THE MICROBIOLOGY OF SOLAR WATER PASTEURIZATION, WITH APPLICATIONS IN EAST AFRICA

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ABSTRACT

In addition to cooking food, solar cookers can also be used to pasteurize contaminated water, by heating the water to 65°C. To verify that water has been heated to 65°C, a reusable, wax-based water pasteurization indicator (WAPI) is added to the water. When the WAPI wax melts, pasteurization has been accomplished. As part of the Sunny Solutions project in Nyakach, Kenya, women are using the Cookit solar cooker to both cook food and to pasteurize their contaminated water. They report a significant decrease in diarrheal diseases as a result. The Nyakach solar cooks and village leaders have been taught how to use innovative water testing methods, Colilert tubes and Petrifilms to test their water before, and after solar pasteurization. The package of water testing materials, Cookit and WAPI combine to address two main problems in developing countries: lack of wood for cooking and unsafe water for drinking.

Keywords: solar, water, pasteurization, Colilert, Petrifilm

1. INTRODUCTION

Because of the small size of bacteria and the unique procedures used to grow them, the major role of bacteria as the cause of infectious disease was not demonstrated until the 1870s, when the German physician, Robert Koch, developed methods to isolate bacteria, and procedures to demonstrate that a specific microbe caused a specific disease. He first showed that the disease of anthrax is caused by a specific bacterium, (1876) and soon thereafter demonstrated that tuberculosis (1882) and cholera (1883) were also caused by bacteria. Using Koch's methods, by 1900, scientists had demonstrated that other water-borne diseases, such as typhoid fever and dysentery, were also caused by bacteria. The understanding that microbes present in human feces could cause major diseases led to the establishment of separate water and sewage systems in many cities by the early 1900s, and greatly reduced the incidence of water-borne diseases in these cities.

Although the incidence of water-borne disease is now negligible in developed countries, it is still a major cause of disease in developing countries (Fig. 1). Estimates from UNICEF are that worldwide, 1.1 billion people do not have access to safe water. This annually leads to approximately 2 million deaths and 1.5 billion incidents of diarrhea, particularly affecting children under five years of age. The majority of the 1.1 billion people who do not have access to safe water are among the 2.4 billion people who use wood or wood products for cooking in a non-sustainable manner. The Millennium Development Goals (MDGs) include reducing by half the number of people without sustainable access to safe drinking water and basic sanitation by 2015. Even if these ambitious goals are achieved, there still will be about 600 million people without access to safe water in 2015. Is there a practical approach to contaminated water which could be available even to the poorest of the poor?

It is well known to conference participants that a great variety of solar cookers are capable of cooking food. The information provided in this paper will enable participants to understand the science behind solar water pasteurization, and to become familiar with the materials and methods that have contributed to successful solar pasteurization projects in Kenya.

2. BACKGROUND

2.1 Pasteurization conditions for water

Most people are aware that contaminated water can be made safe to drink by boiling. Boiling will kill all disease-causing microbes in water, but this amount of heat is far in excess of what is required to kill the disease germs. What has been absent in discussions about unsafe water is the process of pasteurization, which has been an accepted method in the food industry for over a century. Pasteurization is the use of moderate heat to kill disease microbes. It is different from sterilization, in which all microbes are killed. To pasteurize milk in a continuous flow process, only 15 seconds at 71°C is required. This modest heat treatment would also pasteurize water.

What times and temperatures are needed to kill disease-causing microbes in water? From experiments I have conducted, as well as from many published studies, the following generalizations can be made. The temperatures which will kill at least 90% of microbes within one minute are: 55°C (131°F) for worms, and cysts of the protozoa *Giardia, Cryptosporidium, and Entamoeba;* 60°C (140°F) for the bacteria *Vibrio cholerae, Samonella typhi, Shigella sp*, and *Enterotoxigenic Escherichia coli*, and for rotavirus, a major cause of infant diarrhea; 65°C (149°F) for Hepatitis A virus. As the temperature increases above 55°C for protozoa, or above 60°C for bacteria and rotavirus, the time required for 90% inactivation decreases significantly. For example, 90% inactivation of these bacteria at 65°C requires only about 12 seconds, and 99.999% kill would result from one minute at 65°C.

From published data and our own experiments, we established that heating contaminated water to 65°C will pasteurize the water and make it safe to drink (1). As batch heating of water will have the water temperatures from 60-65°C for several minutes, the cumulative heat effect will reduce the level of live pathogens to zero, similar to what is accomplished in milk pasteurization.

2.2 Water Pasteurization Indicator

In order to verify that water temperatures reach 65°C, volunteers for Solar Cookers International, Sacramento, California, developed a reusable water pasteurization indicator, (WAPI, Fig. 2). The WAPI is a clear polycarbonate tube, partially filled with a wax, and sealed at both ends. The WAPI wax melts at 65°C. The WAPI is placed at the bottom of a container, which is heated by sunshine. If the WAPI wax melts and falls to the bottom of the tube, it verifies that pasteurization conditions have been achieved (2).

2.3 Solar Water Pasteurization

The AquaPak (Solar Solutions, San Diego, California) and Sol Saver (Safe Water Systems, Honolulu, Hawaii) are two products specifically designed to convert sunshine to heat and pasteurize water, using a WAPI. I have focused on using the Cookit solar cooker, made from cardboard and aluminum foil, developed by Solar Cookers International. To pasteurize water in a Cookit, a dark, covered metal or glass container containing water and a WAPI is placed in the Cookit, and the Cookit is faced towards the sun (Fig. 3). With full sunshine, it takes about 2 hours to pasteurize 2 liters of water, about 3 hours to pasteurize 4 liters (Fig. 4).

2.4 Solar Water Disinfection (SODIS)

The procedure now best known as SODIS (Solar Water Disinfection) was first reported in 1980 by Aftim Acra et al. At the American University of Beirut in Lebanon. UNICEF published a booklet describing this method in 1984, and it is now promoted extensively by The Swiss Federal Institute for Environmental Science and Technology (EAWAG, www.sodis.ch). The treatment basically consists in filling transparent bottles with water and exposing them to full sunlight for at least six hours (Fig. 5).

2.5 Point Source Water Testing

The best indicator of human or animal fecal contamination of water is the bacterium *Escherichia coli*, which is always present in human feces, at a level of about one hundred million *E. coli* per gram. The presence of *E. coli* in water indicates recent fecal pollution and a public health threat. Water containing one *E. coli* per milliliter is considered heavily contaminated.

In order to do world-class microbiology in developing countries where there is no lab, since 2000 I have used two complementary tests extensively in Tanzania and Kenya. The first test is a presence/absence test using Colilert, the most widely used test in the water industry (IDEXX Laboratories, Westbrook, Maine). I use the Colilert MPN tube, which is inoculated with 10 ml of water, and incubated at body temperature for 10-24 hours. If the tube turns yellow, and fluoresces blue when a battery-operated, hand-held long-wave ultraviolet light shines on the tube, it indicates the presence of *E. coli* in the water sample. If the tube remains clear, or is yellow but does not fluoresce blue under UV light, it indicates that there were no *E. coli* cells in the 10 ml sample, and there is a low risk of disease from the water.

The second test is a quantitative test using the *E. coli* count Petrifilm (3M Microbiology Products, St. Paul, Minnesota), which is used extensively in the food industry. One milliliter of the water sample is added to the Petrifilm, which is incubated at body temperature for 10-24 hours. If *E. coli* is present in the water sample, it will develop into a blue colony surrounded by gas bubbles. By counting the number of blue colonies with gas, the number of *E. coli* in a milliter can be determined. One *E. coli* colony on a petrifilm indicates heavily contaminated water and a high risk of disease, 10 or more *E. coli* on a Petrifilm indicates grossly contaminated water and a very high risk of disease.

When the Colilert and Petrifilm tests are combined with sterile plastic pipettes, sterile plastic sampling bags, and a portable UV light, it becomes a portable kit that enables excellent microbiology to be conducted even in remote places, with clear results present in 12-24 hours (Fig 12).

3. <u>THIS PROJECT</u>

3.1 <u>Comparison of Cookit heating of water with SODIS</u>

In 2002, Christine Polinelli, from the Australian Department of Health, joined me in Meatu District, Shinyanga Region, Tanzania, to conduct tests comparing the Cookit heating method with the SODIS procedure to inactivate *E. coli* in the naturally contaminated water delivered to our guest house (between 10-100 *E. coli* per milliliter). *E. coli* counts in water were followed using the Colilert and Petrifilms.

Water heated in a 2 liter black metal container in a Cookit was free of *E. coli* within 2 hours, when water temperatures reached 60°C. Water from the same source was given the SODIS treatment in 1.5 liter blue-tinted plastic bottles available in Tanzania. Although we obtained over 90% inactivation of *E. coli* in 5-6 hours, live *E. coli* cells were still present in some tests in 1 and 10 ml samples (Fig6).

3.2 <u>Combining Solar Water Pasteurization with Solar Cooking in the Sunny Solutions Project, Nyakach, Kenya</u>

Solar water pasteurization with a Cookit and WAPI is being included in the Sunny Solutions project, which Solar Cookers International started in 2003 in the Nyakach region, Nyanza Province, western Kenya, near Lake Victoria. In this area there is a high incidence of typhoid fever, bacterial and amoebic dysentery. In July, 2003 and July, 2005, Christine Polinelli and I led water testing/solar water pasteurization workshops for community leaders and women chosen to be solar cooker representatives (SCOREPS) in the Sunny Solutions project. The participants performed the Colilert and Petrifilm tests on their local water supplies (Fig.7). The results on the next day showed that their shallow wells and streams were heavily contaminated with *E. coli*, representing a very high risk of disease (Fig. 8). We also demonstrated how to pasteurize contaminated water using a Cookit. The Colilert and Petrifilm tests of the raw water, and the solar heated water, provided powerful visual evidence that the water was initially heavily contaminated, but free of bacteria after heating. When Christine and I visited the homes of 16 SCOREPS in July, 2004, we found that each woman was heating water in a Cookit when she was not cooking, and was pasteurizing 5-10 liters/day (Fig 9). The women reported significant decreases in diarrheal diseases since solar pasteurizing water. A survey in mid 2005 of 47 households in a cluster of villages in Nyakach with high use of the Cookit for cooking found that solar pasteurization was quickly adopted and it reduced diarrhea among small children. Used alone, boiling and solar were about twice as effective as chlorine, and when used together they were four times as effective. In the survey, solar pasteurization in the previous two weeks was mentioned 92% of the time.

3.3 <u>Water Testing With Government Agencies in Kenya</u>

In the summers of 2004 and 2005, Christine Polinelli held water testing/solar water pasteurization workshops for the Kenya Ministry of Water Resources Laboratories in Nairobi, Kisumu, Machakos, Mombasa, Nakuru, and Embu. The standard procedure for water testing these labs followed was a two-step, most-probable number test for thermotolerant coliform bacteria. This cumbersome and less accurate procedure required an autoclave and incubators, and could not be taken to the field.

Water sources tested by the labs included shallow wells, boreholes, rivers, ponds, and city tap water. The Colilert and Petrifilm tests were simpler to inoculate, and provided clear results within one day (Fig. 10). With shallow wells samples, which often had >10 *E. coli*/ml, Petrifilms provided specific quantitation and a permanent record. The Water Ministry staffs were amazed that quality microbiology could be made so easy with these methods, and they would like to obtain sufficient testing materials to bring serious water testing to all of Kenya's 72 districts, which the thermotolerant coliform test cannot do.

4. <u>CONCLUSION</u>

It is vital that the poorest people in the world learn how to use the only energy source they often have in abundance, sunshine, for cooking, and for solar water pasteurization. Solar water pasteurization, using the innovative water testing materials and a WAPI, could accompany solar cooking projects. This would demonstrate that two fundamental problems in developing countries, lack of wood for cooking and unsafe water, can both be addressed by low-cost solar applications.

Fig. 1 Collecting water for microbiology testing from village drinking water source, Meatu District, Tanzania.

Fig. 2 Water Pasteurization Indicator. When water heats to 65°C, the wax melts and falls to the bottom of the WAPI, indicating the water has been pasteurized.

Fig. 3 Pasteurizing contaminated water in a Cookit, Meatu District, Tanzania.

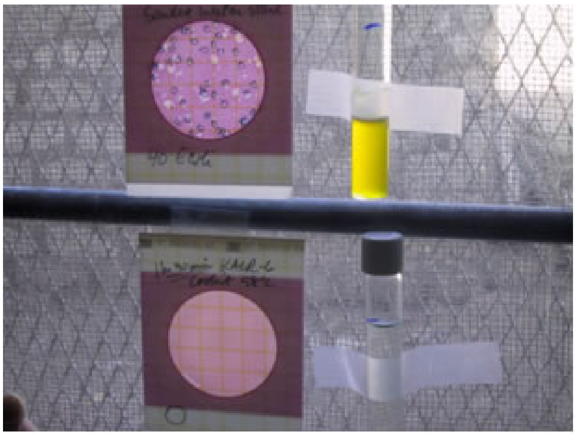

Fig. 4 Petrifilm (left) and Colilert MPN tube (right) tests of Meatu water before and after heating in Cookit. E. coli.= Blue colonies with gas on Petrifilm. Fluorescence of Colilert tube indicates the presence of E. coli.

Fig. 5 Comparing Cookit heating with SODIS with local water in Meatu District, Tanzania.

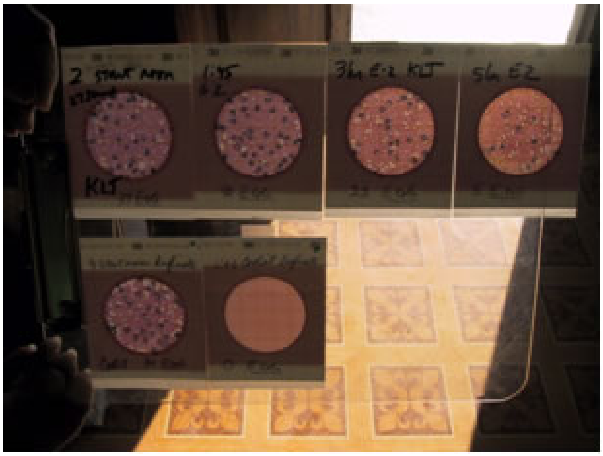

Fig. 6 Results of SODIS vs Cookit. E. coli killed in 2 hr with Cookit heating. E. coli survives 5 hr of SODIS exposure.

Fig. 7 Collecting water from a shallow well, Nyakach, Kenya, for water testing.

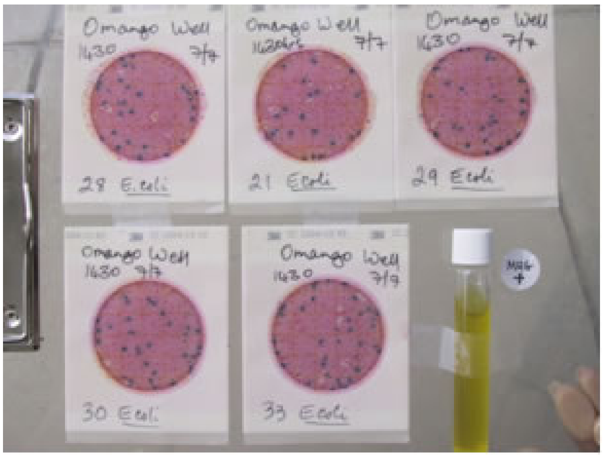

Fig. 8 Results of water from shallow well in Nyakach, heavily contaminated with E. coli, and a danger to health.

Fig. 9 Using Cookits for cooking (left) and pasteurizing contaminated water (right) in Sunny Solutions project, Nyakach, Kenya.

Fig. 10 Robert Metcalf with Nyanza Province, Ministry of Water Staff, Kisumu, Kenya, displaying results of 13 water samples using Colilert & Petrifilms.

Fig. 11 Items used in portable microbiology lab. Petrifilm and spreader, WhirlPak, sterile pipette, Colilert, portable UV light.

REFERENCES

(1) Ciochetti, D. A., and R. H. Metcalf. 1984. Pasteurization of naturally contaminated water with solar energy. Applied & Environmental Microbiology, 47:223-228

2) Safapour, N. and R. H. Metcalf. 1999. Enhancement of Solar Water Pasteurization with Reflectors. Applied & Environmental Microbiology, 65: 859-861

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