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Evaluation of the Potential of using Solar Energy to Pasteurise Drinking Water: Using *Escherichia coli* (*E. coli*) as an Indicator

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Abstract: Potential application of a simple panel solar cooker design (Cookit) to inactivate bacteria in drinking water was investigated. *Escherichia coli* (*E. coli*) was used as an indicator species in this study. Bacterial contaminated water was collected from Mzimnene River in Manzini region of Swaziland. Water samples were put in Cookits and exposed to solar radiation for different time intervals (0, 30, 60, 90, 120, 150 and 180 min). Changes in water temperature were monitored and *E. coli* counts (cfu/ml) were enumerated for each sample. The standard solid plating procedure for enumerating bacteria was used. The results showed rapid decline in *E. coli* count when water temperature reached about 55ºC and this was attained within 2 h of exposure to solar radiation. The findings suggest that there is potential in using the Cookit to inactivate bacteria in drinking water. It is recommended that further investigations be conducted at a larger scale, over longer periods and under different weather and climatic conditions. The effectiveness of the Cookit should also be further evaluated with more resistant waterborne bacteria, bacterial spores, protozoan cysts, and viruses.

Key words: Cookit, drinking water, *Escherichia coli*, panel solar cooker

INTRODUCTION

Despite the effort made by the government of Swaziland to provide essential services to the people, a large proportion of the country's population, especially in the rural areas, still lack access to clean and safe drinking water. The problem becomes more severe in years of drought when water sources do not recharge to adequate capacities. In very dry years, people resort to fetching drinking water from unpotable sources such as unprotected wells, rivers and open reservoirs. For example, in 1997, accessibility to clean water in the country was estimated at 84% in the urban areas and 33% in rural areas (FAO, 2005). At global level, the United Nations International Children Emergency Fund (UNICEF) and the World Health Organization (WHO) estimated that about 60 and 23% of families in rural and urban settlements, respectively; did not have access to safe and clean water for domestic use. This translated to about 1.1 billion people not having access to microbiologically safe drinking water (UNICEF and WHO, 2004). The UN Millennium Development Goal (MDG) 7 (Target 7c) for reduction by half the proportion of people without access to safe drinking water and basic sanitation by 2015, still remain extremely remote as water supplies remain polluted and adequate sanitation is unavailable (Varis, 2007). Water and sanitation are also components that are intricately linked to the MDG 1 for eradication of extreme poverty and hunger.

Water from unprotected sites is often contaminated with pathogens, like bacteria, helminths, protozoa and viruses that cause water borne diseases such as diarrhoea, dysentery, typhoid, shigellosis and cholera (Metcalf, 1993; Elkarmi *et al.,* 2008). These diseases are a major cause of millions of deaths every year around the world, especially in developing countries (Hrudey *et al.,* 2006). An estimated 1.6 million people die every year from diarrhoeal diseases related to lack of access to safe drinking water and basic sanitation and hygiene (Metcalf, 1993; WHO, 2007). About 90% of the deaths are of children under five, mostly in developing countries (WHO, 2007). According to Centres for Disease Control and prevention (CDC, 2009), the recent outbreak of cholera reported by health officials in Zimbabwe claimed 3,181 lives out of an estimated 61,304 suspected cases between August, 2008 and January, 2009. Cases of cholera were reported in all of Zimbabwe provinces and the disease later spread to neighbouring countries of Botswana, Mozambique, South Africa, and Zambia. Other cholera cases were also reported in Angola, Burundi, Democratic Republic of Congo, Kenya, Malawi, Namibia, Nigeria, Guinea-Bissau and Togo. Cholera is a potentially fatal bacterial infection that spread through untreated sewage and contaminated drinking water. There is no

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known cholera vaccine available yet, however, this disease can be prevented by practising basic hygiene and drinking boiled water. (CDC, 2009).

In cases of outbreaks of water-borne diseases, health ministries recommend that people boil water for up to ten minutes before drinking (Metcalf, 1993). Boiling water requires energy, the major sources of which are firewood, coal, paraffin and electricity. These energy sources are not only scarce but are expensive for an average poor family and also some of them result in environmental pollution. A great deal of time and effort is required to walk long distances to fetch firewood, a resource, which is rapidly dwindling. The heat and smoke associated with wood fire also cause discomfort and irritation in the kitchen (Skipton, 1998). Paraffin and electricity costs are rocketing up now and are unlikely to come down again, except perhaps for temporary short-term fluctuations. Modern water treatment techniques like chlorination, ozonation, or ultraviolet light systems are prohibitively too expensive for rural communities to acquire and maintain (Joyce *et al.*, 1996). It is within this challenge that it becomes imperative to explore alternative sources of heating energy that complement the conventional ones and contribute to environmental protection.

While they are not a panacea, solar-based technologies represent one important choice in an increasing array of energy options. Previous researches indicate that there is potential to harness solar energy in improving the quality of drinking water in the regions endowed with sunny climate (Joyce *et al.*, 1996; Safapour and Metcalf, 1999; Yukselen, *et al.*, 2003; Caslake *et al.*, 2004; Walker *et al.,* 2004). For example, solar cooking technology has made a huge contribution towards addressing the problems associated with using firewood in developing countries. Various types of solar cooking devices exist. The simplest of them all is the panel solar cooker, the Cookit, developed by Solar Cookers International (SCI, Sacramento, CA, USA), as an alternative cooking device for refugee camps in Kenya and Ethiopia (Safapour and Metcalf, 1999) and other energy deficient regions.

A recent study demonstrated the potential application of the Cookit in reducing urease activity in full fatty soyabeans (Nyoni *et al.*, 2005). Safapour and Metcalf, (1999), reported effective pasteurisation of water heated in dark containers placed in a Cookit at varied sun angles. This investigation aimed at further improving the effectiveness of the Cookit in pasteurising water by enclosing dark water containers in airtight clear polypropylene bags and regularly repositioning the Cookit to keep trek of the position of the sun.

MATERIALS AND METHODS

Study site: This experiment was conducted over four successive months at the University of Swaziland, Luyengo Campus (altitude 754 m, longitude E 31.18º, latitude S 26.58º) between January and April 2008. Laboratory analyses were conducted in the Department of Animal Production and Health of the same university.

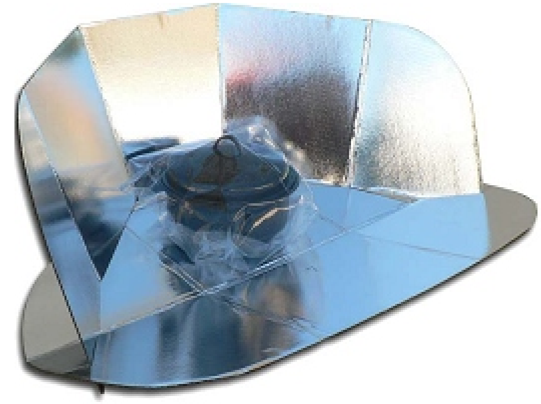

Fig. 1: The SCI Cookit design

Equipment: The equipment used in the experiment included; six Cookits and transparent polypropylene bags, six black plastic water bottles (800 mL), 100ºC thermometer, 10 L plastic bucket, incubator, autoclave, digital balance, water bath, disposable petri dishes, screw cap sample bottles, 500 mL conical Erlenmeyer flasks and 1 mL disposable pipettes.

The cookit: The Cookit (Fig. 1) is made from aluminised cardboard sheeting, which is folded into multiple reflecting surfaces to concentrate solar radiation onto a central space where the cooking vessel is kept. Heating efficiency is improved by positioning the reflective surfaces to directly face the sun. The Cookit is considered the simplest and least expensive design of a panel solar cooker, however, it can heat material up to 125ºC when the ambient temperature is over 20ºC (TFL, 1997).

Reagents: The chemical reagents used were Eosin Methelyne Blue agar (EMB) (Levine CM 0069 Oxoid Ltd., Basingstoke, Hampshire, England), ringer (Oxoid, Ltd, England) solution and ethanol.

Water sampling: Water samples were collected from Mzimnene River in Manzini, Swaziland. The samples were taken from a point where local vendors normally collect water for washing fruits and vegetables. The water was sampled aseptically using a sterile 10 L plastic bucket. The bucket was submerged in the centre of the river to ensure the sample was clear of contaminants from the riverbanks. The bucket was immediately closed and kept from direct sunlight. The samples were transported to the laboratory at the Luyengo Campus where they were stored at 4ºC until studied. *Escherichia coli* were enumerated within 24 h of water sampling using the standard procedure for *E. coli* counts adapted from Feng *et al*., (2002).

Media preparation and enumeration of colonies: One ringer tablet was dissolved in 500 mL of distilled water in a conical Erlenmeyer flask. Then 9 mL of the ringer solution were transferred into screw caped sample bottles and autoclaved at 121ºC for 15 min before use in diluting samples. Dilutions that yielded between 30 and 300 colony-forming units were attained.

Eosin Methylene Blue (EMB) agar was used as the enumeration media. The basal and overlay method (Hartman *et al*., 1975) was adapted and plates were incubated at 37ºC for 48 . *E. coli* colonies were detected by their ability to ferment glucose and produce dark centred metallic sheen green colonies (Feng *et al*., 2002).

Solar water pasteurisation: The experiment started at 1100 h and ended at 1400 h and was carried out in four successive months to determine the potential of using solar pasteurisation in different weather regimes hoping that each month would present a different weather condition. On each day of the study, the weather information was recorded. The mean ambient conditions were conducive for solar water heating with average maximum temperature of 25.4±1.8ºC (sd), 9.3±1.3 (sd) sunshine hours and average wind speed of 2.1±1.3 m/h.

The Cookits were placed in an open space free from shading for maximum reception of solar radiation. The vertical reflective sections were secured in some slits on each side of the front piece and were held in position by laundry fasteners. The Cookits were placed such that the vertical reflective section faced the direction of the sun to maximize incident radiation. Six black plastic water bottles (800 mL) were filled with water samples and were enclosed in airtight polypropylene plastic bags. Each bottle was placed in the centre of a Cookit. The devices were repositioned approximately every hour to keep trek of the position of the sun.

The heating process was accomplished by the reflecting Cookit surfaces bouncing and concentrating solar radiation onto the black water bottle. The polypropylene bag allowed light waves to pass through and get absorbed by the water bottle. The water bottle in turn radiated the absorbed light waves as heat waves (infra-red) to the water and the air entrapped in the polypropylene plastic bag. Heat waves could not escape through transparent surfaces; hence the air trapped by the polypropylene bag heated up and provided a hot air-jacket that helped to continuously heat the water.

Water bottles were withdrawn at random after 30, 60, 90, 120, 150 and 180 min of panel solar heating. The temperature of the water was measured, using a thermometer, concurrently at the removal of the sample

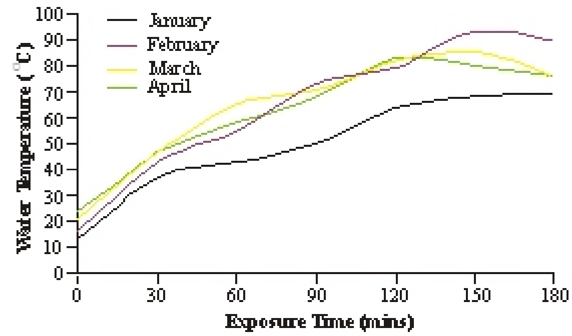

Fig. 2: Water temperatures (ºC) attained at different durations of exposure to solar radiation

from the Cookit. The water was cooled in a refrigerator to a workable temperature before laboratory analysis.

RESULTS AND DISCUSSION

Effect of duration of exposure to solar radiation on water temperature: The changes in water temperature, with exposure time duration to solar radiation, are shown in Fig. 2. In all the months, water temperatures above 65ºC were reached within 3 h of exposure. The highest water temperature of 93ºC, was achieved in February after 2 ½ h of exposure to solar radiation.

The pooled average water temperatures for the four months and the decline in *E. coli* counts showed a negative correlation (r = -0.926) between *E. coli* count and water temperature (Fig. 3). There was a steady increase in water temperature from the beginning of the experiment, reaching temperatures above 60ºC within 1½ h. The temperature reached a peak above 80ºC within 2½ h and then declined towards the end of the 3rd h of exposure. The rate of *E. coli* inactivation was gradual in the 1st h, the count dropped by 0.35-log. There was a highly significant ($p<0.01$) decrease in the *E. coli* count from the time the water temperature reached 65.5ºC (Table 1). Complete *E. coli* inactivation was achieved when the water temperature reached 77ºC. Safapour and Metcalf (1999), recorded complete *E. coli* inactivation when the water temperature reached 60ºC. Joyce, *et al*., 1996, recorded no culturable *E. coli* at maximum water temperature of 55ºC. In the food industry, most coliform species have been observed to be heat sensitive with D- values of less than 2 min at temperatures between 54-65 ºC (Juneja and Marmer, 1999, Oteiza *et al*., 2003, Denis *et al*., 2006). It is possible that complete *E. coli* inactivation was reached soon after rapid decline in counts was recorded at 65.5ºC.

NB Not possible to calculate D-value and z-value because treatments were not kept at constant temperatures

Table 1: *E. coli* inactivation (log_{10} cfu/ml) with changes in water temperature (ºC)

Exposure time (min)	0	30	60	90	120	150	180
Mean water temperature (ºC)	18.75	43.50	55.25	65.50	77.00	81.50	77.75
Mean *E.coli* (log_{10} cfu/mL)	2.00[a]	1.75[a]	1.65[a]	0.70[b]	< 0.1[c]	<0.1[c] 0.1	<0.1[c]

Means followed by the same letter are not significantly different at LSD $_{0.05}$

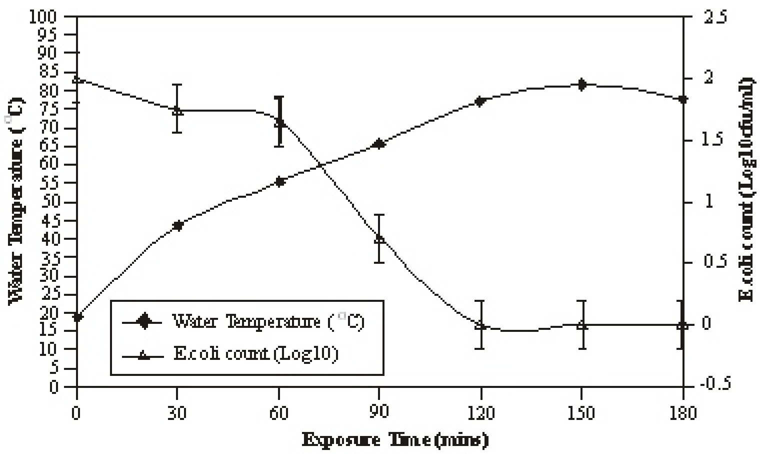

Fig. 3: Water Temperature (ºC) and *E. coli* inactivation (log_{10} cfu/mL) with time of exposure to solar radiation

CONCLUSION

The most commonly recommended water treatment technique is boiling the contaminated water for up to 10 minutes to kill disease-causing microorganisms. This practice is, however, discouraged in most countries for environmental reasons. Poor families in Swaziland cannot afford modern sources of energy and the cost of chemical water treatment, such as chlorination, is prohibitive. This investigation demonstrated that, with regards to the bacterial species studied, water pasteurisation was possible using solar radiation, a resource that is free. The water temperatures attained within comparable time periods, were substantially higher than those recorded by Safapour and Metcalf, (1999). This suggests that when a black water container is enclosed in a clear polypropylene bag, it may be possible to inactivate the more resistant waterborne bacteria, bacterial spores, protozoan cysts, and viruses.

The likely concern on the results of this study is the quantity of water that can be treated in a day with a Cookit (6-7 L). This is a reasonable amount for household needs though it leaves very little possibility of treating water for storage. Small amounts of pasteurised water are, however, useful in preparation of anti-diarrhoeal solutions at rural health centres. Higher capacity solar hot water systems, purpose designed for other domestic hot water applications, are available in the country. These systems, though more expensive, can be exploited for use in pasteurising bigger volumes of drinking water at community level.

RECOMMENDATIONS

There is a need to run further investigations of the effectiveness of the Cookit over longer periods under different weather and climatic conditions. Moreover, there is need to identify the range of waterborne pathogenic species that can be inactivated using solar energy.

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