

Chapter 2

SOLAR DISINFECTION



Introduction

Solar disinfection, or SODIS as it is known, is one of the simplest and least expensive methods for providing acceptable quality drinking water. It is an ideal method for use when economic and sociocultural conditions in the community are not amenable to other treatment or disinfection alternatives, such as filtration or chlorination, even though these are also acknowledged to be simple and inexpensive.

This chapter looks into several low-cost solar disinfection alternatives, particularly ones that can be used in rural communities. These can be broken down into batch and continuous disinfection processes, according to the mechanism used.

It should be pointed out that solar disinfection is a more appropriate water treatment method for households or a small number of houses than for use in conventional or more complex systems. Furthermore, it is obviously possible only where convenient solar radiation exists.

Properties of solar disinfection and description of the method

Solar disinfection is a thermal process consisting of raising water temperature for a long enough period of time in containers that have been prepared to absorb the heat generated by solar radiation. These containers are made of a heat-conducting material and should preferably be black, for this color absorbs heat better than light colors, which, because of their reflective properties hold less heat. Use of a dark color permits the water temperature to rise rapidly and to remain hot for a longer period of time.

SODIS has never become very popular, although the method is interesting and its requirements are few. Too many variables affect its efficiency and the eventual safety of the treated water. Parameters that could interfere with perfect disinfection include geographic latitude and altitude, season, number of hours of exposure, time of the day, clouds, and temperature; volume and material of vessels containing the water; and water turbidity and color.

The World Health Organization considers SODIS to be a valid option, but only as a “lesser and experimental method.” Even so, in areas where no other means are available to disinfect water, this method can improve the bacteriological quality of water considerably. It constitutes a further example bearing out the assertion made in the first chapter that if perfection is not attainable, then a step toward “improvement” is better than nothing. It should be noted that in communities where this disinfection method has been promoted, the best results have been obtained when the measure was promoted and monitored by health officials or trained and dedicated personnel (e.g. volunteers from a community-based NGO).

SODIS technology uses equipment like solar heaters (for continuous production) and for batch systems, solar stoves, solar concentrators and a range of stills that are described in detail below. The Swiss proposal for disinfecting water in bottles and small containers is also referred to.

All of this equipment is simple, inexpensive and easy to operate. The acceptance of SODIS in several regions of the world confirms that it constitutes an attractive and appropriate solution.

Solar disinfection mechanisms

A couple of studies maintain that SODIS owes a large part of its disinfection power to photochemical action. Since ultraviolet radiation has the power to destroy microorganisms, as we will see in a later chapter, it has been claimed that the ultraviolet segment accompanying the visible portion when water is exposed to sunlight is responsible for the germicidal action. The truth is that only a very minor truly germicidal portion of the ultraviolet component, in the range of UV-C (100-280 nm), is present in solar radiation. Assuming that the germicidal portion were large enough to offer some disinfection power, most materials, including those that are transparent in sunlight, like glass and plastic, have been scientifically proven to be completely opaque in the case of ultraviolet radiation. That is why, as the pertinent chapter explains, the ultraviolet pipes that are used for disinfection are cased in protective sleeves made of quartz, the only material that is truly transparent to this type of radiation (teflon, used in some equipment, is the only partially transparent plastic). The conclusion to be reached in this simple analysis is that if water is exposed to poor radiation and a filter that is almost opaque to that UV is inserted between the two, the disinfecting capacity of that radiation will be practically nil or, in the best of cases, negligible. Obviously, then, SODIS does not operate on the basis of photochemistry, but of a thermal process, pasteurization.

High temperatures strongly affect all microorganisms; vegetative cells perish as proteins are denatured and other components undergo hydrolysis. Although some bacteria in the water are capable of forming spores, making them particularly heat-resistant, most are generally killed off at between 40 and 100°C, while algae, protozoa and fungi perish at between 40 and 60°C.

Disinfection by boiling consists of raising the water temperature to 100 °C and keeping it at that level from one to five minutes. Most, if not all, of the microorganisms present are eliminated as a result. Pasteurization, on the other hand, is defined as exposing a substance (generally a food, including water) “for a long enough period to a temperature high enough to destroy the microorganisms that can cause illness or spoil food.” Although heat tolerance is affected by factors such as water turbidity, cell concentration, physiological state and other parameters, pasteurization destroys coliforms and other non heat-tolerant bacteria; this is fortunate, because most pathogens are not heat-tolerant.

In the case of water, an effort has been made to determine the optimum relationship between length of time and temperature needed to destroy pathogenic germs. As a rule of thumb, although not an exact one, either of the following ratios will ensure a reasonable level of safe disinfection of clear water (with a turbidity of less than 5 NTU):

65 °C for 30 minutes or 75 °C for 15 minutes.

From a highly practical and operational viewpoint, these conditions are ensured in sunny zones with four to five hours of exposure during the period of maximum radiation (from 11:00 to 16:00 hours).

Disinfection by-products

The present knowledge of SODIS and the studies that have been made to date reveal that no DBPs are present.

Equipment

A number of devices have been developed that vary as to volume of water produced and cost.

Solar heaters

Commercial solar heaters used to disinfect water are no different from the heaters on the roofs of many homes that are used to heat water for use in the kitchen or shower. The device consists of a collector, which is a box with an aluminum frame and a glass cover. The collector contains copper pipes painted black that are welded to two header pipes and that store the water during the heating process. The collector is connected by means of pipes of the same material to a plastic and fiberglass thermo-tank insulated with polyurethane foam to store the treated effluent. Some of these tanks are divided to allow for a heat exchange between the cold water flowing in and the hot flowing out.

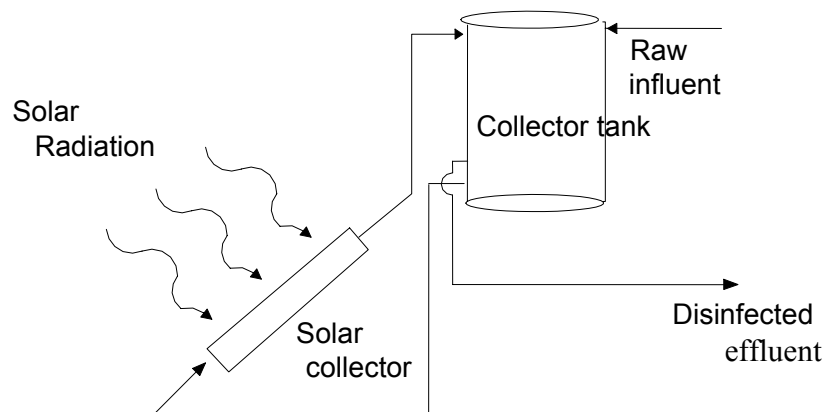


Diagram of a thermosiphon for water heating



These systems operate on the principle of a convector circuit or passive solar heating, in which solar radiation heat is absorbed by black pipes, raising the temperature of the water inside the collector and consequently reducing its density. Under these conditions, the lower-density hot water column no longer balances the cold-water column in the return pipe to the collector; by gravity, the former falls and displaces the latter toward the tank above. This natural circulation known as “thermosiphon” continues so long as there is enough heat to raise the water temperature and the resulting push force can overcome the pressure drop in the system.

When a solar heater is used for disinfection, its efficiency depends directly on the temperature that can be reached for pasteurization. Inasmuch as the water reaches its highest temperature between 14:30 and 15:30 hours, the tank should not be drained before this time in order

Solar heater

to increase the residence time of the water in the collector.

Conventional family solar heaters are able to produce about 15 liters and larger devices yield up to 1 m³ of water after three to four hours of operation at midday. More sophisticated solar heaters can be found in the market today with double glass covered collectors containing finned copper pipes offering selective surfaces that are able to absorb a larger amount of solar energy and convert it to useful heat. Some are able to reach water temperatures of over 90 °C and even to vaporize it. Nonetheless, the climatic conditions must be studied to determine whether the investment is justified; otherwise, less efficient –but also less expensive-- devices can be used.

Solar stoves

In many developing countries, particularly those where deforestation is a serious problem, solar stoves and concentrators are the only option available to the population for cooking their food. “Solar stoves” can also be used to disinfect water through pasteurization.

A solar stove consists of a pair of boxes of wood or cardboard, one inside the other, that are used to trap the heat of the sun and use it, in this case, to heat water. The principle consists of using the heat generated by the sun through radiation by trapping it inside the small box and preventing it from escaping by covering the box with a transparent pane, generally of glass. This heat is transferred by conduction through metal pots to the water they contain. It is desirable to use a reflector to direct the sun’s rays toward the inside of the box in order to maintain the heat. The use of reflectors cuts down the process time by approximately 35%.

The free space between the two boxes is padded with an insulating material that may be wadded newspaper, rubber foam, etc. The inside of the small box is lined with a reflecting material like aluminum foil. A black-colored sheet is placed at the bottom of this box. It is also advisable to paint the metal pots black or smoke them so that they can absorb more heat. Metal pots are preferable because clay pots act as an insulant. Nor is it advisable to use plastic because it melts at high temperatures.



Solar stove

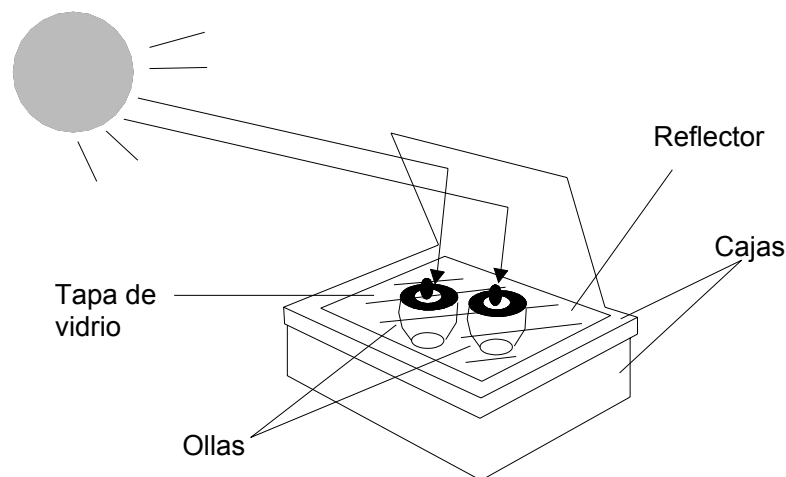
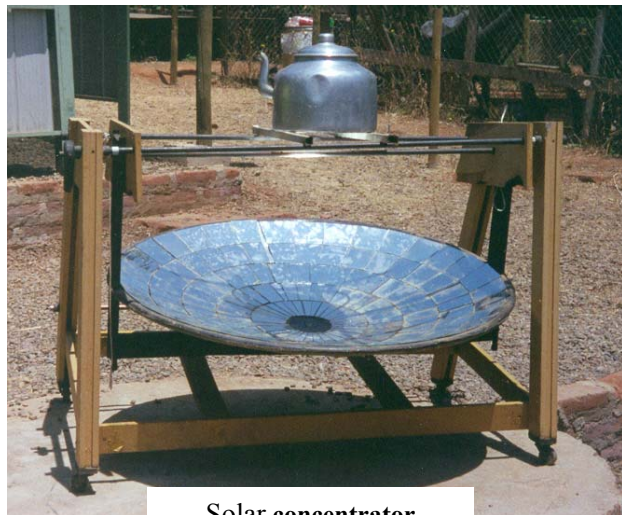


Diagram of a solar stove

-Reflector -Glass lid -Boxes -Pots

Solar concentrators

Solar concentrators are a type of solar heater. They look something like a mirrored parabolic antenna or an open umbrella with a mirrored interior. These devices operate like a concave lens that receives the sun's rays and concentrates them on a point (the focus). In the case of the solar concentrator, the pot or vessel to be heated is placed on a small platform at the focal point. Solar concentrators normally have a diameter of at least 0.80 m and can be made of aluminum covered cardboard or other materials.



Solar concentrator

Few commercial models exist, but books and brochures can be found containing instructions to build them. The concentration of solar rays that is possible with this type of stove, unlike those described earlier, can produce temperatures of up to 350 °C, making it possible to heat water very rapidly. Disinfection can thus be accomplished by pasteurization or direct boiling.

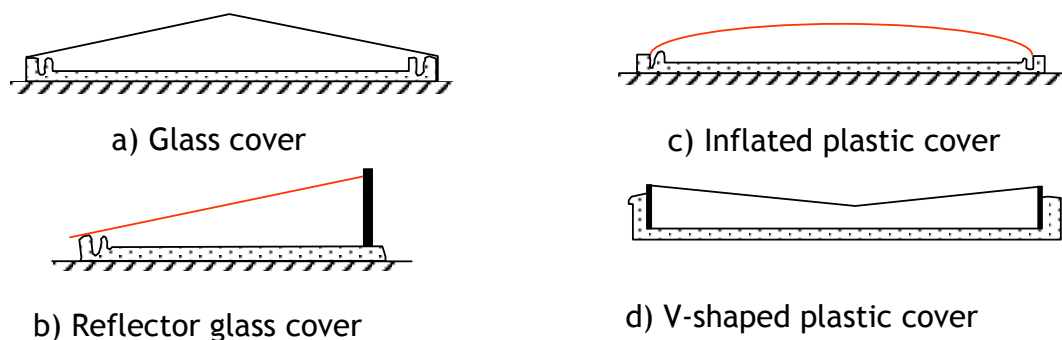
Solar stills

The solar still offers another application of thermal energy that can be handled with very simple to highly sophisticated technology. It is used to produce drinking water from seawater or contaminated fresh water and can also operate as a water disinfection system.

The principle of water disinfection using solar energy is the same as the natural hydrobiological cycle: Water in a reservoir containing salts is evaporated and condensed elsewhere (clouds and then rain), thereby producing purified water.

The solar still requires an element that will convert solar energy into a rise in water temperature so that it can be evaporated. Visible and infrared radiation is absorbed by any dark surface, particularly one that is dull black. A dull finish is used for better absorption and to prevent losses of a fraction of light through reflection. In the simplest solar stills, the solar collector consists of a black horizontal tray containing the water to be distilled, which is known as “distillant.” To prevent undesirable losses of heat, the bottom of the tray must be thermally insulated. Heating of the distillant causes the water to evaporate, leaving the mineral salts trapped in the tray. To facilitate evaporation, the evaporator should have a large area compared with the volume of distillant it can contain. The water that is evaporated in that way is collected by placing a cover of glass or some other transparent material over the evaporator at the right distance and slant.

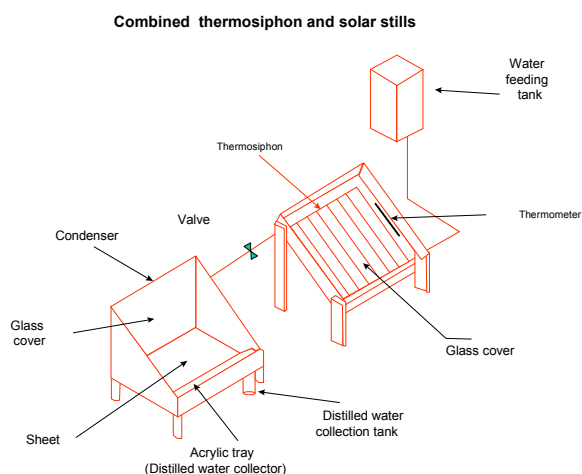
There are several condenser designs. The simplest consists of a glass gable box with a 20° slant from the horizontal, allowing the drops of condensed water to run down into small collector channels.



Diagrams of simple solar stills

Combined process of solar preheating and distillation

The Mexican Health Secretary proposed a device consisting of a water feeding tank, a thermosiphon and a condenser. It is useful in temperate areas where the temperature does not rise high enough for condensation to occur; in such cases, the thermosiphon heats the water before it runs into the condenser.



Disinfection in bottles and small containers

The Swiss Federal Institute for the Environment, Science and Technology (EAWAG), through its Water and Sanitation in Developing Countries Section (SANDEC), is promoting the use by households that disinfect only small amounts of water, of special black bottles and containers. Although this method has been widely accepted wherever it was implemented, information, user awareness heightening and monitoring and follow-up programs have always been necessary.

The technique consists of exposing the water to be disinfected in plastic bottles like those used for soft drinks, which may or may not be painted black, completely or only on the bottom. The Swiss have tested a series of containers, ranging from plastic bags to large narrow mouth cans (to keep hands from entering into contact with the disinfected water). Although the results have been excellent from both a practical and an economic viewpoint, the popular soft drink bottles have been found to be especially attractive because they are so widely available. The required exposure time and temperature are exactly the same as for any of the other techniques. In some cases, a thermometer can be added to measure the temperature reached (see monitoring).



Soft drink bottle with a temperature monitor

Installation requirements

<i>Equipment</i>	<i>Installation and installation requirements</i>
Solar heaters	Solar heaters are fairly easy to install or to adapt to any other installation. All that is needed is to raise the hot water collector tank about 60 cm above the highest point of the collector. No special pressure is required for their operation. It is enough for the water feeding tank to be placed next to the collector, which should be on a slant approximately equivalent to the latitude of the site (between 15° and 35°, for example) and face the sun.
Solar stoves and	These devices can be easily installed anywhere. Before adopting this method,

concentrators	however, it is important to perform some tests by taking the water temperature after four or five hours (in the case of the stoves). The water is drinkable only if the average temperature is always above 60 °C. If solar concentrators are well built, they should disinfect water more by boiling than by pasteurizing.
Solar stills	No special requirements need to be met in the case of solar stills, which are very simple devices with no movable parts. It is important to keep animals away from the equipment, however.
Bottles and containers	Solar disinfection requires clean water with very little turbidity. Otherwise, it must be filtered beforehand using a household sand filter or very fine fabric. The bottles can be placed on any reflecting surface, such as aluminum foil. The use of colored soft drink bottles is not recommended.

Operation and maintenance

<i>Equipment</i>	<i>Operation and maintenance</i>
Solar heaters	Operation of this equipment is simple; all that needs to be done is to open the line valve during the day and close it at night. Its maintenance consists of keeping the collector cover clean; dirt reduces the amount of radiation that can reach the collector. The frequency of cleaning will depend on the degree of atmospheric pollution. The use of acrylic covers is not recommended because they are easily scratched and deformed.
Solar stoves	To operate this device, place the pot inside the solar stove and direct the sun's rays to the inside of the box using the reflector. It is very easy to maintain. All that needs to be done is to keep the inside, glass and reflectors clean. To keep the water clean, it is advisable to leave it in the covered container until it is to be used.
Solar stills	This system requires feeding the still with the water for treatment, either continuously or discretely –in other words- in batches. Rural families tend to use the latter method. Otherwise, the system can be used by combining it with preheating using a solar heater. Common household stills on sunny days produce between three and five liters a day per square meter. This is equivalent to a reduction in the depth of the distillant of from 0.3 to 0.5 cm/day, which means that the feeding process can be done once a day. The water should be either drunk or thrown out within the following 24 hours.
Bottles and containers	The plastic container must be very clean before the water it contains can be purified. In this case, as in all of those described above, the disinfected water must be kept in the same or another closed container in a cool place.

Monitoring

At effluent temperatures of over 55 °C, total coliform inactivation has been demonstrated in 99% of the cases. For safety reasons, however, the golden rule is to have a margin of safety and to set 65 °C as the minimum temperature for disinfection. Monitoring of these systems should confirm that the water at the outlet of any of these systems or following treatment reached 65 °C.

Inasmuch as solar heaters were not designed for water disinfection, but merely to heat it, there is no way to check whether the temperature reached the pasteurization point. Therefore, it would be advisable to install a thermostat connected to a valve that would allow the water passage

only at a temperature of over 65 °C. A thermometer can be attached to the cover of solar stoves or bottles; in other cases, bottles can be fitted with small ampoules containing a substance that will melt at a temperature of above 65 °C, ensuring that the required pasteurization temperature has been attained.

Advantages and disadvantages of solar disinfection

<i>Equipment</i>	<i>Advantages</i>	<i>Disadvantages</i>
Solar heaters	Not dependent on conventional energy, whose cost rises with the growing demand. Avoid the use of toxic chemicals. Require relatively simple and low-cost equipment that is easily recovered and provides drinking water for many years. Not environmentally damaging.	Cannot be used on cloudy or rainy days. Offer no residual protection.
Solar stoves	Do not consume firewood and thus help to avoid deforestation and erosion in rural areas. It has been calculated that approximately one kilogram of firewood is needed to raise one liter of water to a boiling point. Nor do they use fossil fuels. This is particularly useful in the rural area, where it is difficult to obtain gas. Do not smoke like open fires that can cause respiratory diseases. Not expensive and easy to build.	Twice as slow as conventional stoves. Cannot be used on cloudy or rainy days. Provide no residual protection.
Bottles and containers	Extremely simple and inexpensive. Easily accepted by the communities.	Offer no residual protection. Require clean water. Cannot be used to disinfect large volumes of water.

Equipment, operating and maintenance costs

<i>Equipment</i>	<i>Total Costs</i>
Solar heaters	The price of the commercial equipment is between \$ 250 and \$ 500.
Solar concentrators	There are none on the market. They must be custom-built at a cost of from \$ 100 to \$ 200
Solar stoves	These do not exist in all countries. They must be locally made. Their cost varies according to the material used. Normally they cost between \$ 25 and \$ 80, depending on access to local materials.
Solar stills	The same considerations discussed above apply. They cost from \$ 75 to \$ 250, depending on the availability of local materials and size of the device.
Bottles	They do not cost anything.

Information sources

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