The Microbiology of Solar Water Pasteurization, with Applications in East Africa

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California State University, Sacramento
For children in developing countries, each year contaminated water causes:
2 million deaths
1.5 billion episodes of diarrhea
How can contaminated water be made safe to drink?
Milk Pasteurization

71.7°C (161°F)
15 Seconds
Pasteurization of whole eggs

60°C (140°F)

3.5 min
D - Value
(Decimal Reduction Time)

Time to cause 90% kill at a given temperature
Temperatures which kill pathogens in contaminated water

<table>
<thead>
<tr>
<th>Microbe</th>
<th>D value &lt; 1 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Giardia, Cryptosporidium</td>
<td>55°C</td>
</tr>
<tr>
<td>E. coli, cholera, typhoid, Shigella bacteria, rotavirus</td>
<td>60°C</td>
</tr>
<tr>
<td>Hepatitis A virus</td>
<td>65°C</td>
</tr>
</tbody>
</table>
D value, *E. coli* in water

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>60°C</td>
<td>40 seconds</td>
</tr>
<tr>
<td>62°C</td>
<td>25 seconds</td>
</tr>
<tr>
<td>65°C</td>
<td>10 seconds</td>
</tr>
</tbody>
</table>
Solar Water Pasteurization

Heating water to 65°C (149°F) in a solar cooker will pasteurize the water and kill disease causing microbes.
Pasteurization of Naturally Contaminated Water with Solar Energy

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Received 25 July 1983/Accepted 7 November 1983

A solar box cooker (SBC) was constructed with a cooking area deep enough to hold several 3.7-liter jugs of water, and this was used to investigate the potential of using solar energy to pasteurize naturally contaminated water. When river water was heated either in the SBC or on a hot plate, coliform bacteria were inactivated at temperatures of 60°C or greater. Heating water in an SBC to at least 65°C ensures that the water will be above the milk pasteurization temperature of 62.8°C for at least an hour, which appears sufficient to pasteurize contaminated water. On clear or partly cloudy days, with the SBC facing magnetic south in Sacramento, bottom water temperatures of at least 65°C could be obtained in 11.1 liters of water during the 6 weeks on either side of the summer solstice, in 7.4 liters of water from mid-March through mid-September, and in 3.7 liters of water an additional 2 to 3 weeks at the beginning and end of the solar season. Periodic repositioning of the SBC towards the sun, adjusting the back reflective lid, and preheating water in a simple reflective device increased final water temperatures. Simultaneous cooking and heating water to pasteurizing temperatures was possible. Additional uses of the SBC to pasteurize soil and to decontaminate hospital materials before disposal in remote areas are suggested.

Several attempts have been made to use the energy of the sun and solar cookers to cook and bake food. The two most common solar cooker designs are the slant-faced cooker with side reflectors and the antenna dish concentrator. These solar cookers have proven to be impractical for regular cooking and baking because their poor designs allow only one pot to be heated at a time; they have little or no provision for cooking several items simultaneously. We found that several liters of river water in 4-liter cooking pots could be heated to 80°C or greater in 2 h in an SBC, killing coliform and fecal coliform bacteria (M. Logvin, Master's thesis, California State University, Sacramento, 1980). We wanted to expand on this particular use of an SBC, and to we built an SBC which was deep enough to hold three to five 3.7-liter (1-gallon) jugs. We then investigated what temperature and length of time were needed to pasteurize river water.
How can one verify that water has been heated to 65°C?
Water Pasteurization Indicator (WAPI)
Temperatures which kill disease microbes present in contaminated water

<table>
<thead>
<tr>
<th>MICROBE</th>
<th>KILLED RAPIDLY AT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Worms, <em>Giardia</em>, <em>Entamoeba</em>, <em>Cryptosporidium</em></td>
<td>131°F (55°C)</td>
</tr>
<tr>
<td><em>Escherichia coli</em>, <em>Shigella</em>, cholera, Typhoid, Rotaviruses, Polioviruses</td>
<td>140°F (60°C)</td>
</tr>
<tr>
<td>Hepatitis A virus</td>
<td>149°F (65°C)</td>
</tr>
<tr>
<td>WAPI wax melts</td>
<td>149°F (65°C)</td>
</tr>
</tbody>
</table>
Enhancement of Solar Water Pasteurization with Reflectors

NEGAR SAFAPOUR† AND ROBERT H. METCALF*

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Received 13 July 1998/Accepted 3 November 1998

A simple and reliable method that could be used in developing countries to pasteurize milk and water with solar energy is described. A cardboard reflector directs sunshine onto a black jar, heating water to pasteurizing temperatures in several hours. A reusable water pasteurization indicator verifies that pasteurization temperatures have been reached.

Exposing water in clear plastic or glass jars to sunshine has been shown to inactivate bacteria. However, much variability—from no inactivation to an approximately 3-log decrease in 1.5 h—has been reported (1, 2, 10–12, 14, 15, 17, 18, 20). Reasons for this variability include the transparency of the container, water turbidity, water temperature reached, altitude, aerobic or anaerobic conditions, and the amount of solar radiation received (2, 10–12, 15, 17). In addition, only a few studies have included viruses or protozoan cysts, which might not be as sensitive to sunshine as bacteria.

A major limitation of exposing clear containers of water to sunshine is that there is no simple test to perform which would indicate that pasteurization has been achieved. A water temperature indicator is suitable for use with water that is free of turbidity or color, but it cannot verify that pasteurization temperatures have been reached. A visual indicator of the amount of sunlight reaching the water, however, is quite simple and reliable. When the indicator tube, it indicates that pasteurization conditions have been reached.

The bacteriophage T2 was included in these studies. Although T2 is not a human pathogen, its inclusion tests the validity of extrapolating to nonbacterial microbes Escherichia coli's response.

Cultures and test conditions. E. coli ATCC 11775 (American Type Culture Collection, Rockville, Md.) was maintained in brain heart infusion broth (BHI; Acumedia, Baltimore, Md.). A stock of T2 phage with $4 \times 10^9$ PFU/ml was obtained by seeding 100 ml of BHI broth with E. coli B and a drop of T2 and incubating at 35°C for 12 h when complete lysis was observed.
Point Source Water Testing in Developing Countries
The most specific of the readily detectable fecal indicators, and the one present in greatest numbers in feces, is *Escherichia coli*, and it is therefore recommended as the indicator of choice for drinking water.
Colilert®
An easy 24-hour test for coliforms and E. coli

Colilert has become the number one method in countries around the world because:

- Colilert takes less than one minute hands-on time per sample.
- Colilert is approved internationally for compliance testing.
- Colilert has been shown to be 20–50% less expensive than traditional methods.
Petrifilm™ E. coli/Coliform Count Plates

Easiest and fastest confirmed E. coli test available.
SOO Inlet Rikwa River
Near Safari Park Hotel
6 July 2005

Upstream Sample
Taken 1 July (5 days ea 1/4)

3M EC 2006-10 KF 3M EC 2006-10
# Risk Assessment of Water Sources

<table>
<thead>
<tr>
<th>Risk Level</th>
<th>E. coli/sample</th>
<th>Colilert MUG</th>
<th>#Blue/Petrifilm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>&lt; 1/10 ml</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Moderate</td>
<td>1-9/10 ml</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>High</td>
<td>1-10/ml</td>
<td>+</td>
<td>1-10</td>
</tr>
<tr>
<td>Very High</td>
<td>&gt; 10/ml</td>
<td>+</td>
<td>&gt; 10</td>
</tr>
</tbody>
</table>
The Solar Water Disinfection (SODIS) process is a simple technology used to improve the microbiological quality of drinking water. SODIS uses solar radiation to destroy pathogenic microorganisms which cause water borne diseases.

SODIS is ideal to treat small quantities of water. Contaminated water is filled into transparent plastic bottles and exposed to full sunlight for six hours.

Sunlight is treating the contaminated water through two synergetic mechanisms: Radiation in the spectrum of UV-A (wavelength 320-400nm) and increased water temperature. If the water temperatures raises above 50°C, the disinfection process is three times faster.
WATER SOURCES FROM Kitito WORKSHOP
PARTICIPANTS 21 July, 2003
WATER SOURCES FROM KITITO WORKSHOP
PARTICIPANTS 21 JULY, 2003
12 July - from yellow plant in Awacha River
MINISTRY OF WATER AND IRRIGATION
PROVINCIAL HEADQUARTERS
NYANZA PROVINCE
Thermotolerant Coliform Test, Kenya

3 tube MPN, 10, 1, 0.1 ml

1. MacConkey’s broth, 37°C, 1-2 days
2. Gas + to BGLB broth, 44°C, 1-2 days

Gas + = Thermotolerant coliforms
WATER RESOURCES MANAGEMENT AUTHORITY
TANA CATCHMENT REGIONAL OFFICE
P. O. BOX 1930 EMBU TEL. 068-31271
FAX 068-31315  E-MAIL: wrmatana @ winnet.co.ke
WATER RESOURCES MANAGEMENT AUTHORITY

CERTIFICATE OF ATTENDANCE

This is to certify that

Bancy J. Chege

Attended the Training Workshop on Water Testing, Solar Water Pasteurization and Solar Cooking


Topics Covered:

- E. coli: An Indicator of Faecal Contamination of Water
- Principles of Defined Substrate Technology (DST)
- Bacterial Multiplication & Culturing
- Water Testing at community level: Demystifying μ-Biology
- Solar Water Pasteurization
- Use of Water Pasteurization Indicator (WAPI)
- Solar Cooking: A “Vaccine” against Deforestation

Prof. Robert Metcalf
California State University Sacramento

P. Olo
CEO WRMA
Fuelwood = 79% of Kenya’s Total Energy

Energy Usage Per Day
Wood = 81 million lbs
Charcoal = 13 million lbs
TEDI GI CHIENG!
SOLAR COOK!
• RIT NGIMANI
• TET MALER
• CHUAK PI MODHO
• GENG’ TUOCHE
• KUNG PESA

COOKER’S SHOP
HARAMBEE MARKET

OBJECT OF SOLAR COOKERS INTERNATIONAL AND NYAKACH COMMUNITY
7/16/01 Sunday
4L Milk - Start 4/20 1:55 pm
28°C

> 200 E. coli

0 E. coli + Coliforms

7/16/01 Sunday
4 h later - 2 h - 65.7°C