Clean Drinking Water using Advanced Solar Energy Technologies


Clean Energy Research Center
University of South Florida
September 30, 2009
Water Demand

Year 2000 Estimated Water Consumption (Million Gallons / Day)

F

0 - 50
50 - 100
100 - 200
200 - 300
300 - 400
400 - 500
500 - 1000
1000 - 1500
1500 - 3000
3000 - 6000

0 70,000 140,000 210,000 280,000 35,000

Florida Energy Systems Consortium

UNIVERSITY OF SOUTH FLORIDA

USF
Waterborne Disease Outbreaks

- Drinking water requires disinfection to remove pathogens (bacteria, viruses and protozoa)
- It is estimated that 1.2 billion episodes of waterborne infections occur worldwide every year
- The US has a reputation for high drinking water standards, but severe outbreaks have occurred (e.g. Milwaukee 1993 Cryptosporidium outbreak)
- The number of food and waterborne disease outbreaks in Florida averages about 300/yr
Water Disinfection

- Chlorine is the most common disinfection method, but forms potentially carcinogenic byproducts (e.g. trihalomethanes)
- Regulations limit the amount of disinfection byproducts in drinking water
- Alternative disinfection methods are available, but many are energy intensive and require expensive chemicals and equipment

Traditional chlorination contact tank for water disinfection
Clean Drinking Water using Advanced Solar Energy Technologies

A. Sustainable Solar Flash Desalination

B. Photocatalytic Water Disinfection
Desalination - Seawater Flashing
A. Solar Flash Desalination

• Develop an economically viable and environmentally friendly desalination system
  1. Lower its energy demand
  2. Use renewable energy

• Modify the most common desalination technique, multi–stage flash:
  1. Create system vacuum passively
  2. Use solar energy.
Single Stage – System Design/Operation

Solar Heater → Evaporator → Condenser → Fresh Water

Brine Water → Make-Up Tank → Condenser → Evaporator

Sea Water → Make-Up Tank → Condenser → Evaporator

Fresh Water → Make-Up Tank → Condenser → Evaporator

S → W → C → P → E → H → X → H → W → B → Brine Water

Solar Heater
Implementing multi-stage scheme:

1. More evaporation → increased fresh water output.

2. More heat recovery → increased thermal efficiency.

3. \#1 + \#2 → decreased PEC
A model was developed to theoretically simulate the proposed desalination system.

The model assumed total steam condensation and quasi steady state operation accounting for the build up of non-condensable gases.

The model used the Rachford–Rice method for the flash calculations and Bernoulli's fluid equation for the hydrostatic balance relations.

The model is composed of: Physical and thermodynamic relationships + Empirical correlations + mass and energy balances + geometrical formulas + physical property correlations + integrative equation of state.
Prototype Assembly
Experimental Analysis

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<td>Number of experiments</td>
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<td>Duration (hour)</td>
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<td>Initial vacuum (psi)</td>
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<td>Average seawater flow (gpm)</td>
<td>0.128</td>
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<td>Fresh water produced (gal)</td>
<td>0.01</td>
<td>0.09</td>
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<td>Average heat input (W)</td>
<td>986</td>
<td>1195</td>
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<td>Solar collection area (m²)</td>
<td>2.76</td>
<td>3.12</td>
<td>3.34</td>
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<td>Energy Consumption (W-hr/1000 gal)</td>
<td>424</td>
<td>40</td>
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- The average prime energy consumption of an MSF desalination process is 0.36 W-hr/1000 gal
- The average cost of water desalted by an MSF desalination process is $3.41 /1000 gal
Solar Desalination - Milestones

- System Set Up – Completed
- Background Review – Completed
- Design Proposal – Completed
- Theoretical Analysis – Completed
- Prototype Assembly – Completed
- Experimental Simulation – Completed
- Model Development – Fall 2009 Anticipated
- Feasibility Study – Spring 2010 Anticipated
- Prototype Development - 2011
B. Photocatalytic Water Disinfection
A Viable Alternative

- Photocatalysis can kill a wide range of pathogens, including chlorine-resistant Cryptosporidium and Giardia.
- It has the potential to use solar energy directly to drive the disinfection reaction.
- It does not require expensive chemicals and the byproducts are generally benign.
Simplified schematic of photocatalytic disinfection

1. Catalyst absorbs light energy
2. OH radicals generated
3. Radicals oxidize pathogens
4. Pathogens die
There are currently no design methodology for design of photocatalytic systems which prevent full-scale development and use. Current attempts are based on traditional chemical disinfection models, which

1. are empirically-based and fundamentally non-representative and;

2. do not allow for system optimization and the incorporation of biological information about pathogens
Research Objectives

- The long-term goal is to optimize photocatalytic disinfection, so that water can be disinfected quickly, safely and inexpensively.

**Specific goals:**

1. Build a mechanistic model which can form the basis for engineering designs of photocatalytic disinfection systems.
2. Set up a solar lab-scale reactor based on the new disinfection model.
3. Test the accuracy of the model to predict reaction rates under different operating conditions.

- The rationale is that modeling the mechanism will allow us to find ways to improve photocatalytic disinfection.
Proposed Mechanistic Model

• Based on the peroxidation of membrane lipids of microorganisms
• Can incorporate biological information about organisms which may confer difference in resistance to disinfection
• Can be used for batch and plug-flow reactors in real engineering design
• First comprehensive mechanistic model to be proposed
Experimental Setup

- **Batch reactor with black (ultraviolet) light**
  - Jacketed-beaker for temperature control
  - Aerated with oxygen or air
  - Accommodates two (2) lamps per reactor
Preliminary Results

- *E. coli* used as common water pathogen (indicator) for experiments
- Initial results show that photocatalysis is capable of inactivating the pathogen
- The kinetics appear similar to previous studies
Preliminary Results

- The production of MDA has been confirmed in preliminary experiments.
- MDA production is evidence of lipid peroxidation.
- Model will focus on linking peroxidation to inactivation.

Irradiation Experiment with TiO$_2$

- Time (min)
- Cell Concentration [CFU/mL]
- MDA Equivalent (µM)

Viability Curve
Proposed Pilot Setup

- Will be designed based on information from batch studies
- Will use borosilicate glass tubes in parallel
- Set up for solar photocatalytic disinfection
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<td>LITERATURE REVIEW</td>
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<td>Review available literature on water disinfection</td>
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<td>Review history of disinfection model development</td>
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<td>Review inactivation pathways of photocatalysis</td>
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<td>Prepare review paper for publication</td>
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<td>MODEL DEVELOPMENT</td>
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<td>Establish the steps in photocatalytic inactivation</td>
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<td>Develop mathematical relationships</td>
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<td>Test model with preliminary data</td>
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<td>BENCH-SCALE (BATCH) EXPERIMENTS</td>
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<td>Set up bench-scale experiments</td>
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<td>Run batch experiments</td>
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<td>PILOT SET UP AND EXPERIMENTS</td>
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<td>Design pilot-scale system</td>
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<td>Build solar pilot-scale reactor</td>
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<td>Perform preliminary tests and modify</td>
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<td>Run flow-through experiments</td>
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<td>Analyze data</td>
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<td>Compare models</td>
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THANK YOU