto, Yasumichi, Michio Obata, and Jukishi Hombo. "Photocatalytic Reduction of Carbon Dioxide on P-Type **$CaFe_2O_4$** Powder." *J. Phys. **Chem.** 98,* no. 11(1994): 2950-51.
other semiconductor, reductant, aqueous phase, mechanism.

283. Matsunaga, Tadashi, inventor. "Process for Killing Cells." Tokyo Japan Kabashiki Kalsya Advanced Kalhatsu **Kenkyujo,** assignee. United States Patent, 4708038.29 November 1988.
disinfection, immobilized **TiO_2**, other semiconductor, aqueous phase, gas phase.

284. Matsunaga, Tadashi, **Ryuzo** Tomoda, Toshiaki Nakjima, Noriyuki Nakumura, and Tamotsu Komine. "Continuous-Sterilization System That Uses Photo-Semiconductor Powders." *Appl. Environ. **Microbiol.** 54,* no. 6 (1988): 1330-3.
TiO_2, disinfection, aqueous phase, process efficiency, immobilized **TiO_2**.

285. Matsushita, **Atsushi,** inventor. "Manufacture of Titanium Oxide Plate Material for Photocatalyst." Japan Maeda Kosen Kk, assignee. Japan Patent, 06210170 A2.2 August 1994. *CA121:241566.*
TiO_2, aqueous phase, immobilized **TiO_2**.

286. Matthews, R. W. "Environment: Photochemical and Photocatalytic Processes. Degradation of Organic Compounds." *Photochemical Conversion and Storage of Solar Energy, Proceedings of the 8th International Conference on Photochemical Conversion and Storage of Solar Energy,* eds. E. Pelizzetti, and M. Schiavello, 427-3, Dordrecht: Kluwer Academic Publishers, 199 1.
TiO_2, other semiconductor, solar, oxidant, aqueous phase, modified TiO_2, application, mechanism, process efficiency, immobilized TiO_2, photochemistry.

287. Matthews, Ralph, inventor. "Apparatus and Method for Determining Concentration of Organic Carbon in High-Purity Water." Australia Commonwealth Scientific and Industrial Research Organization, assignee. Australia Patent' 657477 B2. 16 March 1995. *CA122:322120.*
TiO_2, other semiconductor, reactor, aqueous phase, application, immobilized TiO_2.

288. Mehos, Mark, Craig S. Turchi, Jim Pacheco, A. J. Boegel, Tim Merrill, and Tim Stanley. *Pilot-Scale Study of the Solar Detoxification of VOC-Contaminated Groundwater,* NREL,TP-432-498 1. NREL, Golden, CO, 1992. DE92016405.
TiO_2, engineering, reactor, solar, aqueous phase, application, process efficiency.

289. Mehos, Mark, Tom Williams, and Craig S. Turchi. *Overview of Solar Detoxification Activities in the United States,* NREL,TP-471-7262. NREL, Golden, CO, 1994. DE95000264.
TiO_2, solar, gas phase, aqueous phase, application, SI Program.

290. Memming, Ruediger. "Photoinduced Charge Transfer Processes At Semiconductor Electrodes and Particles." *Topics in Current Chemistry* 169 (1994): 105-81.
TiO_2, other semiconductor, solar, oxidant' reductant, metallized TiO_2, aqueous phase, modified TiO_2, application, process efficiency, mechanism, immobilized TiO_2, metal removal.

291. Mezza, Michel, and Brigitte Berthomieu, inventors. "Photodegradable Propylene and Ethylene Polymer Compositions."France Patent, 2692583 Al. 24 December 1993. *CA121:302239.*
nonaqueous, TiO_2, solar, application, immobilized TiO_2.

292. Micic, Olga I., Yuenian Zhang, Keith R. Cromack, Alexander D. Trifunac, and Marion C. Thumauer. "Trapped Holes on TiO_2 Colloids Studied by Electron Paramagnetic Resonance." *J. Phys. Chem. 97* (1993): 7277-83.
TiO_2, other semiconductor, reductant, aqueous phase, mechanism.

293. Micic, Olga I., Yuenian Zhang, Keith R. Cromack, Alexander D. Trifunac, and Marion Thumauer. "Photoinduced Hole Transfer From TiO_2 to Methanol Molecules in Aqueous Solution Studied by Electron Paramagnetic Resonance." *J. Phys. Chem. 97,* no. 50 (1993): 13284-8.
TiO_2, oxidant, reductant, aqueous phase, mechanism.

294. Milis, A., J. Peral, and X. Domenech. "Kinetics of Photocatalytic Oxidation of Sulfite-Nitrite Mixtures in Aqueous TiO_2 Suspensions." *Oxid. Commun.* 17, no. 3-4 (1994): 163-9.
TiO_2, aqueous phase, mechanism, metallized TiO_2, oxidant.

295. Milis, Ali, Jose Peral, Xavier Domenech, and J. A. Navio. "Heterogeneous Photocatalytic Oxidation of Nitrite Over Iron-Doped TiO_2 Samples." *J. Mol. Catal. 87,* no. 1 (1994): 67-74.
TiO_2, reductant, aqueous phase, modified TiO_2, adsorption.

296. Militemo, **Simonetta,** Luigi **Campanella,** and Giancarlo Crescentini. "**Photocatalytic** Degradation of Selected Chlorophenols and Pesticides by Immobilized Polyaniline and TiO_2."*Mobility Degrad. Xenobiot., Proc. - Simp. Pestic.* Chem.Attilio A. M. Del Re, 431-O. **Lucca,** Italy: G. Biagini, 1993.
TiO_2, pesticide, aqueous phase, modified TiO_2, immobilized TiO_2.

297. Mills, Andrew, Ahmed **Belghazi,** Richard H. Davies, David Worsley, and Sian Morris. "A Kinetic Study of the Bleaching of Rhodamine 6G Photosensitized by Titanium Dioxide." *J. Photochem. Photobiol., A 79,* no. l-2 (1994): 131-9.
TiO_2, aqueous phase.

298. Mills, Andrew, and Richard Davies. "Activation Energies in Semiconductor Photocatalysis for Water Purification: the **4-Chlorophenol-TiO_2-O_2** Photosystem." *J. Photochem. Photobiol., A 85,* no. 1-2 (1995): 173-8.

299. Mills, Andrew, and Richard Davies. "The Photomineralization of Reactive Black 5 Sensitized by Titanium Dioxide: a Study of the Initial Kinetics of Dye Photobleaching." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. **Ollis** and Hussain **Al-Ekabi,** 595-600, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, aqueous phase, process efficiency.

300. Mills, Andrew, Richard H. Davies, and David Worsley. "Water Purification by Semiconductor Photocatalysis." *Chem. Soc. Rev. 22,* no. 6 (1993): 417-25.
TiO_2, aqueous phase, application.

301. Mills, Andrew, Peter Douglas, Alison Green, and Geraint Williams. "Diffusion- and Activation-Controlled Photoredox Reactions Sensitized by Colloidal **Semiconductors.**"*Electrochem. Colloids Dispersions, [Symp. Electrochem. Microheterog. Fluids]* eds. Raymond A. Texter and John Mackay, 385-97, New York, N.Y: VCH, 1992.
TiO_2, other semiconductor, aqueous phase, process efficiency, mechanism.

302. Mills, Andrew, Carolyn E. Holland, Richard H. Davies, and David Worsley. "Photomineralization of Salicylic Acid: a Kinetic Study." *J. Photochem. Photobiol., A 83,* no. 3 (1994): 257-63.
TiO_2, modeling, aqueous phase, adsorption.

303. Mills, Andrew, and Sian Morris. "Photomineralization of 4-Chlorophenol Sensitized by Titanium Dioxide: a Study of the Effect of Annealing the Photocatalyst At Different Temperatures." *J. Photochem. Photobiol., A* 71, no. 3 (1993): 285-9.
TiO_2, aqueous phase, modified TiO_2, process efficiency.

304. Mills, Andrew, David Worsley, and Richard H. Davies. "Effect of ph on the Stability of TiO_2 Coatings on Glass Photocatalysis Reactors for Water Purification." *J. Chem. Soc., Chem. Commun.,* no. 23 (1994): 2677-8.
TiO_2, aqueous phase, immobilized TiO_2.

305. Mills, German, and Michael R. Hoffmann. "Photocatalytic Degradation of Pentachlorophenol on Titanium Dioxide Particles: Identification of Intermediates and Mechanism of Reaction." *Environ. Sci. Technol. 27,* no. 8 (1993): 1681-9.
TiO_2, oxidant, aqueous phase, process efficiency, mechanism.

306. Minero, C., E. Pelizzetti, S. Malato, and J. **Blanco.** "Large Solar Plant Photocatalytic Water Decontamination: Degradation of **Pentachlorophenol."** *Chemosphere 26,* no. 12 (1993): 2103-19.
TiO_2, solar, engineering, reactor, oxidant, aqueous phase.

307. Minero, C., E. Pelizzetti, P. Piccinini, and M. Vincenti. "Photocatalyzed Transformation of Nitrobenzene on TiO_2 and **ZnO."** *Chemosphere 28,* no. 6 (1994): 122944.
TiO_2, other semiconductor, aqueous phase, mechanism.

308. Minero, C., E. Pelizzetti, R. Terzian, and N. Serpone. "Reactions of Hexafluorobenzene and **Pentafluorophenol** Catalyzed by Irradiated TiO_2 in Aqueous Suspensions." ***Langmuir*** 10, no. 3 (1994): 692-8.
TiO_2, aqueous phase, mechanism.

309. Minoura, Hideki. "Photocatalytic Reactions on Semiconductor Films." ***Kikan*** *Kagaku Sosetsu 23* (1994): 79-85.
nonaqueous, TiO_2, application, immobilized TiO_2.

310. Minsker, L., C. **Pulgarin,** P. Peringer, and J. Kiwi. "Integrated Approach Useful in the Mineralization of Nonbiodegradable, Toxic P-Nitrotoluenesulfonic Acid Vi Photocatalytic-Biological Process." *New J.* ***Chem.*** 18, no. 7 (1994): **793-800.**
TiO_2, oxidant' aqueous phase, biotreatment.

311. **Mitani,** Michiharu, Takuya Kiriyama, and Tomoaki Kuratate. "Addition Reaction of Polychloro Compounds to Carbon-Carbon Multiple Bonds Catalyzed by Semiconductor Particles Under Photoirradiation." J. *Org.* ***Chem.*** *59,* no. 6 (1994): 1279-82.
nonaqueous, TiO_2, mechanism, **reductant.**

312. Miyoshi, Noriomi, **Kazuteru** Shinkai, Toshiharu Sasamoto, and Hitomi Kawakami, inventors. "Method and Apparatus for Removing Harmful Gas From Exhaust Gas." Ltd. Japan Fuji Electric Co., assignee. Europe Patent' 591920 **A2. 13** April 1994. ***CA120:306375.***
TiO_2, other semiconductor, gas phase, modified TiO_2, application, adsorbent, immobilized TiO_2.

313. **Monaci,** Anna' **Aldo** La Ginestra, and Pasquale **Patrono.** "Zirconium Phosphates As Photocatalysts." *J. Photochem. Photobiol. A:* ***Chem.*** *83* (1994): 63-7.
nonaqueous, TiO_2, other semiconductor, mechanism.

314. Murabayashi, Masalyuki, **Kiminori Itoh,** Seiji Suzuki, Koichi Kawashima, and Ryuji Masuda. "Photocatalytic Degradation of Chloroform by Using Titanium Dioxide Thin Films Coated on Solid Substrate." ***Proc.-*** *Electrochem.* ***Soc.*** 93-18, Proceedings of the Symposium on Environmental Aspects of Electrochemistry and Photoelectrochemistry (1993): 13 l-6.
TiO_2, aqueous phase, immobilized TiO_2.

315. Murabayashi, Masayuki, **Kiminori Itoh,** Koichi **Kawashima,** Ryuji **Masuda,** and Seiichi Suzuki. "Photocatalytic Degradation of Chloroform With Titanium Dioxide Coated Glass Fiber Cloth." *Photocatalytic Purification and Treatment of Water and Air, eds.* David F. Ollis and Hussain Al-Ekabi, 783-8, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, aqueous phase, immobilized TiO_2.

316. Murabayashi, Masayuki, and Kazuo **Okamura.** "Degradation of Chlorinated Organic Compounds Using Fixed Photocatalyst." *Yosui to Haisui 36,* no. 10 (1994): 877-2.
TiO_2, gas phase, immobilized TiO_2, modified TiO_2.

317. Muradov, Nazim Z. "Solar Detoxification of Nitroglycerin-Contaminated Water Using Immobilized Titania." *Sol. Energy 52,* no. 3 (1994): 283-8.
TiO_2, solar, **metallized** TiO_2, aqueous phase, immobilized TiO_2.

318. Muradov, Nazim Z., and **Ali** T-Raissi. **"Titania-Catalyzed,** Photooxidative Detoxification of Nitroglycerin-Contaminated Airborne **VOCs."** *Chem.* ***Oxid.*** Volume Date 1993, no. 3 (1994): 172-82.
TiO_2, gas phase, immobilized TiO_2.

319. **Murasawa,** Sadao. "Recent Applications of Photocatalysis." ***Denki*** *Kagaku Oyobi Kogyo* ***Butsuri*** *Kagaku* 63, no. 1 (1995): 9-13.
TiO_2, disinfection, gas phase, aqueous phase, application.

320. Nair, Maya' Zhenghao Luo, and Adam Heller. "Rates of Photocatalytic Oxidation of Crude Oil on Salt Water on Buoyant, Cenosphere-Attached Titanium Dioxide." ***Ind.*** *Eng. Chem. Res. 32,* no. 10 (1993): 23 18-23.
TiO_2, engineering, aqueous phase, modified TiO_2, immobilized TiO_2.

321. Nargiello, Maria, and Ted Herz. "Physical-Chemical Characteristics of P-25 Making It Extremely Suited As the Catalyst in Photodegradation of Organic Compounds." *Photocatalytic* ***Purification*** *and Treatment* ***of*** *Water and Air,* eds. David F. **Ollis** and Hussain Al-Ekabi, 801-7, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, gas phase, aqueous phase, modified TiO_2, cost.

322. **Nishida,** K., and S. Ohgaki. **"Photolysis** of Aromatic Chemical Compounds in Aqueous TiO_2 Suspensions." *Water Sci Technol.* 30, no. 9 (1994): 39-46.
TiO_2, pesticide.

323. Nishiguchi, H., and M. Anpo. "Photochemical Properties of Benzophenone Adsorbed on Ti-Al and Ti-Si Binary **Oxides."*****Chem.*** *Funct. Dyes,* ***Proc.*** *Znt. Symp.,* ***2nd,*** eds. Z. Yoshida, and Y. Shirota, 153-8, Tokyo, Japan: Mita Press, 1993.
TiO_2, other semiconductor.

324. **Nogueira,** Raquel F. P., and Wilson F. **Jardim.** "Photodegradation of Methylene Blue: Using Solar Light and Semiconductor (Titanium Dioxide)." *J. Chem.* ***Educ.*** *70,* no. 10 (1993): 861-2.
Education, TiO_2, reactor, solar, aqueous phase.

325. Nosaka, Yoshio. "Mechanism of Photocatalytic Reactions on Semiconductor Particles." Presented at 17th U.S.-Japan Cooperative Seminar on Photoconversion and Photosynthesis Research, La Jolla, CA, 12-14 March 1995, 3 pp.

326. **Nosaka,** Yoshio. "Photocatalytic Aspects of Ultrasmall Semiconductor Particles." ***Kikan*** *Kagaku Sosetsu* 23 (1994): 62-8.
TiO_2, other semiconductor, aqueous phase, modified TiO_2, process efficiency, mechanism.

327. Notthakun, Sawang, John C. Crittenden, David W. Hand, David L. Perram, and Michael E. Mullins. "Regeneration of Adsorbents Using Heterogeneous Advanced Oxidation." *J. Environ. Eng.* 119, no. 4 (1993): 695-714.
TiO_2, solar, metallized TiO_2, aqueous phase, immobilized TiO_2, adsorbent.

328. O'Shea' Kevin E., and Claudia Cardona "Hammett Study on the TiO_2-Catalyzed Photooxidation of Para-Substituted Phenols. A Kinetic and Mechanistic Analysis." *J. Org. Chem. 59,* no. 17 (1994): 5005-9.
TiO_2, aqueous phase, mechanism.

329. Obee, Timothy N., and Robert T. Brown. "TiO_2 Photocatalysis for Indoor Air Applications: Effects of Humidity and Trace Contaminant Levels on the Oxidation Rates of Formaldehyde, Toluene, and 1,3-Butadiene." *Environ. Sci. Technol. 29,* no. 5 (1995): 1223-3 1.
TiO_2, gas phase, application, immobilized TiO_2.

330. Oberg, V., D. Y. Goswami, and G. Svedberg. "On Photocatalytic Detoxification of Water Containing Volatile Organic Compounds. " *Solar Engineering 1994,* eds. David E. Klett, Roy E. Hogan, and Tadayoshi Tanaka' 147-53, 1994.
TiO_2, engineering, reactor, solar, oxidant, aqueous phase, application, adsorption.

331. Oeste, Franz Dietrich, inventor. "Photocatalytic Purification of Waste Gases." Germany PCP Photocatalytic Purification GmbH, assignee. Germany Patent' 4320218 Al. 21 July 1994. *CA121:186142.*
TiO_2, other semiconductor, engineering, reactor, gas phase, modified TiO_2, aqueous phase, adsorption.

332. Ogawa, Shunjiro, Mamiko Tanigawa, Michiko Fujioka, and Yukiko Hanasaki. "Photocatalyzed Destruction of Humic Acid in Aqueous Semiconductor Suspension and Diminution of Its Trihalomethane Production Potential." *Jpn. J. Toxicol. Environ. Health* 41, no. 1 (1995): 7.
TiO_2, aqueous phase, application.

333. Ogawa, Takatoshi, Toshio Saito, Kenichi Unno, Kan Hasegawa, Yasuhiko Yoshioka, Noburo Tsubochi, Seiichi Hosoiri, Tooru Katayama, Akira Fujishima, and Kazuhito Hashimoto, inventors. "Materials for Construction of Hospitals for Preventing Infections." Japan Takenaka Komuten Co, assignee. Japan Patent, 07000462 A2.6 January 1995. *CA122:170302.*
TiO_2, other semiconductor, metallized TiO_2, disinfection, gas phase, application, IAQ.

334. Ogawa, Talcatoshi, Kenichi Unno, Hidehiko Nakasaki, Takeshi Hiromatsu, Norio Igawa, Shigetaka Magara, Toshio Saito, Akira Fujishima, and Kazuhito Hashimoto, inventors. "Apparatus for Photochemical Synthesis of Methanol." Japan Takenaka Komuten Co, assignee. Japan Patent, 07033697 *A2.3* February 1995. *CA122:239181.*
TiO_2, other semiconductor, reactor, engineering, solar, reductant, aqueous phase, modified TiO_2, immobilized TiO_2.

335. Ogawa, Takatoshi, Yasuhiko Yoshioka, Nobuo Tsubouchi, Toshio Saito, Tamotsu Hasegawa, Akira Fujishima, and Kazuhito Hashimoto, inventors. "Architectural Material Using Metal Oxide Exhibiting Photocatalytic Activity." Japan Takenaka Corp., assignee. Canada Patent, 2106510 AA. 23 March 1994. *CA121:140271.*
TiO_2, other semiconductor, solar, metallized TiO_2, disinfection, gas phase, aqueous phase, modified TiO_2, application, IAQ, immobilized TiO_2.

336. Ohgaki, Shinichiro, and Kei Nishida. "Photocatalytic Degradation of Aromatic Compounds Using Titanium Dioxide." *Yosui to Haisui 36,* no. 10 (1994): 858-63.
TiO_2, pesticide, aqueous phase.

337. Ohnishi, Hideyuki, Michio Matsumura, Hiroshi Tsubomura, and Makoto Iwasaki. "Bleaching of Lignin Solution by a Photocatalyzed Reaction on Semiconductor Photocatalysts." *I&EC Research 28,* no. 6 (1989): 719-24.
TiO_2, other semiconductor, metallized TiO_2, aqueous phase, modified TiO_2, application, mechanism.

338. Ohtani, Bunsho. "Recent Progress in Research of Semiconductor Photocatalysis. Materials, Reactions, and Mechanism." *Shokubai 36,* no. 7 (1994): 515-23.
TiO_2, other semiconductor, aqueous phase, mechanism.

339. Ohtani, Fumiaki. "Photodegradation of Polyolefms by Titanium Oxide Fine Particles." *Kobunshi Kako 42,* no. 5 (1993): 226-31.
Synthetic High Polymers, TiO_2, oxidant, modified TiO_2, application, mechanism, immobilized TiO_2.

340. Ollis, David F. "Comparative Aspects of Advanced Oxidation Processes." Presented at ACS Symposium - Emerging Technologies for Hazardous Waste Destruction, Atlanta' GA, October 1991, 21 pp.

341. Ollis, David F. "Solar-Assisted Photocatalysis for Water Purification: Issues, Data, Questions." *Photochemical Conversion and Storage of Solar Energy, Proceedings of the 8th International Conference on Photochemical Conversion and Storage of Solar Energy,* eds. E. Pelizzetti and M. Schiavello, 593-622, Dordrecht: Kluwer Academic Publishers, 199 1.
TiO_2, engineering, reactor, solar, oxidant, aqueous phase, application, process efficiency, mechanism, immobilized TiO_2, cost.

342. Ollis, David F., Ezio Pelizzetti, and Nick Serpone. "Heterogeneous Photocatalysis in the Environment: Application to Water Purification." *Photocatalysis Fundamentals and Applications,* eds. Nick Serpone and Ezio Pelizzetti, 603-37. New York: John Wiley & Sons, 1989.
TiO_2, other semiconductor, engineering, reactor, modeling, aqueous phase, mechanism, metal removal.

343. Ollis, David F., Ezio Pelizzetti, and Nick Serpone. "Photocatalyzed Destruction of Water Contaminants." *Environ. Sci. Technol. 25,* no. 9 (1991): 1522-9.
TiO_2, other semiconductor, engineering, solar, modeling, aqueous phase, application, process efficiency, mechanism, metal removal.

344. Onoda, Kinji, Yasukiyo Ogose, and Shoichiro Izumi, inventors. "A Redox Method and Membrane-Separated Photoelectrochemical Cell." Ltd. Shiken, assignee. Japan Patent' 63 28895.6 February 1988. ***CA109:63262b.***
TiO_2, other semiconductor, reactor, disinfection, aqueous phase, application, immobilized TiO_2, metal removal.

345. Oozora, Hiroyuki, inventor. "Photochemical Conversion of Carbon Dioxide." Mitsubishi Heavy Ind Ltd, assignee. Japan Patent, 05146671 *A2.15* June 1993. ***CA119(20):213896j.***
TiO_2, **reductant,** aqueous phase, modified TiO_2, immobilized TiO_2.

346. Pacheco, J. E., M. R. Prairie, and L. Yellowhorse. "Photocatalytic Destruction of Chlorinated Solvents in Water With Solar Energy." *J. Sol. Energy Eng.* 115, no. 3 (1993): 123-9.
TiO_2, reactor, solar, aqueous phase, engineering.

347. Pacheco, Kelli, Andrew S. Watt' and Craig S. Turchi. "Solar Detoxification of Water: Outdoor Testing of Prototype Photoreactors." *ASME,ASES Joint Solar Energy Conference,* eds. Allan Kirkpatrick and William Worek, 43-49, New York, NY: ASME, 1993.
TiO_2, engineering, reactor, solar, aqueous phase, immobilized TiO_2.

348. Palmisano, L., M. Schiavello, A. Sclafani, C. Martin, I. Martin, and V. Rives. "Surface Properties of Iron-Titania Photocatalysts Employed for 4-Nitrophenol Photodegradation in Aqueous TiO_2 Dispersion." *Catal. Lett. 24,* no. 3-4 (1994): 303-15.
TiO_2, aqueous phase, modified TiO_2, mechanism, adsorption.

349. Palmisano, L., M. Schiavello, A. Sclafani, G. Martra, E. Borello, and S. Coluccia. "Photocatalytic Oxidation of Phenol on TiO_2 Powders. A Fourier Transform Infrared Study." *Appl. Catal., B 3,* no. 2-3 (1994): 117-32.
TiO_2, gas phase, mechanism, adsorption.

350. Palmisano, Leonardo, Vincenzo Augugliaro, Renzo Campostrini, and Mario Schiavello. "A Proposal for the Quantitative Assessment of Heterogeneous Photocatalytic Processes." *J. Catal.* 143, no. 1 (1993): 149-54.
TiO_2, other semiconductor, modeling, aqueous phase, process efficiency, modified TiO_2.

351. Pandit, Goutam K., Srikumar Pal, and Asit K. Das. "Photocatalytic Degradation of Pendimethalin in the Presence of Titanium Dioxide." *J. Agric. Food Chem. 43,* no. 1 (1995): 171-4.
nonaqueous, application, pesticide.

352. Papp, J., S. Soled, K. Dwight' and A. Wold. "Surface Acidity and Photocatalytic Activity of TiO_2, $W0_3/TiO_2$, and $Mo0_3/TiO_2$ Photocatalysts." *Chem. Mater. 6,* no. 4 (1994): 496-500.
TiO_2, aqueous phase, modified TiO_2, process efficiency.

353. Papp, Jennifer Ellen. "Titanium(IV) Oxide Photocatalysts With Palladium and Surface Acidity and Photocatalytic Activity of Titanium(IV) Oxide, Tungsten(VI) Oxide,Titanium(IV) Oxide, and Molybdenum(VI) Oxide,Titanium(IV) Oxide Photocatalysts." Ph.D. diss., Brown Univ., USA, 1994.
TiO_2, modified TiO_2, catalyst characterization.

354. Pehkonen, Simo O., Ron Siefert, Yigal Erel, Sam Webb, and Michael R. Hoffmann. "Photoreduction of Iron Oxyhydroxides in the Presence of Important Atmospheric Organic Compounds." *Environ. Sci. Technol. 27* (1993): 2056-62.
other semiconductor, solar, reductant, atmosphere.

355. Pelizzetti, E., C. Minero, E. Borgarello, L. Tinucci, and N. Serpone. "Photocatalytic Activity and Selectivity of Titania Colloids and Particles Prepared by the Sol-Gel Technique: Photooxidation of Phenol and Atrazine." *Langmuir 9,* no. 11(1993): 2995-3001.
TiO_2, pesticide, modified TiO_2, aqueous phase, immobilized TiO_2.

356. Pelizzetti, E., C. Minero, and V. Carlin. "Photoinduced Degradation of Atrazine Over Different Metal Oxides." New *J. Chem.* 17, no. 4 (1993): 315-19.
TiO_2, other semiconductor, aqueous phase, modified TiO_2, pesticide.

357. Pelizzetti, E., C. Minero, P. Piccinini, and M. Vincenti. "Phototransformations of Nitrogen Containing Organic Compounds Over Irradiated Semiconductor Metal Oxides. Nitrobenzene and Atrazine Over Titania and Zinc Oxide." *Coord. Chem. Rev.* 125, no. 1-2 (1993): 183-93.
TiO_2, other semiconductor, pesticide, aqueous phase.

358. Pelizzetti, E., C. Minero, E. Pramauro, and M. Vincenti. "Recent Issues on Environmental Detoxification by Solar Photocatalysis." *Photochem. Photoelectrochem. Convers. Storage Sol. Energy, Proc. Int. Conf., 9th,* ed. Zhao Wu Tian, 2 17-33, Beijing, Peop. Rep. China: Int. Acad. Publ., 1993.
TiO_2, reactor, solar, aqueous phase, application.

359. Pelizzetti, E., C. Minero, M. Sega, and M. Vincenti. "Formation and Disappearance of Biphenyl Derivatives in the Photocatalytic Transformation of 1,2,4-Trichlorobenzene on Titanium Dioxide." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 291-300, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, aqueous phase, mechanism.

360. Pelizzetti, Ezio, Claudio Minero, Hisao Hidaka, and Nick Serpone. "Photocatalytic *Processes* for Surfactant Degradation." *Photocatalytic Purification and Treatment of Water and Air, eds.* David F. Ollis and Hussain Al-Ekabi, 261-73, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, solar, aqueous phase.

361. Peral, Jose, and David F. Ollis. "Photocatalyst Deactivation: Oxidation of Decamethyl-Tetrasiloxane, Pyrrole, Indole and Dimethyl Sulfide." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 741-5, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, gas phase, application.

362. Peris-Cardells, E., J. Terol, A. R. Mauri, M. de la Guardia, and E. Pramauro. "Continuous Flow Photocatalytic Degradation of Carbaryl in Aqueous Media." *J. Environ. Sci. Health, Part B* B28, no. 4 (1993): 431-5.
Agrochemical, TiO_2, reactor, pesticide, aqueous phase.

363. Perraud, R., M. Papazian, L. Khidour, B. Pouyet, and J. P. Percherancier. "Suitable Process for Degradation of Malodorous Molecules." *Recents Prog. Genie Procedes 7,* no. 30 (1993): 3 89-94.
TiO_2, engineering, gas phase, immobilized TiO_2, IAQ.

364. Peyton, Gary R., and David W. DeBerry. *Feasibility of Photocatalytic Oxidation for Wastewater Clean-Up and Reuse,* OWRT,RU-81,1. SumX, Corp., Austin, TX, 1981.
TiO_2, other semiconductor, solar, aqueous phase, application, process efficiency.

365. Pham, Hien N., Thomas McDowell, and Ebtisam Wilkins. "Photocatalytically-Mediated Disinfection of Water Using TiO_2 As a Catalyst and Spore-Forming Bacillus Pumilus As a Model." *J. Environ. Sci. Health, Part A: Environ. Sci. Eng. Toxic Hazard. Subst. Control* A30, no. 3 (1995): 627-36.
TiO_2, disinfection, aqueous phase, application.

366. **Pichat,** P. "Photocatalysis: Heterogeneous Regime. Catalysts, Adsorption and New Techniques." *Photochemical Conversion and Storage of Solar Energy, Proceedings of the 8th International Conference on Photochemical Storage Of Solar Energy,* eds. E. Pelizzetti and M. Schiavello, 277-93, Dordrecht: Kluwer Academic Publishers, 199 1.
TiO_2, other semiconductor, gas phase, aqueous phase, modified TiO_2, mechanism, immobilized TiO_2, adsorption, isotope exchange.

367. **Pichat,** Pierre, Jean-Marie Herrmann, Jean Disdier, and Marie-Noelle Mozzanega. "Photocatalytic Oxidation of Propene Over Various Oxides At 320 K. Selectivity." *J. Phys. Chem. 83,* no. 24 (1979): 3122-6.
TiO_2, other semiconductor, gas phase, process efficiency, mechanism.

368. Polo, E., R. Amadelli, V. Carassiti, and A. Maldotti. "Photocatalytic Oxygenation of Hydrocarbons on **Titania,Iron-Porphyrin** Hybrid *Catalysts." Stud. Surf. Sci. Catal.* 78, Heterogeneous Catalysis and Fine Chemicals III (1993): 409-16.
TiO_2, nonaqueous, modified TiO_2.

369. Porter, J. F., and P. L. Yue. "Simple Supported Photocatalysts." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 759-64, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, engineering, reactor, modeling, solar, aqueous phase, modified TiO_2, immobilized TiO_2.

370. Poulios, I., and A. Avranas. "Heterogeneous Photocatalytic Degradation of the **Cationic Surfactants** Cetyldimethylbenzylammonium Chloride and Cetylpyridinium Chloride." *NATO ASI Ser., Ser. E 225,* Chemical Reactor Technology for Environmentally Safe Reactors and Products (1992): **609-** 15.
TiO_2, reactor, metallized TiO_2, aqueous phase.

371. Prairie, M. R., B. M. Stange, and L. R Evans. "Titanium Dioxide Photocatalysis for the Destruction of Organics and the Reduction of Heavy Metals." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 353-63, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, oxidant, reductant, aqueous phase, metal removal.

372. Prairie, Michael R., Lindsey R. Evans, and Sheryl L. Martinez. "Destruction of Organics and Removal of Heavy Metals in Water Via TiO_2 Photocatalysis." *Chem. Oxid.* Volume Date 1992, no. 2 (1994): 428-l.
TiO_2, oxidant, reductant, aqueous phase, metal removal.

373. Prairie, Michael R., Lindsey R. Evans, Bertha M. Stange, and Sheryl L. Martinez. "An Investigation of Titanium Dioxide Photocatalysis for the Treatment of Water Contaminated With Metals and Organic Chemicals." *Environ. Sci. Technol. 27,* no. 9 (1993): 1776-82.
TiO_2, oxidant, reductant, aqueous phase, metal removal.

374. Pramauro, Edmondo, Alessandra Bianco Prevot, Vincenzo Augugliaro, and Leonardo Palmisano. "Photocatalytic Treatment of Laboratory Wastes Containing Aromatic **Amines."** *Analyst* 120, no. 2 (Cambridge, U. K.) (1995): **237-42.**
TiO_2, aqueous phase.

375. Pramauro, Edmondo, Marco Vincenti, Vincenzo Augugliaro, and Leonardo Palmisano. "Photocatalytic Degradation of Monuron in Aqueous Titanium Dioxide Dispersions." *Environ. Sci. Technol. 27,* no. 9 (1993): 1790-5.
TiO_2, pesticide, aqueous phase, mechanism.

376. Presley, R. W. "Characterization of Titanium Dioxide: Factors Affecting Photocatalytic Performance." *Sci. Technol. Alliance, Mater. Conf.* '93, ed. Jagannathan Sankar, 211-16. Lancaster, PA: Technomic, 1993.
TiO_2, aqueous phase, modified TiO_2.

377. Rader, W. Scott' Ljiljana Solujic, E. B. Milosavljevic, J. L. Hendrix, and J. H. Nelson. "Photochemistry of Aqueous Solutions of Dicyanomercury(II) and Potassium Tetracyanomercurate(II)." *J. Sol. Energy Eng.* 116, no. 3 (1994): 125-9.
TiO_2, solar, oxidant' aqueous phase, application, metal removal.

378. Rader, W. Scott, Ljiljana Solujic, Emil B. Milosavljevic, James L. Hendrix, and John H. Nelson. "Sunlight-Induced Photochemistry of Aqueous Solutions of Hexacyanoferrate(II) and -(III) Ions." *Environ. Sci. Technol. 27,* no. 9 (1993): 1875-9.
TiO_2, solar, oxidant, reductant, aqueous phase, metal removal.

379. Rader, W. Scott, Ljiljana Solujic, Emil B. Milosavljevic, James L. Hendrix, and John H. Nelson. "Photochemistry of Aqueous Solutions of Dicyanomercury(II) and Potassium Tetracyanomercurate(II). " *Solar Engineering 1994,* eds. David E. Klett, Roy E. Hogan, and Tadayoshi Tanaka' 111-6, 1994.
TiO_2, solar, aqueous phase, application, metal removal.

380. Rao, N. N., Sangeeta Dube, and P. Natarajan. "Photocatalytic Degradation of Some Chlorohydrocarbons in Aqueous Suspensions of MO_3,TiO_2 (M = Mo or W)." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 695-700, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, modified TiO_2, pesticide.

381. Rao, N. Nageswara, and P. Natarajan. "Particulate Models in Heterogeneous Photocatalysis." *Current Science 66,* no. 10 (1994): 742-52.
TiO_2, other semiconductor, solar, aqueous phase, application, mechanism, metal removal.

382. Raupp, G. B., and J. A. Dumesic. "Adsorption of CO, C02, H2, and H2O on Titania Surfaces With Different Oxidation States." *J. Phys. Chem. 89* (1985): 5240-6.
TiO_2, gas phase, mechanism, immobilized TiO_2, adsorption.

383. Raupp, Gregory B., and Craig T. Junio. "Photocatalytic Oxidation of Oxygenated Air Toxics." *Appl. Surf. Sci. 72,* no. 4 (1993): 321-7.
TiO_2, gas phase, process efficiency.

384. Raupp. Gregory B., Craig T. Junio, R. K. Mallela, and L. A. Phillips. "Destruction of Organics in Gaseous Streams Over W-Excited Titania." *Proc., Annu. Meet. - Air Waste Manage. Assoc.,* Paper No. 92-26.10, 1992.
gas phase, TiO_2, reactor.

385. Richard, C. "Photocatalytic Reduction of Benzoquinone in Aqueous ZnO or TiO_2 Suspensions." *New* J. Chem. 18, no. 4 (1994): 443-5.
TiO_2, other semiconductor, oxidant, reductant, aqueous phase.

386. Richard, C. "Regioselectivity of Oxidation by Positive Holes (h+) in Photocatalytic Aqueous Transformations." *J. Photochem. Photobiol., A 72,* no. 2 (1993): 179-82.
TiO_2, other semiconductor, oxidant, reductant, aqueous phase, mechanism.

387. Richard, C., and P. Boule. "Photocatalytic Oxidation of Phenolic Derivatives: Influence of OH and H+ on the Distribution of Products." New *J. Chem.* 18, no. 4 (1994): 547-2.
TiO_2, aqueous phase, mechanism.

388. Richard, C., A. M. Matre, and P. Boule. "Photocatalytic Transformation of 2,5-Furandimethanol in Aqueous ZnO Suspensions." *J. Photochem. Photobiol. A: Chem. 66* (1992): *225-34.*
other semiconductor.

389. Riegel, Georg, and James R. Bolton. "Photocatalytic Efficiency Variability in TiO_2 Particles." *J. Phys. Chem. 99,* no. 12 (1995): 4215-24.
TiO_2, modeling, aqueous phase, modified TiO_2, process efficiency, mechanism.

390. Rizzuti, L., and A. Brucato. "Recent Developments in Heterogeneous Photoreactor Modelling." *Photochemical Conversion and Storage of Solar Energy, Proceedings of the 8th International Conference on Photochemical Conversion and Storage of Solar Energy,* eds. E. Pelizzetti and M. Schiavello, 561-74, Dordrecht: Kluwer Academic Publishers, 1991.
TiO_2, other semiconductor, engineering, reactor, modeling, solar, application.

391. Robertson, Michael K., and Robert B. Henderson, inventors. "Fluid Purification." London Ontario Canada Nutech Energy Systems Inc., assignee. United States Patent, 5032241.16 July 1991.
TiO_2, other semiconductor, reactor, disinfection, application, immobilized TiO_2.

392. Rose, T. L., J. Ibechem, and B. Aurian-Blajeni. "Photocatalytic Destruction of Dichloroacetic Acid in Aqueous Solutions At Temperatures Above 100 C." *Proc. - Electrochem. Soc.* 94-19(Water Purification by Photocatalytic Photoelectrochemical, and Electrochemical Processes) (1994): *298-308.*
TiO_2, aqueous phase, reductant.

393. Ross, Hardow, Juergen Bendig, and Stefan Hecht. "Sensitized Photocatalytical Oxidation of Terbutylazine." *Sol. Energy Mater. Sol. Cells 33,* no. 4 (1994): 475-8 1.
TiO_2, solar, aqueous phase, modified TiO_2, mechanism, reductant.

394. Ruppert, G., K. Hofstadler, R. Bauer, and G. Heisler. "Heterogeneous and Homogeneous Photoassisted Wastewater Treatment." *Proc. - Indian Acad. Sci., Chem. Sci.* 105, no. 6 (1993): 393-7.
TiO_2, oxidant, aqueous phase, mechanism.

395. Saiga, Tetsuyuki, inventor. "Method for Preparation of 1 ,1'-Dialkyl-4,4'-Dipyridinium Salts." Japan Shingijutsu Kaihatsu Jigyodan, and Saiga Tetsuyuki, assignees. Japan Patent, 06263734 A2. 20 September 1994. *CA122:187400.*
TiO_2, other semiconductor, solar, nonaqueous, application.

396. **Saiga,** Tetsuyuki, inventor. "Semiconductor Modified by Insoluble Polyviologen Derivatives." Japan Shingijutsu **Kaihatsu** Jigyodan, and Saiga Tetsuyuki, assignees. Japan Patent, 06268199 A2.22 September 1994. ***CA122:304360.***
nonaqueous, TiO_2, other semiconductor, modified TiO_2.

397. Saika, Tetsuyuki, Tomokazu Iyoda, and Takeo Shimidzu. "Preparation of Polyviologen-Modified TiO_2 by Photocatalytic Polymerization of **Bis(4-Cyano-1** -Pyridinio)-p-Xylene **Dibromide.**" ***Chem. Lett.,*** no. 12 (1993): 2025-8.
TiO_2, nonaqueous, modified TiO_2.

398. Sakai, Hideki, Ryo **Baba,** Kazuhito Hashimoto, and Akira Fujishima. "Separate Monitoring of Reaction Products Formed At Oxidation and Reduction Sites of TiO_2 Photocatalysts Using a Microelectrode." J. *Electroanal.* ***Chem.*** *379,* no. l-2 (1994): 199-205.
TiO_2, oxidant, **reductant,** aqueous phase, mechanism.

399. Sakai, Hideki, Ru Xiong Cai, Ryo Baba, Kazuhito Hashimoto, Yoshinobu Kubota, and Akira Fujishima "Detection of Intermediates Formed At the Surface of Photoexcited Titanium Dioxide Film Electrode Using Microelectrode." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 651-7, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, aqueous phase, mechanism, immobilized TiO_2.

400. Sakura, Makoto, inventor. "Moisture-Resistant Catalysts Decomposing Ethylene Formed During Storage of Vegetables and Fruits." Japan **Nitsuki Yunibaasaru Kk,** assignee. Japan Patent, 07016473 **A2. 20** January 1995. ***CA122:289437.***
TiO_2, gas phase, modified TiO_2, application, IAQ, adsorbent, immobilized TiO_2.

401. **Sakurada,** Tsukasa. "Sterilization of Microorganisms by Photo-Semiconductor Cloth. On Some Applications of Function Material." *Hyomen* ***Gijutsu*** 41, no. 10 (1990): 1008-l.
TiO_2, metallized TiO_2, disinfection, aqueous phase, modified TiO_2, process efficiency, immobilized TiO_2.

402. **Sampath,** Srinivasan, Hiroyuki Uchida, and Hiroshi Yoneyama "Photocatalytic Degradation of Gaseous Pyridine Over Zeolite-Supported Titanium Dioxide." *J.* ***Catal.*** 149, no. 1 (1994): 189-94.
TiO_2, gas phase, modified TiO_2, immobilized TiO_2, adsorbent.

403. Sanchez, **Beningo,** Manuel Romero, Alfonso Vidal, Begona Fabrellas, Jesus **Blanco,** and Pedro Avila "Destruction of Toluene and Xylene Using Concentrated Solar Photons." *Solar Engineering 1994,* eds. David E. **Klett,** Roy E. Hogan, and Tadayoshi Tanaka' **123-9, 1994.**
TiO_2, solar, gas phase, immobilized TiO_2.

404. Sato, Shigeyuki, and Kenichiro Suzuki, inventors. "Metal Oxide-Based Photocatalysts and the Preparation." Japan Toyoda Chuo Kenkyusho Kk, assignee. Japan Patent, 06182205 A2.5 July 1994. ***CA121:239300.***
TiO_2, metallized TiO_2, gas phase, modified TiO_2, application, immobilized TiO_2.

405. Sato, Shinri, and Toru Kadowaki. "Photocatalytic Activities of Metal Oxide Semiconductors for Oxygen Isotope Exchange and Oxidation Reactions." *J.* ***Catal.*** 106 (1987): **295-300.**
TiO_2, gas phase, modified TiO_2, mechanism.

406. Sato, Shinri, A. Sobczynski, J. M. White, A. J. Bard, A. Campion, M. A. Fox, T. E. Mallouk, and S. E. Webber. "Photochemical Properties of Ultrathin TiO_2 Films Prepared by Chemical Vapor Deposition." *J. Photochem. Photobiol. A: Chem. 50* (1989): 283-90.
TiO_2, metallized TiO_2, aqueous phase, modified TiO_2, immobilized TiO_2.

407. Sauer, Michael L., and David F. Ollis. "Acetone Oxidation in a Photocatalytic Monolith Reactor." *J. Catal.* 149, no. 1 (1994): 81-91.
TiO_2, reactor, gas phase, application, IAQ, immobilized TiO_2, adsorbent, adsorption.

408. Sauve, Genevieve, Prashant V. Kamat, and Rodney S. Ruoff. "Excited Triplet and Reduced Forms of C_{84}." *J. Phys. Chem. 99,* no. 7 (1995): 2162-5.
TiO_2, aqueous phase, modified TiO_2.

409. Schaper, K., and D. Hesse. "Photocatalytic Flue Gas Cleaning." *IChemE Res. Event, Two-Day Symp.,* 380-2, Rugby, UK: Inst. Chem. Eng., 1994.
TiO_2, reductant, gas phase, application, immobilized TiO_2, catalyst reactivation.

410. Schaper, Klaus, and Diethard Hesse. "Problem of Catalyst Deactivation During Photocatalytic Flue Gas Treatment." *Chem.-Ing.-Tech. 66,* no. 1 (1994): 86-9.
TiO_2, reductant, gas phase, catalyst reactivation.

411. Schertz, Paul, Dee Kelly, and Luke Lammert. *Analysis of Cost of Generating or Capturing Ultraviolet Light for Photocatalytic Water Detoxification Systems. Final Report for NREL Subcontract No. AF-2-11252-1,* NREL Subcontract No. AF-2-11252-1 Final Report.
cost, engineering, lamps.

412. Schmelling, D. C., and K. A Gray. "Feasibility of Photocatalytic Degradation of TNT As a Single or Integrated Treatment *Process." Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 625-3 1, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, aqueous phase, biotreatment.

413. Schneider, M., E. D. Duff, T. Mallat, M. Wildberger, and A. Baiker. "High Surface Area Platinum-Titania Aerogels: Preparation, Structural Properties, and Hydrogenation Activity." *J. Catal.* 147 (1994): 500-14.
TiO_2, metallized TiO_2, modified TiO_2, catalyst characterization.

414. Schwitzgebel, Jorg, Ekerdt, J. G., Gerischer, H., and Heller, Adam. "Role of the Oxygen Molecule and of the Photogenerated Electron in TiO_2 Photocatalyzed Air Oxidation Reactions." Presented at 17th U. S.-Japan Cooperative Seminar on Photoconversion and Photosynthesis Research, La Jolla' CA, 12-14 March 1995, 4 pp.
aqueous phase, application, immobilized TiO_2, mechanism, oxident

415. Sclafani, A., A. Brucato, and L. Rizzuti. "Mass Transfer Limitations in a Packed Bed Photoreactor Used for Phenol Removal." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 533-45, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, reactor, aqueous phase, mechanism, immobilized TiO_2.

416. Sclafani, A., L. Palmisano, M. Schiavello, V. Augugliaro, S. **Coluccia,** and L. **Marchese.** "The Photodecomposition of Ethanoic Acid Adsorbed by Semiconductor and Insulator Oxides. Part 1. Pure Oxides." New ***J. Chem.*** 12 (1988): 129-35.
TiO_2, aqueous phase other semiconductors.

417. **Sclafani,** A., L. Palmisano, M. Schiavello, V. Augugliaro, S. Coluccia, and L. Marchese. "The Photodecomposition of Ethanoic Acid Adsorbed by Semiconductor and Insulator Oxides. Part 2. Mixed Insulator Oxides." New ***J. Chem.*** 12 (1988): 137-41.
TiO_2, aqueous phase, modified TiO_2.

418. Sczechowski, J. G., C. A. Koval, and R. D. Noble. "Improved Photoefficiencies for Titanium Dioxide Photocatalytic Reactors Through the Use of Controlled Periodic Illumination. " *Photocatalytic* ***Purification*** *and Treatment of Water and Air,* eds. David F. **Ollis** and **Hussain** Al-Ekabi, 645-50, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, reactor, engineering, aqueous phase, process efficiency.

419. Sczechowski, **Jeffrey** G. "Applying Controlled Periodic Illumination in a Taylor Vortex Reactor to Increase the Photoeffrciency in Heterogeneous Photocatalysis." *Solar Engineering 1995, eds.* William B. Stine, Tadayoshi Tanaka' and David E. Claridge, 459-66, New York, NY: **ASME,** 1995.
TiO_2, engineering, reactor, modeling, aqueous phase, process efficiency, mechanism.

420. Sczechowski, Jeffrey G., Carl A. Koval, and Richard D. Noble. "Evidence of Critical Illumination and Dark Recovery Times for Increasing the Photoefficiency of Aqueous Heterogeneous Photocatalysis." *J.* ***Photochem.*** *Photobiol., A 74,* no. 2-3 (1993): 273-8.
TiO_2, engineering, reactor, aqueous phase, process efficiency.

421. Selzer, Volker H., and John C. Crittenden. *Technological and Economic Feasibility of Full Scale Photocatalytic Oxidation Processes Applied to Air and Water Treatment,* Michigan Technological University, Houghton, MI, 1995. National Center for Clean Industrial and Treatment Technologies, Michigan Technological University, Houghton, MI 4993 1.
TiO_2, engineering, reactor, modeling, solar, metallized TiO_2, gas phase, aqueous phase, modified TiO_2, application, process efficiency, mechanism, immobilized TiO_2, cost, catalyst reactivation.

422. Serpone, N., D. Lawless, R Terzian, C. Minero, and E. Pelizzetti. "Heterogeneous Photocatalysis: Photochemical Conversion of Inorganic Substances in the Environment: Hydrogen Sulfide, Cyanide, and Metals." *Photochemical Conversion and Storage of Solar Energy, Proceedings of the 8th International Conference on Photochemical Conversion and Storage of Solar Energy,* **eds.** E. Pelizzetti and M. Schiavello, 45 l-75, Dordrecht: Kluwer Academic Publishers, 199 1.
TiO_2, other semiconductor, **reductant,** metallized TiO_2, aqueous phase, application, adsorption.

423. Serpone, N., P. Maruthamuthu, P. **Pichat,** E. Pelizzetti, and H. Hidaka "Exploiting the Interparticle Electron Transfer Process in the Photocatalyzed Oxidation of Phenol, 2-Chlorophenol and Pentachlorophenol: Chemical Evidence for Electron and Hole Transfer Between Coupled Semiconductors." *J.* ***Photochem.*** *Photobiol., A 85,* no. 3 (1995): 247-55.
TiO_2, other semiconductor, aqueous phase, modified TiO_2, mechanism.

424. Serpone, Nick. "A Decade of Heterogeneous Photocatalysis in Our Laboratory: Pure and Applied Studies in Energy Production and Environmental Detoxification." *Res. Chem. Intermed. 20,* no. 9 (1994): 953-2.
TiO_2, other semiconductor, reactor, solar, **reductant**, aqueous phase, application, process efficiency, mechanism, immobilized TiO_2, metal removal.

425. Serpone, Nick. "Heterogeneous Photocatalysis for Environmental Water Purification: *Why, What,* and How?" *Proc. Electrochem Soc.* **94**- 19 (1994): 236-54.
TiO_2, other semiconductor, solar, aqueous phase, application, mechanism.

426. Serpone, Nick, Darren Lawless, Rita Terzian, and Dan Meisel. "**Redox** Mechanisms in Heterogeneous Photocatalysis. The Case of Holes Versus Hydroxyl Radical Oxidation and Free Versus Surface Bound Hydroxyl Radical Oxidation **Processes."***Electrochem. Colloids Dispersions, [Symp. Electrochem. Microheterog. Fluids]*Raymond A., and John Texter, 399-416, New York, NY: Mackay VCH, 1992.
TiO_2, other semiconductor, oxidant, aqueous phase, mechanism.

427. Serpone, Nick, Ezio Pelizzetti, and Hisao **Hidaka.** "Identifying Primary Events and the Nature of Intermediates Formed During the Photocatalyzed Oxidation of **Organics** Mediated by Irradiated Semiconductors." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 225-50, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, aqueous phase, mechanism.

428. Serpone, Nick, Rita Terzian, Darren Lawless, Pierre Kennepohl, and Genevieve Sauve. "On the Usage of Turnover Numbers and Quantum Yields in Heterogeneous Photocatalysis." *J. Photochem. Photobiol., A 73,* no. 1 (1993): 11-16.
TiO_2, aqueous phase, process efficiency.

429. Serpone, Nick, **Rita** Terzian, Claudio Minero, and Ezio Pelizzetti. "Heterogeneous Photocatalyzed Oxidation of Phenol, Cresols, and Fluorophenols in Titanium Dioxide Aqueous Suspensions." *Photosensitive Metal-Organic Systems, 28* 1-3 14. Adv. Chem. Ser., eds. Charles Kutal and Nick Serpone. Washington, DC: American Chemical Society, 1993.
TiO_2, aqueous phase, mechanism.

430. **Serra,** Francesca, Maria **Trillas,** Josep Garcia' and Xavier Domenech. "Titanium Dioxide-Photocatalyzed Oxidation of 2,4-Dichlorophenol." *J. Environ. Sci. Health, Part A A29,* no. 7 (1994): 1409-21.
TiO_2, aqueous phase, adsorption.

431. **Sharma,** S. K., D. Yogi **Goswami,** and C. K. **Jotshi.** "Techno-Economic Analysis of Solar Detoxification Systems." *Solar Engineering 1995,* eds. William B. Stine, Tadayoshi Tanaka' and David E. Claridge, 467-73, New York, NY: **ASME,** 1995.
TiO_2, engineering, reactor, modeling, aqueous phase, cost.

432. Sherrard, Kim B., Philip J. Marriott, Malcolm J. McCormick, Ray **Colton,** and Geoff Smith. "Electrospray Mass Spectrometric Analysis and Photocatalytic Degradation of Polyethoxylate Surfactants Used *in* Wool Scouring." *Anal. Chem. 66,* no. 20 (1994): 3394-9.
TiO_2, aqueous phase, application.

433. Shiragami, Tsutomu, Shinako Fukami, Yuji Wada, and Shozo Yanagida. "Semiconductor Photocatalysis: Effect of Light Intensity on Nanoscale CdS-Catalyzed Photolysis of Organic Substrates." *J. Phys. Chem. 97,* no. 49 (1993): 12882-7.
other semiconductor, reductant, nonaqueous.

434. Sierka, R. A., and C. W. Bryant "Enhancement of Biotreatment Effluent Quality by Illuminated Titanium Dioxide and Membrane Pretreatment of the Kraft Extraction Waste Stream and by Increased Chlorine Dioxide Substitution." *Water Sci Technol. 29,* no. 5-6 (1994): 209-18.
TiO_2, aqueous phase, application, engineering.

435. Sierka, Raymond A., and Curtis W. Bryant. "Biological Treatment of Kraft Wastewater Following Pretreatment of the Extraction Waste Stream by Illuminating Titanium Dioxide and Membranes." *Photocatalytic Purification and Treatment of Waer and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 275-90, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, engineering, aqueous phase, application.

436. Sirota, Vitaly. "Estimation of the Efficiency of Atmospheric Ozone Aerosol Sink." *Proc. SPIE-Int. Soc. Opt. Eng.* 2047, no. Atmospheric Ozone (1993): 216-18.
TiO_2, other semiconductor, oxidant' gas phase, mechanism.

437. Sjogren, Jon C., and Raymond A. Sierka "Inactivation of Phage MS2 by Iron-Aided Titanium Dioxide Photocatalysis." *Appl. Environ. Microbiol. 60,* no. 1 (1994): 344-7.
Microbial, TiO_2, disinfection, aqueous phase, modified TiO_2.

438. Solymosi, Frigyes, and Imre Tombacz. "Photocatalytic Reaction of H_2O + CO, Over Pure and Doped Rh/TiO_2." *Catal. Lett.* 27, no. 1-2 (1994): 61-5.
TiO_2, reductant, metallized TiO_2, aqueous phase.

439. Somasundaram, Narayanan, Kasi Pitchumani, and Chockalingam Srinivasan. "Photoinduced Reduction of Aryl Methyl Sulfones on Titanium Dioxide." *J. Chem. Soc., Chem. Commun.,* no. 12 (1994): 1473-4.
TiO_2, reductant, nonaqueous.

440. Sopyan, Iis, Sadao Murasawa, Kazuhito Hashimoto, and Akira Fujushima. "Highly Efficient TiO_2 Film Photocatalyst. Degradation of Gaseous Acetaldehyde." *Chem. Lett.,* no. 4 (1994): 723-6.
TiO_2, gas phase, modified TiO_2.

441. Soria, J., M. J. Lopez-Munoz, V. Augugliaro, and J. C. Conesa. "Electron Spin Resonance Study of Radicals Formed During Photooxidation of Phenol on Titania" *Colloids Surf., A 78,* no. l-3 (1993): 73-83.
TiO_2, gas phase, mechanism, immobilized TiO_2.

442. Spacek, W., R. Bauer, and G. Heisler. "Heterogeneous and Homogeneous Wastewater Treatment-Comparison Between Photodegradation With TiO_2 and the Photo-Fenton Reaction." *Chemosphere 30,* no. 3 (1995): 477-84.
TiO_2, aqueous phase, mechanism.

443. Stafford, Ulick, Kimberly A. Gray, and Prashant V. Kamat. "Radiolytic and TiO_2-Assisted Photocatalytic Degradation of 4-Chlorophenol. A Comparative Study." *J. Phys. Chem. 98,* no. 25 (1994): 6343-51.
TiO_2, aqueous phase, mechanism.

444. Stafford, Ulick, Kimberly A. Gray, Prashant V. Kamat, and Arvind Varma. "An in Situ Diffuse Reflectance **FTIR** Investigation of Photocatalytic Degradation of **4-Chlorophenol** on a TiO_2 Powder Surface." *Chem. Phys. Lett. 205,* no. 1 (1993): 55-61.
TiO_2, gas phase, mechanism.

445. Stradella, Luigi. "Photochemical Reactions of Halogenated Hydrocarbons on Pure and Doped Titanium Dioxide." *Chemosphere 27,* no. 7 (1993): 1129-36.
TiO_2, gas phase, mechanism.

446. Sugimura, Hiroyuki, Tatsuya **Uchida,** Nobuo Shimo, Noboru **Kitamura,** and Hiroshi Masuhara "Scanning Tunneling Microscopy,Spectroscopy of Surface Oxide on Titanium: Photoexcitation Effect and Nanoanodization." *Mol. Cryst. Liq. Cryst. Sci. Technol., Sect. A 252-253* (1994): 497-506.
TiO_2, modified TiO_2.

447. Sullivan, Jack M., John H. Grinstead, Jr., Douglas J. Kiserow, Kathleen C. Pugh, and Joe Gautney. "TiO_2 Catalyzed Photo Oxidation of Atrazine in Dilute Aqueous Solutions Under Solar Irradiation: Process Development. " *Solar Engineering* 1994, eds. David E. Klett, Roy E. Hogan, and Tadayoshi Tanaka' **131-8, 1994.**
TiO_2, reactor, solar, pesticide, aqueous phase, immobilized TiO_2, application.

448. Suri, Rominder P. S., Junbiao Liu, David W. Hand, John C. Crittenden, David L. **Perram,** and Michael E. **Mullins.** "Heterogeneous Photocatalytic Oxidation of Hazardous Organic Contaminants in Water." *Water Environ. Res. 65,* no. 5 (1993): 665-73.
TiO_2, other semiconductor, metallized TiO_2, aqueous phase, modified TiO_2.

449. Sychev, M., N. Kostoglod, A. Kosorukov, V. Goncharuk, and V. Kashkovski. "Pillared Clays: Preparation and Investigation of **(Physicochemical)** and Catalytic **Properties."***Proc. - Pol.-Ger. Zeolite Colloq.,* ed. **Michal** Rozwadowski, 63-78, **Torun,** Pol.: Publisher: Nicholas Copernicus Univ. Press, 1992.
TiO_2, aqueous phase, modified TiO_2, immobilized TiO_2.

450. T-Raissi, A., and N. Z. Muradov. "Flow Reactor Studies of Titanium Dioxide Photocatalytic Treatment of Airborne Nitroglycerin." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and **Hussain** Al-Ekabi, 435-54, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, gas phase, application, oxidant.

451. **Tahara,** Shu, and Youzo **Morita,** inventors. "Method and Apparatus for Analyzing Nitrogen Compounds and Phosphorus Compounds in Water." Japan Shimadzu Corp., assignee. Europe Patent, *634646* Al. 18 January 1995. ***CA122:273701.***
TiO_2, aqueous phase, application.

452. **Takahama,** Koichi, **Toshiharu** Sako, Masaru Yokoyama, and Shozo Hirao. "Preparation of Platinum-Loaded Supercritically-Dried TiO_2 Pillared Clays and Their Photocatalytic Activities in Oxidation of Carbon Monoxide." *Nippon Kagaku Kaishi 7* (1994): 613-18.
TiO_2, metallized TiO_2, gas phase, modified TiO_2, immobilized TiO_2, adsorbent, adsorption, carbon monoxide.

453. Takeuchi, Koji, Kosuke Toyose, Shuzo **Kutsuna,** and Takashi Ibusuki. "Removal of Nitrogen Oxides From Air by Catalytic Oxidation With Photoenergy." *Shigen to Kankyo 3,* no. 2 (1994): 103- 10.
TiO_2, gas phase, modified TiO_2, application, immobilized TiO_2, adsorbent.

454. Takiyama, Marcia M. K., Luis R. Takiyama, C. P. Huang, and Harm S. Huang. "Recovery of **Fe(II)-EDTA** From Wet-Scrubber Liquid Using TiO_2,**UV** System." *Hazard. Ind. Wastes 26* (1994): 595-60 1.
TiO_2, **reductant,** oxidant, aqueous phase, application.

455. Tanaka' K., and T. Hisanaga "Photodegradation of Chlorofluorocarbon Alternatives on Metal Oxide." *Sol. Energy 52,* no. 5 (1994): 447-50.
TiO_2, other semiconductor, gas phase, mechanism.

456. Tanaka' Keiichi, and Teruaki Hisanaga, inventors. "Photocatalytic Wastewater Treatment Apparatus." Japan Kogyo Gijutsuin, assignee. Japan Patent, 06328068 A2.29 November 1994. ***CA122:196089.***
TiO_2, other semiconductor, reactor, aqueous phase, application.

457. Tanaka' Shuzo, and Uttam K. Saha. "Effect of **pH** on Photocatalytic Degradation of Trichlorophenol Using Titanium Dioxide." *Yosui to Haisui 36,* no. 10 (1994): 883-6.
TiO_2, aqueous phase, anion inhibition.

458. Tanaka' Shuzo, and Uttam Kumar **Saha.** "Effects of **pH** on Photocatalysis of **2,4,6-Trichlorophenol** in Aqueous TiO_2 Suspensions." *Water Sci Technol. 30,* no. 9 (1994): 47-57.
TiO_2, aqueous phase, anion inhibition.

459. Tang, Xiangping, Weichuan Jiang, Hong Xu, and **Hongjun** Wang. "Study on Photodegradation of Printing and Dyeing Wastewater by Silver-Containing TiO_2 Semiconductor Catalyst." *Huanjing Wuran Yu Fangzhi* 16, no. 5 (1994): **5-7, 21.**
TiO_2, metallized TiO_2, aqueous phase, application.

460. Taqui Khan, M. M., D. Chatterjee, A. Hussain, and M. A. Moiz. "Synthesis and Characteristics of Mixed Ligand **Ru(III)** Complexes With EDTA-Polypyridyl, and $Pt/TiO_2/RuO_2$ Semiconductor Particulate System Modified by the Complexes." *J.* ***Photochem.*** *Photobiol., A 76,* no. l-2 (1993): 97-101.
TiO_2, reductant, aqueous phase, modified TiO_2.

461. **Tennakone,** K., 0. A. **Ileperuma,** C. T. K. Thaminimulla, and J. M. S. Bandara "Photo-Oxidation of Nitrogen to Nitrite Using a Composite $ZnO\text{-}Fe_2O_3$ Catalyst." *J. Photochem.* ***Photobiol.*** *A: Chem. 66* (1992): 375-8.
other semiconductor.

462. Tennakone, K., and U. S. Ketipearachchi. "Photocatalytic Method for Removal of Mercury From Contaminated Water." *Appl. Catal., B 5,* no. 4 (1995): 343-9.
TiO_2, reductant, aqueous phase, application, metal removal.

463. Tennakone, K., S. Senadeera, and A. Priyadharshana "Titania Catalyzed Photooxidation of Water in the Presence of Methylene Blue." *Sol. Energy Mater. Sol. Cells 29,* no. 2 (1993): 109-3.
TiO_2, reductant, aqueous phase, modified TiO_2.

464. Terzian, R. "Fundamental and Applied Studies in Heterogeneous Photocatalysis. Primary Radical Intermediates and Kinetics of Photo-Oxidation of Creosote Phenolics." Ph.D. diss., Concordia University, 1993.
aqueous phase, application, TiO_2.

465. Tinucci, L., E. Borgarello, C. Minero, and E. Pelizzetti. "Treatment of Industrial Wastewaters by Photocatalytic Oxidation on Titanium Dioxide." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 585-94, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, aqueous phase, application, reactor.

466. Tomkiewicz, M., Geula Dagan, and Zhu Zhu. "Morphology and Photocatalytic Activity of TiO_2 Aerogels." *Res. Chem. Intermed. 20,* no. 7 (1994): 701-10.
TiO_2, modeling, aqueous phase, modified TiO_2, process efficiency, aerogel.

467. Trillas, Maria' Jose Peral, and Xavier Domenech. "Redox Photodegradation of 2,4-Dichlorophenoxyacetic Acid Over TiO_2." *Appl. Catal., B 5,* no. 4 (1995): 377-87.
TiO_2, metallized TiO_2, pesticide, aqueous phase.

468. Trillas, Maria' Jose Peral, Xavier Domenech, and Jaime Gimenez-Farreras. "Photocatalytic Oxidation of Phenol and 2,4-Dichlorophenol Over TiO_2." *Solar Engineering 1994,* eds. David E. Klett, Roy E. Hogan, and Tadayoshi Tanaka' 171-4, 1994.
TiO_2, aqueous phase.

469. Tseng, Jesseming. "Photocatalytic Oxidation of Phenols by Titanium Dioxide Suspension." Ph.D. diss., Univ. Delaware, 1991.
TiO_2, aqueous phase, mechanism.

470. Turchi, Craig S., James F. Klausner, D Yogi Goswami, and Edward Marchand. *Field Test Results for the Solar Photocatalytic Detoxification of Fuel- Contaminated Groundwater,* NREL,TP-471-5345. NREL, Golden, CO, 1993.
aqueous phase, TiO_2, engineering, process efficiency, reactor, solar.

471. Turchi, Craig S., and Mark S. Mehos. "Solar Photocatalytic Detoxification of Groundwater: Developments in Reactor Design." Chem. *Oxid.* Volume Date 1992, no. 2 (1994): 301-14.
TiO_2, engineering, reactor, solar, aqueous phase, immobilized TiO_2.

472. Turchi, Craig S., Edward J. Wolfrum, and Richard A. Miller. *Gas-Phase Photocatalytic Oxidation: Cost Comparison With Other Air Pollution Control Technologies,* NREL,TP-47 l-7014. NREL, Golden, CO, 1994. DE95000241.
TiO_2, engineering, reactor, gas phase, application, cost, competing technologies.

473. Uchida, Hiroyuki, Shigeyoshi Itoh, and Hiroshi Yoneyama "Photocatalytic Decomposition of Propyzamide Using TiO_2 Supported on Activated Carbon." *Chem. Lett.*, no. 12 (1993): 1995-8.
TiO_2, pesticide, aqueous phase, immobilized TiO_2, adsorbent.

474. Uchida, Hiroyuki, Shinobu Katoh, and Masahiro Watanabe. "Photocatalytic Decomposition of Trichlorobenzene Using TiO_2 Supported on Nickel-Poly(Tetrafluoroethylene) Composite Plate." *Chem. Lett.*, no. 4 (1995): 261-.
TiO_2, metallized TiO_2, aqueous phase, immobilized TiO_2.

475. Valladares, Julio E., and James R. Bolton. "A Method for the Determination of Quantum Yields in Heterogeneous Systems: the Titanium Dioxide Photocatalyzed Bleaching of Methylene Blue." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 11 l-20, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, reactor, aqueous phase, process efficiency.

476. van Groenestijn, J. W., H. J. Doddema, H. J. G. Kok, and T. P. M. Koster. "Combined Photochemical and Biological Treatment of Off-Gases."*Int. Symp. Environ. Biotechnol., Three-Day Symp., 2nd,* 37-9, Rugby, UK: Inst. Chem. Eng., 1994.
TiO_2, gas phase, biotreatment.

477. Vidal, A., J. Herrero, M. Romero, B. Sanchez, and M. Sanchez. "Heterogeneous Photocatalysis: Degradation of Ethylbenzene in TiO_2 Aqueous Suspensions." *J. Photochem. Photobiol., A* 79, no. 3 (1994): 213-19.
TiO_2, aqueous phase, mechanism.

478. Vidal, Alfonso, Manuel Romero, Benigno Sanchez, and Ferenc Mogyorodi. "Photocatalytic Degradation of Thiocarbamate Pesticides in Water. " *Solar Engineering 1994,* eds. David E. Klett, Roy E. Hogan, and Tadayoshi Tanaka' 117-21, 1994.
TiO_2, pesticide, aqueous phase, application.

479. Vinodgopal, K. "Environmental Photochemistry: Electron Transfer From Excited Humic Acid to TiO_2 Colloids and Semiconductor Mediated Reduction of Oxazine Dyes by Humic Acid." *Res. Chem. Intermed. 20,* no. 8 (1994): 825-33.
nonaqueous, TiO_2, reductant, aqueous phase, mechanism.

480. Vinodgopal K., Idriss Bedja, Surat Hotchandani, and Prashant V. Kamta. "A Photocatalyzed Approach for the Reductive Decolorization of Textile Azo Dyes in Colloidal Semiconductor Suspensions." *Langmuir* 10, no. 6 (1994): 1767-71.
TiO_2, other semiconductor, reductant, aqueous phase, efficiency.

481. Vinodgopal, K., S. Hotchandani, and P. V. Kamat. "Electrochemically Assisted Photocatalytic Degredation of 4-Chlorophenol Using TiO_2 Particulate Films."*Symp. Environ. Aspects Electrochem. Photoelectrochem.,* 122-30, Proc.- Electrochem. Soc., no. 93-18. 1993.
TiO_2, reactor, aqueous phase, modified TiO_2, process efficiency, immobilized TiO_2.

482. Vinodgopal, K., and Prashant V. Kamat. "Enhanced Rates of Photocatalytic Degradation of an Azo Dye Using SnO_2,TiO_2 Coupled Semiconductor Thin Films." *Environ. Sci. Technol. 29,* no. 3 (1995): 841-5.
TiO_2, other semiconductor, aqueous phase.

483. Vinodgopal, K., and Prashant V. Kamat. "Photochemistry of Textile Azo Dyes. Spectral Characterization of Excited State, Reduced and Oxidized Forms of Acid Orange *7." J. Photochem. Photobiol., A 83,* no. 2 (1994): 141-6.
TiO_2, aqueous phase, mechanism, reductant.

484. Vinodgopal, K., Ulick Stafford, Kimberly A. Gray, and Prashant V. Kamat. "Semiconductor Particulate Films for the Photocatalytic Degradation of Organic Contaminants." *Proc.- Electrochem. Soc.* 94-19(Water Purification by Photocatalytic Photoelectrochemical, and Electrochemical Processes) (1994): 332-4 1.
TiO_2, other semiconductor, aqueous phase, immobilized TiO_2.

485. Vinodgopal, K., Ulick Stafford, Kimberly A. Gray, and Prashant V. Kamat. "Electrochemically Assisted Photocatalysis. 2. The Role of Oxygen and Reaction Intermediates in the Degradation of 4-Chlorophenol on Immobilized TiO_2 Particulate Films." J. *Phys. Chem. 98,* no. 27 (1994): 6797-803.
TiO_2, aqueous phase, mechanism.

486. Viswanathan, B., U. D. Mary, and R. P. Viswanath. "Photocatalytic and Physicochemical Studies on Metalized Titania Systems." *Stud. Surf. Sci. Catal.* 75, New Frontiers in Catalysis, Pt. C (1993): 2147-50.
TiO_2, metallized TiO_2, gas phase, nonaqueous, mechanism.

487. Wada, Kenji, Kiyomi Yoshida, Tsuyoshi Takatani, and Yoshihisa Watanabe. "Selective Photooxidation of Light Alkanes Using Solid Metal Oxide Semiconductors." *Appl. Catal., A 99,* no. 1 (1993): 21-36.
TiO_2, other semiconductor, gas phase, mechanism, process efficiency.

488. Wada, Yuji, Masahiko Taira, Dongyang Zheng, and Shozo Yanagida. "TiO_2-Catalyzed Exhaustive Photooxidation of Organic Compounds in Perfluorotributylamine." New J. *Chem.* 18, no. 5 (1994): 589-96.
TiO_2, nonaqueous, mechanism.

489. Wake, Hitoshi, and Tadashi Matsunaga, inventors. "Redox Reaction Using Photocatalysis of Semiconductor." Japan Pentel Kk, and Matsunaga Tadashi, assignees. Japan Patent, 06134476 A2. 17 May 1994. *CA122:20314.*
TiO_2, other semiconductor, reactor, aqueous phase.

490. Waki, Kunio, Lingxuan Wang, Kayo Nohara, and Hisao Hidaka "Photocatalyzed Mineralization of Nitrogen-Containing Compounds At TiO_2,H_2O *Interfaces." J. Mol. Catal. A: Chem. 95,* no. 1 (1995): 53-9.
TiO_2.

491. Wamhoff, Heinrich, Helmut Koch, Rolf Foerster, Christiane Herrmann, Sanaa m. S. Atta, M. Refat Mahran, and Mahmoud M. Sidky. "Photochemistry of Plant Protectants. On the Photodegradation of 1-(4-Chlorophenyl)-4,4-Dimethyl-3-(1 H-1,2,4-Triazol- 1 -Ylmethyl)- Pentan-3-ol (Folicur)." Z. *Naturforsch., B: Chem. Sci. 49,* no. 2 (1994): 280-l.
nonaqueous, TiO_2, pesticide, reductant, aqueous phase, mechanism.

492. Wang, Aihua, Jimmie G. Edwards, and Julian A. Davies. "Photooxidation of Aqueous Ammonia With Titania-Based Heterogeneous Catalysts." *Sol. Energy 52,* no. 6 (1994): 459-66.
TiO_2, aqueous phase, modified **TiO_2**.

493. Wang, **FaYang, YuPan** Weng, and **LiangMu** Lin. "Direct Observation of Crystal Surface Structure of Powdery Titanium Dioxide Photocatalyst by *SAD* in TEM." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain AI-Ekabi, 753-8, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, mechanism.

494. Wang, Ko Ming, and Benito J. Marinas. "Control of VOC Emissions From Air-Stripping Towers: Development of Gas-Phase Photocatalytic *Process." Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and **Hussain** Al-Ekabi, 733-9, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, gas phase, application.

495. Wang, Ko-ming, and Benito J. Marinas. "Gas-Phase Photocatalytic Process for the Control of VOC Emissions From Air-Stripping **Towers."*Proc. - Annu. Conf., Am. Water Works Assoc.,*** **585-605, 1993.**
TiO_2, gas phase, immobilized **TiO_2**.

496. Wang, **Koming** Vincent. "Gas Phase Photocatalytic Treatment of **Trichloroethylene** Using Titanium Dioxide Irradiated With Near Ultraviolet Light." Ph.D. diss., Purdue Univ., West Lafayette, IN, USA, 1994.
TiO_2, gas phase.

497. Wang, Kuo-Hua, **Yung-Hsu** Hsieh, and Kuo-Shu Huang. "Study on the Control of Aquatic Monochlorophenol Through Photocatalytic Decomposition." *Zhongguo Huanjing Gongcheng **Xuekan** 4,* no. 2 (1994): 111-8.
TiO_2, aqueous phase.

498. Wang, Yuh-Yuan, and Chi-Chao Wan. "Investigation of Photoelectrochemical Reduction of Cupric Ions Over **TiO_2** *in the* Presence of Methanol." *J. Photochem. Photobiol. A: Chem. 84* (1994): 195-202.
TiO_2, reductant, metallized **TiO_2**, aqueousphase, mechanism.

499. Wang, **Zeng-Hua,** and **Qi-Xing Zhuang**. "Photocatalytic Reduction of Pollutant **Hg(II)** on Doped WO, Dispersion." *J. Photochem. Photobiol. A: Chem. 75* (1993): **105-** 1.
other semiconductor, solar, reductant, aqueous phase.

500. Wang, **Zhikai,** and Charles Kutal. "Photocatalytic Mineralization of **2,4,6-Trinitrotoluene** in Aqueous Suspensions of Titanium Dioxide." *Chemosphere 30,* no. 6 (1995): 1125-36.
TiO_2, aqueous phase.

501. Ward, Michael D., James R. White, and Allen J. Bard. "Electrochemical Investigation of the **Energetics** of Particulate Titanium Dioxide Photocatalysts. The Methyl Viologen-Acetate System." *J. Am. **Chem. Soc.*** 105 (1983): 27-31.
TiO_2, oxidant, aqueous phase, mechanism.

502. Watabe, Tosha, and Eiichi Kojima, inventors. "Manufacture of Photocatalysts Containing Titanium Oxide and the Photocatalysts." Japan Toto Ltd, assignee. Japan Patent, 06205977 A2.26 July 1994. *CA121:237634.*
TiO_2, gas phase, aqueous phase, modified TiO_2, application, immobilized TiO_2.

503. Watanabe, Toshiya, Atushi Kitamura, Eiichi Kojima, Kazuhito Hashimoto, and Akira Fujishima, inventors. "Air Treating Method Using Photocatalyst Under Interior Illumination." Japan, assignee. International Patent, 9411092 Al. 26 May 1994. *CA121:140666.*
TiO_2, other semiconductor, disinfection, gas phase.

504. Watanabe, Toshiya, Atushi Kitamura, Eiichi Kojima, Chiaki Nakayama, Kazuhito Hashimoto, and Akira Fujishima "Photocatalytic Activity of Titanium Dioxide Thin Film Under Room Light." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 747-5 1, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, gas phase, IAQ, immobilized TiO_2.

505. Watts, Richard J., Sungho Kong, Margaret P. Orr, Glenn C. Miller, and Berch E. Henry. "Photocatalytic Inactivation of Coliform Bacteria and Viruses in Secondary Wastewater Effluent." *Water Res. 29,* no. 1 (1995): 95-100.
TiO_2, disinfection, aqueous phase.

506. Watts, Richard J., Sungho Kong, Margaret P. Orr, and Glenn C. Miller. "Titanium Dioxide-Mediated Photocatalysis of a Biorefractory Chloroether in Secondary Wastewater Effluent." *Environ. Technol.* 15, no. 5 (1994): 469-75.
TiO_2, aqueous phase, application.

507. Wei, Chang, Wen Yuan Lin, Zulkamain Zainal, Nathan E. Williams, Kai Zhu, Andrew P. Kruzic, Russell L. Smith, and Krishnan Rajeshwar. "Bactericidal Activity of TiO_2 Photocatalyst in Aqueous Media: Toward a Solar-Assisted Water Disinfection System." *Environ. Sci. Technol. 28,* no. 5 (1994): 934-8.
TiO_2, solar, disinfection.

508. Weng, Yupan, Fayang Wang, Liangmu Lin, and Ru Xie. "The Photocatalysis of Anatase Type Titanium Dioxide." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 713-18, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, nonaqueous, mechanism.

509. Wilkins, Frank W., and Daniel M. Blake. "Use Solar Energy to Drive Chemical Processes." *Chem. Eng. Prog. 90,* no. 6 (1994): 41-9.
TiO_2, engineering, reactor, solar, gas phase, aqueous phase, application.

510. Willner, I., Y. Eichen, and B. Willner. "Supramolecular Semiconductor Receptor Assemblies: Improved Electron Transfer At TiO_2 -Beta-Cyclodextrin Colloid Interfaces." *Res. Chem. Intermed.* 20, no. 7 (1994): 681-700.
TiO_2, metallized TiO_2, aqueous phase, modified TiO_2.

511. Willner, Itamar, Yoav Eichen, Arthur J. Frank, and Marye Anne Fox. "Photoinduced Electron-Transfer Processes Using Organized Redox-Functionalized Bipyridinium-Polyethylenimine-Titania Colloids and Particulate Assemblies." *J. Phys. Chem.* 97, no. 28 (1993): 7264-l.
TiO_2, aqueous phase, modified TiO_2.

512. Wyness, P., J. F. Klausner, D. Y. Goswami, and K. S. Schanze. "Performance of Nonconcentrating Solar Photocatalytic Oxidation Reactors, Part II: Shallow Pond Configuration." *J. Sol. Energy Eng.* 116, no. 1 (1994): 8-13.
TiO_2, reactor, solar, engineering, aqueous phase, immobilized TiO_2.

513. Wyness, P., J. F. Klausner, D. Y. Goswami, and K. S. Schanze. "Performance of Nonconcentrating Solar Photocatalytic Oxidation Reactors, Part I: Flat-Plate Configuration." *J. Sol. Energy Eng.* 116, no. 1 (1994): 2-7.
TiO_2, engineering, reactor, solar, aqueous phase, immobilized TiO_2.

514. Wyness, P., James F. Klausner, D. Yogi Goswami, and Kirk S. Schanze. "Performance of Nonconcentrating Solar Photocatalytic Reactors: Part I - Flat Plate Configuration." *Solar Engineering 1993,* eds. Allan Kirkpatrick, and William Worek, 19-24, New York, NY: ASME, 1993.
aqueous phase, engineering, solar, TiO_2.

515. Yamashita, H., H. Nishiguchi, N. Kamada, M. Anpo, Y. Teraoka, H. Hatano, S. Ehara, K. Kikui, L. Palmisano, and et al. "Photocatalytic Reduction of CO, With H_2O on TiO_2 and Cu/TiO_2 *Catalysts." Res. Chem. Intermed. 20,* no. 8 (1994): 815-23.
TiO_2, reductant, metallized TiO_2, aqueous phase, modified TiO_2.

516. Yamashita, Hiromi, Nobuhiro Kamada, Hong He, Kenichi Tanaka, Shaw Ehara, and Masakazu Anpo. "Reduction of CO, With H_2O on TiO_2(100) and TiO_2(110) Single Crystals Under W-Irradiation." *Chem. Lett.*, no. 5 (1994): 855-58.
TiO_2, gas phase, mechanism.

517. Yamazaki, Suzuko. "Destruction of Groundwater Contaminants Using Photocatalyst." *Kagaku to Kogyo 47,* no. 2 (Tokyo) (1994): 152-5.
TiO_2, reactor, aqueous phase, modified TiO_2, immobilized TiO_2.

518. Yanai, Koichi, inventor. "Harmful Substance-Removing Agents, the Removal, and Apparatus." Japan Nippon Zeon Co., assignee. Japan Patent' 06327965 A2.29 November 1994. *CA122:141313.*
TiO_2, other semiconductor, gas phase, modified TiO_2, application, immobilized TiO_2, adsorbent.

519. Yang, Junlin, Daohui Lu, and Guangzhi Xu. "Study of Free Radicals Generated in the Photoreaction of Co-Colloidal System." *Bopuxue Zazhi* 11, no. 1 (1994): 107-l.
TiO_2, other semiconductor, aqueous phase, modified TiO_2, mechanism.

520. Yasumori, Atsuo, Koji Yamazaki, Shuichi Shibata, and Masayuki Yamane. "Preparation of TiO_2 Fine Particles Supported on Silica Gel As Photocatalyst." *J. Ceram. Soc. Japan* 102, no. 8 (1994): *702-07.*
TiO_2, reductant, metallized TiO_2, aqueous phase, modified TiO_2, process efficiency, immobilized TiO_2, mechanism.

521. Yatmaz, H. C., C. R. Howarth, and C. **Wallis.** "Photocatalysis of Organic Effluents in a Falling Film Reactor." *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 795-800, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, reactor, aqueous phase, process efficiency.

522. Yoneyama, Hiroshi. "Effect of Supports for TiO_2 Loading on the Rate of Photo-induced Oxidative Decomposition of **Propionaldehyde."** Presented at 17th U.S.-Japan Cooperative Seminar on Photoconversion and Photosynthesis Research, La Jolla' CA, 12-14 March **1995, 4** pp.

523. Yoshida, Katsuhiko, Kazuo **Okamura,** Koji Hirano, Kiyoshi Iguchi, Kiminori **Itoh,** and Masayuki Murabayashi. "Photocatalytic Degradation of Trichloroethylene in Water by Using Thin-Film TiO_2 Prepared by Sol-Gel *Process." Mizu **Kankyo Gakkaishi*** 17, no. 5 (1994): 324-9.
TiO_2, aqueous phase, immobilized TiO_2.

524. Yost, Eric C., Isabel Tejedor-Tejedor, and Marc A. Anderson. "In Site **CIR-FTIR** Characterization of Salicylate Complexes At the **Geothite,Aqueous** Solution Interface." ***Environ. Sci.*** *Technol. 24,* no. 6 (1990): 822-28.
other semiconductor, aqueous phase, mechanism, surface binding.

525. You, Daoxin, Yongsheng Chen, and Shugui Dai. "Sunlight Photocatalytic Degradation of o-Chloroaniline." *Water Qual. Res. J. Can. 30,* no. 1 (1995): 61-7.
TiO_2, other semiconductor, solar, pesticide, aqueous phase.

526. Yu, Ying, Boe Gu, Zhenxiao Wu, and Yajie **Zhu.** "Photo-Degradation of **Organics** in Wastewater With Catalysts of Titanium Dioxide." *Shiyou **Daxue** Xuebao, Ziran Kexueban* 18, no. 2 (1994): 90-5.
TiO_2, aqueous phase, modified TiO_2.

527. Yue, P. L., and D. Allen. "Photocatalytic Degradation of **Atrazine."** *Photocatalytic Purification and Treatment of Water and Air,* eds. David F. Ollis and Hussain Al-Ekabi, 607-l 1, Trace Metals and the Environment' ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, pesticide, aqueous phase, modified TiO_2, mechanism.

528. **Zhang, Manping, Shinan Xie,** and **Weiping** Chen. "Study on the Isotherm for Adsorption of Dye on Titanium **Dioxide."*Haiyang Huaxue Lunwenxuan*,** ed. **Manping Zhang,** 41-4, Beijing, Peop. Rep. China: Haiyang Chubanshe, 1994.
TiO_2, aqueous phase, adsorption.

529. **Zhang,** P., R. J. Scrudato, J. J. Pagano, and R. N. Roberts. "Photocatalytic Decomposition of **PCBs** in Aqueous Systems With Solar Light." *Photocatalytic Purification and Treatment of Water and Air, eds.* David F. Ollis and Hussain Al-Ekabi, 619-24, Trace Metals and the Environment, ed. Jerome 0. Nriagu, New York, NY: Elsevier, 1994.
TiO_2, aqueous phase, application.

530. **Zhang,** Yin, J. C. Crittenden, D. W. Hand, D. L. **Perram,** and E. G. Marchand. "Solar Detoxification of Groundwater Using Fixed-Bed Photocatalysis." *The Proceedings of the Water Environment Federation 67th Annual Conference, 659-70,* 1994.
TiO_2, engineering, reactor, solar, metallized TiO_2, aqueous phase, application, immobilized TiO_2.

531. **Zhang,** Yin, John C. Crittenden, and David W. Hand. "The Solar Photocatalytic Decontamination of Water." *Chem. Ind* September (1994): 714-17.
TiO_2, other semiconductor, engineering, reactor, solar, aqueous phase, modified **TiO_2**, application, cost.

532. Zhang, Yin, John C. Crittenden, David W. Hand, and David L. **Perram.** "Fixed-Bed Photocatalysts for Solar Decontamination of Water." *Environ. Sci. Technol. 28,* no. 3 (1994): 435-2.
TiO_2, aqueous phase, modified **TiO_2**, immobilized **TiO_2**, solar, process efficiency.

533. **Zhao,** Jincai, Hisao **Hidaka,** Akira Takamura, Ezio Pelizzetti, and Nick Serpone. "Photodegradation of Surfactants. 11. Zeta-Potential Measurements in the Photocatalytic Oxidation of Surfactants in Aqueous Titania Dispersions." ***Langmuir*** *9,* no. 7 (1993): 1646-50.
TiO_2, aqueous phase, mechanism, adsorption.

534. **Zhou,** Yongqiu, Yunzhi Cai, and Yiyi Bau. "Study on the Photocatalytic Degradation of Trichloroacetic **Aldehyde** Solution Containing Semiconductor Compound." ***Huanjing*** *Wuran Yu* ***Fangzhi*** 16, no. 1 (1994): 15-17.
TiO_2, aqueous phase.

5.1. Supplemental References

535. Augustynski, Jan. "Aspects of Photo-Electrochemical and Surface Behavior of Titanium(IV) Oxide." 61 pp. Structure and Bonding, 69. Berlin, Germany: Springer Verlag, 1988.
adsorption/ aqueous phase/ catalyst characterization/ immobilized TiO_2/ process efficiency/ mechanism/ TiO_2.

536. Barbeni, Massimo, Edmondo Pramauro, Ezio Pelizzetti, Enrico Borgarello, Nick Serpone, and Mary A. Jamieson. "Photochemical Degradation of Chlorinated Dioxins, Biphenyls, Phenols and Benzene on Semiconductor Dispersions." *Chemosphere* 15, no. 9-12 (1986): 1913-6.
aqueous phase.

537. Bickley, R. I. "Fundamental Aspects of the Adsorption and the Desorption of Gases At Solid Surfaces Under Illumination." *NATO ASI Ser., Ser. C* 146 (1985): 379-88.
adsorption/ catalyst characterization/ photocatalysis.

538. Borgarello, Enrico, Nick Serpone, Michael Gratzel, and Ezio Pelizzetti. "Photodecomposition of Hydrogen Sulfide in Aqueous Alkaline Media Catalyzed by Ruthenium Dioxide-Loaded Alumina in the Presence of Cadmium Sulfide. Application of the Inter-Particle Electron Transfer Mechanism." *Inorg. Chim. Acta* 112, no. 2 (1986): 197-201.
aqueous phase/ other semiconductor.

539. Borgarello, Enrico, Nick Serpone, Paul Liska, Wilson Erbs, Michael Gratzel, and Ezio Pelizzetti. "Photocleavage of Hydrogen Sulfide in Alkaline Aqueous Media With a Ruthenium Dioxide-Loaded Cadmium Sulfide Catalyst Supported on a Polycarbonate Matrix." *Gazz. Chim. Ital.* 115, no. 11-12, Pt. A (1985): 599-602.
aqueous phase/ other semiconductor.

540. Borgarello, Enrico, Rita Terzian, Nick Serpone, Ezio Pelizzetti, and Massimo Barbeni. "Photocatalyzed Transformation of Cyanide to Thiocyanate by Rhodium-Loaded Cadmium Sulfide in Alkaline Aqueous Sulfide Media." *Inorg. Chem. 25,* no. 13 (1986): 2135-7.
aqueous phase/ other semiconductor.

541. Chen, Dezhi, and Xuezhu Wen. "Oxidation of Sulfite With the Heterogeneous Tungsten Trioxide/.Alpha.-Ferric Oxide/Tungsten Photocatalyst in Aqueous Solution." *Huaxue Tongbao,* no. 5 (1988): 32-3.
aqueous phase/ other semiconductor.

542. Chen, Dezhi, Xuezhu Wen, and Wennu Jin. "Study of Oxidation of Iodide on a Heterogeneous Photocatalyst Tungsten Trioxide/.Alpha-Ferric Oxide/Tungsten in Aqueous Solution." *Huaxue Tongbao,* no. 2 (1989): 32-4.
aqueous phase/ other semiconductor.

543. Childs, Lorette Pruden, and David F. Ollis. "Is Photocatalysis Catalytic?" *J. Catal. 66,* no. 2 (1980): 383-90.
aqueous phase/ mechanism.

544. Daroux, M., Y. Parent' and D. Klavana. "A New Reactor for the Study of Photocatalytic Reactions." *Chem. Eng. Commun. 4* (1980): 501-6.
gas phase/ reactor / engineering.

545. Domenech, J., and J. Peral, Cerdanyola, Spain. "Removal of Toxic Cyanide From Water by Heterogeneous Photocatalytic Oxidation Over Zinc Oxide." Sol. *Energy* 41, no. 1 (1988): 55-9.
aqueous phase/ other semiconductor.

546. Fox, Marye Anne, Austin, TX 78712, USA. "Organic Heterogeneous Photocatalysis: Chemical Conversions Sensitized by Irradiated Semiconductors." *Acc. Chem Res.* 16, no. 9 (1983): 314-21.
aqueous phase/ mechanism/ nonaqueous.

547. Henglein, Arnim. "Small-Particle Research: Physicochemical Properties of Extremely Small Colloidal Metal and Semiconductor Particles." *Chem. Rev. 89,* no. 8 (1989): 1861-73.
catalyst characterization/ modified TiO_2/ other semiconductor.

548. Hodes, Gary, and M. Gratzel. "Photoelectrochemistry At Semiconductor Electrodes and Small Particles: A Comparative Study." *Nouveau J. De Chemie* 8 (1984): 509-20.
photocatalyst/ mechanism/ process efficiency.

549. Kalyanasundaram, K. "Semiconductor Particulate Systems for Photocatalysis and Photosynthesis: an Overview." *Energy Resources Through Photochemistry and Catalysis*, ed. Michael Gratzel, 217-60. New York: Academic Press, 1983.
aqueous phase/ catalyst characterization/ mechanism/ metallized TiO_2/ other semiconductor/ oxidant.

550. Kalyanasundaram, Kuppuswamy, and M. Graetzel. "Heterogeneous Photocatalysis With Semiconductor Particulate Systems." *Springer Ser. Chem. Phys 35* (1984): 11 l-39.
mechanism.

551. Lewis, Nathan S. "Mechanistic Studies of Light-Induced Charge Separation At Semiconductor/Liquid Interfaces." *Acc. Chem. Res. 23* (1990): 176-83.
mechanism/ nonaqueous/ aqueous phase.

552. Marinangeli, R. E., and D. F. Ollis. "Photo-Assisted Heterogeneous Catalysis With Optical Fibers. Part III. Photoelectrodes." *AIChE J. 28,* no. 6 (1982): 945-55.
aqueous phase/ engineering/ reactor / immobilized TiO_2.

553. Marinangeli, R. E., and D. F. Ollis. "Photo-Assisted Heterogeneous Catalysis With Optical Fibers. II. Nonisothermal Single Fiber and Fiber Bundle." *AIChE J. 26,* no. 6 (1980): 1000-8.
aqueous phase/ engineering/ reactor / immobilized TiO_2.

554. Marinangeli, Richard E., and David F. Ollis. "Photoassisted Heterogeneous Catalysis With Optical Fibers. I. Isolated Single Fiber." *AIChE J. 23,* no. 4 (1977): 415-26.
aqueous phase/ immobilized TiO_2/ engineering/ reactor.

555. Muto, H., M. Shinada, and Y. Takizawa. "Heterogeneous Photolysis of Polychlorinated Dibenzo-p-Dioxins on Fly Ash in Water-Acetonitrile Solution in Relation to the Reaction With Ozone." *Environ. Sci. Technol. 25* (1991): 3 16-22.
Dibenzo-p-dioxins/ other semiconductor/ nonaqueous.

556. Ollis, David F. "Contaminant Degradation in Water." *Environ. Sci. Technol.* 19, no. 6 (1985): 480-84.
aqueous phase.

557. Ollis, David F. "Process Economics for Water Purification: a Comparative Assessment." *NATO ASI Ser., Ser. C, Photocatal. Environ.* 237 (1988): 663-77.
aqueous phase/ engineering/ cost.

558. Ollis, David F., Ezio Pelizzetti, and Nick Serpone. "Photocatalyzed Destruction of Water Contaminants." *Environ. Sci. Technol.* 25, no. 9 (1991): 1522-29.
aqueous phase/ metal removal/ oxidant/ mechanism/ pesticide.

559. Ollis, David F., and Ann L. Pruden. "Photostimulated Heterogeneous Catalysis: Description of the Process; Oxidation of Hydrocarbon and Chlorohydrocarbon Compounds." *Geterogen. Khimiya Atmosf., L* (1987): 251-63.
aqueous phase.

560. Pelizzetti, E., E. Pramauro, C. Minero, N. Serpone, and E. Borgarello. "Photodegradation of Organic Pollutants in Aquatic Systems Catalyzed by Semiconductors." *NATO ASI Ser., Ser. C, Photocatal. Environ. 237* (1988): 469-97.
photocatalysis.

561. Pelizzetti, Ezio. "Homogeneous and Heterogeneous Photocatalysis." *Chim. Ind., Milan 68,* no. 10 (1986): 51-2.
aqueous phase/ photocatalysis.

562. Pelizzetti, Ezio, Massimo Barbeni, Edmondo Pramauro, Wilson Erbs, Enrico Borgarello, Mary A. Jamieson, and Nick Serpone. "Photocatalytic and Photosynthetic Processes With Semiconductor Particulates." *Quim. Nova 8,* no. 4 (1985): 288-302.

563. Pelizzetti, Ezio, Enrico Borgarello, and Nick Serpone. "Photocatalytic Reactions of Organic Compounds. Hydrogen Generation From Organics and Degradation of Wastes." *NATO ASI Ser., Ser. C* 146 (1985): 305-19.
aqueous phase/ mechanism.

564. Pelizzetti, Ezio, and Nick Serpone. "Homogeneous and Heterogeneous Photocatalysis. [Proceedings of the NATO Advanced Research Workshop on Homogeneous and Heterogeneous Photocatalysis, Maratea Potenza, Italy, September 1-7, 1985]." 721 pp. NATO Advanced Science Institutes Series C: Mathematical and Physical Sciences, 174. Dordrecht, Neth: D. Reidel Publishing Co., 1986.
photocatalysis.

565. Peral, J., and D. F. Ollis. "Heterogeneous Photocatalysis for Air Purification." *1991 Summer National Meeting of AIChE.*
gas phase/ immobilized TiO_2.

566. Peral, Jose, Juan Casado, and Javier Domenech. "Light-Induced Oxidation of Phenol Over ZnO Powder." *J. Photochem. and Photobiol., A: Chem.* 44 (1988): 209-17.
aqueous phase/ other semiconductor.

567. Sato, S., and J. M. White. "Photoassisted Catalysis Using Platinized Titania." *Stud. Surf. Sci. Catal., Pt. B 7* (1981): 1500- 1.
aqueous phase.

568. Sato, Shinri. "Gas Phase Photoelectrochemical Reactions Over Metalized, Powdered Semiconductors." *Denki Kagaku Oyobi Kogyo Butsuri Kagaku 53,* no. 1 (1985): 9-14.
aqueous phase/ metallized TiO_2.

569. Scaife, D. E. "Oxide Semiconductors in Photoelectrochemical Conversion of Solar Energy." *Solar Energy 25,* no. 1 (1980): 41-54.
catalyst characterization/ other semiconductor/ TiO_2/ modeling.

570. Serpone, Nick. "Solar Photochemistry and Heterogeneous Photocatalysis: a Convenient and Practical Utilization of Sunlight Photons." *Photochem. Energy Convers., Proc. Int. Conf. Photochem. Convers. Storage Solar Energy,* eds. James R. Norris, Jr. and Dan Meisel, 297-3 15, 1989.
aqueous phase/ metal removal/ other semiconductor.

571. Serpone, Nick, Enrico Borgarello, and Ezio Pelizzetti. "Photoreduction and Photodegradation of Inorganic Pollutants: I. Cyanides." *NATO ASI Ser., Ser. C, Photocatal. Environ. 237* (1988): 499-526.
aqueous phase/ other semiconductor.

572. Turchi, Craig S., and David F. Ollis. "Photocatalytic Reactor Design: An Example of Mass-Trasfer Limitations With an Immobilized Catalyst." *J. Phys. Chem. 92* (1988): 6852-53.
engineering/ reactor / immobilized TiO_2/ aqueous phase.

573. Vinodgopal, K., and P. V. Kamat. "Environmental Photochemistry on Surfaces. Charge Injection From Excited Fulvic Acid into Semiconductor Colloids." *Environ. Sci. Technol. 26* (1992): 1963-66.
fulvic acid/ aqueous phase/ other semiconductor.

574. Watanabe, Tadashi, Takuo Takizawa, and Kenichi Honda. "Heterogeneous Photocatalytic Processes and Semiconductor Photoelectrode Reactions." *Shokubai 20,* no. 6 (1978): 370-80.
photocatalysis/ solar.

5.2. Key Words Used in the Bibliography

adsorbent
adsorption
anion inhibition
application
aqueous phase
biotreatment
catalyst characterization
catalyst reactivation
cost
disinfection
engineering
gas phase
IAQ
immobilized TiO_2
mechanism
metal removal
metallized TiO_2
modeling
modified TiO_2
nonaqueous
other semiconductor
oxidant
pesticide
photocatalysis
process efficiency
reactor
reductant
solar
TiO_2

5.3. Address to Send Corrections or References to Work Appearing Prior to 1995 that May Have Been Left out of the List of References in this and the Previous Report.

Dr. Daniel M. Blake
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

INTERNET: BLAKED@TCPLINK.NREL.GOV

6.0 Distribution List

Civil Engineering Research Foundation
1015 15th Street NW, Suite 600
Washington, DC 20005

Dr. Craig Adams
Clemson University
Environmental Systems Engineering
Clemson Research Park
Clemson, SC 296340919

Dr. Hussain Al-Ekabi
Hitech Advanced Photo-Oxidation
71 Brandy Lane Road
London, Ontario,
CANADA, N6G 4S2

Dr. Manuel Romero Alvarez
CIEMAT-IER
Avda. Complutense 22
28040 Madrid
SPAIN

Dr. Marc Anderson
University of Wisconsin
Water Chemistry Program
660 North Park Street
Madison, WI 53706

Mr. R. D. Andrew
Mobil Research and Development Corp.
Engineering Department
P.O. Box 1026
Princeton, NJ 08543

Dr. James A. Armstrong
Manager of Air Quality Services
Foster Wheeler Environment Corporation
143 Union Blvd., Suite 1010
Lakewood, CO 80228 1824

Ms. Karen Atkinson
WasteTech News
13 1 Madison Street
Denver, CO 80206

Professor Jan Augustynski
Université de Genève
Chimie Appliquée
Sciences II
30 quai E. Ansermet, CH-1211 Geneve 4
SWITZERLAND

Ms. Sayward Ayre
114 Pear Street NE, No. 2
Olympia, WA 98506

Mr. Mike Bahm
Senior Program Manager
Radian Corporation
1801 Broadway, Suite 1000
Denver, CO 80202

Dr. Detlef Bahnemann
Institut fur Solarenergieforschung GmbH
Sokelantstrasse 5
D-30165 Hannover
GERMANY

Dr. Ron Balkissoon, M.D.
Staff Physician
National Jewish Center for Immunology
and Respiratory Medicine
1400 Jackson St.
Denver, CO 80206

Dr. Alan Bard
University of Texas
Department of Chemistry
Austin, TX 78712-1167

Mr. Herb Bassow
Germantown Friends School
31 West Coulter Street
Philadelphia, PA 19 144

Mr. Chuck Beck
Coors Brewing Co
Golden, CO 80401

Mr. Gino Beer
5 via Risorgimento
16033 Lavagna,
Genoa
ITALY

Mr. Kelly Beninga
Science Applications International Corp.
15000 W. 6th Ave., Suite 202
Golden, CO 80401

Dr. Jaime Benitez
Chemical Engineering Department
R.U.M., Mayaquez
Puerto Rico 00681

Ms. Kathleen Bennett
Vice President
James River Corporation
P.O. Box 2218
Richmond, VA 23217

Dr. Elliot Berman
Resident
Photox Corporation
P. 0. Box 15717
Boston, MA 02215

Mr. Darsh Bhutra
Chevron Research and Technology
Company
Health, Environment & Safety Group
P.O. Box 4054
Richmond, CA 94804

Dr. Gale Biggs
W. Gale Biggs Associates
P.O. Box 3344
Boulder, CO 80303

Mr. Peter J. Blake
Dir. of Pub. And Env. Affairs
North East Fabricare Association
343 Salem Street
Wakefield, MA 01880

Dr. Julian Blanco
CIEMAT-PSA
Aptdo, 22
E-4200 Tabernas (Almeria)
SPAIN

Ms. Cathy Blount
Chemical Engineering Department
University of Colorado
Campus Box 424
Boulder, CO 80309

Mr. David Bluestein
Dow Environmental
49 Stevenson Street
Suite 600
San Francisco, CA 94105

Dr. Jim Bolton
Solarchem Environmental Systems
130 Royal Crest Court
Markham, Ontario
CANADA L3R 0A1

Dr. Paul Bonczyk
UTRC - M.S. 30
Silver Lane
East Hartford, CT 06108

Ms. La Ronda V. Bowen
Public Advisor
South Coast Air Quality Management District
21865 Copley Drive
Diamond Bar, CA 91765

Mr. Steven Bowles
Kleinfelder
3249 East Harbour Drive
Phoenix, AZ 850347227

Mr. Mark Burger
U.S. Department of Energy
1 South Wacker Drive, Suite 2380
Chicago, IL 6060646 16

Mr. Heyward Burnette
LOGTEC, Incorporated
2900 Residential Drive
Fairborn, OH 45324

Mr. Brian Butters
General Manager
Pulifics
161 Mallard Road
Hyde Park, Ontario NOM 1Z0
CANADA

Mr. Beningo Cabrero
CIEMAT-IER
Avda. Complutense 22
28040 Madrid
SPAIN

Mr. Mark Camenzind
Balazs Labs
252 Humboldt Court
Sunnyvale, CA 94089- 13 15

Dr. Luis Canas
Savanah River Westinghouse Co.
Mail Stop 244-2h
P.O. Box 616
Aiken , SC 29802

Dr. Nelson Cardona
University of Puerto Rico at Mayaguez
Chemical Engineering Dept.
P.O. Box 5000
Mayaguez, PR 00681-5000

Mr. Jeffrey Carmody
Santa Barbara Air Pollution Control District
Innovative Technologies Group
26 Castilian Drive, Suite B-23
Goleta, CA 93117

Mr. Clifton Carwile
U.S. Dept. of Energy
EE-222, 5G-035
Office of Industrial Technologies
1000 Independence Ave. SW
Washington, DC 20585

Dr. Stephen R. Cater
Manager, Research & Process Engineering
Solarchem Environmental Systems
130 Royal Crest Court
Markham, Ontario LeR0A1
CANADA

Mr. Jerry Ceasar
BP
17618 Plum Creek Trail
Chagrin Falls, OH 44023

Dr. Eileen Chant
University of Turabo
School of Engineering
Apartado 3030
Gurabo, Puerto Rico 00778

Mr. James M. Chavez
Sandia National Laboratories
Solar Thermal Test
Department 6215, MS1 127
Albuquerque, NM 87 185

Mr. Daniel Chen
Lamar University
Department of Chemical Engineering
P.O. Box 10053
Beaumont, TX 77710

Mr. James D. Chrisman
Vice President
Stapleton Redevelopment Foundation
730 17th Street, Suite 340
Denver, CO 80202

Dr. Ronald Clazie
Vice President, Engineering
Free-Flow Packaging Corporation
1903 Charter Street
Redwood City, CA 94063

Dr. Armin Clobes
Senior Research Associate
S.C. Johnson & Son, Inc.
1525 Howe Street
Racine, WI 53403-50 11

Mr. James L. Condit
Project Manager
Kleinfelder
3249 East Harbour Drive
Phoenix, AZ 850347227

Mr. Richard Consolas
Editor
Environtech
P. 0. Box 640310
Oakland Gardens, NY 11364

Dr. Donald Conte
California University of Pennsylvania
Earth Science Box 55
California, PA 154 19

Mr. Gerald Cooper
Photocatalytics, Inc.
755 South 42nd Street
Boulder, CO 80303

Dr. John A. Cooper
TRC Environmental Corp.
12242 SW Garden Place
Tigard, OR 97223

Mr. Douglas Cregar
DuPont Chemicals R&D
Jackson Laboratory
Deepwater, NJ 08023

Dr. John Crittenden
Michigan Technological University
Environmental Engineering Center
1400 Townsend Drive
Houghton, MI 49931

Dr. Donald Cropek
USA CERL
P. 0. Box 9005
Champagne, IL 618269005

Dr. John Daily
Department Chair
University of Colorado
Department of Mechanical Eng.
Engineering Center
Boulder, CO 80309

Dr. Chuck **Darvin**
U.S. **EPA/AEERL**
Research Triangle Park, NC 277 11

Dr. Abhaya Datye
University of New Mexico
Center for Microengineered Ceramics
Albuquerque, NM 87 13 1

Mr. Roger Davenport
Science Applications International Corporation
15000 W. 6th Ave., Suite 202
Golden, CO 80401

Mr. Arthur Davidson
Davidson **&** Associates Environmental
4814 Somerset Drive
Bellevue, Washington 98006

Dr. David Deberry
Corporate Fellow
Radian Corporation
8501 Mapac Blvd.
Austin, TX 78759

Dr. Barry Dellinger
UDRC
300 College Park
Dayton, OH 45469

Ms. Cathy Dombrowski
Haz TECH News
14120 Huckleberry Lane
Silver Springs, MD 20906-2012

Dr. Xavier Domenech
Univ. Autonoma Barcelona
Dtp. Quimica, Bellaterra
08 193 Barcelona
SPAIN

Dr. Jose M. Doiia
Departamento de **Química**
Universidad de Las **Palmas** de Gran **Canaria**
Campus Universitario de **Tafira**
35017 - Las **Palmas**
SPAIN

Mr. **Roch** Ducey
U.S. Army Corps of Engineers, CERL
P.O. Box 9005
Champaign, IL 61826

Mr. Mike Dunn
Air Manager
Naval Surface Warfare Center, Indian Head
101 Strauss Ave.
Indian Head, MD 20640

Dr. David **Ensor**
Research Triangle Institute
P. 0. Box 12194
Research Triangle Park, NC 27709-2194

Dr. Gary Epling
University of Connecticut
Department of Chemistry
215 Glenbrook Road U-60
Storrs, CT 06269-3060

Dr. John Falconer
University of Colorado
Department of Chemical Engineering
Campus Box 424
Boulder, CO 80309

Mr. William Fisher
International Fabricare Institute
12251 Tech Road
Silver Spring, MD 20904

Dr. Renee Ford
Editor, Materials Technology Magazine
P.O. Box 72
Harrison, NY 10528-0072

Dr. **Fardad** Forouzan
University of Texas
Department of Chemistry
Austin, TX 78712

Dr. Nancy Foster-Mills
New Mexico State University
2241 Entrada Del Sol **#1J**
Las **Cruces,** NM 88001

Dr. Mary Anne Fox
University of Texas
Department of Chemistry
Austin, TX 78712-1167

Mr. Randy Fox
Kleinfelder
3249 East Harbour Drive
Phoenix, AZ 850347227

Mr. Robert Fox
Vice President
IT corporation
3 12 Directors Drive
Knoxville, TN 37923

Mr. Norman **Francinques**
US Army Engineers
3909 Halls Ferry Rd.
Mail Code CEWES-EE-R
Vicksburg, MI 39180-6199

Mr. **Allan** L. Frank
Editor
The Solar Letter
9124 Bradford Rd.
Silver Springs, MD 20901-4918

Dr. Jim Freihaut
United Technologies Research Center
411 Silver Lane, MS 129-24
East Hartford, CT 06108

Mr. Ralph Froehlich
Resident
Helix Environmental, Inc.
7720 Paragon Road, Suite B
. Dayton, OH 45459

Dr. Karl-Heinz **Funken**
German Aerospace Research Development
Energy Technology Division
D-5 1140 **Koln**
GERMANY

Mr. David Gaboardi
Mark III Industries
P.O. Box 2525
Ocala, FL 34478-2525

Mr. James Garmaker
Senior Project Engineer
3M Company
P. 0. Box 33331
Building **42-4E-03**
St. Paul, MN 55 133-3331

Mr. Gary Garner
3M Company
P. 0. Box 33331
Building **21-2W-05**
St. Paul, MN 55133-3331

Mr. Ranji George
South Coast Air Quality Management District
21865 Copley Drive
Diamond Bar, CA 91765-4182

Dr. Anne Giesecke
Vice President, Environmental Activities
American Bakers Association
1350 I Street NW, Suite 1290
Washington, DC 20005

Dr. William Glaze
University of North Carolina
Environmental Science **&** Engineering
Rosenau Hall, **CB#** 7400
Chapel Hill, NC **27599-7400**

Mr. James Goodrich
Environmental Scientist
U.S. EPA
Drinking Water Research
26 W. Martin Luther King Dr
Cincinnati. Ohio 45268

Mr. Steven **Gorman**
American Energy Technologies, Inc
P.O. Box 1865
Green Cove Springs, FL 32043

Dr. Yogi **Goswami**
Professor of Mechanical Engineering
University of Florida
College of Engineering
220 MEB
Gainesville, FL 326 1 l-2050

Mr. John Graf
NASA JSC
Mail Code EC3
Houston, TX 77058

Dr. **Vicki Grassian**
University of Iowa
Iowa City, IA 52242

Dr. Michael **Grätzel**
Institut de Chemic Physique
EPFL
1015 Lausanne
SWITZERLAND

Dr. Kimberly Gray
Notre Dame University
Dept of Civil Engineering
Notre Dame, IN 46556

Dr. Robert Hall
Sr. Research Scientist
UTRC - M.S. 30
Silver Lane
East Hartford, CT 06108

Dr. Adam Heller
Professor of Chemical Engineering
University of Texas
Austin, TX 78712-1062

Mr. Ephraim Heller
E. Heller & Company
1311 Harbor Bay Parkway, Suite 1000
Alameda, CA 94501

Mr. Bob Henderson
Matrix Photocatalytic, Inc.
22 Pegler Street
London, Ontario N5Z 2B5
CANADA

Dr. Thomas Hess
University of Idaho
Department of Agricultural Engineering
Moscow, ID 83843

Mr. Michael Hoffman
Business Development Manager
NEPCCO
2140- 100 N.E. 36th Ave.
Ocala, FL 34470

Dr. Michael Hoffmann
W. M. Keck Laboratories
California Institute of Technology
Pasadena, CA 91125

Dr. Jeffrey Hoke
Staff Chemist, Corporate Research
Engelhard Corporation
101 Wood Avenue
Iselin, NJ 08830-0770

Mr. Bennett Howell
Solar Kinetics, Inc.
P.O. Box 540636
Dallas, TX 75354

Mr. Robert Hulsey
Black & Veatch
8400 Ward Parkway
Kansas City, MO 64114

Mr. Gus Hutchinson
Solar Kinetics Inc.
10635 King Williams Drive
Dallas, Texas 75220

Dr. Bruce Hutton
University of Denver
College of Business Administration
2020 South Race Street
Denver, CO 80208

Dr. John Ireland
U.S. EPA
Office of Research and Development
Risk Reduction Engineering Lab
26 W. Martin Luther King Dr.
Cincinnati, OH 45268

Mr. Avtar Jassal
ES&H Project Manager
SEMATECH
.2706 Montopolis Drive
Austin, TX 78741

Mr. Ohad Jehassi
Economist
U.S. EPA
Office of Toxic Substances
401 M Street, S.W. (TS-779)
Washington, DC 20460

Ms. Sandra Jenkins
Parsons Engineering Science
Woodruff Annex Complex
P. 0. Box 1625
Idaho Falls, ID 83415-3954

Dr. Mark Jones
DOW
1776 Building
Midland, Michigan 48674

Dr. Prashant V. Kamet
University of Notre Dame
Radiation Laboratory
Notre Dame, IN 46556-0579

Mr. Mike Kemme
U.S. Army Construction
Engineering Research Laboratories
P. 0. Box 9005
Champaign, IL 61826

Ms. Deborah Kielian
City of Denver
Department of Health and Hospitals
Environmental Section
605 Bannock Street
Denver, CO 802044707

Mr. J. R. Kittrell
Resident
KSE Inc.
P. 0. Box 368
Amherst, MA 01004

Dr. Jim Klausner
University of Florida
College of Engineering
Dept. of Mech. Engineering
Gainesville, FL 32611

Mr. Nick Korte
Oak Ridge, Grand Junction
Oak Ridge National Lab
2597 B 3/4 Road
Grand Junction, CO 81503

Dr. Carl Koval
University of Colorado
Department of Chemistry
Boulder, CO 80309-0215

Mr. Raymond Krishock
Corporate Staff Engineer
E/M Corporation
P.O. Box 2400
West Lafayette, IN 47906

Dr. Peter Kuhn
Paul Scherrer Institute
CH-5232 Villigen
SWITZERLAND

Dr. Charles Kutal
University of Georgia
Department of Chemistry
Athens, GA 30602-2556

Ms. Linda Ladas
Solar Energy Industries Association
777 North Capitol St. NE
Suite 805
Washington D.C. 20002-4226

Mr. Lawrence Laitres
Lawter Associates
157 Hillcrest Rd.
Fairfield, CT 06430

Mr. Jack Lauber
New York State Dept. of Environmental Conservation
Division of Air Resources
50 Wolf Road
Albany, NY 12233-3254

Dr. C.C. Lee
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
26 West Martin L. King Drive
Cincinnati, OH 45268

Ms. Gretchen Leslie
Technical Librarian
Washington State Energy Office
P.O. Box 43171
925 Plum Street S.E., Bldg. #4
Olympia, WA 98504-3 171

Dr. Miriam Lev-On
Senior Consultant, Environmental Protection
ARC0
515 South Flower Street
Los Angeles, CA 90071

Ms. Norma Lewis
U.S. EPA
Emerging Technology Section
Cincinnatti, OH 45268

Dr. Norman Lichtin
Boston University
Chemistry Department
590 Commonwealth Avenue
Boston, MA 02215

Mr. Clovis Linkous
Research Engineer
Florida Solar Energy Center
300 SR 401
Cape Canaveral, FL 32920

Dr. Noam Lior
University of Pennsylvania
Dept. of Mech. Engineering
297 TB/6315
Philadelphia, PA 19104-6315

Mr. Douglas P. Lorriman
Chairman
Solarchem Environmental Systems
130 Royal Crest Court
Markhcem, Ontario L3R0A1
CANADA

Dr. John Malanchuk
IT Corporation
Regional Office
3 12 Directors Drive
Knoxville, TN 37923-4799

Dr. Sixto Malato
CIEMAT-PSA
Aptdo.22
E-04200 Tabernas (Almeria)
SPAIN

Dr. Blair Martin
Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

Dr. Paul Martino
American Petroleum Institute
1220 L. Street, NW
Washington, DC 20005

Mr. Keith Mason
Senior Economic Analyst
U.S. EPA
Office of Air and Radiation
401 M Street, S.W. (6103)
Washington, D.C. 20460

Mr. Ken May
Industrial Solar Technology
4420 McIntyre Street
Golden, CO 80403

Ms. Naydene Maykut
Senior Air Quality Scientist
Puget Sound Air Pollution Control Agency
110 Union Street, Suite 500
Seattle, Washington 9810 1 - 1038

Dr. Augustus McEvoy
Institut de Chemic Physique
EPFL
1015 Lav sanne
SWITZERLAND

Dr. Thomas McKinnon
Colorado School of Mines
Department of Chemical Engineering
Golden, CO 80401

Mr. Derek McManus
Wheelabrator Clean Air Systems
1501 E. Woodfield Rd., Suite200 West
Schaumburg, IL 60 173

Mr. Richard Miller
IT Corporation
3 12 Directors Drive
Knoxville, TN 37923

Mr. Terrell **Minger**
Center for Resource Management
1410 Grant Street, Suite **C307**
Denver, CO 80203-l 846

Mr. Nazim Muradov
Research Associate
Florida Solar Energy Center
30 1 State Road
Cape Canaveral, FL

Dr. J.H. Nelson
University of Nevada at Reno
Department of Chemistry
Reno, NV 89557

Dr. **Manfred** Noack
Senior Consulting Chemist
350 Knotter Drive
P.O. Box 586
Cheshire, CT 06410-0586

Dr. David **Ollis**
Chemical Engineering Department
N.C. State University
Box 7905
Raleigh, NC 27695-7905

Dr. Arijit Pakrasi
Senior Project Engineer
IT Corporation
3 12 Director's Drive
Knoxville, TN 37923

Mr. Tom Paul
Aegis Environmental, Inc.
2470 Wrondel Way
Suite 208
Reno , NV 89502

Mr. Steve Miller
Jacobs Engineering
175 Freedom Blvd
Kevil, KY 42053

Mr. Lawrence **Mireles**
2063 A San Antonio Ave
Alameda, CA 94501

Ms. Maria Murray
INRAD, Inc
181 **La Grand** Ave
Northvale, NJ 07647

Mr. Timothy Nicely
Solutions International
19528 Ventura Blvd., Suite 278
Tarzana, CA 91356

Dr. Richard Noble
University of Colorado, Boulder
Dept of Chemical Engineering
Engineering Center, CH l-60
Campus Box 424
Boulder, CO 80309-0424

Mr. Tim **O'Neill**
Measurement Technologies Northwest
3822 **Latone** Lane, NE
Seattle, WA 98105

Dr. Bill Parker
Editor
Solar Progress
Box 175
North Perth 6006
AUSTRALIA

Mr. Chris Paulson
Friedlob Sanderson Raskin Paulson **&**
Tourtillott
1400 **Glenarm** Place
Denver, CO 80202-5099

Dr. Emil Milosavljevic
University of Nevada, Reno
Mackay School of Mines
Reno, NV 89557

Dr. Booker Morey
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

Ms. Maria Nargiello
Degu ssa Corp
Applied Technology Pigment Group
Suite 110, 150 Springside Drive
Akron, OH 44333

Dr. David E. Nicodem
Instituto de **Química-UFRJ,** CT
Bloco A, Ilha do Fundao, 21949-900
Rio de Janeiro, RJ
BRAZIL

Mr. Carlos Nunez
U.S. EPA
AEERL-OCT (MD-6 1)
Research Triangle Park, NC 27711

Dr. Kevin O'Shea
Florida International University
College of Arts **&** Sciences
Miami, FL 33199

Mr. Gerald Parkinson
McGraw-Hill, Inc.
17432 Teachers Ave.
Irvine, CA 927 14

Mr. Greg Peebles
American Energy Technologies, Inc.
P.O. Box 1865
Green Cove Springs, FL 32043

Dr. Phyllis Pei
Manager, ES&H
SEMATECH
2706 Montopolis Drive
Austin, TX 78741-6499

Dr. Nicola Peill
California Institute of Technology
Environmental Engineering Science
Department
MC 138-78
Pasadena, CA 91125

Dr. Ezio Pelizzetti
Institute di Chimica Fisica
Universita di Parma
43100 Parma
ITALY

Mr. Keith Pettus
Huck International, Inc.
Safety, Health and Environmental Affairs
P.O. Box 19590
Irvine, CA 92713

Dr. Gary Peyton
Illinois State Water Survey
Office of Environmental Chemistry
1008 S. Mattis Ave
Champaign, IL 61820

Dr. Pierre Pichat
U.R.A. au C.N.R.S.
Ecole Central de Lyon
E.P. 163, 69131 Eculty Cedex
FRANCE

Ms. Anne Polanski
Solar Energy Industries Association
777 North Capitol St. NE
Suite 805
Washington D.C. 20002-4226

Dr. Wade Ponder
U.S. EPA
Air and Energy Engineering Research
Laboratory
Research Triangle Park, NC 27711

Dr. Michael Prairie
Chemical Engineer
Sandia National Laboratories
P.O. Box 5800, Division 6216
Albuquerque, NM 87185-0703

Mr. Steve Pratt
Merrick Engineers & Architects
10855 East Bethany Drive
P.O. Box 22026
Denver, CO 80222

Dr. Charles Quinlan
KSE, Inc.
P.O. Box 368
Amherst, MA 01004

Dr. Krishnan Rajeshwar
University of Texas at Arlington
Dept of Chemistry & Biochemistry
Box 19065
Arlington, TX 76019-0065

Dr. Greg Raupp
Arizona State University
Dept of Chemical Bio & Materials
Engineering
Tempe, AZ 85287-6006

Mr. John S. Reese
NEPCCO
2140 N.E. 36th Ave.
Ocala, FL 34470

Mr. Mark Rinaman
Law Environmental
112 Town Park Drive
Kennesaw, GA 30144

Dr. Mary Clare Robbins
Assistant Professor
Univ. of Texas at El Paso
M&I Engineering
College of Engineering
El Paso, Texas 79968-0521

Dr. Tim Rose
EIC Laboratories Inc.
Research Division
111 Downey St.
Norwood, MA 02062

Dr. Kathy Rowlen
University of Colorado
C.B. 215
Boulder, CO 80309

Dr. Shabbar Saifee
Senior Renewable Energy Spec.
Virgin Islands Energy Office
81 Castle Coakley
Christiansted, St. Croix
U.S. Virgin Islands 00820

Dr. Craig Saltiel
University of Florida
CASE
3950 RCA Blvd., Suite 5003
Palm Beach Garden, FL 33410

Dr. Peter Schaeffer
West Virginia University
Agricultural Services Building
Division of Resource Management
P.O. Box 6108
Morgantown, WV 26506-6 108

Ms. Linda Schneider
Trojan Industries
3020 Gore Rd.
London, Ontario N5V4T7
CANADA

Dr. Judith Schreiber
Director, Bureau of Toxic Sub.
State of New York Dept. of Health
2 University Place, Rm. 240
Albany, NY 12203-3399

Dr. Jeffrey Sczechowski
California Polytechnic State University
Civil & Environmental Engineering Dept
San Luis Obispo, CA 93407

Mr. Richard Segrave-Daly
Small Business Ombudsman
Pennsylvania Department of Commerce
Fulton Bank Building, Suite 901
Harrisburg, PA 17101

Mr. L.M. Seigel
PRC Environmental Management, Inc.
1505 PRC Drive, Suite 220
McLean, Virginia 22102

Dr. Nick Serpone
Department of Chemistry
Concordia University
1455 DeMaisonneuve Blvd. West
Montreal, Quebec H3G1M8
CANADA

Mr. Nanjun Shetty
Geraghty & Miller
2840 Plaza Pl., Suite 350
Raleigh, NC 27613

Dr. Raymond Sierka
University of Arizona
Dept of Civil Engineering and Engineering Mechanics
Tucson, AZ 85721

Dr. Subhas Sikdar
EPA
Risk Reduction Engrg Lab
26 W. Martin Luther King Drive
Cincinnati, OH 45268

Dr. Kurt Sisson
U.S. Dept. of Energy
NP-42 1 H-088
1000 Independence Ave. SW
Washington DC 20585

Mr. David Skiles
The Denver Smart Places Project
605 Bannock Street, Room 333
Denver, CO 802044707

Mr. Jake Smith
Hennepin County Environmental Management
417 North Fifth Street
Minneapolis, MN 55401-1309

Mr. Mark Smith
Tyndall AFB
Air Force Civil Engineering Support Agency
Tyndall AFB, FL 32403-6001

Dr. Russell Smith
University of Texas at Arlington
Department of Chemistry
P. 0. Box 19065
Arlington, TX 76019

Dr. Wayde Smith
UTRC - M.S. 30
Silver Lane
East Hartford, CT 06 108

Mr. Stephen Snyder
Energy Management Division Chief
HQ, Fort Carson & 4th Infantry Division
Attention: AFZC-ECM-EM
Fort Carson, CO 80913-5000

Dr. Herbert Spencer
EC&C Technologies
4234 Chevy Chase Dr.
Lacanada, CA 91011

Dr. Donald Stedman
University of Denver
Department of Chemistry
2101 East Wesley Avenue
Denver, CO 80208

Mr. Stephen Stiles
Chemist
Energetic Materials Chemistry Division
Indian Head Division, NSWC
Indian Head, MD 20640-5035

Mr. Jack Sullivan
Research Chemist
Tennessee Valley Authority
P.O. Box 1010
Muscle Shoals, AL 35660

Dr. Ken-ichirou Suzuki
Toyota Central R&D Labs
41-1 Yokomichi, Nagakute
Nagakute-cho, Aichi-gun
Aichi-ken 480- 11
JAPAN

Mr. Michael Swan
Vice Resident
Process Technologies, Inc.
910 Main Street
Boise, ID 83701-0476

Mr. Bob Sweeney
New Mexico Environmental Dept.
Groundwater Bureau
Harold Runnels Building
1190 St. Francis Dr.
Sante Fe, NM 87502

Ms. Denise Swink
U.S. Dept. of Energy
EE-20 6B-052
Office of Industrial Technologies
1000 Independence Ave. SW
Washington DC 20585

Dr. Ali T-Raissi
Florida Solar Energy Center
300 State Road 401
Cape Canaveral, FL 32920

Mr. Hal Taback
Hal Taback Company
378 Paseo Sonrisa
Walnut, CA 91789

Dr. Walter Tang
Florida International University
Dept of Civil and Environmental Engineering
Miami, FL 33199

Dr. Marion Thumauer
Argonne National Lab
9700 S. Cass Ave.
Argonne, IL 60439-4815

Dr. Micha Tomkiewicz
Department of Physics
Brooklyn College, C.U.N.Y.
Brooklyn, NY 11210

Mr. Ronald J. Turner
Regional Manager
Kleinfelder
3249 East Harbour Drive
Phoenix, AZ 850347227

Dr. Craig Tyner
Manager
Sandia National Laboratories
Solar Thermal Technology Department
Albuquerque, NM 87185-0703

Mr. John Vig
Army Research Lab
AMSRL-EP-ME
Ft. Monmouth, NJ 07703-5601

Dr. Darryl Von Lehmden
Midwest Research Institute
401 Harrison Oaks Blvd
Cary, NC 27513

Ms. Rebecca Vories
Infinite Energy
P.O. Box 481905
Denver, CO 80248

Dr. Richard Watts
Washington State University
Department of Civil Engineering
Pullman, WA 991642910

Mr. David Wickham
TDA Research
12421 West 49th Ave
Wheatridge, CO 80033

Mr. Frank Wilkins
U.S. Dept. of Energy
EE-222 5G-067
1000 Independence Ave. SW
Washington DC 20585

Ms. Suzanne Wilson
Environment and Safety Division
Anaheim Public Utilities Dept.
201 South Anaheim Blvd., Room 1102
Anaheim, CA 92805

Dr. Aaron Wold
Brown University
Department of Chemistry
Providence, RI 02912

Dr. John Yates, Jr.
University of Pittsburgh
Department of Chemistry
Chevron 234
Pittsburgh, PA 15260

Professor Courtney Young
219 ELC Building
Dept. of Metallurgical Engineering
Montana Tech.
Butte, MT 59701

Dr. Po Lock Yue
Hong Kong University of Science &
Technology
Room 457 1, Academic Building
Clear Water Bay
Kowloon, HONG KONG

Dr. Mark Zappi
US Army Engineers
3909 Halls Ferry Rd.
Vicksburg, MI 39180-6199

Dr. R.G. Zepp
U.S. EPA
960 College Station Road
Athens, GA 30613-7799

REPORT DOCUMENTATION PAGE

Form Approved
ORB NO. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 1995	Technical Report

4. TITLE AND SUBTITLE

Bibliography of Work on the Heterogeneous Photocatalytic Removal of Hazardous Compounds from Water and Air, Update Number 1, to June, 1995

5. FUNDING NUMBERS

(TA) SI51.3020

6. AUTHOR(S)

Dan Blake

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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

8. PERFORMING ORGANIZATION REPORT NUMBER

NRELITP-47320300

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

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

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NA

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

12b. DISTRIBUTION CODE

UC-1404

13. ABSTRACT *(Maximum 200 words)*

This report is an update of a bibliography, published in May, 1994, of research performed on the photocatalytic oxidation of organic or inorganic compounds in air or water and on the photocatalytic reduction of metal-containing ions in water. The general focus of the research is on removing hazardous contaminants from air or water to meet environmental or health regulations. The processes covered are based on the application of heterogeneous photocatalysts. The current state-of-thsart in catalysts are forms of titanium dioxide or modifications of titanium dioxide, but work on other heterogeneous catalysts is also included in this compilation. This update contains 574 references, most published between January, 1993 and June, 1995, but some references are from earlier work that were not included in the previous report.

14. SUBJECT TERMS

adsorbent, adsorption, anion inhibition, aqueous phase, biotreatment, catalyst characterization, catalyst reactivation, disinfection, gas phase IAQ, immobilized TiO_2, metal removal, metallized TiO_2, modified TiO_2, nonaqueous, photocatalysis, process efficiency, reductant, TiO_2

15. NUMBER OF PAGES

104

16. PRICE CODE

A06

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT