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Performance of a 2-Element Plane Reflector Augmented Galvanised Pipe Flat Plate Collector for Solar Water Pasteurisation

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Abstract: About 80% of all infectious diseases including diarrhoea, typhoid, cholera in developing countries are transmitted through consumption of contaminated water. This study reports on the concept of heating water using low cost solar thermal energy systems to kill disease-causing microorganisms and gives the design philosophy, construction and measured thermal performances of a 2-element plane reflector augmented flat plate solar collector. A solar water pasteurization system was designed and constructed using locally available materials for direct water heating using solar energy in a flow-through system made of copper pipes. Standard car radiator thermostat valve was used to regulate pasteurization temperature at 82°C. The results demonstrated that solar heating of contaminated water could be achieved through a 2 m^2 flat plate collector with mounted with a 2-element plane mirror reflector with an aperture area of 4 m^2. The experimental collector was constructed with 20 mm diameter galvanized pipe fixed onto mild steel absorber plate. The collector without reflectors was used as control experiment. Under fair weather conditions, it was observed that the use of mirrors tremendously improved the performance of the collector by up to 94% producing 49-95 L of pasteurized water using the galvanized pipe collector. The microbiology water quality tests using presumptive test for total coliform and confirmed by Eijkman test showed no presence of *E. coli* in the solar pasteurized water samples. On the basis of the results, it was concluded that the solar water pasteurization system developed provides a cheaper alternative for water disinfection in Kenya and other sunny countries.

Key words: Solar thermal disinfection, solar flat plate collector, specular plane mirror solar concentrator, design, theory solar water pasteurization, solar water pasteurization, microbiological water quality

INTRODUCTION

About 80% of all infectious diseases including diarrhoea, typhoid, cholera in developing countries are transmitted through consumption of contaminated water (National Health Sub-sector Strategic Plan, 1999-2004). The World Health Organization estimates that diarrhea kills about 400 children per hour in the world and nearly more than four million children every year. In Kenya, 50% of the rural population and 20% of the urban population have no access to safe drinking water (National Development Plan, 2002-2008). Typhoid and cholera have been identified as major causes of morbidity due lack of potable water, hygiene and sanitation. Most people drink directly contaminated surface water and open wells without boiling and this has created tremendous stress on health and huge medical bills (McDonald and Kay, 1994; Burris and Jorgensen, 2001). The surface water contain up to 1000-feacal coliform per deciliter of water due to pollution from animal and human life (Feachim, 1980).

The convectional chlorine water disinfection technology is widely used in planned urban centers in Kenya while most rural settlements are unplanned with no centralized clean water supply systems. However, chlorine water disinfection technology is costly in terms of installation and operational costs in distant remote areas. Although more advanced water disinfection technologies including ozone gas, UV and Mixed Oxidant Gas System exists, but they are too expensive for rural communities in Kenya to afford. Traditionally, most people living in the rural areas disinfect drinking water using biomass fuels through water boiling. However, with increasing biomass fuel shortages combined with the rising costs of wood-fuels, charcoal and modern fuels, boiling water using wood fuel and charcoal as means of physical

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water disinfection before drinking is often ignored (Holfkes, 1983). Therefore, making use of freely available solar energy estimated at an 700 W/m^2 with mean daily sun shine duration of 7 h (National Atlas of Kenya, 2003) to pasteurize contaminated water has potential to provide a new approach to reduce water borne diseases (Sommer *et al*., 1997; Walker *et al*., 2004; Caslake *et al*., 2004).

A number of solar powered water pasteurization devices have been developed around the world but their poor performance; low outputs and high production costs have limited their widespread to developing countries. These include flow through solar box cooker/pasteurization system without storage tank and solar box cooker fitted with a thermostatic valve, pre-filtering material and storage tank with low outputs (viz. 16-24 L day^{-1}) (Metcalf, 1994). Others include a parabolic trough pasteurization system fitted with standard automotive thermostatic valve and a PV powered water-pumping unit capacity to produce 2500 L of pasteurized water per day using a 28 m^2 collector. Other solar water treatment technologies developed include solar pasteurization filtration system that makes use of UV light to disinfect contaminated water using a PV powered-battery system (Anderson, 1996; Venczel and Sobsey, 1997; Gadgil and Shown, 1998). However, despite their impressive performance, the systems were found too expensive for families in developing countries to afford. The low cost version solar powered pasteurization system, include solar water puddle (Andreatta, 1994) and the solar still (Parker, 1991) have been developed, however, they are dodged with the problem of low outputs and durability for widespread use in developing countries.

This research reports on a new approach to development of a more robust solar powered water pasteurization device for heating water using low cost solar thermal energy system to kill water borne disease-causing microorganisms. The objective of this study was to develop a simple, robust and reliable solar powered device to pasteurize water for use in Kenya and other sunny countries.

Design of the experimental solar pasteurization system: Past studies shows, that solar thermal pasteurization or solar thermal heating of water to 65°C for 6 min, or to a higher temperature for a shorter time kills all microbes including germs, viruses and parasites (Metcalf, 1994). In our project, we opted to use a 2-element plane reflector to model the compound parabolic concentrator (Rabl, 1976) to operate during cloudy weather conditions. The reflector was integrated it to a simple convectional flat plate collector to produce continuously pasteurized water in the typical sunny areas of Kenya.

Theory reflective concentrators mounted on flat absorber plates: In order to maximize solar energy collection, we used the procedure developed by Winston (1974) to obtain the best mirror profile for a given acceptance angle for a linear concentrator. The mirror profile was shown to mimic a compound parabolic reflector mounted on top a flat horizontal absorber plate. Therefore, a design consisting of plane mirror elements was used to simplify the fabrication problem although with some loss in concentration. The widths of the reflective elements were selected carefully in order to yield maximum concentration. The widths of the elements, which are functions of their angles of inclination, were ascertained by applying Winston (1974) edge ray principle (Welford and Winston, 1978; Goswami *et al*., 1992). An optimization procedure for designing multi-element concentrator based on the discrete maximum principle was applied to give optimal angles and widths of the reflector elements. The reflectors were assumed to be perfectly specular and with length longer than their width in the analysis (Mannan and Bannerot, 1978; Mullick *et al*., 1986).

Conceptual design: The experimental solar pasteurization system designed is a flat-plate collector mounted with 2-element symmetrical plane mirror reflectors. The essential features of the solar collector with mirror concentrators are illustrated in Fig. 1.

Among the design features introduced to enhance the overall performance for water pasteurization over the ordinary solar flat plate collector include: The specular plane mirror reflectors that increases the magnitude of the solar radiation incident on the collector absorber surface, the non-return valve that ensures one way flow and the thermostatic valve that ensures attainment of the desired valve opening temperature to allow pasteurized discharge into storage tank.

Construction procedure: An experimental solar flat plate collector was designed, constructed and tested in this study. It was constructed using a 20 mm diameter galvanized pipe with 26-gauge stainless steel absorber plate. The absorber plate was painted matt black and covered with a 5 mm glass single glazing. The design parameters were as follows: Drinking water requirements, 2 L/person/day as recommended by WHO (1993-1998). Design data: assumed 100 school children; implying daily

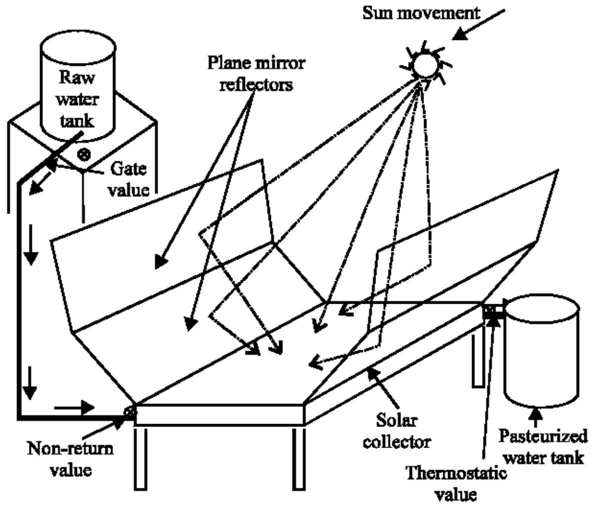

Fig. 1: Schematic illustration of the solar pasteurization system

drinking water requirement of 100 people, 200 L day^{-1}; desired pasteurization Temperature, (T_o) 82°C; average inlet water Temperature, (T_i) 22°C; specific heat capacity of water at constant pressure, (C_p) 4200 J kgK^{-1}; anticipated day average solar radiation in Kenya, (I) 800 W m^{-2}; assumed collector day average efficiency, 0.5.

Daily energy load required to pasteurize 200 L of water is given by the relationship,

$$Q_L = mC_p\Delta T = 50.4 \text{ MJ/day} \tag{1}$$

Required solar energy collection area is given by

$$A_c = \frac{mC_p\Delta T}{I_{av}\eta t} = 4.13 \text{ m}^2 \tag{2}$$

For a prototype design, a standard collector with absorber area of 1 m × 2 m (2 m^2) was considered to supply 100 L of pasteurized water per day. Parallel piping configuration was chosen using 20 mm diameter pipe with a manifold header having a diameter of 25 mm to encourage a uniform flow distribution in the parallel risers. A pipe (tube) spacing of 175 mm was chosen based on the recommended spacing range of 150-180 mm, typical for domestic solar water heating for optimal effectiveness of the collector relative to cost (Gillet and Moon, 1985; Ghamari and Worth, 1992).

Number of parallel risers at spacing of 175 mm = 5 and absorber plate thickness = 0.5 mm.

Value of heat transfer coefficient, h_f was taken to be 300 W/m^{2}K. Values ranging $200<h_f<400$W/m^{2}K have been recommended for parallel riser tube with sandwich absorber (Gillet and Moon, 1985).

Value of collector heat loss coefficient, U_L was taken as 8 W/m^{2}K, this has also been recommended by Gillet and Moon (1985) for a single glazed collector with absorber painted matt black.

Using Eq. 3 and 4 the standard fin efficiency (Duffie and Beckman, 1991), F was calculated to be 0.7.

$$F = \tanh\left[\frac{m(W-D)}{2}\right] \tag{3}$$

$$m = \left[\frac{U_L k}{\delta}\right]^{0.5} \tag{4}$$

This was used to calculate the collector efficiency factor, F' using Eq. 5 (Duffie and Beckman, 1991) and found to be 0.697 (the value of bond conductance, C_b was assumed to be 0).

$$F' = \frac{1/U_L}{W\left[\frac{1}{U_L[D+(W-D)F]} + \frac{1}{C_b} + \frac{1}{\pi D_i h_{fi}}\right]} \tag{5}$$

The dimensionless mass flow-rate of the collector was found using Eq. 4 and found to be 3.12. This was used to calculate the collector flow factor, F'' using Eq. 7 (Duffie and Beckman, 1991) and calculated to be 0.855.

$$F_R = \frac{\dot{m}c_p(T_f - T_i)}{A_c[S - U_L(T_i - T_a)]} = \frac{\dot{m}c_p}{A_c U_L}\left[1 - \exp\left(\frac{A_c U_L F'}{\dot{m}c_p}\right)\right] \tag{6}$$

$$F'' = \frac{F_R}{F'} = \frac{\dot{m}c_p}{A_c U_L F'}\left[1 - \exp\left(\frac{A_c U_L F'}{\dot{m}c_p}\right)\right] \tag{7}$$

Where:

$$\frac{\dot{m}c_p}{A_c U_L F'}$$

is the collector capacitance rate (mass flow-rate). Heat removal factor, F_R was then calculated from the relationship $F_R = F'F'' = 0.696$.

Construction of the solar pasteurisation system: The prototype solar water pasteurization system was constructed in several parts including collector support structure, rectangular collector casing, absorber assembly, reflector assembly, piping, water supply and water storage tanks as shown in Fig. 1 and 2. The construction work was conducted in Kenyatta University Science workshop

Fig. 2: Photo of the prototype solar pasteurization system at Kenyatta University, Nairobi, Kenya

with the assistance of technicians. All materials used for construction were purchased locally at relatively low costs. A galvanized pipe heat exchanger was constructed.

Experimentation: A total of 40 tests were conducted between Jan 2004 to December 2005 at Kenyatta University, 25 km North of Nairobi. Kenya using a galvanized pipe collector fitted with the thermostatic valve to regulate the water discharge temperature. Only tests performed under clear sky conditions starting 9:00 am to 5:00 pm were selected for analysis. Several tests were performed using the galvanized pipe collector. In each case tests were conducted with reflectors in position and also without reflectors and served as a control. Nine runs of each experiment were selected for comparisons and to check repeatability. The thermocouples (copper-nickel) with a temperature range of -185°C to 300°C were glued on the absorber plate at inlet, within the heat exchanger and at the exit sections of the system for temperature measurements.

A 10 L bucket was used to collect each batch of water discharged and a 1 L graduated flask was used to measure the volume of water discharged. The measured water was then poured back into the pasteurized water tank. Volume, average temperature and time of each batch discharged were recorded manually. The average temperature of each discharge was measured using a portable digital thermometer. Amount of solar radiation, ambient, inlet, outlet and average absorber temperatures were recorded using FLUKE 2286 series (USA) data logger at 15 min intervals. Similarly, wind speed was recorded at corresponding 15 min interval using VELOCICALC portable air velocity meter model 8357 connected to a portable printer model 8925 both manufactured by TSI, USA. At the end of each day, data was retrieved from the data logger and entered into an Excel spreadsheet together with the manually collected data. Descriptive statistics was then used for the analysis.

Microbiology water quality testing: The microbiology testing of water was undertaken using the standard presumptive coliform test (WHO, 1997) and confirmed by Eijkman test (WHO, 1993-1998) for presence of *E. coli* in water.

Sampling procedure: Water sample were collected from three randomly selected sites along Kamiti River next to Kenyatta University in accordance to procedure for sampling water from a watercourse or reservoir (WHO, 1997).

Presumptive coliform test: All water samples were subjected to presumptive coliform test to detect presence of coliform bacteria in water (WHO, 1993-1998). The bottles containing the samples were vigorously shaken to achieve homogeneous dispersion of bacteria. With a sterile 10 mL pipette, 10 mL of water sample was inoculated into each of the 5 McCarteney bottles containing 10 mL of McConkey broth purple (double strength). About 50 mL of sample was added to a tube containing 50 mL McConkey broth purple (double strength) and 1 mL of water sample into each of 5 tubes containing 5 mL McConkey broth purple (single strength). Durham tubes were inserted in each bottle making sure that each tube was inverted and filled completely with the solution by gently shaking the bottles to distribute the sample evenly ensuring that the samples are devoid of any air bubbles.

The tubes were incubated at 36-38°C for 24 h after which each tube was examined for presence of gas and for fermentation (change of medium color from purple to yellow). The number of positive tubes was recorded and tubes with negative results were re-incubated for a further 24 h period after which they were checked for fermentation and gas production as described above. Acid and gas production at the end of 24 or 48 h of incubation was presumed to be due the presence of coliforms because coliform organisms are able to ferment lactose at 35-37°C with production of gas and acid within 24-48 h. The number of positive tubes after 48 h was recorded and results interpreted using McCrady's most probable number (mpn) probability tables. Negative reaction was indicated by either no growth or growth without gas. This excludes the coliform group of bacteria.

Eijkman test for confirmation of *E. coli* presence in water: All tubes positive for presumptive coliform test were subjected to the Eijkman test. Unlike other coliforms, *E. coli* is capable of fermenting lactose with subsequent production of gas and indole from tryptophan at 43.5-44°C (WHO, 1993-1998). *E. coli* is an indicator of recent faecal contamination of either human or animal origin and should not be detected in water used for drinking.

A drop of broth was transferred from each presumptive positive tube into a bottle containing 5 mL single strength McConkey broth and to a bottle containing Tryptone water, respectively. A different pipette was used for each positive bottle. The sub-cultured samples were incubated for 24 h at 43.5-44.5°C. At the end of the 24 h of incubation, each tube was examined for fermentation and gas production (positive test) and results recorded. To each of the Tryptone water tubes, a drop of Kovacs reagent was added and gently mixed. The presence of indole was indicated by a red colour in the Kovacs reagent, forming a film over the aqueous phase of the medium. Confirmatory tests positive for indole, fermentation and gas production indicated the presence of *E. coli* while growth and gas production in the absence of indole production confirmed thermo-tolerant coliforms (WHO, 1997). McCrady (mpn) probability tables were used to interpret the results and counts were expressed per 100 mL.

RESULTS AND DISCUSSION

Table 1 and 2 shows summary of selected solar pasteurization experiments conducted under clear sky conditions in Kenya between December 2004 and February 2005 using galvanized pipe flat collector with and without reflectors, respectively.

Solar energy and ambient temperature profiles: All experiments were conducted at an average daily solar radiation of 699.3±21.5 W/sq-m w for the selected tests while the overall ambient average temperature was 28.4±0.7°C. All experiments were conducted at an average daily wind speed of 1.5±0.3 m s^{-1}.

Daily averaged inlet raw water and pasteurized water temperature profiles: On average during the day, the solar collector with and without reflectors heated the inlet raw water from 25.9±.0.9-83.5±0.2°C. The high outlet water temperature generated by the device demonstrated high potential in solar water pasteurization. It was concluded that the system could effectively be used in sunny countries for water pasteurization. The water borne microbes get destroyed by heating water at temperatures above 75°C for 10 min (Andreatta, 1994).

Thermal performance using solar pasteurization tests: Figure 3 shows typical temperature profiles generated by the solar pasteurization system under clear sky conditions in Kenya conducted on 9th October 2004. The day average solar radiation and ambient temperature attained were 689.4 W m^{-2} and 32.1°C, respectively. The ambient temperature increased progressively to a maximum of 35°C due to the continuous accumulation of heat on the earth's surface with time during the sunshine period. The day average absorber plate temperature reached 77.8°C while the highest temperature attained was 101.1°C. The high temperature may be attributed to the collector getting heated due the sun's rays that are normally incident on its surface around mid-day. The raw water with an average 27.7°C entered the absorber heat exchange unit and was heated to a maximum of 79.4°C and eventually forced to exit through thermostat valve to a pasteurized water storage tank.

It was observed that the volume of pasteurized water discharged per day under clear sky condition increased by 107% that is from 38-79 L day^{-1} for galvanized pipe collector with concentrating reflectors as compared to galvanized pipe collector without reflectors. This could be explained by increased energy input/unit area on the absorber using reflectors thereby exceeding the thermal and optical energy losses by conduction, convection and radiation.

The number of valve openings shown in Table 1 and 2 is an indication of the number of batches collected as the system operated in an automatic batch process where by water was filled in the collector from the raw water tank and heated until it reached valve-opening temperature. This was then discharged creating space for another batch. The discharge temperature for each batch ranged from 83-84°C at the time the valve closed giving an average discharge temperature of 83.5°C per batch. The volume of water that could be held in the header pipe and the parallel riser pipes governed the discharged volume of each batch.

Water quality analysis: In this study, results of the bacteriological water analysis using the presumptive coliform test for total coliforms and Eijkman test for the confirmation of *E. coli* in water are presented and discussed. A total number of 30 samples for both raw and pasteurized water were analyzed using multiple tube

Table 1: Daily averaged solar pasteurization results using galvanized pipe collector with reflectors

Date and time	GI pipe collector system	Test No.	Day Av. wind velocity $(m\ s^{-1})$	Day Av. Rad. I $(W\ m^{-2})$	Day Av. ambient T_a (°C)	Day Av. inlet water T_i (°C)	Day Av. absorber T_p(°C)	Day Av. discharge T_d (°C)	Day total # valve opening in batches	Day total pasteurized water (L)
23-12-04 9am-5pm	With reflectors	16	1.8	716.3	28.3	26.2	73.6	83.7	23.0	74.6
24-12-04 9am-5pm	With reflectors	17	1.0	741.5	30.2	27.6	72.9	83.9	24.0	79.1
26-12-04 9am-5pm	With reflectors	19	2.0	700.1	28.0	25.1	72.7	83.3	19.0	67.6
27-12-04 9am-5pm	With reflectors	20	1.8	691.4	27.8	25.2	72.5	84.0	18.0	62.6
03-01-05 9am-5pm	With reflectors	22	1.7	693.6	27.7	24.3	73.4	83.3	18.0	65.4
04-01-05 9am-5pm	With reflectors	23	1.5	706.5	28.0	26.0	72.3	83.7	18.0	67.4
Average			1.6	708.2	28.3	25.7	72.9	83.5	20.0	69.5
Maximum			2.0	741.5	30.2	27.6	73.6	84.0	24.0	79.1
Minimum			1.0	691.4	27.7	24.3	72.3	83.3	18.0	62.6
SD			0.3	18.6	0.9	1.1	0.5	0.3	2.8	6.2

Table 2: Solar pasteurization results using galvanized pipe collector without reflectors conducted in Kenya

Date and time	GI pipe collector system	Test No.	Day Av. wind velocity $(m\ s^{-1})$	Day Av. Rad. I (W/m^2)	Day Av. ambient T_a (°C)	Day Av. inlet water T_i (°C)	Day Av. absorber T_p(°C)	Day Av. discharge T_d (°C)	Day total # valve opening in batches	Day total pasteurized water (L)
05-01-05 9am-5pm	No reflectors	24	1.0	673.7	28.3	26.4	70.2	83.5	10.0	38.30
06-01-05 9am-5pm	No reflectors	25	1.0	678.9	29.0	27.0	70.1	83.7	10.0	37.70
07-01-05 9am-5pm	No reflectors	26	1.4	675.1	28.9	26.6	69.5	83.3	9.0	36.40
08-01-05 9am-5pm	No reflectors	27	1.4	720.4	28.0	25.5	70.5	83.3	10.0	39.40
12-01-05 9am-5pm	No reflectors	29	1.8	677.7	28.4	25.7	71.0	83.6	9.0	36.90
18-01-05 9am-5pm	No reflectors	30	1.4	716.0	27.9	24.8	69.8	83.7	10.0	41.70
Average			1.3	690.3	28.4	26.0	70.2	83.5	9.7	38.40
Maximum			1.8	720.4	29.0	27.0	71.0	83.7	10.0	41.70
Minimum			1.0	673.7	27.9	24.8	69.5	83.3	9.0	36.40
SD			0.3	21.7	0.4	0.8	0.5	0.2	0.5	1.90

technique for the 2 tests mentioned. Descriptive statistics has been used for the analysis of data. Summarized results for the laboratory analysis of the samples are given in Table 3.

Water sample positivity was high for the raw water with all samples (15/15) testing positive for total coliforms and 87% (13/15) testing positive for *E. coli* (Table 3). A maximum total coliform count >180/100 mL of sample of raw water was recorded for both total coliform and *E. coli*.

The presence of *E. coli* was an indication of recent feacal contamination of either human or animal origin. This contamination could be due to the run-off caused by rainfall in the up-stream areas where there are slums without sanitary facilities or raw sewage discharged into the river and also semi-intensive livestock production systems, which may increase the chances of feacal contamination. The high positivity for the raw water collected from River Kamiti confirms the high prevalence of waterborne diseases resulting from drinking untreated surface water that is open to pollution and is typical of developing countries (Feachem, 1980).

For the pasteurized water, there was no *E. coli* detected in all the 15 samples taken indicating that the solar pasteurizer was effective in destruction of disease causing bacteria. Two samples of pasteurized water tested positive for total coliforms with a low count of 2/100 and 4/100 mL of the pasteurized water sample. This could be attributed to contamination during sampling or presence of thermo-tolerant coliforms and these don't cause diseases to people (Ciochetti and Metcalf, 1994).

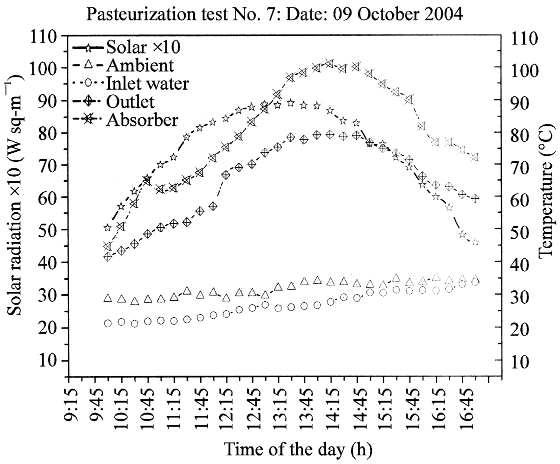

Fig. 3: Typical temperature profile of 2-element plane reflector solar pasteurisation system under weather conditions in Kenya

Economic comparison for a pasteurization system using alternative fuel: The alternative fuel considered in this study was charcoal although firewood is the most widely used source of energy in the urban and some rural areas.

Table 3: Total coliform and *E. coli* counts obtained from raw and pasteurized water samples

Water sample type	Total # of samples taken	# Positive for total coliforms	# Positive for *E. coli*	Maximum count of total coliforms MPN/100 mL	Maximum count of *E. coli* MPN/100 mL
Raw water	15	15	13	>180	>180
Pasteurized water	15	2	0	3	<1
Total	30	17	13	-	-

The reason being charcoal has a more standardized pricing compared to firewood and charcoal being derived from wood, it is possible to estimate the quantity of wet firewood from that of charcoal using the ratio of 9:1 for the conversion process using traditional earth kilns that are common in developing countries (Owino, 2004). Details for the calculations using alternative fuel.

The following have been considered in the calculations that follow:

- Daily collector output of pasteurized water of 100 L
- Average inlet temperature of 23°C and thermostatic valve discharge temperature of 83°C
- Charcoal of calorific value of 28 MJ kg^{-1} and cost of Ksh 25 kg^{-1}
- Institutional stove efficiency of 20%
- For every 1 kg of charcoal 9 kg of wet wood is required (Owino, 2004)

The daily energy load required to raise the temperature of 100 L of water from 23-83°C is given by

$$Q_L = \dot{m}C_p(T_o - T_i) = 100\times 4200\times 60 = 25.2\ \text{MJ}$$

- Quantity of charcoal required to meet the energy load = 25.2/28×0.2 = 4.5 kg
- Daily cost of charcoal to meet energy load = 25×4.5 = Kshs 112.50
- Annual cost for daily water pasteurization = 112.50×365 = Kshs 42,062.50 (USD540)
- Equivalent amount of wet wood required to meet the daily energy load = 4.5×9 = 40.5 kg
- Equivalent amount of wood required to meet the annual energy load = 15 tons

Considering a lifespan of 20 years then an equivalent of 300 tons of wet wood would be required to meet the energy load for this period.

CONCLUSION

There was up to 107% increase in the volume of pasteurized water discharged with the use of 2-element plane mirror concentrators from an aperture area of 4 m^2 (from 38-79 L for the galvanized pipe collector for a day under clear sky condition with an average solar radiation of 699.3±21.5 W m^{-2}, ambient temperature of 28±0.7°C and an average wind speed of 1.6±0.3 m s^{-1}. It is therefore, justifiable to use concentrators for flat plate collectors for solar water pasteurization as the enhancement of solar radiation by plane mirror reflectors is of great importance due to its potential application on various solar thermal devices.

There was up to 81% increase in the volume of pasteurized water using galvanized pipe collector (from 38.4±1.9-69.5 L day^{-1} for collector without and with reflectors under the clear sky conditions.

The experimental solar pasteurization system was 100% effective in the destruction *E. coli* in water. The maximum *E. coli* counts in the raw water was >180 and there was no *E. coli* detected in the pasteurized water samples and thus in conformity with WHO requirement that no *E. coli* should be detected in drinking water.

Economic analysis has also indicated that a solar pasteurization system with an output of 100 L day^{-1} at a discharge temperature of 83.5±0.2°C could save up to 300 tons of wet wood during the estimated useful life span of 20 years. The adoption of this system would also contribute towards environmental conservation through minimizing the use of biomass fuel to boil drinking water and also reducing the amount of greenhouse gas emissions that result from combustion of biomass fuel and the health effects associated with it.

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