Solar disinfection of drinking water

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A young Cambodian boy stands watch over his family's SODIS platform.

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pathogen
disinfection
water purity
ultra-violet radiation

The problem

Nearly a billion people across the globe are without access to safe drinking water. They may have to queue for hours or walk many kilometres to collect water that is contaminated with pathogens that can cause life-threatening diseases such as cholera and dysentery. Reliance on unsafe water is often associated with extreme poverty so the people who need to treat contaminated water are usually those who can least afford it. There are several effective water treatments that can be used within the household such as boiling, filtration or chlorine tablets but all of these require a significant investment of money, time or both.

A young girl collects treated water from a cracked supply pipe directly above an open sewer in the slums of Nakuru in Kenya. Since her container is in contact with the contents of the sewer, the water will inevitably be contaminated.

A young boy collects water for his house from an unprotected open water source that is also used to water nearby livestock in rural Uganda. The water is heavily contaminated with faecal bacteria.

Solar UV is divided into 3 sections according to its wavelength and energy: UVA (315 nm – 400 nm), UVB (280 nm – 315 nm) and UVC (100 nm – 280 nm).

Solar disinfection

One household water treatment that is now becoming widely used is solar disinfection, more commonly known as SODIS. The technique is very simple. Ordinary transparent bottles are filled with the available (contaminated) water. These bottles are then placed in direct sunshine for a minimum of 6 hours, after which time the microbial pathogens are killed. In practice users have two sets bottles on the go, one set is left out for a full day and you drink from the other set which was solar disinfected on the previous day.

The majority of SODIS practitioners use plastic bottles because they are light, robust and easy to obtain but glass bottles and even plastic bags are equally effective. Container volumes up about 3 litres are suitable for SODIS.

This graphical demonstration of solar disinfection has been designed for use in those parts of the world where potential users have low levels of literacy.

Experience has shown that the most effective way of introducing solar water disinfection into an area is to find a well-respected member of the community, such as a local mid-wife or head of the village women's committee, and convince her of the potential benefits. This person then acts as an ambassador for the water treatment and promotes it throughout the locality.

Field trials of the solar water disinfection technique that have been carried out in Africa and Asia have shown children who drink SODIS water suffer 25%-50% less dysentery and diarrhoea compared with children who do not drink treated water. Even larger reductions can be achieved when SODIS is used in conjunction with good hygiene practices.

How does it work?

The light that comes from the Sun is quite energetic. About 1360 joules of solar energy falls onto every square metre of the Earth's upper atmosphere every second (irradiance = 1.36 kWm^{-2}). Water vapour, carbon dioxide, ozone, oxygen and aerosol pollutants in the atmosphere scatter and absorb some of the sunlight so that for a typical cloudless day the power falling onto a horizontal surface at the equator reduces to roughly 1.12 kWm^{-2}. So, when the Sun is overhead, we have just over 1 kilowatt of solar power available on every square metre of illuminated surface. For comparison you could think of a typical electric kettle which uses about 2000 W (i.e. 2 kJ of energy each second).

Strong sunlight can cause very painful damage on unprotected human skin in the form of sunburn. This is caused by solar ultraviolet (UV) energy. Solar UVC is completely absorbed by the atmosphere and most of the UVB does not penetrate the SODIS bottle material. It is the solar UVA which causes most of the microbial damage in solar disinfection.

Careful microbiological analysis has shown that solar disinfection disrupts several key processes within the cells. Shortly after the start of solar exposure, cells stop producing adenosine triphosphate (ATP) which is an important biochemical responsible for making energy available for most cellular functions. This is quickly followed by a reduction in uptake of glucose and the cell membrane gradually deteriorates to a point where the contents leak out to the surrounding environment causing cell death. Most cells have mechanisms to repair this kind of damage but these become less and less efficient as water temperature within the bottle rises.

This rise in water temperature is driven by a mini-Greenhouse Effect. The bottle material is transparent to UV and visible wavelengths which are then absorbed by the water. Since neither glass nor plastic is transparent to infrared wavelengths the absorbed energy, in the form of heat, cannot escape from the SODIS bottle and the temperature rises sometimes to temperatures above 45°C.

Even when strong sunlight is not reliably available, SODIS has been found to be surprisingly effective. This may be because roughly half of the incident solar UV is received at ground level as diffuse sunlight which is present even on cloudy days. In addition, infectivity studies using the bacteria *Salmonella typhimurium* and oocysts of the protozoa *Cryptosporidium parvum* have proven that, even when the microbe is not completely killed, the surviving pathogens lose much of their capacity to cause disease. It's almost as if they are suffering from sun-stroke.

Salmonella typhimurium bacteria, seen under the electron microscope.

Cloudy water

If the water is very cloudy (turbid), as is often the case, you might expect that solar disinfection would struggle to inactivate the cells since the UV light is scattered and absorbed very quickly by the suspended matter and thus does not penetrate far into the water. However SODIS is still surprisingly effective. Turbid water is very good at absorbing heat so we find that the maximum water temperature can rise to above 50°C causing a slow pasteurization. Additionally convection takes place within the bottle so that there is a constant movement of water throughout the bottle. Bacteria caught up in this convective mixing process receive a fatal dose of solar UV photons as they pass close to the container wall.

Water is set out for solar disinfection outside a Ugandan primary school. The children fill their bottles at home and then expose the water while they are in class. The bottles are clearly from a variety of sources since their cloudiness (turbidity) varies from bottle to bottle.

The SODIS process can be easily enhanced. Often the rear-surface of the container is painted black to allow more heat to be absorbed. Alternatively the bottles can be placed on polished corrugated iron which reflects the energy back up through the bottle and provides a second chance for the photons to be absorbed.

SODIS pros and cons

Apart from lack of sufficient sunlight (in which case we recommend that the bottles are left out for 2 days so that the diffuse UV that filters through clouds can complete the disinfection) there are some significant obstacles to wider usage of SODIS.

SODIS does not change the taste or appearance of the treated water. Consequently, many people find it hard to believe that SODIS actually works. The problem here is that to prove that the system works you have to conduct a full exposure and then incubate cultures from the before-and-after water samples, all of which can take up to 48 hours. In such cases we can leave a simple demonstration kit with trusted SODIS ambassadors within the community. The packs contain bottles and microbiological dip-slides. They conduct the simple experiments using the local water and then show the results to the people who are considering adopting SODIS.

A SODIS ambassador conducts a follow-up visit with a new solar disinfection user in one of the slum areas of Harare in Zimbabwe.

Another significant obstacle is concerns about the health effects of chemicals leaching from plastic bottles during solar exposure. We have investigated this and have not found any hazardous substances coming from the plastic under such conditions. Nevertheless, we still recommend that plastic bottles be replaced after 6 months just in case. Alternatively glass bottles can be used if they are available.

On the other hand SODIS has many things going for it. It is by far the cheapest and most economical method of treating household water. A single bottle can be used for up to 6 months before it should be changed. The bottles are relatively easy to obtain and very little training is required. It is for this reason that SODIS is currently in daily use by more than 5 million people in more than 50 developing countries across the globe.

Map showing the 55 countries where we know SODIS is used.

SODIS has been found to reduce childhood diarrhoeal disease by up to 50%. If there is no sickness in the house, the child can attend school, there is no need to purchase fuel to boil water or medicine to treat the illness. The caregiver does not have to tend the sick child, bring the patient to the clinic or spend time away from the normal income-generating activities. In this age of ever increasing technology it's wonderful to see such a low-tech solution have such a huge impact not only on health but also on childhood education and reduction in poverty.

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