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Solar Water Disinfection Considerations: Using Ultraviolet Light Methods to Make Water Safe to Drink

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Abstract

Through many decades of research and innovation-development. UV disinfection technology has seen significant advances in the types of water that can be treated, the operation and maintenance of the UV equipment, and the overall cost effectiveness of a UV system. Solar water disinfection, also known as SODIS, is a water treatment system using two readily available materials: sunlight and plastic PET bottles. SODIS solves the problem of making water safe from micro-organisms that cause water-borne diseases simply by placing contaminated water into clear plastic bottles and exposing them to the sunlight. This makes SODIS an excellent tool in the survivors kit. In order to make water safe to drink, further treatment is necessary. The most recognized and established treatment is to boil the water to kill the micro-organisms, such as bacteria and viruses, in the water. The type and shape of the container used for SODIS water treatment is important. SODIS efficiency depends on the physical condition of the plastic bottles. Mechanical scratches and aging reduce the efficiency of SODIS. Heavily scratched or old bottles should be replaced.

Keywords: *Solar Water Disinfection (SODIS), Ultraviolet (UV), Polyethylene Terephtalate (PET), Water-borne, Treatment.*

1. Introduction

Solar water disinfection (SODIS) is a simple, environmentally sustainable, low cost solution for drinking water treatment at household level for people consuming microbiologically contaminated raw water. SODIS uses solar energy to destroy pathogenic micro-organisms causing water borne diseases and there with it improves the quality of drinking water. Pathogenic micro-organisms are vulnerable to two effects of the sunlight: radiation in the spectrum of UV-A light (wavelength 320-400 nm) and heat (increased water temperature). A synergy of these two effects occurs, as their combined effect is much greater than the sum of the single effects. This means that the mortality of the micro-organisms increases when they are exposed to both temperature and UV-A light at the same time [1].

For over 4000 years, sunlight has been used as an effective disinfectant [2]. When organisms are exposed to sunlight, photosensitizers absorb photons of light in the UV-A and early visible wavelength regions of 320 to 450 nm. The photosensitizers react with oxygen molecules to produce highly reactive oxygen species. In turn, these species react with DNA; this leads to strand breakage, which is fatal, and base changes, which result in mutagenic effects such as blocks to replication. For bacteria, the process is reversible as the bacteria may again become viable if conditions allow cells to be repaired [3, 4]. Viruses are unable to repair DNA damage and are therefore sensitive to optical inactivation [5].

The safe and reliable application of UV disinfection is only possible with qualified technology and qualified partners representing current best practice. The research project also produced proof that UV disinfection is ecologically viable and that no by-products are produced as long as the pertinent technical rules are adhered to. The thermal technologies are mainly using heat from burning fuel as the mechanism to disinfect water from micro-organisms. Boiling or heating water through pasteurization or solarization to a certain temperature is the recommendations for water treatment [6]. Then the water should cool naturally after treatment and kept storage afar from additional risk of contamination. Water can also be disinfected from pathogens only by using the sun as a source of energy. The sun destroys pathogens both by heating up the water though pasteurization and also using UV light as disinfection.

As each of these procedures has its own drawbacks, their application is extremely limited in the developing regions of the world where water-borne diseases are prevalent, and the safety of drinking water supplies cannot always be assured. Availability and costs are only part of the problem. In the case of boiling, for instance, the need for about one kilogram of wood to boil on liter of water is totally unjustifiable in fuel-short regions already suffering from aridity and desertification. Besides, the disagreeable taste of boiled water often discourages consumers. The addition of 1 to 2 drops of 5% sodium hypochlorite solution per liter of water requires the use of a dropper and liter measure, both being uncommon devices in most homes [7]. In view of these difficulties and constraints, it was deemed necessary to search for an alternative method for the disinfection of water on an individual basis using simple and inexpensive technology that would be more appropriate for application in the third world.

Previous studies have found that solar disinfection is affected by numerous variables. These variables include solar radiation wavelengths, water temperature, turbidity, and container selection. Several process enhancements have also been studied.

There are a few methods commonly advocated for the disinfection of drinking water at the household level. These include boiling of water for about 10 minutes, or the use of certain chlorine compounds available in the form of tablets (Halazone tablets, or calcium hypochlorite tablets) or solutions (sodium hypochlorite solutions). Water purification tablets containing tetraglycine hydroperiodide as the active ingredient are also available for such use. These tablets have an expiration date, and the instructions call for the addition of 1 to 2 tablets per litre of water and waiting for 25 minutes before use [7-9].

Water in sufficient quantity and good quality is essential for live. However, at the beginning of the year 2000 one sixth of the world’s population, 1.1 billion people, is without access to improved water supply and many more lacking accesses to safe water [10]. The following technologies are regarded as improved water supply: household connection, public standpipe, borehole, protected dug well, protected spring, rainwater collection. The water quality in improved water supply systems often is affected from unreliable operation and lack of maintenance, or the water is subject to secondary contamination during collection, transport and storage.

Indonesia is a developing country that still faces problems with the availability and accessibility of safe drinking water, especially for those living in rural areas. In many areas people still drink untreated water, to save fuel or because of a taste preference, and neglect the possible negative health consequences [9]. Surface water sources of drinking water in Bangladesh have historically been contaminated with pathogenic micro-organisms, which cause a significant burden of disease and mortality. Diarrhoeal disease is the second leading cause of mortality in children under five years old in the world [11].

The researchers established the potential for field use of solar disinfection by demonstrating that this process reduced the risk of diarrhoeal in children [2, 12]. The studies were conducted in the Kajiado province of Kenya using Maasai children between 5 and 16 years of age. In 1996, the first test group consisted of 108 children that drank solar treated water. These children were given two 1.5 liters plastic bottles to be filled with drinking water and put on the roof of their huts from dawn until midday. The water could then be used for drinking. The control group consisted of 98 children that were given the same directions, but rather than putting the bottles on the roof, they kept the bottles indoors. The results of this study showed that the children in the first group averaged 4.1 diarrhoeal episodes over a twelve-week period, versus an average of 4.5 episodes in the control group [2]. In 1999, the test group was expanded to children less than six years of age. The children drinking treated water had a 19 two-week period diarrhoeal prevalence of 48.8%, versus 58.1% in the control children [12].

Five years later, the researchers learned of a cholera outbreak in the test villages. They returned and found that the test families had continued to treat their drinking water with solar disinfection. However, while there was no statistical difference in the risk of contracting cholera between families using solar disinfection and those that did not, the continued use of the process by the villagers was promising as shown by the earlier successes in reducing diarrhoeal incidences.

SODIS has been known for more than 30 years. The technique consists of placing water into transparent plastic or glass containers which are then exposed to the sun. Exposure times vary from 6 to 48 hours depending on the intensity of sunlight and sensitivity of the pathogens. Its germicidal effect is based on the combined effect of thermal heating of solar light and UV-A radiation. It has been repeatedly shown to be effective for eliminating microbial pathogens and reduce diarrhoeal morbidity including cholera. Since 1980 much research has been carried out to investigate the mechanisms of solar radiation induced cell death in water and possible enhancement technologies to make it faster and safer [13].

Since SODIS is simple to use and inexpensive, the method has spread throughout the developing world and is in daily use in more than 50 countries in Asia, Latin America, and Africa. More than 5 million people disinfect their drinking water with the solar disinfection technique. This review attempts to revise all relevant knowledge about solar disinfection from microbiological issues, laboratory research, solar testing, up to and including real application studies, limitations, and factors influencing adoption of the technique and health impact [7, 13].

In addition to boiling, chlorination and filtration another household water treatment which has gained popularity over the past 10 years is that of SODIS [14].

2. Solar Water Disinfection Considerations

Studies have shown that visible violet and blue light have liter disinfection capability. However, the other components of sunlight, UV-A, UV-B, and UV-C radiation, are able to inactivate organisms. UV-C radiation, at approximately 260 nm, has the greatest potency because it corresponds to maximum absorption by DNA. Municipal treatment plants use UV-C (at 254 nm) to disinfect drinking waters and secondary wastewater effluents because of its germicidal ability to initiate changes in nucleic acids and other structures such as enzymes and immunogenic antigens. However, near ultraviolet (UV-A) light has been found to be the most significant component of sunlight that is responsible for the inactivation of microorganisms, with an increase in effectiveness due to the synergistic effects of UV-A and violet light. This is because the UV-C component of solar radiation does not reach the earth [15].

The SODIS water treatment method requires solar radiation and temperature to destroy micro-organisms. Using the solar water disinfection method does not remove chemical contamination.

The SODIS system works best in areas between 35 degrees north latitude and 35 degrees south latitude. The water to be treated should be exposed to the full sun for six hours when the sky is bright. If cloud cover is more than fifty percent, expose the contaminated water for two full days before drinking. If the temperature of the water can reach at least 50 °C (122 °F) the time required for the solar disinfection of water can be as little as one hour under ideal conditions [1].

Particles that are suspended in the contaminated water will shield micro-organisms from the full impact of solar radiation, so it is important to make the water as clear as possible. Water filtering or allowing the suspended particles to settle out before using the SODIS water treatment system will aid greatly in the solar disinfection process. The type and shape of the container used for SODIS water treatment is important.

Plastic PET bottles, which are made of PolyEthylene Terephtalate (PET) are considered the best choice since they do not have as much UV stabilizer as compared to PVC bottles, which are made of PolyVinylChloride (PVC). Bottles that are scratched will not work as well as clear clean plastic. Glass bottles can be used for SODIS but are not nearly as efficient as PET bottles. Window glass in not recommended as it does not transmit enough UV radiation.

Another important consideration when using SODIS to disinfect water is the depth of water in the container. The thinner the container the better, especially if the water has suspended particles. It has been found that if the depth of water inside the PET container is ten centimeters, or about four inches, and the water has a moderate amount of suspended particles, the amount of UV-A radiation from the sun that penetrates the full volume is reduced by half. This will therefore increase the amount of time needed to successfully implement the SODIS process.

Other UV light Methods to Make Water Safe to Drink: Fortunately, there are many solutions of how to disinfect the surface water by using various technologies and methods of water treatment for microbial contamination. Depending on the condition of the water and the surrounding possibilities. For example, steripens take the UV light method a step further. A steripen is a handheld battery operated device that emits 90% UV light and disinfects your water in under a minute [16].

Typical UV disinfection systems involve the flow of water through a vessel containing a UV lamp as shown in Fig. 1. As the water passes through this vessel, micro-organisms are exposed to intense ultraviolet light energy which causes damage to genetic molecules (i.e. nucleic acids: DNA or RNA) needed for reproductive functions. This damage prevents the micro-organism from multiplying or replicating in a human or animal host. Because the micro-organism cannot multiply, no infection can occur. Disinfection of water is achieved when UV light causes microbial inactivation.

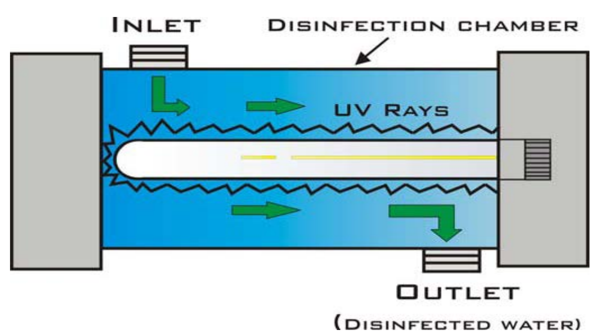

Fig. 1 Basic schematic of UV unit with bulb [17]

The UV irradiation chamber of a typical UV disinfection unit consists of an interior irradiation chamber and its connecting branches and is usually made of stainless steel. Depending on the application and on the type and quantity of employed UV lamps, irradiation chambers can be of various design (Fig. 2), the main distinguishing feature being the arrangement of UV lamps within the irradiation chamber.

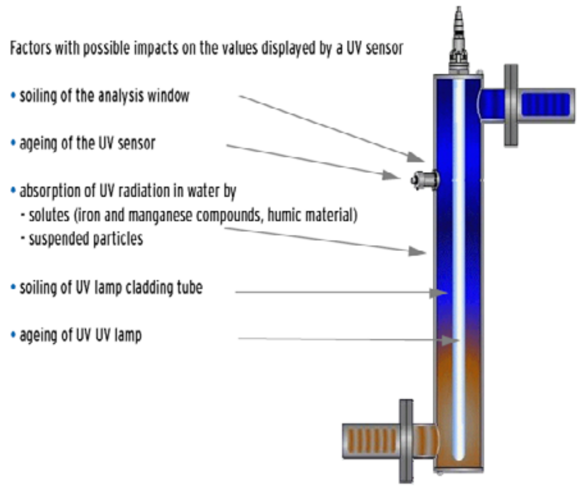

Fig. 2 Schematic diagram of a UV unit [18]

A water purification process is any one of a number of methods used to create clean water from natural water sources or human drainage systems. The most common water purification process involves taking water from a constant source, such as a lake, stream or sewer system, and mechanically removing all the physical impurities. After the impurities are removed and the harmful organisms in the water are killed, the water is safe for use.

Generally, the first step in a water purification process is removing the water from its source. This generally means the water is pumped from it source system into a holding tank. This is actually a very important step; since these holding tanks allow the water to sit motionless, they allow many of the materials kept in suspension to separate out.

The actual water purification process begins with flocculation. Very small particles are added to the water; these particles vary based on the source of the water and the location of the plant. These particles are naturally attracted to each other and many common impurities. The particles begin to combine with material in the water and one another until they make little balls of impurities. The water then enters a tank where the balls settle out to the bottom. After settling, the water purification process moves to active filtering. There are a number of different filtering methods used, but most of them involve forcing the water through sand. Some processes go a step further, using a specialized polymer net that literally catches impurities as they go by. After filtration is complete, the water is either clean for human use or sent to settling ponds where it evaporates back into the local water system [16].

2.1 How SODIS Works?

SODIS is a water treatment method that:

- improves the microbiological quality of drinking water,
- does not change the taste of water,
- is applicable at household level,
- is simple in application,
- relies on local resources and renewable energy,
- is replicable with low investment costs.

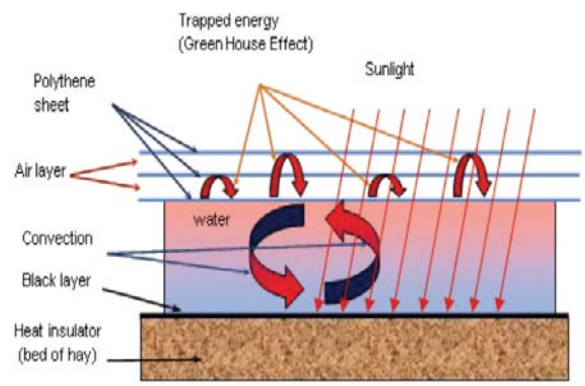

Fig. 3 Schematic picture of how solar water pasteurization and trapping solar radiation works [18]

A potential alternative to the common disinfection methods mentioned previously is solar disinfection. Solar water disinfection is a process that entails filling a transparent bottle with water and placing it in the sun for several hours. The following sections describe the process, its potential for use, and the enhancements that can be employed to increase its effectiveness. Limitations of solar disinfection are also presented (Fig. 3).

However, there are several limitations to the further application of SODIS technology [9]:

- SODIS is unable to be used with larger containers. The best size of PET plastic bottles to be used for SODIS is 1.5 liters and maximum size is 2 liters.
- SODIS application is dependent on the climate.
- SODIS cannot be applied to muddy water. Therefore, if the water is muddy, the water must be pre-treated in order to clarify it.

Sunlight is treating the contaminated water through three synergistic radiation mechanisms:

- UV-A light (wavelength 320-400 nm) which react with oxygen dissolved in the water produces highly reactive forms of oxygen (oxygen free radicals and hydrogen peroxides) in the water. These reactive forms of oxygen kill the micro-organisms.

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- UV-A light also interferes with the reproduction cycle of bacteria by damaging their DNA. Produced by the sun passing through a layer of the atmosphere at different wavelengths of UV-rays come up to our world. UV light and micro-organisms that are in direct lethal effects on a large proportion of UV radiation in the 230-280 nm range is filtered by the ozone layer in the atmosphere, thereby protecting life on earth [19].
- Infrared heating the water. If the water temperatures rise above 50 °C or 122 °F, the disinfection process is three times faster. Amongst disinfection technologies, UV has a distinctive mode of action as it does not necessarily kill all the target organisms. Instead, UV light is absorbed by the micro-organisms, damaging genetic nucleic acids (DNA, RNA) responsible for replicating or multiplying. Because the organisms cannot replicate, a human or animal host cannot be infected [19, 20]. The most frequently encountered microbiological problem with heated water is the proliferation of legionella bacteria. These thermophilic pathogens are able to enter building plumbing systems by way of the public water supply grid [21].

The combined effect of all three mechanisms is greater than that of each individual components.

In as much as UV light leaves no residual disinfectant what so ever, the entire system must be thoroughly disinfected with an appropriate chemical disinfectant before activating the unit for the first time. Any external contamination of the distribution system due to return siphoning or a crossed connection must also be remedied and the system disinfected before starting it up again.

The highly encouraging results of the numerous experiments demonstrated repeatedly the destructive effect of sunlight on pathogenic and non pathogenic organisms. Some of these results and the pertinent conclusions derived from the study as a whole are highlighted hereunder for the benefit of those interested in confirming our work, and in adapting the technology to suit local conditions. The conclusions are presented somewhat in the form of constructive instructions of practical value to users of the technology, with explanations being included wherever feasible and necessary [19, 22].

2.2 Using SODIS in Survival Situation

It is a sad fact that discarded plastic bottles can be found just about everywhere in the world. Even the remotest beach or river valley often contains a variety of human cast offs, one of the most common of which are plastic bottles.

- If you are going to be in an area for an extended time, collect as many plastic PET bottles as you can, fill them with the water to be treated and place them in direct sunlight as shown in the SODIS instructions above.
- If you are short on clean uncontaminated water, try to go as long as possible, at least a day, before drinking the SODIS treated water. Keep the plastic water bottles exposed to the sun as long as you are using them to insure the water remains free of pathogens. If possible place the bottles on a metal or dark surface to take advantage of heat and speed up the SODIS process. Refill bottles as soon as they are emptied, being sure to remember which bottles contain water that has been treated for the longest time and which have been most recently filled.
- If you are travelling, try to rig your water filled containers outside your pack or on the roof of your vehicle in order to expose them to the sun and heat as much as possible. This will help to further treat the water and prohibit the growth of new pathogenic micro-organisms.

SODIS is a five star method of making water safe to drink. SODIS materials are readily available, is environmentally friendly, is easy to implement, and can easily be taught to others. This makes the SODIS method of water treatment an excellent tool of the survivor. In many areas of the world the SODIS method of making water safe to drink is being used, and with great success [1, 7, 22].

Water treatment systems can incorporate UV as a useful method of disinfecting treated water for safe use. Many other applications of this technology are possible, depending on the desired outcome. For instance, UV disinfection used in conjunction with chlorination can be a very effective disinfection system. UV is a cost effective method for treating bacteria, viruses and protozoa, while chlorine provides a chemical residual offering additional protection in the event of contamination being introduced in the distribution system or plumbing. For surface water systems and ground water under the direct influence of surface water, filtration pre-treatment and other processes are required [22, 23].

The selection and application of an appropriate disinfection technology should have regard to the following principles:

- The assessment of catchment and source risks with respect to the clarity, organic content, and the likely risk of pathogenic micro-organisms in the source water. The evaluation of particular source risk following analysis of raw water monitoring to determine that extent of the pathogen removal/inactivation required of the disinfection system. The disinfection technology must be capable of removing or inactivating all pathogens potentially present in the final water.

- The determination of the pre-treatment processes, necessary to ensure the required pre-treatment of the water and/or inorganic chemical removal, upstream of the disinfection system to ensure it is capable of performing adequately. An assessment of the adequacy of contact time for chemical disinfection technologies and the necessity to ensure that minimum contact times required for disinfection are achieved. The verification of the efficiency of the disinfection treatment. Any disinfection technology used must be capable of being verified.
- An assessment of the requirement to ensure that a residual disinfectant is present in the distribution network for all but very small distribution networks. An assessment of the capital and operational cost of the disinfection technology. Where disinfection technologies achieve equally effective outcomes the water supplier should have regard to the financial implications from the capital and ongoing operational aspects to ensure that the most cost effective solution is selected.

The ability of UV light to promote photochemical reactions underlies two UV light based environmental technologies UV disinfection and advanced oxidation. Advanced oxidation uses the energy of UV light, alone or in combination with added oxidants, to promote the destruction of hazardous organic chemicals. Advanced oxidation, however, uses a greater UV dose than UV disinfection to obtain practical oxidation rates with a wide variety of organic compounds [21, 22].

2.3 How to Use the Sun to Make Water Safe to Drink

The Swiss Federal Institute for Environmental Science and Technology and Department of Water and Sanitation in Developing Countries conducted extensive laboratory and field tests to develop and test the SODIS process [1]. These efforts again proved this simple low cost method of making water safe to drink has great potential for those without access to safe drinking water:

- Find a clean, transparent plastic PET bottle of up to three liters in volume.
- Fill the plastic PET bottle about three quarters full with clear water, or water that has been filtered through sand, or whatever you have at hand.
- Shake the bottle vigorously for twenty seconds in order to dissolve as much oxygen as possible into the water to be disinfected.
- Fill the remainder of the plastic PET bottle and replace the cap.
- Place the plastic bottle in direct sunlight for six to eight hours. Resting on a highly reflective surface such as metal, light colored rock, or tin foil will improve the process.
- If the weather is cloudy, the length of daylight short, or the water is murky with suspended particles, leave the bottle outdoors in the sun for two full days.
- The water is now disinfected and drinkable with 99% of living micro-organisms having been destroyed.

The capital cost of a UV system is higher than a typical sodium hypochlorite system. Fortunately, the operating cost of a typical UV system is significantly lower than a hypochlorite system due to the increasing cost of chemicals. The retrofit of an existing hypochlorite system to UV has a high initial capital cost, but over a span of a few years, the cost of the UV system would provide a return investment [24].

In as much as UV light leaves no residual disinfectant what so ever, the entire system must be thoroughly disinfected with an appropriate chemical disinfectant before activating the unit for the first time. Any external contamination of the distribution system due to return siphoning or a crossed connection must also be remedied and the system disinfected before starting it up again. The ability of UV light to promote photochemical reactions underlies two UV light based environmental technologies UV disinfection and advanced oxidation. Advanced oxidation uses the energy of UV light, alone or in combination with added oxidants, to promote the destruction of hazardous organic chemicals. Advanced oxidation, however, uses a greater UV dose than UV disinfection to obtain practical oxidation rates with a wide variety of organic compounds.

In view of the increasing scarcity of potable drinking water resources all around the world, the disinfection of wastewater for use as utility water, i.e., for such applications as irrigation, reinfiltration and drinking water supplementation is becoming increasingly important. Disinfection with UV light is employed as the last stage of wastewater treatment prior to discharge or reuse. The process can be applied both to free flowing water in clarifier discharge channels for disinfecting utility water in and with enclosed UV units in closed pressure pipes [25].

Container Selection: Container shape and color may have significant impacts on the effectiveness of solar disinfection. The bottle shape may interfere with the sun's disinfection capabilities: as the sun moves across the sky, the intensity will change and may be reduced depending on 16 the bottle shape. Therefore recommend using round, conical bottles as opposed to square or irregularly shaped containers. However, the major limiting factor is the availability of the bottles themselves, with variables such as plastic thickness and light transmittance characteristics being difficult to assess in the field [26, 27].

Also noted that colorless containers allow the most transmittance of ultraviolet wavelengths and are therefore the optimal choice for use in solar disinfection. Blue and violet tinted containers also transmit radiation, yet other colors, such as orange, yellow, red and green, will absorb wavelengths with the most lethal bactericidal effects and therefore must be avoided [28]. With regard to pasteurization, a water sample exposed to sunlight increases in temperature due to the red and infrared components of sunlight. Blue containers would therefore absorb these components and minimize any temperature increases [27]. Therefore, to maximize the effects of both solar radiation and heating, colorless containers are recommended.

Container size may also be an important parameter in the solar disinfection process. To specify that container size is a variable that affects solar disinfection [27]. However, their studies do not specifically test the effect of volume size on solar disinfection. That found no significant difference in the population dynamics of 0.5 and 1.5 liters samples [3]. In contrast, compared the time needed to achieve a 99.9% reduction in the initial faecal coliform counts of 22 liters and 25 liters samples and found that exposure times of 150 minutes and 290 minutes were required, respectively [29]. A more extensive study on volume variations may be useful.

SODIS efficiency in field research; SODIS efficiency was systematically tested for different pathogens, using different water qualities, various types of containers and under different climatic conditions. Workshops offer a good opportunity to test SODIS efficiency under a wide range of conditions [18, 26]. Parameters like water, weather, and exposure time are set by the local conditions. Often, different types of containers and bottle supports can be tested, so that the participants themselves can assess the most suitable conditions for SODIS and promote it accordingly.

Water quality at user level: Normally, SODIS treated water is analysed simultaneously with raw water. The raw water is taken from the same water source as the SODIS water was taken earlier, but it is not exactly the same water. Therefore, it is not possible to measure the exact SODIS inactivation rate, but the quality of SODIS water is compared with the general water quality of the user's drinking water taken directly from the source. During follow up visits to each household, an adult was asked for two samples of untreated and SODIS water from the household storage recipient. In most cases, the SODIS treated water was taken directly from the plastic bottles, although some households stored it in a clay pot, with a potential risk for secondary contamination. Both samples of treated and untreated water were tested for faecal coliforms, allowing to indirectly calculate the SODIS efficiency [1, 26, 30].

Comparing SODIS with other water disinfection methods; We can conclude that SODIS proved to be efficient not only under laboratory conditions, but also at user level, provided that the basic technical requirements are fulfilled. However, SODIS will probably never supply 100% safe water to the whole population. Poor handling practices and inadequate application of the method lead to a reduced SODIS efficiency, or the treated drinking water is subject to secondary contamination. The objective of SODIS therefore is to significantly reduce the risk of microbiological infection [26]. After years of research and field testing, the challenge of reducing the incidence of water-borne diseases through SODIS use is now lying in the hands of the institutions and field workers in charge of hygiene education and sanitation programs. Through appropriate diffusion of the information, intensive training of users and follow up, people will have access to a simple and affordable alternative to improve the microbiological quality of their drinking water at household level.

Prompted by an understanding of the prevailing conditions and needs in the developing countries regarding the safety of water supplies in rural communities, and the rampant enteric diseases, a pertinent study was launched. The study, involving a series of experiments carried out over a period of more than two years, aimed at assessing the feasibility of solar disinfection of small quantities of drinking water that would satisfy the daily needs of individuals or a family. These experiments essentially consisted of subjecting artificially contaminated water in small, transparent containers, 1 to 3 liters in capacity, to direct sunlight for varying periods of exposure [31].

The experimental water used was deliberately contaminated with municipal sewage to high levels not normally encountered even with untreated water used for drinking in rural areas. Occasionally some experimental waters were inoculated with cultured pathogenic micro-organisms [32].

Data from previous batch inactivation experiments provided baseline information and criteria for the design, operation, and expected performance of the continuous flow prototypes [27, 28]. They included the following:

- nature, density, and relative sensitivity of indicator and pathogenic micro-organisms to be tested,
- presence of nutrients or inhibitory factors (e.g., water temperature and predators),
- solar intensity and effective radiation wavelengths,
- penetration power of the effective radiation and, hence, the transparency and wall thickness of the reactor material, as well as the depth of the water to be penetrated,
- the optical characteristics of the water and its interfering constituents (e.g., colouring substances, soluble salts, and suspended particles),
- design, configuration, hydraulic loading, and orientation of the solar reactor.

3. Enhancement Technologies for SODIS

A number of process enhancements have been studied in order to increase the effectiveness of solar disinfection. Such efforts have included periodic agitation, using foil to increase reflectivity, and painting half the bottle black to increase achievable temperatures.

Impurities in a water sample that cause it to be colored also have an effect on the disinfection potential for a given drinking water sample. In highly colored samples, sunlight may not have a lethal effect because the colored water may absorb wavelengths in a certain range. In these cases, it is recommended that the water sample be treated to reduce coloration before sun exposure [26, 27, 29, 33].

Basically, the criteria for both the UV equipment and the water itself in private systems are the same as those discussed above for the disinfection of drinking water. In connection with private water supply systems, however, there is greater likelihood of encountering humic acids and undesirable inclusions, either from surface runoff and rainwater or due to unsound wells. In view of the increasing scarcity of potable drinking water resources all around the world, the disinfection of wastewater for use as utility water, i.e., for such applications as irrigation, rein filtration and drinking water supplementation, is becoming increasingly important. Disinfection with UV light is employed as the last stage of wastewater treatment prior to discharge or reuse. The process can be applied both to free flowing water in clarifier discharge channels for disinfecting utility water in and with enclosed UV units in closed pressure pipes [1, 21, 31].

Heating: This is the very basic and simplest method of disinfection. Temperature of water is raised to its boiling point and maintained for 15-20 minutes to kill all the bacteria [30]. This method is suitable for household purpose or in case of epidemics. The germicidal action of sunlight has long been recognized, but the ecological implications and the potentials for practical applications have to be researched more thoroughly [1, 29, 34-36]. Accordingly, simple prototype units were designed, and their effectiveness in decontaminating water by exposure to sunlight was assessed. The advantages of this method are no taste and odour is produced and complete destruction of micro-organism. The limitations of this method are required more space and uniform solar radiation thought day.

Titanium dioxide films and sunlight method, the efficiency of solar disinfection by heterogeneous photo catalysis with sol-gel immobilized titanium dioxide films over glass cylinders. The advantages of this method are it is more efficient than solar water disinfection, inactivating total as well as fecal coliform and keep water free of coliform at least for seven days after sun irradiation. The limitations of this method are, it is costly and uniform solar radiations are required [37].

In the past, two different water treatment processes using solar energy were used to improve the microbiological water quality. The first, UV radiation was used for its bactericidal effect. The second, infrared radiation raising the water temperature, is known as pasteurization. During research phase one, the researchers at the Swiss Federal Institute for Environmental Science and Technology combined the two effects and discovered a strong synergy between radiation and heat. The experiments showed that at a water temperature of 50°C, only a fourth of the amount of UV light required at 30°C is necessary to inactivate the same amount of faecal coliforms [15, 38].

Pasteurization may not be ideal for some drinking water treatment situations. Effective treatment by heating requires knowledge of the water quality in order to determine the temperature the water must reach and the duration of heating that is needed. In addition, disinfection by heating may be impractical for wide scale use because pasteurization is a labor intensive process and requires a significant amount of fuel [39]. However, heating may be accomplished by using sunlight, thus alleviating the problem of needing wood or other fuels for boiling.

Pasteurization is an effective treatment option for liquids. However, a false sense of security may mislead one to under treat the drinking water. As detailed above, certain organisms cannot survive temperatures of 55 °C while others are still viable at 75 °C. Without knowing the exact composition of organisms in the water, the user may not adequately treat the drinking water before use. There is also a high capital cost associated with purchasing pasteurization equipment if the process is used for a community. However, pasteurization of liquids is independent of turbidity and pH [7]. This, coupled with the fact that solar energy is free and solar disinfection is a simple process to employ, warrants further study for use by individuals or small families in developing countries.

Chemical additives: In addition to the photocatalyst titanium dioxide several other chemical additives have been investigated as possible enhancements for SODIS inactivation [40].

Inorganic chemicals present in water as natural constituents, or as extraneous contaminants, are generally not expected to be affected by sunlight. Very little is known about photo-decomposition of photo-sensitive organic compounds upon exposure to sunlight. From a practical standpoint, however, the presence in reasonable concentrations of both inorganic and organic impurities would not hinder the disinfection of water by sunlight [41]. In exceptional cases not encountered in drinking water supplies, highly colored waters may absorb appreciable solar energy in the range of wavelengths effective against micro-organisms.

Solar mirrors: The SODIS bottles are usually only illuminated on the upper side of the reactor that faces the sun. There have been several attempts to concentrate solar radiation using solar mirrors with the aim of increasing the radiation inside the bottles. Aluminum foil attached to the back of the bottles increased disinfection rate constants by a factor of 2. Rijal and Fujioka [42] used also solar reflectors and observed improved efficiencies which they attributed solely to the increase in water temperature of the system. Reflective solar boxes can reduce disinfection time to 3-4 hours.

3.1 Advantages of SODIS

Solar disinfection is at great advantages compared to other household water treatment and storage techniques such as chlorination or filtration:

- SODIS improves the microbiological quality of drinking water.
- SODIS improves the family health.
- SODIS can serve as an entry point for health and hygiene education.
- Public water supply systems in developing countries often fail to provide water safe for consumption. SODIS provides individual users a simple method that can be applied at household level under their own control and responsibility.
- SODIS is easy to understand.
- Everybody can afford SODIS, as the only resources required are sunlight, which is cost free and plastic bottles.
- SODIS does not require a large and costly infrastructure and therefore easily is replicable in self help projects.
- SODIS reduces the need for traditional energy sources such as firewood and kerosene/gas.
- Consequently the use of SODIS reduces deforestation, a major environmental problem in most developing countries, and SODIS decreases air pollution created by burning conventional energy sources.
- Women and children often spend much of their time and energy collecting firewood. SODIS reduces this workload as less firewood needs to be collected.
- Financial advantages; household expenditures can be reduced when the user's family health is improved: less financial resources are required for medical care. In addition, expenses for traditional energy sources such as gas, kerosene and firewood are reduced. Only limited resources are required for the procurement of transparent plastic bottles. Therefore even the poorest can afford SODIS.

4. Conclusions

UV disinfection is the process of choice for numerous applications involving the disinfection of water:

- drinking water,
- product and utility water,
- food and beverage industry,
- pharmaceutical-cosmetic and electronic industry,
- gardening/horticulture and irrigation,
- wastewater (municipal and industrial).

Most processes use this point to disinfect the water. As the water moves from the holding tank to the purification area, harmful microbes in the water are killed. While chlorine based methods were common in the past, these methods are used less today. The common modern methods include hydrogen peroxide, ozone and UV light.

If the bacteriological innocuousness of supplied drinking water cannot be permanently and uninterruptedly assured, the water must be disinfected. For a long time now, the UV disinfection of drinking water has been in application around the world as a safe and reliable solution to the problem. Even such parasites as cryptosporides and giardia are reliably inactivated. Especially during the past decade, more and more public water utilities have adopted UV technology for the nonchemical disinfection of drinking water. Indeed, low-maintenance, user friendly UV disinfection is now the process of preference for private water supply systems, too. Used properly, UV equipment generates no by-products. Of particular importance is the fact that the process does not alter the natural odour or taste of drinking water [43]. Generally accepted rules of engineering practice; with reference to the strict requirements concerning disinfection safety in the food and beverage industry, the use of certified UV equipment for water disinfection is recommended.

In the good and beverage industry, water is needed for the product itself (e.g., table water, beer, sweetened beverages) as well as for cooling and washing. In the course of production, there is direct or indirect contact between water and food. Hence, the quality of the water has a major impact on the quality and microbiological stability of the product. One of the main advantages of UV disinfection is that it requires no addition of chemical substances that could undesirably alter the beverage/food. Generally accepted rules of engineering practice; with reference to the strict requirements concerning disinfection safety in the food and beverage industry, the use of certified UV equipment for water disinfection is recommended.

The most effective form of training is to personally explain SODIS to the user family. This approach however, is very time consuming. When addressing a single family, it is best to practically demonstrate the application of SODIS. Nevertheless, also the transfer of knowledge to groups of people is a valid approach. While addressing groups, it is very important to use participatory approaches stimulating the contribution of each participant. During follow up visits to each household, an adult was asked for two samples of untreated and SODIS water from the household storage recipient. In most cases, the SODIS treated water was taken directly from the plastic bottles, although some households stored it in the clay pot, with a potential risk for secondary contamination. Both samples of treated and untreated water were tested for faecal coliforms, allowing to indirectly calculate the SODIS efficiency.

It is important to note that SODIS does not produce sterile water. Organisms other than human pathogens such as for example algae, are well adapted to the environmental conditions in the SODIS bottle and may even grow there. These organisms however do not pose a danger to human health. As SODIS does not produce sterile water, it is necessary to use adequate parameters to assess it’s efficiency [44].

Solar disinfection is a process that is simple and effective. It could prove valuable for use in developing countries and in areas that need a small scale drinking water treatment method. Studies have shown that it is effective in reducing diarrhoeal illness in children when implemented in field trials. However, the process does have limitations and several variables influence the effectiveness of the process such as solar intensity, temperature, turbidity, container shape, and sample volume [7]. Therefore, this study was aimed at establishing relationships between these variables and the effectiveness of solar disinfection.

Further studies, especially regarding microbiology, should be implemented, taken from various watercourses such as rivers, ponds and lakes in rural areas. This since the solar radiation probably is stronger in rural areas due to less traffic pollution and could therefore obtain a higher water temperature faster and for longer time. To complete the study more tests should also be performed with the device using a base constructed of materials that exist in the rural areas, for instance on a bed of mud, straw and grass to provide required insulation. The user friendliness of the device would be interesting to monitor, when families actually are using it. Paraffin wax could also be used as an indicator for the device, in the same way as SODIS are instructing, but needs to be tested to assure safe drinking water quality [26].

Solar disinfection is at a great disadvantage compared to other household water treatment and storage techniques such as chlorination or filtration [32]. The future challenges now lie in enhancing the microbiological process and developing effective strategies to assist in household water treatment and storage scale up. A bright future: the advancements in the UV industry have benefit municipalities through the application of UV in challenging effluents, reduction in maintenance requirements, and implementation of a cost effective disinfection solution. The installation of UV in communities has allowed operators to leverage UV as an effective public relations tool to educate the public on how water is treated in an environmentally friendly way.

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