Solar-Powered Water Pasteurizer
Engineers for a Sustainable World

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Outline

- Brief Project Overview
- Design Verification
- Final Design
- Project Status
Project History

- USDA Higher Education Challenge
- 3-yr Collaboration with Montana State University (11 year history in Mali)
- HED (Higher Education in Development)
  - 7 Malian Scholars in US
  - Establish entrepreneurial center
- Ex-peace corps volunteer established an NGO Shea Yeleen
Our Customer:
- An average village family in Mali

Our Main Objective:
- To provide safe drinking water to our customer by harnessing the sun’s heat and radiation to destroy harmful bacteria and viruses within the water.
# Customer Requirements

<table>
<thead>
<tr>
<th>Customer Requirements</th>
<th>Engineering Specifications</th>
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<tr>
<td>Clean water for average family</td>
<td>15-50 L/day, no pathogens</td>
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<tr>
<td>Use renewable power</td>
<td>Solar heat. Heat flux $\approx 650 \text{ W/m}^2$ for 4 hours of non-cloudy sunlight</td>
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<td>Non-toxic</td>
<td>No chemicals</td>
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<td>Affordable</td>
<td>$100</td>
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<td>Manufacturable in Mali</td>
<td>Entrepreneurial Program</td>
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<td>Small and <strong>stationary</strong></td>
<td>5ft x 10 ft.</td>
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<td>User friendly and minimal user intervention</td>
<td>Tamper-proof control valve (opens at 73.5°C)</td>
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<td>System must function in a dusty environment</td>
<td>Dry season</td>
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<td>Reliable and robust</td>
<td>Must last 5 yrs.</td>
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<td>Culturally acceptable</td>
<td><strong>Design/materials acceptable</strong></td>
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Concepts/Solutions Considered

- **General systems considered**
  - Filtration
  - Chemicals
  - Water Density
  - Boiling
  - UV
  - Solar heat

- **Solar heat systems considered**
  - Batch
  - Flow through

- **Solar heat system chosen**
  - Meets all customer requirements
  - Safest and most reliable
  - Cost Effective
  - Less Maintenance
Design Concept Choice

- Gravity Driven, Solar Powered Water Pasteurizer
Design Concept Tested

- Prototype tested in Mali
  - Amount of water pasteurized: 16.5 L in 3.25 hours
  - Exit water ranged from 70-87 °C
- Water for tea?
Onsite Data Collection

- Measured heat flux
- Measured temperature
- Obtained user suggestions
- Introduced idea of using solar energy to heat water
Onsite water testing

Local health providers were most interested
Design Iteration

- **Design Improvements**
  - **Solar Collector Box**
    - Smaller solar box, same tubing length
    - Different absorber plate material
  - **Heat Exchanger**
    - Increase volume production
  - **Valve Casing**
    - Rugged design to prevent leaking
    - High temperatures
    - Safe in a system for potable water
Final Design Verification

- Analytical Models
- Testing
  - Solar Box
  - Heat Exchanger
  - Control Valve
Final Design Verification

Analytical Models – Solar Box

\[ \frac{dE}{dt} = \dot{Q}_{net} - \dot{W}_{net} + \dot{m}_{in}(KE + PE + h)_{in} - \dot{m}_{out}(KE + PE + h)_{out} \]

\[ Q_{net} = Q_{useful} = \dot{m}\Delta h = \dot{m}C_p \Delta T = \dot{m}C_p (T_{fo} - T_{fi}) \quad (1) \]

\[ Q_{useful} = Q_G - Q_L = A_c[S - U_L (T_{fi} - T_a)] \quad (2) \]

\[ \dot{m}C_p (T_{fo} - T_{fi}) = A_c F_r [S - U_L (T_{fi} - T_a)] \]

Sources:
“Solar Engineering of Thermal Processes”, Duffie, Beckman.
Analytical Models – Optimizing Absorber Plate

Final Design Verification

- Final Water Temperature - Absorber Plate Variation

**Analysis calculations based on experimental time dependant heat flux and temperature measurements collected in Mali**
Final Design Verification

- Analytical Models – Minimizing Glass

**Analysis calculations based on experimental time dependant heat flux and temperature measurements collected in Mali**
Final Design Verification

- Experimental – Solar Box

3’ x 5’

3’ x 4’

WOOD

Painted Black

STEEL
Final Design Verification

- Experimental - Solar Box Size and Material Comparison
- Temperature of Exiting Water

**Values based on an experimental lab test with constant heat flux**
Final Design Verification

- Heat Exchanger - Tube-in-Tube
  - ¼” Copper tubing inside ½” PVC tubing

![Diagram of a heat exchanger with copper tubing inside PVC tubing.]
Final Design Verification

- Testing – Thermostatic Control Valve
  - Successful Results in Mali
  - Water flowed through the valve at 73.5 °C
    - Constant flow of water
Final Design Verification

- Valve Casing Design:
  - Tig Welded
  - Rugged Design
  - Few Parts
  - Easy Assembly
Final Design Verification

- ENTIRE SYSTEM Outdoor Test in MN!
- Time: 3 hours
- Produced 26.5 L of pasteurized water
- Flow Rate: 8.8 L/hr.
- 60% increase with heat exchanger, steel absorber plate, & smaller box size
Final Design

- **Solar Box**
  - 3’ x 4’ box
  - Steel absorber plate
  - Glass
  - Black Silicone Rubber Tubing
- **Heat Exchanger**
  - 5’ Countercurrent concentric
- **Valve and Casing**
  - Thermostatic valve
  - Welded casing
- **Structural Design**
  - Brick Structure
  - Plastic In & Out tanks
  - Thatch insulation
Project Status

- Solar Pasteurizer at the school in Dio
- Used to educate about solar energy
- Hope it will inspire young generation
- Design handed off to entrepreneurial group
Questions??
References

• “Introduction to Thermal Systems Engineering”, Moran, Shapiro, Munson, Dewitt

• “Solar Energy: Fundamentals, Design Modeling and Applications”, G.N. Tiwari

• “Solar Engineering of Thermal Processes”, Duffie, Beckman.