Sunshine and fresh air: A practical approach to combating water-borne disease

by Rob Reed

Sunlight will destroy much of the faecal bacteria present in contaminated drinking-water — but only as long as the water contains sufficient oxygen. What opportunities are there to improve the quality of drinking-water in consistently sunny climates?

WHILE THE ANTIMICROBIAL properties of sunlight have been known for many years, it is only recently that solar radiation has been proposed as a means of decontaminating water. The pioneering work of Professor Acra and his colleagues at the University of Beirut in the 1980s demonstrated that a wide range of microbes, including pathogenic bacteria and viruses, can be inactivated by the exposure of contaminated water to sunlight in transparent glass or plastic containers.[1] Others have suggested that solar disinfection can give variable results, casting doubt on its practical application.[2]

Significance of oxygen

Recent research in the UK has shown that the effectiveness of solar decontamination of water is strongly dependent upon the oxygen status of the water.[3] In controlled tests using water contaminated with either pure cultures of faecal bacteria, freshly voided faeces or raw sewage, exposure to full-strength, natural sunlight for several hours caused a substantial decrease in the bacterial count when the water was fully oxygenated, while deoxygenated water gave a far slower rate of decrease.[4]

Figure 1 below shows a representative set of data for faecal coliform bacteria in sewage-contaminated water[5]: it is worth noting that the vertical axis is a logarithmic one, showing a decrease in the number of bacteria of more than one thousand-fold in less than five hours under oxygen-saturated conditions, with a decrease of approximately ten-fold over the same period under deoxygenated conditions.

Consistent microbiological results have been obtained on illumination of fully-oxygenated water on dozens of occasions over several months in summer, and in winter conditions at various water temperatures, with a range of bacteria including faecal indicators and pathogens. These findings provide a plausible explanation for the variable results of earlier researchers, who used water of unknown oxygen content — since natural waters will vary in their oxygen status, any use of oxygen-depleted water would have led to a lower, variable rate of bacterial inactivation.

The underlying reason for the rapid decrease in bacterial numbers illustrated in Figure 1 is the light-dependent production of reactive forms of oxygen, including oxygen-free radicals and hydrogen peroxide, which are similar to those implicated in ageing and in some forms of human disease. These reactive oxygen intermediates are a temporary product of the action of sunlight in oxygenated water, with no significant residual effect, once the sample is removed from sunlight. The process has been termed solar photo-oxidative disinfection,[3] or 'sol-air' water treatment,[4] to emphasize the combined roles of light from the sun and oxygen from the air. There is also some evidence that other microbial groups may be inactivated including viruses[1] and selected protozoal pathogens (e.g. *Giardia lamblia*[6]), though to a lesser extent than for most bacteria.

Sean Sprague/Panos Pictures

Burkina Faso: Practical solutions are needed where tap-water is not available.

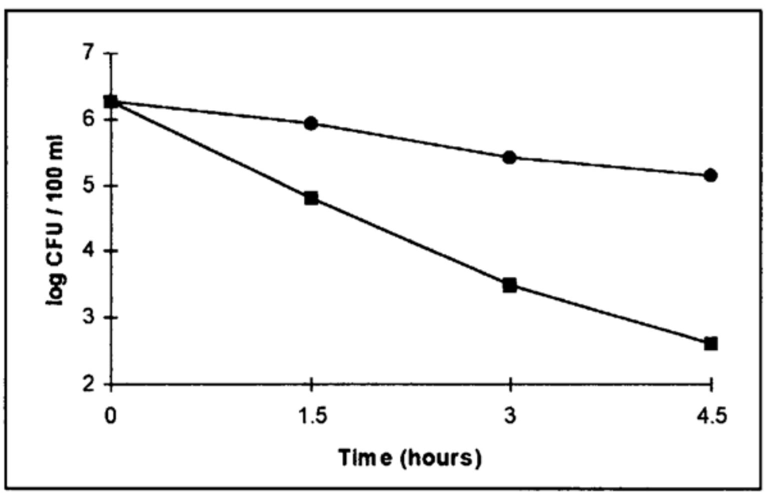

Figure 1. Inactivation of faecal coliform bacteria in sewage-contaminated water exposed to sunlight under aerobic conditions (squares), and anaerobic conditions (circles).

Practical considerations

Clearly, over several hours, sunlight and oxygen can act together to inactivate faecal bacteria. This has important implications for the use of sunlight in small-scale water treatment (typically, in vessels containing up to 2 litres of contaminated water). The most significant practical aspect of solar photo-oxidative disinfection is that the oxygen level of the water must be kept close to its maximum value during exposure to full-strength sunlight —

one easy way to ensure this is to oxygenate the water beforehand, by mixing it with air.

Simple experiments show that a plastic or glass bottle three-quarters filled with deoxygenated water, and capped, if shaken vigorously for a couple of minutes, will create air bubbles which will restore its oxygen level to near saturation. During exposure to sunlight, any microbes present in the water may consume dissolved oxygen, reducing the effectiveness of the disinfection process. Because of this, it is worth shaking each bottle a few times during its exposure to sunlight, to ensure that the oxygen level is kept close to its maximum.

A fieldworker should find it relatively simple to test the oxygen status of a particular water source under field conditions using a dilute solution of an oxygen-sensitive dye such as resazurin or methylene blue, which will decolourize as the dissolved oxygen is used up — a pilot study would show how rapidly the oxygen was consumed for a particular water source, enabling a mixing regime to be used which ensures that a high oxygen level is maintained during the illumination period. In the absence of such testing, the bottles should be shaken at the outset, and at least four times during illumination.

Solar photo-oxidative disinfection gives consistently effective results when bottles are illuminated by sunlight of sufficient intensity to give clearly-defined shadows, removing the need to assess the amount of sunlight accurately. Of course, the process is slowed under cloudy conditions. Professor Acra's team has shown that the most favourable solar conditions are obtained between the latitudes of 15° and 35° North and South of the equator, where sunlight is both consistent and predictable, with slightly less favourable conditions in equatorial and tropical regions (between latitudes of 0° and 15°), due to higher cloud cover.[1]

Water turbidity and colour will reduce the rate of bacterial inactivation, but such negative effects will only be significant for highly turbid or highly coloured waters, where the light transmission is reduced to less than half of the surface value. Consequently, solar photo-oxidative disinfection may be of practical significance only for relatively clear water sources (<100 NTU), where the turbidity or colour of the water does not restrict substantially the penetration of sunlight. During flood conditions, water turbidity and colour may increase significantly, making the process ineffective: such waters could only be decontaminated after initial processing, for example, small-scale rapid sand filtration, flocculation, coagulation or settlement might be used to reduce the gross turbidity and colour of the water, before illumination. An additional advantage of such pre-treatment would be the removal of a proportion of the contaminating microbes, prior to solar photo-oxidation.

Clear-glass bottles restrict the penetration of the short-wave ultra-violet component of sunlight (UV-B), leading to a slightly slower rate of microbial inactivation.[1] They may prove to be more durable in the long term, however, and an additional advantage is that they are completely inert — some plastic bottles may leach small amounts of plasticizers into the water as the temperature increases during illumination, and they may become increasingly opaque to short-wavelength light through prolonged exposure to the sun.

Step by step

Solar photo-oxidative disinfection can be carried out in the home by individuals, families or small communities, with no need for significant financial investment or external agency support — the only requirement is sufficient bottles to provide enough drinking-water to meet each person's daily needs. Solar water treatment might be an attractive approach in low-income communities lacking the funding for high-cost engineering solutions. The following procedure — illustrated in Figure 2 on page 29 — should ensure optimum results:

- fill bottles (leaving an air space of approximately one-quarter of the vessel volume) early in the morning, direct from the contaminated source;
- cap each bottle, then shake vigorously for a few minutes, to ensure oxygen-saturation. Wipe away any visible dirt from the surface of the bottle;
- leave bottles upright in full sunlight all day; but shake regularly (at least four times during the day), to ensure maximum photo-oxidation. Choose your site carefully — the bottles must not be shaded by each other, or by trees, walls, etc. at any stage;
- store treated bottles overnight, allowing the water to cool down for next-day use: prepare and treat fresh bottles every day.
- rinsing and cleaning should present few problems, since the same (contaminated) water source can be used — any contaminant bacteria on the outside of the bottles will be inactivated rapidly on exposure to sunlight. Using clear plastic bottle-tops allows sunlight to penetrate to the very top of the neck, ensuring a hygienic surface when the top is removed, for drinking. Counter the

Sean Sprague/Panos Pictures

Collecting water from the river at Bamako, Mali — storing drinking-water in open containers can result in dangerously high levels of contamination.

possibility of long-term algal growth on the inner walls of the bottles by vigorous cleaning, shaking and rinsing each time they are used.

Applications

Solar photo-oxidative disinfection is too slow a process to make it an attractive option for those communities where a reliable bulk water-treatment process currently exists, for example, chemical disinfection or bed filtration. But it can be appropriate where there is no realistic alternative, and where there is an unfulfilled need for water treatment, which might include:

- the provision of treated water for people in rural villages and urban shanty communities, who may have access only to sewage-contaminated surface water;
- the provision of decontaminated water to widely-dispersed rural populations, where a piped supply is impractical, and where chemical treatment is too costly;
- emergency water supplies for refugees and in war zones, where conventional water supplies may be unavailable or inoperative (though the large-scale provision of sufficient bottles represents a significant practical limitation);
- short-term treatment, in response to a specific contamination event, for example stormwater/flooding;
- the provision of treated drinking-water for babies and infants, most at risk from diarrhoeal disease; it may be most realistic to target such 'at risk' individuals, rather than trying to change the drinking habits of a whole community;
- short-term treatment of a source contaminated with pathogenic bacteria, such as during an outbreak of cholera or bacterial diarrhoea, in the absence of an alternative treatment or a suitable water source; and
- provision of decontaminated water for preparing oral rehydration solution where no reliable, safe water supply exists.[1]

Solar photo-oxidation and hygiene education

While solar photo-oxidative disinfection has been shown to be effective under controlled laboratory conditions, it is likely to be restricted in its practical applications, and cannot be regarded as a panacea for all water-borne disease. It may, however, offer fieldworkers who are interested in encouraging safe practices a number of possible advantages:

Figure 2. The four stages of solar photo-oxidative disinfection.

- it could be taught and used as a routine preventative measure, in contrast to microbiological testing and treatment procedures, which are often retrospective and require additional apparatus and chemicals;
- it would eliminate the possibility of post-collection contamination of water — the treated water remains within a uncontaminated, closed container, until consumption;
- it could be incorporated into a village or school hygiene-education programme — if necessary, a simple microbiological tube test for faecal coliforms could be used at the outset, to demonstrate practically that contaminated water can be treated by exposure to sunlight, in contrast to an equivalent water sample kept in darkness;
- it could be used to encourage the integration of water provision and health; and
- education — for example, the illustration shown in Figure 2 could be used, in poster format, as part of a hygiene education programme.

Notes and references

1. Acra, A., Raffoul, Z., and Y. Karahagopian, *Solar Disinfection of Drinking-water and Oral Rehydration Solutions: Guidelines for household application in developing countries*, Unicef, 1984.
2. MacKenzie, T.D., Ellison, R.T., Mostow, S.R., 'Sunlight and cholera', *Lancet*, Vol. 340, 1992.
3. Reed, R.H. 'Solar inactivation of faecal bacteria in water: The critical role of oxygen', *Letters in Applied Microbiology* (in press), 1997.
4. Reed, R.H. 'Sol-air water treatment', 22nd WEDC Conference Proceedings, 1996.
5. Raw sewage was used to contaminate oxygenated (aerated) and deoxygenated (helium-bubbled) water, which was then transferred to clear-plastic drinks bottles (2-litre capacity), exposed to full-strength sunlight and sampled at hourly intervals by membrane filtration, with subsequent incubation on membrane lauryl sulphate medium at 30°C for 4 hours, followed by 14 hours at 44°C, in accordance with standard UK methods — *Report 71*, Department of Environment, HMSO, London, 1994.
6. Lawand, T.A., Alward, R., Odeyemi, O., Hahn, J., Kandpal, T. C., and J. Ayoub, *Solar Water Disinfection: Proceedings of a workshop held at the Brace Research Institute*, Montreal, Canada, IRDC, 1988.

Dr R.H. Reed is the senior microbiologist in the Division of Biomedical Sciences, University of Northumbria, Newcastle upon Tyne NE1 8ST, UK. Fax: +44 191 227 3519. E-mail: rob.reed@unn.ac.uk. Dr Reed is keen to communicate with fieldworkers and researchers in developing countries who are interested in applying the principles of solar photo-oxidative disinfection under appropriate conditions. Further information, copies of relevant articles and advice on microbiological field-testing for faecal bacteria or oxygen status will be provided, on request.