Using Solar Energy to Treat Microbiologically Contaminated Water: A Multidisciplinary Approach to Public Health and Aboriginal Science Education

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INTRODUCTION

On a global scale microbiologically contaminated water is a primary cause of morbidity and mortality. The use of simple, but effective technologies to harness solar energy for disinfection has gained increasing attention in recent years. Since it encompasses a wide range of science and public health topics, solar disinfection provides an excellent opportunity for problem centered learning in the university and college environment. Problem centered learning is a valuable pedagogical approach: students are engaged by relevant, contemporary problems and are challenged to develop effective problem solving skills using an integrated, multidisciplinary per-spective.

In 2002, a series of laboratories was developed to allow students the opportunity to explore problems associated with waterborne disease and the role simple solar technologies could play in their solution. This initiative was a joint teaching collaboration between two programs offered at the University College of Cape Breton (UCCB) in Sydney, Nova Scotia. The Public Health Program[1] is one of only five in Canada, and the only one in Atlantic Canada, that offers students a Bachelor's Degree in Public Health and the opportunity to become certified by the Canadian Institute of Public Health Inspectors. The Integrative Science Program[2] is a new educational initiative in Aboriginal science education and the first of its kind in Canada. The Integrative Science Program explores the interface of science and traditional knowledge, especially Aboriginal knowledge. Science topics are examined from a multi and transdisciplinary perspective and many of the students in the integrative science program come from the Mi'kmaq First Nation of eastern Canada.

Waterborne Disease: A Global and Local Problem

Throughout recorded history water has been an important cause and focus for prevention of some of the most dangerous human diseases. The application of basic hygienic principles to water is very well understood, yet for a great number of the world's population, water brings disease, and for far too many people, especially children, death. The majority of water related disease and death is due to diarrhea caused by a variety of microbial pathogens, including bacteria, parasites and viruses.[3] In 2000, the World Health Organization (WHO) estimated that 1.1 billion people lack access to improved or microbiologically safe sources of water for drinking and other essential purposes. This estimate is considered low because protected or improved sources such as boreholes and treated urban water supplies can still become

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fecally contaminated and therefore deliver unsafe water.[4] According to a 1998 estimate, unsafe drinking water leads to 4 billion cases of diarrhea worldwide and 2.2 million diarrhea-related deaths per year, mainly among children under five years old.[3]

Water related disease is not limited to less developed countries. In the United States, the Centers for Disease Control and Prevention (CDC) estimates there are up to 900,000 cases of illness and possibly 900 deaths annually that occur as a result of waterborne microbial illnesses[5]. Based on these estimates Environment Canada's National Water Research Institute (NWRI) projects about 90,000 cases of illness and 90 deaths occur annually in Canada due to acute waterborne infections. Between 1974 and 1996 there were over 200 reported outbreaks, with over 8000 confirmed cases, of drinking water related disease, in Canada.[6]

According to the NWRI waterborne pathogens are likely to be a growing problem in Canada and around the world. Increasing human population densities coupled with intensive livestock and poultry production creates important challenges.[6] The American Society for Microbiology (ASM) suggests that waterborne micro-organisms pose increasingly greater threats to public health. The ASM notes an "alarming lack of focus on microorganisms" in the U.S. Environmental Protection Agency's (EPA) watershed initiatives, which are more strongly focused on chemical contaminants. Current evidence suggests that when compared to chemicals, microbial pollutants pose greater risks to communities.[5]

In its scientific assessment report, *Threats To Sources Of Drinking Water and Aquatic Ecosystem Health in Canada*, the NWRI claim there is only limited surveillance data and knowledge of waterborne pathogens in Canada. They make the point that new knowledge is needed about the ecology of pathogens in aquatic ecosystems and infectious diseases should be studied from a broader ecosystem perspective.[6]

Simple Solutions

The ASM sees water quality and quality of life as intimately intertwined and believe many serious health problems could be eliminated if more countries adopted simple water quality practices such as source water protection and disinfection.[5] When one investigates the cause and control of infectious waterborne diseases, complexity often outweighs simplicity in preventative strategies, often to the detriment of those in developing nations without the social and technical infrastructure to support complex technology. According to the WHO there are now simple, acceptable, inexpensive interventions at the household and community level that can dramatically improve the microbial quality of household water and subsequently reduce the risks of diarrheal disease and death.[4]

Simple, inexpensive solar water treatment systems have focused on the combined effect of heat and ultraviolet A radiation (UV-A) or the use of heat alone. UV-A and heat have a synergistic effect that has been developed into a number of water treatment systems. The Swiss Federal Institute for Environmental Science and Technology, for example, developed the Solar Water Disinfection Process (SODIS). SODIS is a simple eight step method using plastic or glass bottles that has been extensively laboratory and field tested since 1991. It is meant for use at the household level.[7] Other groups have developed slightly more complex and expensive combined UV-heat treatment systems. For example, the design and field-testing of a PVC-acrylic unit capable of processing up to 8 liters per day were published in 2004.[8] American's Barbara Kerr and Sherry Cole developed the first practical solar cooking device in 1976, which was soon applied to the problem of water pasteurization by M. Logvin in a M.A. thesis in 1980.[9] Solar water pasteurization uses the heat of the sun to raise the temperature of water to a point where microbial pathogens are destroyed. Since most solar heating devices cannot actually boil water this conflicts with conventional require-ments for water pasteurization unequivocally stating the need to boil water for five to ten minutes to ensure effective disinfection.

The central question, then, surrounding the use of simple solar technologies for water pasteurization is that of the temperature necessary to effectively destroy common pathogens. "Most of the people I've talked to about solar water pasteurization over the past 20 years are astonished to learn that water does not have to be boiled to make it safe microbiologically," says California State University professor Robert Metcalf in his paper *The Science of Safe Water*.[10] Given the significant energy requirement for a five to ten minute boil, this method of disinfecting water is problematical for many citizens of developing nations. Clearly a science based understanding of the temperature-time relationships required for pasteurization are necessary to provide a foundation for the development of effective pasteurization technologies. A recent SODIS Conference report noted that teachers, health workers and medical personnel have long taught that water must be boiled to make it safe. While it is now known that with the SODIS system exposure to UV-A from the sun at a temperature of at least 50 degrees C for at least 5 hours is all that is required, "this message is difficult to understand not only by the target population, but also by the community responsible for public health."[11]

Solar Water Pasteurization in the University Laboratory

Waterborne disease and solar water pasteurization provide an excellent opportunity for problem based learning at senior levels of university education. Students are engaged by relevant, contemporary problems and have the opportunity to apply knowledge acquired from a diversity of previous courses. The Canadian National Water Research Institute's concept of a "broader ecosystem perspective" to understanding disease is fundamental to one of the Integrative Science Program's core courses focused on health and healing, and is also relevant to many issues in public and environmental health today.

In the laboratories developed at the University College of Cape Breton students are introduced to the global problem of waterborne disease and the relationship between microbiological contamination and human health. Specific pathogens are discussed along with the possible human health effects of exposure through contaminated food and water. The role of fecal coliform and total coliform bacteria as indicator organisms of contaminated water and not necessarily pathogens themselves is explained to the students. Emphasis is placed on the role *Escherichia coli* plays as a key indicator in the fecal coliform group of bacteria. Recently the ASM endorsed the US EPA's conclusion that *E. coli* is a better indicator of fecal contamination of drinking water than total coliforms and recommended using *E.coli* as the primary public health indicator of drinking water.[12]

Water quality has become an important issue in Canada after a particular serotype of *E. coli* (*E.coli* O157:H7) contaminated the town of Walkerton, Ontario's water supply and resulted in seven deaths. The importance of distinguishing pathogenic serotypes of *E.coli* from fecal contamination indicator *E.coli* is stressed due to the continuous confusion regarding this matter as is often seen in mainstream media reports. There are dozens of different serotypes of *E.coli* and not all are pathogenic to humans. The majority of serotypes are actually part of normal bowel function, though some strains such as O157:H7 are quite harmful and even lethal.

The main source of *E.coli* in drinking water is contamination from human and/or animal waste. Many urban communities in eastern Canada still discharge untreated sewage directly into waterways. First Nations communities in Unama'ki (the island of Cape Breton) have been leaders in addressing water quality. Students are asked to discuss the water management systems used in their communities.

The web-based material for the laboratories includes a link to Dr. Robert Metcalf's paper *The Science of Safe Water* on the Solar Cookers International web site solarcooking.org. The students are also directed to an interview with Dr. Metcalf (also on the SCI web site) explaining the problem of waterborne diseases and the use of solar water pasteurization in developing countries.

In addition to basic water microbiology relevant both nationally and globally, the students are introduced to the human health, economic and environmental problems associated with traditional cooking fuels in many developing countries. Respiratory diseases associated with chronic exposure to smoke from cooking fires, deforestation associated with fuel wood gathering, and the economic burden of cooking fuel are highlighted. A major problem with boiling water for disinfection is its energy consumption in relation to cost, availability and sustainability of the fuel supply. Approximately one kilogram of wood is needed to boil one liter of water.[8] In Africa more than 85 % of the harvested wood is used for fuel in comparison to only 15 % in developed countries. In some developing countries up to 50 % of the fuelwood is used for boiling water.[11] An illustration is used as a visual learning tool to show the relationships involved in the

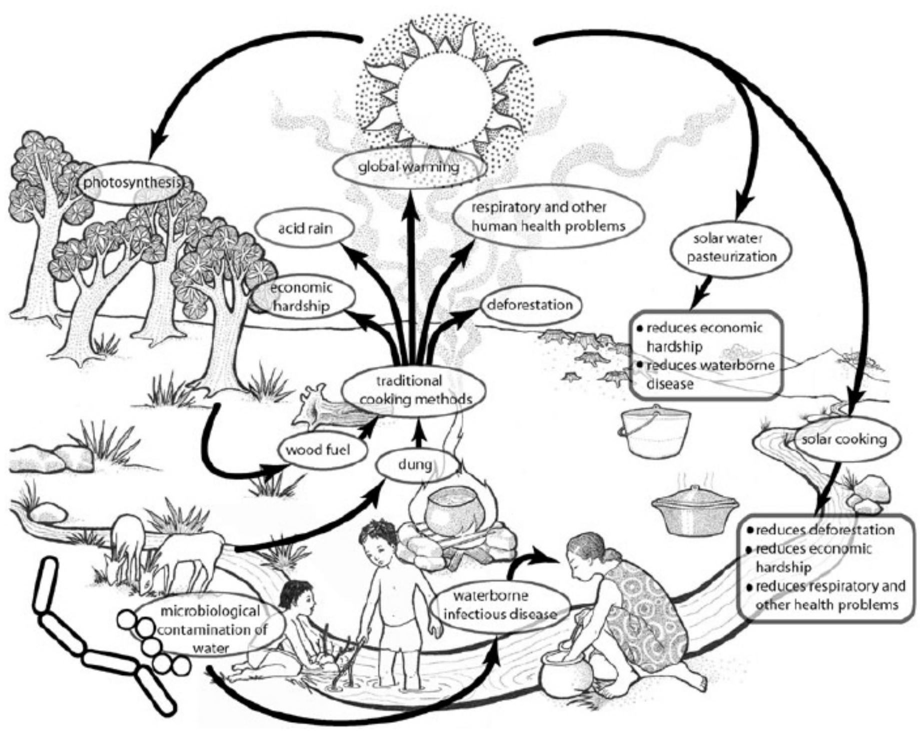

Figure 1

problem of waterborne disease and the application of solar energy to cooking and water pasteurization. (Figure 1)

An explanation of basic solar energy physics, which includes the nature of light as electromagnetic energy and its conversion to thermal energy, provides the necessary background to introduce techniques for practical use of solar thermal energy. Students are introduced to the "CooKit," a simple panel style solar cooker widely used in developing countries because of its simplicity and low cost. Despite several years of university level science education, students, and other faculty as well, are amazed to learn that solar energy can be easily and inexpensively harnessed to provide heat for cooking or disinfecting water, even at the mid-northern latitude of Nova Scotia.

Temperature-Time Pasteurization Requirement

The temperature requirements for disinfection are put into perspective for the students by describing the upper temperature limits on various microorganisms. In general only prokaryotic life forms exist over 65 °C. Most thermophiles cannot survive temperatures in excess of 68 °C and the higher temperature requirements of hyperthermophiles limits their survival at typical ambient temperatures. For *E.coli,* a typical mesophile, the optimal temp is 39 °C, the maximum is 48 °C and the minimum is 8 °C. The upper temperature limit for protozoa is 56 °C and algae between 55-60 °C.[13] In essence temperatures in excess of 60 °C and up to 70 °C will inactivate microbial pathogens found in water, with effective disinfection being dependent on the duration of high temperature exposure.[9, 10]

The first practical component of the lab involves subjecting standardized samples of *E. coli* to increasing temperatures for various lengths of time using a hot plate. The Colilert® method (IDEXX laboratories Inc.) is used to measure the number of the bacteria present before and after the samples were heat-treated. We use *E.coli* and the Colilert® method for two obvious reasons:

1) *E.coli* is considered the key indicator of fecal pollution of water and

2) IDEXX's Colilert® method is the most widely used indicator system in North America and the most commonly encountered by public health students when they join they workforce. Students are taught how to use the Colilert® method and its advantages and limitations compared to other methods such as membrane filtration and most probable number testing. After the samples are prepared, incubated for 24 hours, and the bacteria counts read, students create graphs of the temperature and time relationship in the disinfection process.

WAPI (Water Pasteurization Indicator)

The standard public health policy of using boiling for disinfection is a sound one. Boiling is a clear indicator that temperatures sufficient for pasteurization have been achieved. Because of the challenges often associated with boiling in developing nations, lower disinfection temperatures would be advantageous, but only if a simple, effective indicator of pasteurization can be found. The next component of the lab involves introducing the students to the Water Pasteurization Indicator (WAPI), a simple tube containing wax that melts at 70 degrees Celsius, a temperature sufficient for effective disinfection. The WAPI and CooKit were purchased as part of the "teacher's kit" from Solar Cookers International.

The WAPI is an inexpensive and effective alternative to a thermometer. Once the wax melts and slides down the small tube in which it is encased, water can be confidently assumed to be disinfected. A string allows the WAPI to hang from the top of the container and a metal ring at the bottom of the tube keeps the WAPI at the bottom of the container where the coolest temperatures are to be found. Once the wax hardens, sliding the string and ring to the other end of the tube makes the WAPI reusable.

Solar Pasteurization

The effectiveness of solar pasteurization is tested using 100 mL samples of *E. coli*-containing water prepared in the lab. Several samples are placed in a water filled pot within the CooKit while control samples are maintained at room temperature for the duration of the experiment. Once the WAPI melts (usually in several hours depending on the intensity of the solar radiation and ambient temperature), samples are collected and tested with the Colilert® method. Solar heated samples are observed to be free of bacteria while control samples show counts of greater than 200 *E.coli*/100 mL, the maximum number achieved with Colilert®.

In the final component of the lab, the practical application of solar pasteurization is tested using contaminated water collected from a local brook. Solar heated samples are compared to unheated control samples using the Colilert® method. No coliforms (including *E.coli*) can be found in the solar heated samples whereas controls show varying counts depending on the degree of contamination of the brook chosen by the student. Despite being March at a latitude of approximately 49 degrees with snow still on the ground and an air temperature of 7 °C, students in 2004 were able to successfully disinfect standardized *E. coli* samples as well as water samples from a brook. The contrast between large banks of snow and steam rising from the pot of water containing the samples provided an impressive visual feature from this teaching exercise.

Real World Applications

Several teams of researchers have recently completed projects involving solar disinfection of water. In 1999 an Irish group reported on a community based study in a Maasai community in Kenya.[14] Two groups of children were randomized by household to drink water either left in plastic bottles on the roof of their houses or kept indoors as a control. Children drinking solar treated water had a modest, but statistically significant lower incidence of severe diarrheal disease, which was sustained for over a year of the study.

The researchers noted that following the study period almost all the households that were drinking solar treated water continued to do so, and this acceptance was attributed to the fact that Maasai workers and elders conducted the research and reported the findings to the community. This is of particular interest to UCCB's aboriginal students in the Integrative Science program because of the role elders play in their own communities and its relevance to current community based participatory research initiatives.

Science often advances as a result of serendipity and this was clearly the case here. Shortly after completion of the solar disinfection trial amongst the Maasai, a cholera epidemic hit the area. Most of the households using solar disinfected water for the children had continued to do so, so an ideal test situation developed which otherwise would have been unethical to pursue. In 155 children under six years old drinking solar disinfected water only three developed cholera, whereas 20 children out of 144 drinking untreated water developed cholera. The incidence of cholera in adults and older children did not differ between the two groups of households as expected since it was only young children who were using the solar treated water. These results confirmed point of consumption solar disinfection is useful in reducing risk of water borne disease in children, who are always the most susceptible.[15]

This study also provides an excellent example of the value of traditional knowledge in health research. Because there were no medical facilities available to the people in this community, bacteriological con-firmation of cholera was not possible. Cholera was diagnosed retrospectively using detailed descriptions of symptoms provided by the Maasai themselves. The Maasai carefully distinguish symptom patterns using a rich linguistic toolbox. The traditional Maasai word *enchelele,* which means repeated watery stools "more times than the fingers on one hand" (the literal translation of the Maasai word for often) and three other typical features of cholera well described in the Maasai language: *enkalokani* (voluminous water diarrhea), *nepuk* (marked reduction in urine), and *nerrutoisinyi* (painful calf muscles) were used to confirm a diagnosis of cholera. This method of using traditional medical knowledge to identify cholera was later tested by the Kenyan Ministry of Health. Of 43 cases identified as cholera using traditional knowledge 42 were confirmed bacteriologically.[15]

The authors conclude that solar disinfection is a low cost intervention that can be rapidly put in place as a first line of defense in an epidemic situation. It can decrease risk while more permanent solutions are implemented and can play a role in coping with emerging chlorine resistant strains of cholera. Effective public health measures have to be taken at the community level and must emphasize disinfection in control and prevention of waterborne disease. Additional, traditional cultures with their rich taxonomies of disease can provide reliable diagnostic information and are an underutilized resource in health promotion and disease investigation.

CONCLUSION

Solar water disinfection and pasteurization are simple, extremely low cost technologies requiring minimal infrastructure for successful application. Through a series of laboratory exercises we are able to convey the importance of water microbiology, teach the use of the most up to date indicator methods, relate pubic health concerns to water quality both globally and regionally, explain disease prevention at source, energy availability and conversion and traditional approaches to diagnosis, as well as provide an example of how simple solutions to problems are often overlooked and ignored.

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