Simple filtration and low-temperature sterilization of drinking water

Nandini Nimbkar and Anil K. Rajvanshi*

Nimbkar Agricultural Research Institute, Phaltan 415 523, India

Waterborne infectious diseases are transmitted primarily through contamination of the water sources with excreta of humans and animals. The water treatment technologies available are fairly costly and not sustainable. Solar energy can be used effectively for sterilizing drinking water during clear and partially cloudy days. However, during mostly cloudy days the temperatures required may not be reached. A combination of traditional cotton-sari filtration and heating of water to simulate a solar boiler was evaluated as a water sterilization treatment. Experimental data showed that filtration of raw water through four-layered cotton-sari cloth (250 μm) reduced the coliform count and further heating to sub-boiling temperatures (55–60°C) for less than an hour resulted in complete inactivation of coliforms. The use of cloth filtration and low-temperature solar sterilization can be an effective, feasible and environmentally sustainable technique of disinfection to obtain clean drinking water.

Keywords: Coliforms, drinking water, solar sterilization, waterborne pathogens.

SAFE drinking water is the basic need of human beings. Microbial contamination of drinking water is a common pollution hazard. Every day diarrhoeal diseases from easily preventable causes claim the lives of approximately 5000 young children throughout the world[1]. There are many types of bacteria, viruses and protozoans responsible for diarrhoeal diseases with a range of persistence in water, infectious dose and health significance. The methods to isolate and enumerate the different organisms are complex, expensive, time-consuming and specific to each organism. Coliform bacteria are good indicator organisms for the presence of pathogenic bacteria due to their relationship with the pathogenic bacteria, their relative ease of determination by simple methods and their occurrence in large quantities in human faeces. For drinking water, WHO recommends that *Escherichia coli* or thermotolerant coliforms must not be detectable in any 100 ml sample[2].

Disinfection of water may be accomplished by chemicals, direct application of heat and filtration techniques. The methods like chlorination and ozonation have side effects[3]. Boiling of water is not necessary for disinfection and only low-temperature sterilization is sufficient. In fact, boiling requires about twice the energy as heating to 65°C (sterilization temperature), plus the extra time of monitoring, and the time and expense of obtaining fuel[4].

Sterilization via solar energy can play an important role in improving water quality, particularly in those regions that enjoy a hot, sunny climate[5]. It has been reported that coliform bacteria in raw river water heated in a solar box cooker were inactivated at temperatures of 60°C or greater, although it is not indicated how long the water samples were maintained at this temperature before being tested for bacteria[6]. Spinks *et al.*[7] carried out thermal inactivation analyses on eight species of non-spore-forming bacteria and concluded that the temperature range from 55°C to 65°C was critical for effective elimination of enteric pathogenic bacterial components. Again, there was no mention of how long the water needs to be kept at these temperatures to achieve inactivation. When a solar heater was used for disinfection, it was observed[8] that in 99% of the cases, coliform removal was total for effluent temperatures of 55°C. However, for safety reasons 60°C was established as the minimum disinfection temperature. Jorgensen *et al.*[9] showed that it is possible to eliminate coliform and thermotolerant coliform bacteria from naturally contaminated river water by heating to temperatures of 65°C and above with solar radiation in a flow-through system of copper pipes. However, they recommended that to provide a good safety margin an outlet temperature of 75°C be used. Overall, none of these

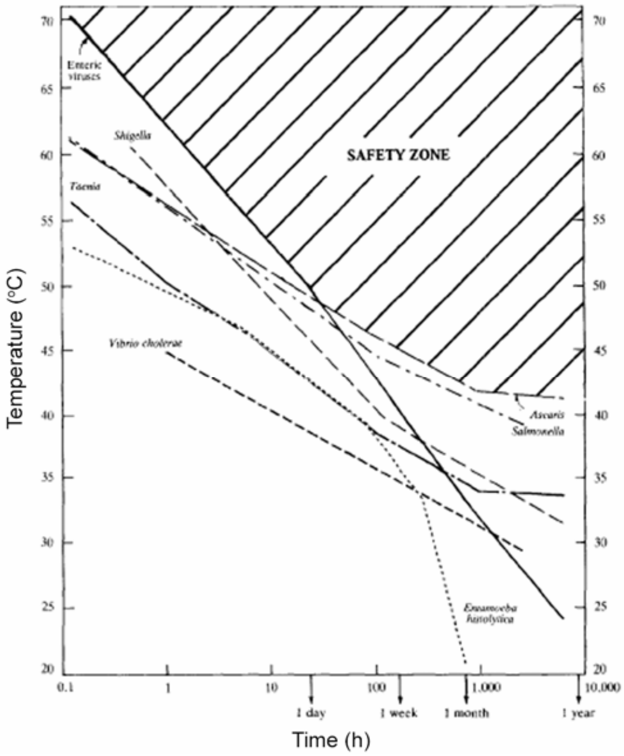

Figure 1. Temperature–time relationship for safe water pasteurization. The hatched area is the safe zone for all common pathogens. (Source: Feachem *et al.*[10].)

*For correspondence. (e-mail: anilrajvanshi@gmail.com)

studies specifies the time period for which the water has to be maintained at a given temperature for reliable pasteurization.

Feachem *et al.*[10] gave conservative estimates of the amount of time needed at various temperatures to inactivate the various pathogens found in human and animal excreta (Figure 1). This semi-log plot of time versus temperature shows that the time required to pasteurize decreases exponentially with temperature. Therefore, rapid sterilization can be achieved at temperatures of 70°C. However, solar collectors (even efficient ones) cannot reach this temperature during cloudy days. Though Feachem *et al.*[10] have shown that pathogen inactivation is possible at 50–55°C, it may require one day to achieve this. This is more or less impossible to do with a solar hot-water system.

Colwell *et al.*[11] found that four-layered saris if used for filtering water removed the plankton and particulate matter of > 20 μm size from water, thus eliminating 99% of *Vibrio cholerae* cells attached to them and reducing turbidity and pathogen count simultaneously. Also a large number of women using such filtration perceived a positive decline in the incidence of diarrhoea in their families. Therefore, to test if disinfection could be achieved rapidly at a temperature lower than 60–65°C, we filtered the water through four-layered cotton-sari cloth (250 μm) before heating it. Cloth filtration is already a common practice in rural areas, especially when water becomes turbid during the rainy season and when bacteriological quality of water is poor.

Hence a strategy to filter the water through a cotton-sari cloth and then to use thermal inactivation was followed. With this strategy excellent water treatment can be effected rapidly at 55°C. Details of this procedure follow.

Solar disinfection or SODIS is one of the simplest methods for providing acceptable quality drinking water. The SODIS technique involves storing contaminated drinking water in transparent plastic or glass bottles that are placed in direct sunlight for periods of up to 8 h before consumption[12]. If water temperatures exceed 50°C in SODIS, 1 h of exposure is sufficient to obtain safe drinking water[13]. This is due to the synergy between the optical and thermal inactivation processes. However, the use of plastics in SODIS is known to be a problem for environment and human health. The leaching of antimony from polyethylene terephthalate (PET) containers may lead to endocrine-disrupting effects[14]. Westerhoff *et al.*[15] found that exposure to elevated temperatures (60°C or more) significantly increases the concentration of antimony in PET-bottled water. The evidence suggests that PET bottles may yield endocrine disruptors under conditions of common use, particularly with prolonged storage and elevated temperatures[16].

Due to the chemical leaching and other perceived problems in SODIS, such as requirement of low turbidity in water and good sunshine, it was decided to study only thermal inactivation of indicator bacteria at sub-boiling temperatures.

To simulate the sterilization of water in a solar boiler, a laboratory experiment was carried out using a constant temperature water bath. Untreated water of Nira Right Bank Canal used by the local people for drinking was used in the experiments. Water samples were collected in 1 liter sterilized flasks directly from the tap originating from the tank in which the canal water was stored and their temperature was recorded. The water sample was sub-divided into 100 ml aliquots which were poured into a set of sterilized 100 ml glass flasks and plugged with sterile cotton. These flasks were immersed in the constant temperature water bath and heated. A series of temperature treatments of 50°C, 55°C, 60°C, 65°C and 70°C were carried out separately each for 15, 30, 45 or 60 min.

Immediately after heating, the water sample was analysed using a standard total coliform fermentation technique to determine the most probable number (MPN) of coliform bacteria present per 100 ml of water sample[17,18]. The test was performed in three steps: presumptive phase, confirmed phase and completed phase. Three replications of each test were carried out. From the results of the confirmed phase, the MPN of organisms per 100 ml water was obtained from the standard five-tube MPN statistical table[19].

The initial MPN count of the original water sample in this experiment before the heat treatments was 350–920 coliforms per 100 ml. From the data of standard multiple tube fermentation assay (Table 1), it was observed that at 60°C and above the coliforms were inactivated within 15 min (MPN = 0). But at 55°C the coliforms in unfiltered water were inactivated only when it was heated for more than 30 min. Treatment temperature of 50°C was ineffective to inactivate coliforms in unfiltered water unless heating was carried out for more than an hour. Therefore, water was filtered through a four-layered sari cloth before heating.

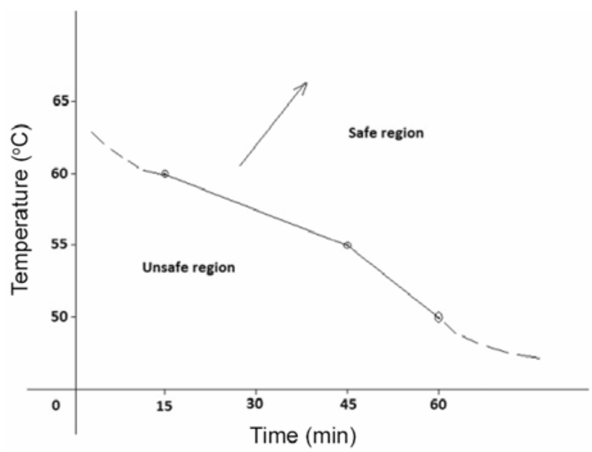

Figure 2. Temperature–time relationship for safe water pasteurization. In the area above the line no colony forming units of coliforms survive.

Table 1. Most probable number (MPN) of organisms in unfiltered and cloth-filtered water per 100 ml

Temperature (°C)	Time of treatment (min)	MPN in unfiltered water	MPN in filtered water
50	15	213	59
	30	131	51
	45	7.5	11.5
	60	4.6	0
55	15	11.2	0
	30	5.7	0
	45	0	0
	60	0	0
60, 65, 70	15	0	0
	30	0	0
	45	0	0
	60	0	0

Table 2. Comparative data of MPN and colony forming units (CFUs) of coliforms in cotton sari-filtered water

Sample		MPN	CFU count	Remarks
Raw water		350–920	125	Untreated canal water
Raw water filtered with four-layered cotton-sari cloth		215–825	97	Coliform count declines
Raw water filtered with four-layered cotton-sari cloth and heated				
50°C	15 min	14–130	55	Coliforms in water sample were inactivated after heating for 60 min
	30 min	3.7–130	32	
	45 min	3.7–23	2	
	60 min	0	0	
55°C	15 min	0	3	Coliforms in water sample were inactivated after heating for 45 min
	30 min	0	1	
	45 min	0	0	
	60 min	0	0	
60°C	15 min	0	0	Coliforms in water sample were inactivated after heating for 15 min
	30 min	0	0	
	45 min	0	0	
	60 min	0	0	

From Table 2 it can be seen that the filtration of water through four-layered cotton-sari cloth and further heating at 55°C for a minimum of 45 min inactivated the coliforms. MPN of coliforms in the water was zero even when heated at just 55°C for 15 min after filtering. However, only when heating was carried out for a duration of 60 min at 50°C or 45 min at 55°C did it give both zero MPN and colony forming units (CFU).

It has been reported that the coliform bacteria may not always show up in every water sample from a given source. They can be sporadic and sometimes seasonal[20]. Nevertheless, the results of our experiment indicated that heating of water at sub-boiling temperatures (50–60°C) for a short duration after filtering it can significantly reduce the pathogen population by an order of magnitude.

Thus a good strategy for sterilization of water is its filtration through four-layered cotton-sari cloth and further heating for a minimum of 45 min at 55°C or 60 min at 50°C, to completely eliminate the coliform population (Table 2 and Figure 2). These heating conditions for water can be achieved even on a partially cloudy day in a not-so-efficient solar boiler.

1. WHO/UNICEF, Water for life: making it happen. WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation, 2005; www.who.int/water_sanitation_health/waterforlife.pdf (accessed on 24 April 2012)
2. Gadgil, A., Drinking water in developing countries. *Annu. Rev. Energy Environ*., 1998, **23**, 253–286.
3. Saitoh, T. S. and El-Ghetany, H. H., A pilot solar water disinfecting system: performance analysis and testing. *Sol. Energy*, 2002, **72**, 261–269.
4. Pejack, E., Solar pasteurization. In *Drinking Water Treatment, Focusing on Appropriate Technology and Sustainability* (eds Ray, C. and Jain, R.), Springer Science + Business Media B.V., 2011, pp. 37–54.
5. Joyce, T. M., McGuigan, K. G., Elmore-Meegan, M. and Conroy, R. M., Inactivation of fecal bacteria in drinking water by solar heating. *Appl. Environ. Microbiol*., 1996, **62**, 399–402.

6. Ciochetti, D. A. and Metcalf, R. H., Pasteurization of naturally contaminated water with solar energy. *Appl. Environ. Microbiol.*, 1984, **47**, 223–228.
7. Spinks, A. T., Dunstan, R. H., Harrison, T., Coombes, P. and Kuczera, G., Thermal inactivation of water-borne pathogenic and indicator bacteria at sub-boiling temperatures. *Water Res*., 2006, **40**, 1326–1332.
8. Marquez-Bravo, L. G., Solar disinfection. In Regional Symposium on 'Water Quality: Effective Disinfection', CEPIS, OPS. Lima, Peru, 27–29 October 1998, pp. 1–21; www.bvsde.ops-oms.org/bvsacg/i/fulltext/symposium/ponen14.pdf (accessed on 27 April 2012).
9. Jorgensen, A. J. F., Nohr, K., Sorensen, H. and Boisen, F., Decontamination of drinking water by direct heating in solar panels. *J. Appl. Microbiol*., 1998, **85**, 441–447.
10. Feachem, R. G., Bradley, D. J., Garelick, H. and Mara, D. D., *Sanitation and Disease: Health Aspects of Excreta and Wastewater Management*, John Wiley, Chichester, 1983.
11. Colwell, R. R. *et al*., Reduction of cholera in Bangladeshi villages by simple filtration. *Proc. Natl. Acad. Sci. USA*, 2003, **100**, 1051–1055.
12. Wegelin, M., Canonica, S., Mechsner, K., Fleischmann, T., Pesaro, F. and Metzler, A., Solar water disinfection: scope of the process and analysis of radiation experiments. *J. Water SRT-Aqua*, 1994, **43**, 154–169.
13. Mahvi, A. H., Feasibility of solar energy in disinfection of drinking water in Iran. *Am.-Eurasian J. Agric. Environ. Sci*., 2007, **2**, 407–410.
14. Choe, S. Y., Kim, S. J., Kim, H. G., Lee, J. H., Choi, Y., Lee, H. and Kim, Y., Evaluation of estrogenicity of major heavy metals. *Sci. Total Environ*., 2003, **312**, 15–21.
15. Westerhoff, P., Prapaipong, P., Shock, E. and Hillaireau, A., Antimony leaching from polyethylene terephthalate (PET) plastic used for bottled drinking water. *Water Res*., 2008, **42**, 551–556.
16. Sax, L., Polyethylene terephthalate may yield endocrine disruptors. *Environ. Health Perspect*, 2010, **118**, 445–448.
17. Steel, E. W., *Water Supply and Sewerage*, McGraw-Hill Series in Sanitary Science and Water Resource Engineering, McGraw Hill, New York, 1960, 4th edn, pp. 209–211.
18. Anon., *Guidelines on Standard Analytical Procedures for Water Analysis*, Water Quality Analysis, Technical Assistance, Hydrology Project, Government of India and Government of The Netherlands, New Delhi, 2003, vol. 7, pp. 4–25.
19. Anon., In *Official Methods of Analysis of AOAC International* (ed. Cunniff, P.), Arlington, Virginia, 1995, 16th edn, vol. 1, p. 16.
20. Anon, Coliform bacteria and drinking water. In *Environmental Health Fact Sheet*, Michigan Department of Environmental Quality, 1998, p. 2.

ACKNOWLEDGEMENT. We thank Mr Abhijit Ranaware, Hyderabad and Mr Matt DeAmico, USA for help.

Received 27 June 2012; revised accepted 7 January 2013