University of South Florida

Fresh Water Using low Grade Heat and Alternative Energy
(Formerly titled: Clean Drinking Water using Advanced Solar Energy Technologies)
(Final Report)

PI: E.K.Stefanakos **Co-PIs:** Yogi Goswami
Students: Chennan Li (PhD), Mohammad Abutayeh, Yangyang Zhang(PhD), Omatoyo Dalrymple

Description: This project is being pursued by means of two tasks: Task 1: Water desalination by the use of optimized thermodynamic systems; and Task 2: Design of a photocatalytic reactor for air purification.

Budget: $326,756
Universities: USF

Executive Summary

Photocatalysis is a promising technique for air/water disinfection and decontamination. Photocatalysis utilizes semiconductor photocatalysts (such as TiO_2 or ZnO) and appropriate light to produce strong oxidizing agents (OH•) that are able to break down organic compounds and inactivate bacteria and viruses. The construction of an effective photocatalytic disinfection system for water purification is currently limited by the lack of reliable models to aid in the design and testing of these systems. Simplified models have been proposed, but most are inadequate because they rely on traditional disinfection theories which are not applicable to photocatalysis. Therefore, it is important to develop a model for photocatalytic disinfection based on fundamental processes which may then be used to design water treatment systems in the state of Florida. A mechanistic model has been developed that simulates the effect of light intensity and catalyst concentration on the disinfection process. The simulations show good agreement with the experimental data for stable colloidal suspensions.

Photocatalyst development has also been studied. Zinc oxide (ZnO) and iron doped zinc oxide (ZnO/Fe) nanowires were synthesized on glass substrates through a conventional hydrothermal method. The photocatalytic activities under ultraviolet (UV) light and white light irradiation were separately investigated. The ZnO/Fe nanowires exhibited an enhanced photocatalytic activity as compared to ZnO nanowires regardless of the type of contaminants and light sources.

Photocatalytic reactor design for indoor air purification has been studied. The overall goal of the research is to develop an efficient photocatalytic reactor based on mass transfer for indoor air purification. This study has focused on the enhancement of the effectiveness of the photocatalytic process by the introduction of artificial roughness on the reactor catalyst surface. The major effect of artificial roughness elements on the catalytic surface is to create local wall turbulence and enhance the convective mass transfer of the contaminants to the catalyst surface and thus lead to an increase in the effectiveness of photocatalysis. Air flow properties in a model photoreactor channel with various roughness patterns on the interior wall surface were theoretically investigated. The optimum shapes, sizes, and arrangements of roughness were determined for the maximum enhancement of turbulence intensity in the channel. The possible order of photocatalytic reactor performance for various roughness patterns was also determined. In order to verify the theoretical analysis results, experimental studies were carried out. A plate type photocatalytic reactor was designed and fabricated on the basis of the theoretical results. It was determined that the photocatalytic reactor performance is greatly improved with various rough catalyst

surfaces. The experimental results verified the theoretical results. The relationship between the overall reaction rate constant (k) of the reactor and the magnitude of the turbulence intensity was found out. An empirical correlation expression was also proposed. This is the first study of the effect mass transfer in a rough catalytic surface for photocatalytic reactor.

A simple photocatalytic reactor for water treatment was designed and fabricated. Degussa P25 TiO_2 was used as photocatalyst and was immobilized on flat plates. The effects of catalyst loading, water flow rate, water deep, and the materials of the catalyst support substrate have been studied. The results demonstrated that the reactor configuration is simple but effectiveness for wastewater treatment. The simple reactor configuration could benefit to practice application.

Water and energy crises have forced researchers to seek alternative water and energy sources. Seawater desalination can contribute towards meeting the increasing demand for fresh water using alternative energy sources like low-grade heat. Industrial waste heat, geothermal, solar thermal, could help to ease the energy crisis. Unfortunately, the efficiency of the conventional power cycle becomes uneconomically low with low-grade heat sources, while, at the same time, seawater desalination requires more energy than a conventional water treatment process. However, heat discarded from low-grade heat power cycles could be used as part of desalination energy sources with seawater being used as coolant for the power cycles. Therefore a study of desalination using low-grade heat is of great significance. The research has comprehensively reviewed the current literature and proposes two systems that use low-grade heat for desalination applications or even desalination/power cogeneration. The proposed two cogeneration systems are a supercritical Rankine cycle-type coupled with a reverse osmosis (RO) membrane desalination process, and a power cycle with an ejector coupled with a multi-effect distillation desalination system. The first configuration provides the advantages of making full use of heat sources and is suitable for hybrid systems. The second system has several advantages, such as handling highly concentrated brine without external electricity input as well as the potential of water/power cogeneration when it is not used to treat concentrated brine. Compared to different stand-alone power cycles, the proposed systems could use seawater as coolant to reject low-grade heat from the power cycle to reduce thermal pollution.

Goals and Objectives

The overall goal is to develop efficient photocatalytic reactors for air/water treatment and desalination systems that use of low-grade heat sources. This goal could be divided into several objectives.

- Develop a mechanism-based model for photocatalytic disinfection of bacteria in water using suspended catalyst particles in batch reactors.
- Develop new photocatalysts for increasing the photoactivity especially under visible light conditions.
- Increase the performance of photocatalytic reactors for indoor air applications by increasing the probability of contact between the contaminants and the catalyst.
- Design a simple photocatalytic reactor for water treatment.
- Develop suitable desalination systems that make use of low-grade heat sources.

The photocatalytic disinfection process occurs as a semiconductor photocatalyst, most commonly titanium dioxide (TiO_2), is irradiated with light of wavelength less than 380 nm to produce hydroxyl radicals and other highly reactive oxidants which can inactivate microorganisms. Photocatalytic disinfection involves a complex interaction of many fundamental mechanisms such as light absorption and scattering by semiconductor particles, electrochemical surface reactions, and heterogeneous colloidal stability. Current models, based largely on chemical reacting systems, do not adequately account for these fundamental mechanisms. Even the Langmuir model developed for heterogeneous systems cannot describe the interactions of such large colloidal particles. As a result, it is difficult to assess the combined effects of many important factors which go into the design of a photocatalytic disinfection system.

A mechanistic modeling approach is desirable because it provides a framework to understand the influence of many important parameters on the disinfection process. It requires a description of the physical properties of the catalyst, the nature of the suspending electrolyte solution, the physical and chemical properties of the cell surface, and the energetic aspects that influence the interaction of the particles. All these aspects are interrelated. While it is customary to envision the adsorption of reactants unto a catalyst surface, for photocatalytic disinfection involving suspended catalyst particles, multiple catalyst particles adhere to the bacterial surface.

In this work a mechanistic model has been developed that simulates the effect of light intensity and catalyst concentration on the disinfection process. The simulations show good agreement with the experimental data for stable colloidal suspensions, that is, suspensions in which rapid aggregation of cells and TiO_2 do not occur. Increased disinfection rates and high levels of inactivation can be achieved by maintaining a relatively low catalyst-to-microbe ratio while maximizing the light intensity. The influence of pH and ionic strength on the disinfection process have been included in the model, but these are only expected to be accurately predicted when the solution remains stable.

Water and energy crises have forced researchers to seek alternative water and energy sources. Seawater desalination can contribute towards meeting the increasing demand for fresh water using alternative energy sources like low grade heat. Industrial waste heat, geothermal, solar thermal, etc. could help to ease the energy crisis. Unfortunately, the efficiency of the conventional power cycle becomes uneconomically low with low-grade heat sources, while, at the same time, seawater desalination requires more energy than a conventional water treatment process. However, heat discarded from low-grade heat power cycles could be used as part of desalination energy sources with seawater being used as coolant for the power cycles. Therefore a study of desalination using low grade heat is of great significance.

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Photocatalysis is a promising technique for the remediation of indoor air pollution. Photocatalysis utilizes semiconductor photocatalysts (such as TiO_2 or ZnO) and appropriate light to produce strong oxidizing agents (OH•) that are able to break down organic compounds and inactivate bacteria and viruses. The overall goal of the research is to develop an efficient photocatalytic reactor base on mass transfer for indoor air purification. This study has focused on the enhancement of the effectiveness of the photocatalytic process by the introduction of artificial roughness on the reactor catalyst surface. The major effect of artificial roughness elements on the catalytic surface is to create local wall turbulence and enhance the convective mass transfer of the contaminants to the catalyst surface and thus lead to an increase in the effectiveness of photocatalysis.

Air flow properties in a model photoreactor channel with various roughness patterns on the interior wall surface were theoretically investigated. The optimum shapes, sizes, and arrangements of roughness were determined for the maximum enhancement of turbulence intensity in the channel. The possible order of photocatalytic reactor performance for various roughness patterns was also determined. In order to verify the theoretical analysis results, experimental studies were carried out. A plate type photocatalytic reactor was designed and fabricated on the basis of the theoretical results. It was determined that the photocatalytic reactor performance is greatly improved with various rough catalyst surfaces. The experimental results verified the theoretical results. The relationship between the overall reaction rate constant (k) of the reactor and the magnitude of the turbulence intensity was found out. An empirical correlation expression was also proposed. This is the first study of the effect mass transfer in a rough catalytic surface for photocatalytic reactor.

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Patents

1. Chennan Li, D. Yogi Goswami, and Elias Stefanakos. "Method and systems for water and power cogeneration using organic Rankine Cycle-Ejector-Thermal Desalination for low- and mid-grade temperature sources", U.S. 11A070. (Prepared to file; disclosure issued)

2. Chennan Li, D. Yogi Goswami, and Elias Stefanakos. "Method and systems for water and power cogeneration using supercritical power cycles for low- and midgrade temperature sources", U.S. 11A071. (Disclosure issued)

3. Chennan Li, D. Yogi Goswami, and Elias Stefanakos. "Enhancement of photocatalytic effect with surface roughness in photocatalytic reactors," 2013 (Invention disclosure)

Publications

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12) Li, Chennan, George Kosmadakis, Elias Stefanakos, Yogi Goswami, (2013) "Parabolic Trough Solar Collector Driven Supercritical Cycle for Power-Desalination Cogeneration", *Renewable Energy*, (In Press)

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