

## Sol-air water treatment

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THE LACK OF clean water is a significant problem in many developing countries and there is an urgent need for practical, inexpensive, sustainable methods for the production of drinking water, especially on a small scale at the individual and family levels. While the antimicrobial properties of solar radiation have been known for centuries, the recent work of Acra and his colleagues has shown that natural sunlight may be used to decontaminate water in countries with a consistently sunny climate (Acra et al., 1984). However, other studies have provided conflicting data on the effectiveness of solar water disinfection, indicating that additional factors may be involved and limiting the practical application of this technique in the prevention of water-borne disease (e.g. Miller, 1988; MacKenzie et al., 1992). The present study was carried out to evaluate the role of oxygen in solar water disinfection.

### Experimental work and results

Initial experiments were carried out using pure cultures of the indicator bacteria *Escherichia coli* NCTC 8797 and *Enterococcus faecalis* NCTC 775 exposed to mid-day sunlight in 2 litre plastic bottles, filled with either (i) fully oxygenated water (bubbled with sterile air) or (ii) deoxygenated water (bubbled with sterile helium). Samples were shielded from sunlight and processed in dim room light, to avoid photoinactivation. After dilution, known volumes of each sample were surface spread onto non-selective media (nutrient agar or brain-heart infusion agar) and incubated at 37°C for 18 hours: Colony counts (CFU/ml) are shown in Figures 1 and 2.

The exposure of actively growing cultures of *E. coli* and *Ent. faecalis* to sunlight caused a rapid decrease in the bacterial count under aerobic conditions, while the illuminated, anaerobic samples showed far slower rates of inactivation. In darkness, there were no significant changes in CFU/ml, irrespective of oxygen status (data not shown). The dynamics of inactivation broadly follow first order kinetics, based on log-linear plots. The times required to inactivate 99.9 per cent of the bacteria ( $T_{99.9}$ ) have been calculated by linear regression analysis from the data shown in Figures 1 and 2. For both micro-organisms, the  $T_{99.9}$  values were lowest in sunlight under aerobic conditions, with *E. coli* having a  $T_{99.9}$  of 100 minutes under aerobic conditions and 360 minutes in the absence of oxygen while the corresponding  $T_{99.9}$  values for *Ent. faecalis* were 90 minutes (aerobic) and 1030 minutes (anaerobic). Under anaerobic conditions, *Ent. faecalis* was more resistant to the effects of sunlight than *E. coli*. However, both organisms showed comparable rates of inactivation under aerobic conditions. Similar trends have been observed in several separate experiments with actively growing bacterial cultures.

The possibility that the bacteria were sub-lethally injured, rather than killed, by the combination of sunlight and oxygen was assessed by performing further counts on each sample 24 hours after they had been illuminated: no increases in CFU/ml were observed, indicating that the bacteria had been irreversibly inactivated.

Subsequent experiments have shown a similar trend with bacteria obtained directly from human faeces, sus-

Figure 1. *Escherichia coli*

Figure 2. *Enterococcus faecalis*

Figure 3. Faecal coliforms

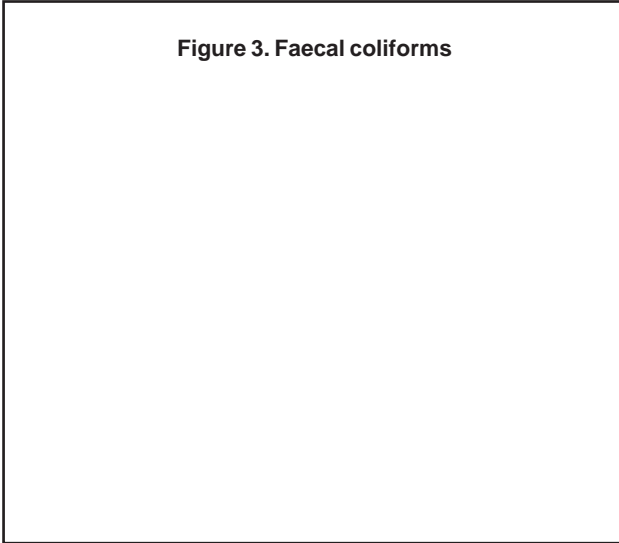
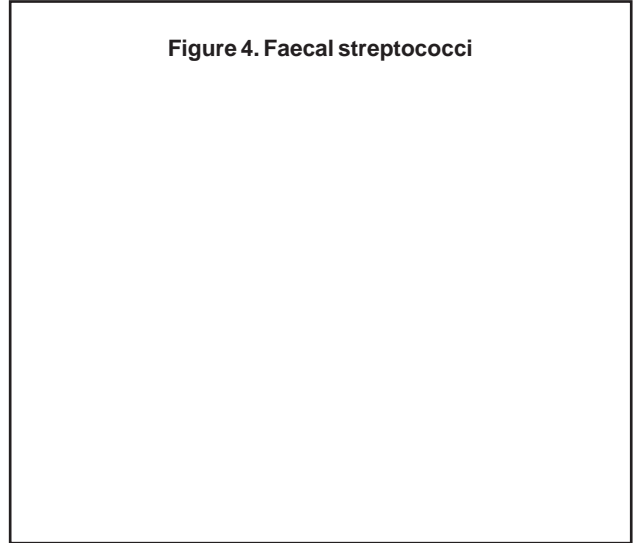


Figure 4. Faecal streptococci



pended (at  $\gg 0.05$  per cent w/v) in plastic bottles containing oxygenated or deoxygenated water and illuminated in mid-day sunlight, as before. Samples were assayed for faecal coliforms (FC) and faecal streptococci (FS) using selective conditions (membrane filtration and incubation on membrane lauryl sulphate medium for FC and Slanetz and Bartley medium for FS, with pre-incubation at 30°C followed by culture at 44°C, according to standard microbiological methods (Anon., 1994). Despite the somewhat slower rates of inactivation of these natural populations of faecal bacteria compared to their counterparts in laboratory culture, Figures 3 and 4 show similar trends to those seen with individual pure cultures, with a rapid decrease in the counts (expressed as CFU/100 ml) for FC and FS in the illuminated, oxygenated sample and a slower decrease in the illuminated, deoxygenated sample.  $T_{99.9}$  values were 210 minutes (FC aerobic), 520 minutes (FC anaerobic), 190 minutes (FS aerobic) and 1600 minutes (FS anaerobic).

### Discussion

The results of the present study indicate that dissolved oxygen is essential for the rapid solar inactivation of faecal bacteria in water. Previous studies have shown that the responses of these organisms are representative of a broader range of faecal bacteria, including pathogens. Based on the present study, it would seem more appropriate to describe this phenomenon as solar photooxidative disinfection, or 'sol-air' water treatment, to stress the combined effects of light from the sun and oxygen from the air. The different rates of inactivation of bacteria in aerobic and anaerobic water samples may also help to explain some of the inconsistencies of earlier studies, which were carried out using natural water samples of unknown oxygen status.

The present research clearly demonstrates that solar disinfection of water will only be fully effective under aerobic conditions. On a practical level, this could be achieved either by manual mixing, or using an air pump. For small-scale systems such as a 2 litre plastic bottle containing  $\gg 1.5$  litres of water and  $\gg 0.5$  litre of air, simple experiments have shown that vigorous shaking for 1 minute can restore the dissolved oxygen content of deoxygenated water to over 90 per cent of the air-equilibrated value. For natural waters, the native microflora may utilise any dissolved organic matter, consuming oxygen at a rate that will vary with the water sample and the ambient temperature. Preliminary studies would be required to establish the likely rate of oxygen consumption and the requirement for aeration of a particular water source, in advance of practical implementation of this technique.

The next step will be to determine the responses of faecal microbes, including pathogens, under appropriate field conditions, so that the inactivation process can be optimised. The author is keen to establish collaborative links with researchers in developing countries who are interested in assessing the practical application of solar photooxidative disinfection.

### References

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