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Pasteurization of Naturally Contaminated Water with Solar Energy

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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 insulation, which makes it difficult to cook on partly cloudy days and to keep foods warm when the sun is low in the sky; they need constant refocusing towards the sun; and they are susceptible to being blown over by strong winds. Because of the understandable failure of these solar cookers to be used by anyone for regular solar cooking, the few solar researchers in this area concluded that solar cookers would be used only as novelties (8).

A major breakthrough in making solar cooking practical came in 1976 when Barbara Kerr and Sherry Cole of Tempe, Arizona, developed the solar box cooker (SBC). The Kerr-Cole SBC design was simply a large box within a box, insulation between the boxes, and a tight-fitting lid with a large piece of glass. Sunlight would enter the cooking chamber either directly through the glass or indirectly, first being reflected by an adjustable, hinged, back reflector covered with aluminum foil. Sunlight would then be absorbed and converted to infrared heat rays by either dark covered pots or by a blackened metal drip pan in the bottom of the cooking chamber.

Unlike previous novelty solar cookers, SBCs have been used for regular cooking and baking by their owners, now numbering ca. 1,000 in the United States. Since we obtained an SBC in 1978, we have done more of our annual cooking and baking outside with SBCs than we have inside with our electric stove and oven. Cooking with an SBC is easier than conventional cooking in the total time and effort involved, and foods cooked in an SBC have a superior flavor. Because SBCs have a large cooking area, they can be used for purposes other than cooking food. A previous study had 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 all coliform and fecal coliform bacteria (M. Logvin, M.A. thesis, California State University, Sacramento, 1980). We wanted to expand on this particular use of an SBC, and thus we built an SBC which was deep enough to hold three to four 3.7-liter (1-gallon) jugs. We then investigated what temperatures would be reached in 1, 2, and 3 jugs of water in this SBC at various times of the year and under different weather conditions. We also investigated what time-temperature combinations would be sufficient to kill coliform bacteria in river water and used the heat inactivation of coliforms as an index of water pasteurization.

We felt this study had significance in that in many parts of the world, people do not have access to a safe water supply, and many diseases are transmitted by consumption of this contaminated water. Many countries where contaminated water supplies contribute to intestinal diseases have abundant sunshine, particularly those within 20° of the equator. There is the possibility that solar energy and a type of SBC could be used to provide pasteurized water for drinking, meal preparation, tooth cleaning, and preparation of infant formula when breast feeding cannot be maintained.

The present investigation indicates the feasibility of using solar energy and an SBC to pasteurize contaminated water on sunny or partly cloudy days during the solar season.

MATERIALS AND METHODS

SBC construction. The SBC used in this study was built similarly to, but deeper than, the Kerr-Cole Eco-Cooker (Kerr Enterprises, Inc., Tempe, Ariz.). The SBC was made of three basic components: a well-insulated large cardboard box which contained the rectangular cooking area; a removable cardboard lid with a glass window; and a hinged, adjustable reflector shield attached to the lid. The main insulating material of the SBC was multiple layers of regular aluminum foil glued onto cardboard with an equal mix of water and white glue (Elmer's Glue-All, Borden Inc., Columbus, Ohio). All components were made from standard appliance shipping cardboard.

The insulated cardboard box had four components (Fig.

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1). (i) The first was an outer box 85.7 by 65.4 by 39.4 cm deep, foiled on the inner side only. (ii) The second was an inner box 69.8 by 48.9 by 35.5 cm deep, covered on both sides with aluminum foil. The inner box rested on a foiled cardboard support piece, and this was supported by eight stacks (10 by 10 cm) of cardboard 3 cm high, glued to the bottom of the outer box. (iii) The third component was side insulators, foiled on both sides, extending diagonally from the inside bottom of the outer box to the outside top of the inner box. The short side insulators measured 64.1 by 40.6 cm, and the long side insulators measured 83.8 by 40.6 cm. (iv) The fourth was four straddling pieces for each side of the SBC. The straddlers covered the outside of the outer box, extended 10.1 cm over the tops of the outer box, side insulator, and inner box, and then folded to cover completely one side of the inner box and form one wall of the cooking chamber. Aluminum foil was glued to the underside of the straddler and to all but the 39.4-cm-long portion which covered one side of the outer box and was the outermost side of the SBC. The outermost section was 79.2 cm wide on the long sides and 66 cm wide on the short sides. The inner sections which formed the walls of the cooking chamber were 35.5 cm deep by 48.2 cm wide for the short sides and 68.5 cm wide for the long sides. To attach the outside corners together, holes were drilled 2.5 cm from the bottom and side of each straddler, string was placed through these holes on adjacent straddlers, and they were tied together. The outside part of the straddler could be glued to the outer box, but by tying instead of gluing, the SBC could be taken apart easily to show its component parts. The resulting cooking chamber was 68 cm long, 48 cm wide, and 35.5 cm deep. A piece of aluminum metal (66 by 42 cm) was cut into a tray with 2.5-cm sides, painted black with nontoxic paint, and placed in the bottom of the cooking area. This tray absorbed sunlight and converted it to infrared heat rays.

The cardboard lid was built with a 7.6-cm overhang on each side, and it was lifted off the box when adding or removing the glass jugs or metal pots. The back reflector on the lid was made by making a continuous cut 11.4 cm in from one long and both short sides and then folding back the cardboard on the remaining long side. The bottom of the reflector piece was foiled, and when it was raised it exposed the cooking area in the box. On the bottom of this opening a piece of single-strength window glass (73 by 53 cm) was attached with silicon caulk (General Purpose Sealant, Dow-Corning Corp., Midland, Mich.). The reflective lid (48 by 66 cm) was propped up by a piece of wood (52 by 1.9 by 0.6 cm) whittled to a point at one end and rounded at the other end. The rounded end was attached to the reflective lid by drilling a 0.6-cm hole 1.3 cm from the tip and passing string through this hole and then through holes 2 cm from the edge and 11.4 and 12.7 cm from the top of the reflective lid. The string was tightened and tied. The whittled end of the prop stick rested in one of a dozen 0.6-cm holes in a wooden prop stick holder (35.5 by 1.9 by 0.6 cm). This holder was glued to the lid 3.8 cm from the glass, 8.9 cm from the right short side, and 3.8 cm from the front. The prop stick was then able to fit into the holes to adjust the angle of the reflective lid.

A safety and insulation shield (77 by 54 cm) was cut from a piece of flexible glass polymer fiber designed for solar purposes (type 540, Filon Division, Vistrom Corp., Hawthorne, Calif.). This was placed on top of the glass and was held 0.6 cm above the glass by 5 silicon caulk drops attached to the bottom of the shield. The safety and insulation shield reduced heat losses through the window of the SBC by about 50%, while reducing the amount of sunlight entering the cooking chamber by only about 15%.

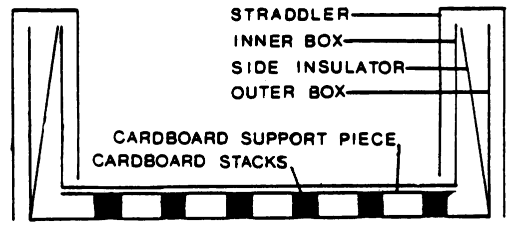

FIG. 1. Cross-sectional diagram of insulated cardboard box portion of SBC.

Water heating procedure in the SBC. Water heated in the SBC was added to glass 3.7-liter cider jugs or similar jugs spray-painted black with High Heat 260 Bar BQ Black (Top Brands, Inc., North Highlands, Calif.). The jugs were filled with tap water or river water to the bottom of the neck and were placed on cake racks (24.4 by 35.5 cm) in the SBC to allow heat to flow to the water from all directions. Temperatures were recorded with a Trendicator 400 T/°C digital, 5-probe thermometer (Doric Scientific, San Diego, Calif.). For water temperatures, probes were placed at the top and bottom of the water so that the sides of the glass jug were not touched. Some oven air temperatures were taken by placing a probe flat on the blackened aluminum tray so that the probe tip measured air and not metal, glass, or foil. Other oven temperatures were taken with an oven thermometer (John L. Chaney Instruments Co., Lake Geneva, Wis.) placed at the back of the cooking chamber. Outside air temperatures were taken with the probe shaded from direct sunlight. The lid of the SBC was carefully placed over the probe cords so as not to disturb their placement, and the reflective lid was propped perpendicular to the glass. For the duration of all SBC experiments, unless otherwise mentioned, the SBC was positioned towards magnetic south, about 17° west of true south in Sacramento. In this position, the sun would shine directly on the SBC at approximately 1:00 p.m. Pacific standard time (2:00 p.m. Pacific daylight savings time [PDT]), about an hour after the sun was at its highest position in the sky for the day.

Inactivation of coliforms in river water heated on a hot plate. Eight experiments were performed as follows. Water from the American River (1.5 liters) was collected in a sterile 2-liter wide-mouth Erlenmeyer flask. The initial water temperature was taken with the Doric thermometer, and samples were then removed for a five-tube most-probable-number (MPN) enumeration of coliforms following standard procedures (3), using lauryl sulfate broth (LSB; BBL Microbiology Systems, Cockeysville, Md.) as the presumptive medium and brilliant green-lactose-bile (BBL) broth as the confirmed medium. The flask was set on a four-unit stirrer with hot plate (MAGNE-4; Cole Parmer Instrument Co., Chicago, Ill.) and stirred with a sterile plastic-coated metal stir bar. A thermometer probe was inserted about 2 cm below the water surface, and the heater was turned on to 10 and the stirrer to 4. At about 52.5°C, the heater was turned down to 3.5 where it remained for the duration of the experiment.

Five 10-ml samples were taken at 2°C intervals from 53 to 63°C and inoculated into 10 ml of double-strength LSB. After sampling was completed for all temperatures, the LSB tubes were incubated at 35°C for 24 to 48 h. Positive presumptive tubes were confirmed for coliforms by transferring a loopful of the LSB into a brilliant green-lactose-bile tube and incubating it at 35°C for 24 to 48 h.

Inactivation of coliforms in river water heated in an SBC. Water was collected from the American River in a sterile 3.7-liter black jug. The initial water temperature was taken with the Doric thermometer, and samples were removed to estimate the initial coliform MPN. Thermometer probes were inserted in the top and bottom of the water, and the jug was placed on the east side of the SBC in two experiments and on the west side in the third experiment. A second 3.7-liter black jug was filled with tap water and placed on the opposite side of the SBC. Water, oven, and outside air temperatures were recorded every hour until the first sampling temperature, 50°C, was reached in the bottom of the river water jug. The water temperatures were then monitored more closely until all sampling temperatures had been reached.

Water samples were taken at 5°C intervals between 50 and 65°C. Sterile 25-ml volumetric pipets were used to remove slightly more than 50 ml from the bottom of the river water jug. This was first added to a sterile 125-ml Erlenmeyer flask and then five 10-ml samples were inoculated into double-strength LSB. These samples were incubated in a water bath at 34 to 35°C in a Gott Tote 12 plastic cooler (Gott Manufacturing Co., Winfield, Kans.) until all samples had been taken. The samples were then removed from the water bath and incubated at 35°C for 24 to 48 h to complete the presumptive test for coliforms. Positive presumptive tubes were confirmed with brilliant green-lactose-bile broth, and only those samples positive in brilliant green-lactose-bile broth were considered to contain coliforms. A completed test for coliforms was performed on about 25% of the positive confirmed samples. On the two occasions when the completed test did not yield coliforms, the entire sample was considered negative for coliforms.

RESULTS

Solar heating of water. In all experiments heating two jugs of water, a difference in the heating rate of the water in the jugs was observed which correlated with the position of the jug in the SBC (Fig. 2). The water on the west side of the cooking chamber heated more rapidly in the prenoon hours, comparable heating rates in both jugs occurred from about noon to 2 p.m. Pacific standard time (or 1 to 3 p.m. PDT), and after 2 p.m. (Pacific standard time) the east water would heat faster than the west water. The top water temperature in each jug was always greater than the bottom water temperature, particularly during the initial heating period (Fig. 2).

Using milk pasteurization conditions of 62.8°C for 30 min as an initial guideline for successful water pasteurization, we felt the bottom water temperature in the jugs should reach at least 65°C. If 65°C were obtained, the total time the water would be at 62.8°C or greater would be ca. 1 h or more (Fig. 2), particularly as the bottom water would cool only about 4°C/h when no sunlight entered the SBC.

From mid-March through mid-September, both 3.7-liter jugs of water could be heated to at least 65°C on sunny or partly cloudy days (Table 1). The highest temperatures recorded for comparable heating times occurred in July and August, the experiments conducted closest to the optimum sun angle on the summer solstice, June 21. By mid-October, the sun angle was too low to heat two 3.7-liter jugs of water to 65°C.

In July, when three 3.7-liter jugs were heated for 7 h starting at 10:00 a.m. PDT, bottom water temperatures above 65°C were obtained in all jugs on sunny days. In early

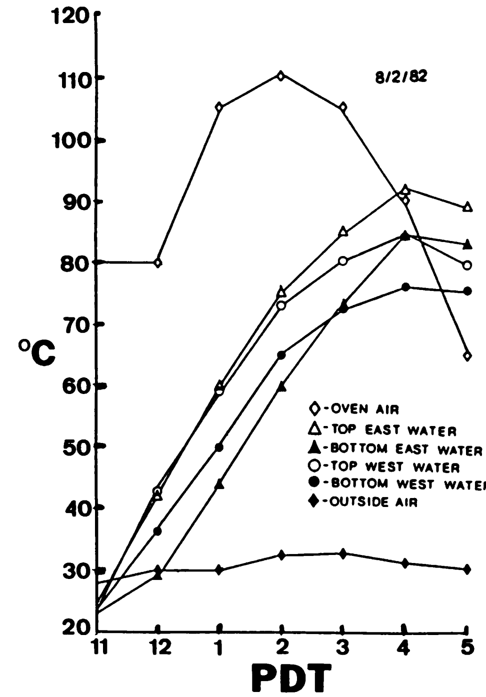

FIG. 2. Solar heating of two 3.7-liter jugs of water in the SBC facing magnetic south. Air and water temperatures were monitored by thermocouple probes placed in the different locations.

August, on comparable days, three 3.7-liter jugs of water were heated for 6 h in the SBC, starting at 11:00 a.m. PDT. In the first experiment, the SBC faced magnetic south and was not repositioned. The resulting maximum bottom water temperatures were 64.1, 67.5, and 70.5°C, respectively. In the second experiment, the SBC was repositioned towards the sun every hour. The resulting maximum bottom water temperatures were 68.4, 73.9, and 78.8°C, respectively, indicating the greater heating ability if the SBC is periodically repositioned.

Heating only one 3.7-liter jug of water for 6 h in the SBC resulted in a bottom water temperature of 94.4°C in late July. When 3.7 liters of water were similarly heated on clear days in November, December, and January, bottom water temperatures of 59.0, 48.2 and 52.2°C, respectively, were obtained. By early March, a bottom water temperature of 65°C or greater could be achieved on sunny days when 3.7 liters were heated in the SBC.

Inactivation of coliforms in river water heated on a hot plate. To determine the temperatures at which coliforms would be inactivated, we performed eight separate experiments in which river water was sampled for an initial coliform MPN and was then heated on a hot plate. Above 50°C, the heating rate was ca. 1°C/2.5 min.

Initial coliform MPN values ranged from 33 to 350/100 ml in the eight experiments. Coliforms were commonly recovered when the river water was heated to 53 to 57°C. At 59°C, there was only one sample in one experiment which was positive for coliforms. No coliforms were recovered at 61 or 63°C. Completed tests were run on 20 to 30% of the confirmed coliform samples, and of the 43 samples, only one from 55°C and one from 57°C failed to give a positive completed coliform test.

Inactivation of coliforms in river water heated in an SBC. In

TABLE 1. Solar heating of two 3.7-liter jugs of water in the SBC at various times of the year[a]

Date	Heating time (h)	Maximum outside air temp (°C)	Maximum water temp (°C)			
			East jug		West jug	
			Bottom	Top	Bottom	Top
7/24/82	6	33.6	84.1	84.1	75.7	78.5
8/2/82	6	33.0	84.5	92.0	72.2	84.6
9/12/82	4.5	32.0	65.0	80.3	71.0	81.4
9/19/82	5	25.0	66.2	67.1	67.0	73.2
10/17/82	7	22.6	61.7	73.3	59.5	69.6
3/15/83	6	22.2	67.1	72.6	67.1	75.8
3/31/83	6	22.5	68.2	77.8	66.5	74.6

[a] Weather conditions were sunny for all experiments except those on 9/19/82 and 3/31/83, when partly cloudy conditions prevailed (30 min of sunshine per h). Experiments started at 11:00 a.m. PDT except those on 9/12/82 and 3/31/83, which started at 10:00 a.m. PDT and those on 10/17/82, which started at 9:30 a.m. PDT.

three experiments, coliforms were assayed in river water heated in the SBC in two 3.7-liter jugs (Table 2). Coliforms were commonly recovered at 50 and 55°C. At 59.5°C, the maximum bottom water temperature reached in one experiment, one of the five 10-ml samples was positive for coliforms. No coliforms were recovered at 60 or 65°C.

Simultaneous water heating and cooking in an SBC. Two experiments were conducted in June in which two 3.7-liter jugs of water were heated while 1.2 and 2.2 kg of potatoes were simultaneously cooked in covered, black porcelain-coated pots (General Housewares Corp., Terre Haute, Ind.). In the first experiment, the first black-painted jug was placed in the SBC with 2.2 kg of potatoes at 10:00 a.m. PDT. The second black jug of water was preheated in the sun in a two-sided aluminum reflector facing south, as described by Metcalf and Logvin (9). After 4 h of heating, the first jug in the SBC reached a bottom water temperature of 66.7°C and was removed. The preheated second jug had a bottom water temperature of 50°C when placed in the SBC at this time and reached 65°C after 2 h of heating. In the second experiment, the water was heated in two 3.7-liter clear glass jugs. Both jugs of water were placed in the SBC with 1.2 kg of potatoes at 10:00 a.m. PDT. After 7 h of heating, the bottom water temperatures were 67 and 69°C, respectively. In both experiments, the potatoes were thoroughly cooked, reaching internal temperatures of ca. 90°C.

Attempts to improve the efficiency of water heating in an SBC. We investigated several water-holding containers to see if the efficiency of water heating in an SBC could be improved. Water in clear glass jugs heated at a rate comparable to that of water in black-painted jugs, but clear jugs lost heat at a slightly greater rate when sunlight no longer entered the SBC.

In two experiments in which 7.5 liters of water were heated in the SBC in a black, metal, 15.1-liter pot with a lid, the bottom water temperature was 3 to 5°C below that reached when two black jugs were used under similar conditions.

In an attempt to maximize the efficiency of heating water in the SBC, four 3.7-liter jugs of water were heated in late May by first heating two jugs 4.5 h until their bottom water temperatures were 65°C, removing them, and adding two other jugs which had been preheated outside in a two-sided aluminum reflector (9) to 46 and 49°C, respectively. After an additional 2 h in the SBC, the bottom water temperature in these two jugs was 65°C. The SBC was initially positioned to be in line with the sun about halfway through the first heating and was repositioned when the second pair of jugs was added to be in line with the sun about an hour later.

DISCUSSION

The differences in the water heating rates when two or more jugs were in the SBC is explained by the constant position of the jugs in the SBC and the variable position of the sun. With the SBC facing magnetic south for the duration of the experiment, the jug on the west side of the SBC received abundant prenoon direct sunlight, whereas the east jug was partially shaded by the east side of the SBC. At solar noon both jugs received equal direct sunlight and the heating rates were comparable. As the sun moved to the west, direct sunlight shifted to the east jug, while the west jug was partially shaded. In experiments extending into the late afternoon, final water temperatures would be greater in the east jug than in the west jug (Fig. 1). In a given jug, top water temperatures were hotter than bottom water temperatures because hot air and water rise and sunlight would fall directly on the tops of the jugs where it would be absorbed and converted to heat. The final water temperatures were a function of the sun angle (time of day and year), weather conditions, and heating time. Outside air temperatures had little effect on the final water temperatures because the SBCs were well insulated. Initial water temperatures could vary by about 10°C without having much effect on the final water temperature, except in the solar-poor period, from November through February.

For the duration of most of our experiments, the SBC faced magnetic south, and the reflective lid was perpendicular to the glass window. One could improve the water-heating ability by repositioning the SBC towards the sun approximately every 2 to 3 h and by adjusting the reflective lid from its perpendicular position early and late in the day, to reflect maximum sunlight into the cooking area. These adjustments would be particularly useful at the beginning and end of the local solar season (March and October in Sacramento). However, we wanted to test the heating ability of the SBC under the least optimal solar conditions but most convenient human conditions. These conditions would allow one to simply place the water jugs in the SBC at the start of the day and remove them when it was convenient either in the evening or on the following day.

Over a 6-month period, from mid-March through mid-September, the SBC could heat two 3.7-liter jugs of water to satisfy requirements for milk pasteurization. One 3.7-liter jug of water could be heated in the SBC to satisfy require-

TABLE 2. Inactivation of coliforms in river water heated in an SBC[a]

Avg heating time (h)	Bottom water temp (°C)	No. of tubes positive for coliforms in five 10-ml samples
0	15.0–16.5	5[b]
3.7	50.0	5
4.1	55.0	3–5
6.5	59.5[c]	1
4.0	60.0[d]	0
4.5	65.0[d]	0

[a] Two 3.7-liter jugs were heated in each of three experiments. River water sampled for coliforms came from the coolest jug. Experiments were performed on 9/12/82, 9/19/82, and 10/17/82.

[b] Initial coliform MPN of samples was 460 to 3,500/100 ml.

[c] 10/17/82 experiment only.

[d] 9/12/82 and 9/19/82 experiments only.

ments for milk pasteurization an additional 2 to 3 weeks at the beginning and end of the solar season. Three 3.7-liter jugs of water could be heated to satisfy requirements for milk pasteurization about 6 weeks on either side of the summer solstice, June 21. Successful water heating could be accomplished even under partly cloudy conditions when there was ca. 30 min of sunshine per h (Table 1, experiments on 9/19/82 and 3/31/82). Care must be taken not to touch heated jugs with unprotected hands, as water at 60 and 70°C takes only 5 and 1 s, respectively, to cause a severe skin burn (10).

We were able to simultaneously cook 1 to 2 kg of potatoes and heat two 3.7-liter jugs of water to satisfy requirements for milk pasteurization during the best solar season. If the SBC were used only for cooking, it could easily cook 7 kg of food on sunny or partly cloudy days from mid-March through mid-September, like the Kerr-Cole Eco-Cooker our SBC was designed after. The flexibility of the SBC to serve both cooking and water pasteurizing functions enhances its practicality. The amount of food and the cooking requirements of the food will determine how much water can simultaneously be heated to pasteurizing conditions in the SBC and whether rotating water jugs in the SBC or preheating water in a simple reflective device is needed.

The main objective of this study was to explore the possibility of using an SBC and solar energy to pasteurize relatively large quantities of water. Previous studies indicated that the time-temperature conditions for milk pasteurization (62.8°C for 30 min or 71.7°C for 15 s) should be sufficient to kill the bacteria, rotaviruses, and enteroviruses commonly transmitted in contaminated water (1, 6, 13, 14; M. K. Estes and D. Y. Graham, Abstr. Annu. Meet. Am. Soc. Microbiol. 1978, S338, p. 268). Although *Giardia lamblia* cysts are somewhat resistant to chlorine in cold water (7), they are readily inactivated by heat. *G. lamblia* cysts prepared for immunization studies were inactivated in distilled water at 56°C for 10 min (11; K. DuPuis, personal communication). Cysts of *Giardia muris* had a thermal death point of 54°C (F. W. Schaeffer, E. W. Rice, and J. C. Hoff, personal communication), and the thermal death point of *Entamoeba histolytica* cysts has been reported to be 50°C (4). All of these data indicate that temperatures around 60°C or greater for an hour or longer will inactivate microbial pathogens found in water. As temperatures increase from 60 to 70°C, the time required for microbial inactivation is expected to decline significantly, as it does with milk pasteurization.

In our studies, we found that coliform bacteria in raw river water heated either in the laboratory or in the SBC were inactivated at temperatures of 60°C or greater. It is possible that pathogenic microbes found in raw water are more heat resistant than the coliform group, although the bacteria, viruses, and protozoans responsible for diarrheal diseases in Bangladesh and The Gambia do not include microbes with unusual heat resistance (2, 12). Our results indicate that if the bottom water temperature in a glass jug heated with solar energy in an SBC is raised to 65°C or greater, the water will be above the milk pasteurization temperature of 62.8°C for at least an hour. This heat should be sufficient to kill pathogenic microbes and thus pasteurize the water. If some waterborne microbe is found with unusual heat resistance properties, adjustments could be made to achieve higher water temperatures by placing less water in the SBC, by refocusing the SBC periodically and adjusting the reflective lid, by rotating jugs in the SBC and preheating the latter jugs with a simple two-sided reflective device, or by building a larger SBC which would receive greater amounts of solar energy.

When water is obtained from a potentially contaminated source, one recommendation made to ensure the microbiological safety of the water is to boil the water (5), sometimes for as long as 20 min. When one considers the pathogenic microbes found in water, however, this drastic heating seems excessive, just as milk need not be boiled to pasteurize it. We suggest that the reason for recommending boiling water results not from the need to reach near 100°C to kill the pathogenic microbes, but from the difficulty of determining the accurate temperature of heated water by visual observation alone. When water is heated on a stove, water vapor appears at about 50°C, and the first good bubbles appear at about 55°C, which could be misinterpreted for boiling temperatures. A recommendation to boil would ensure that water would continue to be heated to temperatures which would actually kill all pathogens.

When conventional energy sources are used to heat water to pasteurizing temperatures, such massive amounts of energy are consumed that it is economically prohibitive to do this routinely. Using solar energy for applications with microbiological significance is a new concept which the Kerr-Cole SBC has made possible. We built an SBC with a cardboard exterior which could be taken apart to show its construction. However, for usage over many years, an SBC with a wood exterior, like the Kerr-Cole patio stove (Kerr Enterprises) would be preferable.

Pasteurization of water with solar energy could be practical in remote areas in the United States or in emergency situations. However, the major application of solar water pasteurization could come in countries rich in sunshine but without reliable water purification systems. In countries near the equator, significant solar heating should be possible at any time of the year on days which have at least 30 min of sunshine per h. Cloudy days would preclude solar heating of water to pasteurization temperatures.

The large capacity and ease of use of the SBC has led from the cooking of a complete meal to the possibility of pasteurizing several gallons of water with solar energy. Similarly, SBCs could be used to pasteurize 7 to 10 kg of soil which could then be used for planting seeds to grow healthy seedlings, and contaminated hospital materials could be disinfected before disposal. The versatility of the SBC will probably lead to other novel uses for solar energy which have microbiological implications.

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