Technical Background and Principles for the Application of Solar Water Disinfection

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Abstract—*Conventional methods of drinking water disinfection, such as chemical treatment, heat pasteurization, and filtration, require facilities, materials, and fuel that may not be readily available or feasible to attain. An alternative treatment option is to utilize solar energy, which has been shown to inactivate pathogens through pasteurization and radiation effects. Over 30% of the population in developing countries is in need of access to safe drinking water. The lack of adequate drinking waters in developing countries is a continually growing problem due to population increases and increased demands on source waters. Therefore, water disinfection methods that are easily employed in developing countries are needed. The most recognized and established treatment is to boil the water to kill the microorganisms, such as bacteria and viruses, in the water. Solar disinfection is a water treatment method where a drinking water sample is exposed to solar radiation to inactivate pathogenic organisms. The type and shape of the container used for SODIS water treatment is important.*

Keywords—*Disinfection, Treatment, Waterborne, Drinking water, Solar water disinfection (SODIS), Microorganisms.*

I. Introduction

Contaminated drinking water poses a major health threat to human beings worldwide. The problem is particularly significant in developing countries and in arid areas where water sources are scarce. In developing countries, surface waters such as rivers, streams and lakes are used for multiple activities, including livestock watering, bathing, and cooking. Defecation and urination often occur near water sources as well. This water, which may be contaminated with pathogenic microorganisms, is also used for drinking water. People in developing countries may have no other options for drinking water because there is a lack of water distribution infrastructure and lack of funding for developing water treatment systems.

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 [1]. 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.

The lack of adequate drinking waters in developing countries is a continually growing problem due to population increases and increased demands on source waters. Therefore, water disinfection methods that are easily employed in developing countries are needed. Chemical disinfection options such as chlorine and iodine treatment require chemicals that must be purchased. These chemicals can be expensive and also have a limited shelf life. Physical treatment options such as boiling, UV treatment, and filtering require materials that may not be easily acquired or purchased. One alternative drinking water treatment method that has been proposed is solar disinfection, a process that is simple and easily utilized.

Adequate water treatment methods and avoidance of secondary contamination of drinking water, combined with hygiene promotion, are required to prevent the population without access to safe drinking water from illness and death. The simple act of washing hands with soap and water can reduce diarrhoeal disease transmission by one third [2]. Promotion of household centred water treatment methods should therefore always be combined with hygiene training.

The public health condition in developing countries can abruptly lead to the dramatic spread of epidemics. Cholera for example remains a risk for such epidemic outbreaks. It is endemic in 80 countries and still of concern to all regions of the world. The number of deaths caused by cholera has declined over the last decades due to the application of simple and adequate curative treatment methods (oral rehydration therapy).

Solar disinfection is a water treatment method where a drinking water sample is exposed to solar radiation to inactivate pathogenic organisms. The method has been shown to reduce the incidence of diarrhoeal in children living in a Massai village in Kenya [3]. Previous studies have found that solar disinfection is affected by numerous variables. These variables include the wavelengths of solar radiation, water temperature, turbidity, and container selection.

Many common pathogens are not only transmitted through water but also follow other infectious pathways. Poor general hygiene practices often are a significant source of infection. Furthermore, secondary contamination of drinking water due to incorrect water handling is frequently observed in developing countries [4]. Therefore, interventions aiming at improving the water quality should always consider introducing general hygiene messages. Through such combined measures, significant positive health effects in the target population can be achieved.

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 microorganisms causing water borne diseases and there with it improves the quality of drinking water [5]. Pathogenic microorganisms 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).

SODIS is ideal to disinfect small quantities of water of low turbidity. Contaminated water is filled into transparent plastic bottles and exposed to full sunlight for six hours. During the exposure to the sun the pathogens are destroyed. If cloudiness is greater than 50%, the plastic bottles need to be exposed for 2 consecutive days in order to produce water safe for consumption. However, if water temperatures exceed 50°C, one hour of exposure is sufficient to obtain safe drinking water. The treatment efficiency can be improved if the plastic bottles are exposed on sunlight reflecting surfaces such as aluminium or corrugated iron sheets [6].

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 [7].

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 microorganisms, damaging genetic nucleic acids (DNA, RNA) responsible for replicating or multiplying. Because the organisms cannot replicate, a human or animal host cannot be infected [8, 9].

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 [1, 10]. In addition to boiling, chlorination and filtration another household water treatment which has gained popularity over the past 10 years is that of SODIS [11, 12].

The literature review discusses developing countries, the drinking water challenges these countries face, various water disinfection options, and previous research on solar disinfection. The methodology describes the experimental design; including variables tested, test procedures used, and analytical methods employed. The literature review discusses developing countries, the drinking water challenges these countries face, various water disinfection options, and previous research on solar disinfection.

II. Historical Background

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. Although water disinfection is a crucial step in preventing waterborne diseases, there are several aspects of the water collection, treatment, and distribution cycle that affect whether drinking water arrives at a home in potable condition. First, source water should be carefully selected and protected to ensure it is free of contaminants. Water that receives runoff from land used for agriculture and livestock farming is likely to have pesticides, fecal matter, and other constituents that were applied to the surrounding grounds. That suggests relocating cattle and other livestock from the vicinity of drinking water sources [13, 14].

In addition, improving the sanitation practices of the local population can reduce the potential for water supplies to be polluted. It is not considered uncommon, especially in developing countries, for defecation and urination to occur in rivers, lakes, and other bodies of water that are also used for domestic and recreational purposes. These practices continue a cycle of recontamination. The second factor in preventing waterborne disease is adequate and reliable water treatment. This can be addressed by properly training water plant operators and by providing funding to ensure all necessary chemicals and equipment can be purchased. Third, distribution systems must be built and improved to prevent recontamination of treated water. Other intervention measures, such as increasing public awareness, should also be employed [1, 15].

Physical treatment methods such as boiling water and UV treatment may also be used to treat drinking water. Boiling water is a simple process, but requires resources that may not be readily available. This is especially true for areas concerned with the effects of desertification and deforestation because boiling one liter of water requires approximately one kilogram of wood. The process is also time consuming and boiling water has been found to impart a disagreeable taste [13].

UV radiation is the process where water is exposed to a lamp generating light at a wavelength of approximately 250 nm. This wavelength is in the middle of the germicidal band and is responsible for damaging the DNA of bacteria and viruses. However, UV treatment is only effective for low turbidity waters and therefore pretreatment such as filtering is required for poor water quality sources. Also, developing and maintaining UV radiation treatment requires the initial cost of purchasing equipment, a knowledgeable operator to properly use the equipment, and sufficient funds for maintenance. For areas that are unable to financially support such a treatment scheme, UV radiation is not a viable treatment option [15].

A. Solar Radiations as A Disinfection Mechanism

For over 4000 years, sunlight has been used as an effective disinfectant [3]. 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 [6, 16]. Viruses are unable to repair DNA damage and are therefore sensitive to optical inactivation [8].

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.

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 [17].

Particles that are suspended in the contaminated water will shield microorganisms 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.

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 [12].

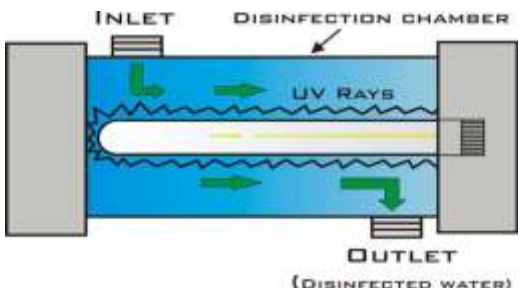

Fig.1 Basic schematic of UV unit with bulb [18]

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, microorganisms 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 microorganism from multiplying or replicating in a human or animal host. Because the microorganism cannot multiply, no infection can occur. Disinfection of water is achieved when UV light causes microbial inactivation.

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 [12].

B. How does SODIS Work?

The electromagnetic radiation emitted by the sun shows a wide range of wavelengths. It can be divided into two major regions with respect to the capability of ionizing atoms in radiation absorbing matter: ionizing radiation (X-rays and gamma-rays) and nonionizing radiation (UV light, visible light, and infrared radiation). Fortunately, the highly injurious ionizing radiation does not penetrate the earth's atmosphere.

Solar radiation is becoming increasingly appreciated because of its influence on living matter and the feasibility of its application for useful purposes. It is a perpetual source of natural energy that, along with other forms of renewable energy, has a great potential for a wide variety of applications because it is abundant and accessible. Solar radiation is rapidly gaining ground as a supplement to the nonrenewable sources of energy, which have a finite supply.

The solar radiation is reflected and scattered primarily by clouds (moisture and ice particles), particulate matter (dust, smoke, haze, and smog), and various gases. The two major processes involved in tropospheric scattering are determined by the site of the molecules and particles and are known as selective scattering and nonselective scattering. Selective scattering is caused by smoke, fumes, haze, and gas molecules that are the same size, or smaller, than the incident radiation wavelength. Scattering in these cases is inversely proportional to wavelength and is most effective for the shortest wavelengths.

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.

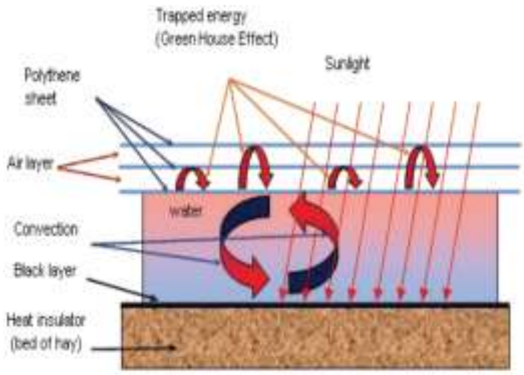

Fig. 2 Schematic picture of how solar water pasteurization and trapping solar radiation works [19]

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. 2).

However, there are several limitations to the further application of SODIS technology [20]:

- 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 pretreated 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 microorganisms.
- 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 microorganisms 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 [8].
- 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 microorganisms, damaging genetic nucleic acids (DNA, RNA) responsible for replicating or multiplying. Because the organisms cannot replicate, a human or animal host cannot be infected [8, 9]. 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 component.

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 (obtainable from Wisconsin Pharmacal, Milwaukee, Wisconsin 53223, USA) 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.

As each of these procedures has its own drawbacks, their application is extremely limited in the developing regions of the world where waterborne 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 kilogramme of wood to boil on litre 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 litre of water requires the use of a dropper and litre measure, both being uncommon devices in most homes. 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.

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 [22].

Temperatures at or above boiling can be used to effectively pasteurize water. Liquids may also be pasteurized using lower than boiling temperatures, provided the liquids are kept at such temperatures for an extended period of time. For example, enteric viruses in water can be pasteurized in approximately 1 hour at 62°C or in 1 day at 50°C [15]. 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 labour intensive process and requires a significant amount of fuel. However, heating may be accomplished by using sunlight, thus alleviating the problem of needing wood or other fuels for boiling.

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 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.

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.

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. 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.

C. Effect of SODIS on Pathogens

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 microorganisms.

In each case, the water was initially examined bacteriologically just before sunlight exposure, and at intervals of 15 to 30 minutes for a few hours during exposure of the containers to direct sunlight. All containers were kept in an upright position, except for the polyethylene bags which were laid flat on the floor, with the screw caps kept tightly in place. The other containers were left open. Removable paper labels on some of the commercial bottles were detached prior to exposure to allow penetration of light. The standard plate count and membrane filter technique were applied routinely for the estimation of total bacterial counts and coliform densities, respectively. Identical batches of water in similar containers kept in the dark, and also under room conditions of lighting, served as controls for comparison and assessment of the effect of sunlight. The experiments were generally run from 9:00 a.m. to 2:00 p.m., when the solar intensity reaches its highest levels. The roof of one of the buildings within the campus of the American University of Beirut served as the site for these experiments [5, 22].

The objective of this research was to first test the effects of water temperature and solar radiation on artificially contaminated water samples. The first phase of experiments consisted of placing artificially contaminated sample solutions in direct sunlight and enumerating viable bacterial counts over time to quantify disinfection by solar radiation and heating. In the second phase, inactivation was quantified in samples that were heated in a water bath. These results were then compared to the solar inactivation results to determine the role of heating in solar disinfection.

The results of each set of experiments have consistently confirmed the fact that the bacteria contaminating water from faecal sources are, as a general rule, susceptible to destruction upon exposure to sunlight for an adequate period of time. The rate of destruction actually depends upon a number of influencing factors. The most important ones that became clear in the course of the study include the following:

- the intensity of sunlight at the time of exposure, which in turn depends upon the geographic location (i.e. latitude), seasonal variations and cloud cover, the effective range of wavelengths of light, and the time of day;
- the kind of bacteria being exposed, the nature and composition of the medium, and the presence of nutritive elements capable of supporting the growth and multiplication of the various microorganisms;
- the characteristics of the containers in which the contaminated water is kept during exposure (e.g. colour, shape, transparency to sunlight, size, and wall thickness);
- clarity of the water (i.e. degree of turbidity), and its depth, both being important factors that determine the extent of penetration of sunlight, as well as the possibility of shielding the microorganisms from its lethal effects.

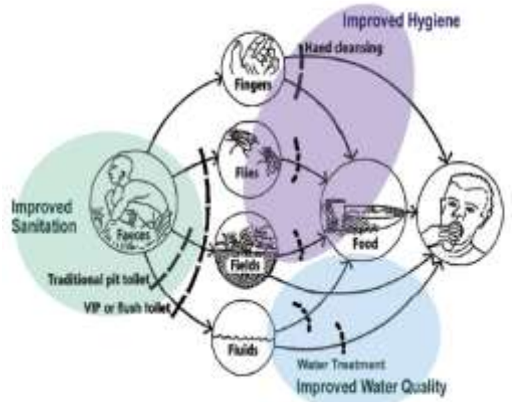

Fig.3 Pathogens follow different transmission routes "F-Diagram" (adapted from Meierhofer and Martin [5])

The application of SODIS improves the quality of drinking water and therewith reduces the risk of contracting a disease mainly transmitted via drinking water. Unfortunately, many of those so-called waterborne diseases have multiple transmission routes. Consuming water of pure quality helps to reduce the number of diarrhoeal illnesses. However, as the human pathogens can be transmitted through multiple routes from faeces via fingers, flies, food and fluids (Fig. 3), appropriate hygiene practices have a great influence on community health.

Consequently diarrhoea causing pathogens can be transmitted to humans through food, person to person contact, flies or through inadequate hygiene behaviour (e.g. not washing the hands). Children are particularly exposed to many different ways of becoming infected, as illustrated (Fig. 3) in the "F-Diagram": fluids/water, via faeces, fingers, flies/insects, food, and field/environment.

Interventions simultaneously addressing different contamination routes such as water or surface transmission as well as secondary contamination, are more effective. Furthermore, if general hygiene education is disseminated at the same time as the technology, other main transmission routes such as person to person and food borne transmission can be prevented. Multiple interventions can thus achieve a considerable effect on the population's health. Interventions at specific points in the water management cycle should address characteristics and survival tactics of a specific pathogen [23].

The highly encouraging results of the numerous experiments demonstrated repeatedly the destructive effect of sunlight on pathogenic and nonpathogenic 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.

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. In exceptional cases not encountered in drinking water supplies, highly coloured waters may absorb appreciable solar energy in the range of wavelengths effective against microorganisms. On the other hand, turbidity due to suspended particulate matter would hinder to some extent the penetration of sunlight. This depends on the degree of turbidity, and the depth of water being exposed. Besides, the suspended particles would protect any microorganisms adhering to their surfaces.

D. Can SODIS be Used for Babies?

SODIS removes 99.9% of the bacteria and viruses and also removes parasites to a certain degree from contaminated water, but the water is not sterilised through SODIS and a certain risk of contamination and consequential infection remains. As babies are fragile and very quickly dehydrated, they are subjected to a very high death risk due to diarrhoeal illnesses. The remaining infection risk from consumption of SODIS water therefore must be eliminated and only boiled water, which is sterile, should be used for the preparation of powder milk or weaning food for babies.

When babies are about 6 months old, women successively start to complement breast milk with other food. This is a very critical time for the children. Health statistics from the developing world show that this age group has a very high morbidity and death risk due to diarrhoeal diseases. Therefore, it is important that all food given to children of this age in addition to milk is carefully being prepared through boiling. SODIS may be introduced to children at the moment when they actively move around and start to drink on their own at the age of about 18 months.

Women who cannot breastfeed their babies may be forced to prepare food for their babies from powder milk. During project implementation at users' level the question may come up if SODIS treated water can be used for the preparation of powder milk for babies or for weaning food.

The transmittance of sunlight though the plastic bottles was tested. Three different bottle sizes were used. Measurements were taken using the detector that measures solar radiation wavelengths below 400 nm. First, solar intensity readings were taken while the detector was laid flat. Readings were then taken while the detector was held overhead and aimed directly at the sun. Next, readings were taken with the detector placed inside each bottle when the bottle was laid flat. The bottle and detector were then held overhead to obtain a direct solar intensity reading. Last, the detector was removed from the bottle and another set of horizontal and direct solar intensity readings were taken to ensure sun conditions had not significantly changed during the bottle readings.

Boiled water instead of SODIS water should also be used by persons with a considerably increased risk of infectious diarrhoeal diseases including:

- Severely ill children and adults
- Severely malnourished children and adults
- Patients with decreased immuno-deficiency (AIDS)
- Patients with gastro-intestinal abnormalities or chronic gastrointestinal illnesses

As SODIS is a method to improve the quality of drinking water, it is important, that the promoters have good knowledge about all issues related with water and sanitation. They must be able to explain local communities the relation between the quality of drinking water, safe handling of water, contamination of water, disposal of excreta, and the effects on health.

The promoters must have knowledge on water sources and water distribution systems and the problems connected with maintenance. They must understand different methods and possibilities to disinfect drinking water at central or household level and know the advantages and disadvantages of the different water treatment methods.

E. Mistakes often Made by the Users

More than half of the households are without running water. One of the day to day problems is gathering and carting sufficient water for domestic use from communal water sources. The water is often of dubious quality, and waterborne pathogens cause a range of bacterial, viral and parasitic diseases. Children and people with compromised immunities are especially at risk. The technology of solar water heating to temperatures below the boiling point of water is fairly mature. The dos and don'ts are well established, and the efficiencies of more than 50% for the more sophisticated systems are impressive.

The SODIS water treatment method is easy to apply. Nevertheless, people need to be trained carefully in its application. Trainers and resource persons should control the application procedure in the local communities regularly in order to ensure a correct and successful SODIS application, especially during the first months of applying SODIS. Repeated visits to communities that recently had been trained in SODIS revealed that the users made a number of mistakes in the application of SODIS:

- Bottles were exposed to the sun in the morning, but after two hours the area was in the shade.

- Some users put their bottles on a chair, not considering that the back of the chair does shade the bottles at some point in time.
- The bottles were exposed with the wrong side to the sun, i.e. with the black part on top.
- Some users put their bottles on wooden racks; but wind moving underneath the rack cools down the temperature and reduces the effectiveness of SODIS.
- Exposed bottles were not closed tightly or different elements were used to close the bottle, if bottle lids were unavailable, as consequence, the water leaked out.
- Only partially filled bottles were exposed to the sun. The air bubbles inside the bottle then reduced the UV-A radiation.
- Turbid, not filtered water, containing small particles such as for example insects, was exposed.

Different ethnic groups have their own cultural beliefs, they use their individual ways of communicating, and perceive the world in their own manner. Each SODIS team intending to work with a specific group therefore has to adapt their communication and training methods to the group addressed. The cultural context provides the basic framework for each SODIS project.

Important elements in the case of solar water disinfection are the sun and water. These two elements can have different meanings and levels of importance in specific cultural groups. Another aspect is the fact that in certain cultures women do not speak in public meetings or that villagers refuse to speak of certain issues without the authorisation of the community leader. It is therefore a good idea to have group meetings with potential SODIS users in order to understand their cultural thinking, their concepts and myths related to water, sun and hygiene practices before taking up SODIS activities.

The method of focal group discussions has been used in Bangladesh and Bolivia to obtain more information about local customs. Although it is not possible to know all the beliefs and myths surrounding water and hygiene, it is necessary to have some guidelines for the cultural adaptation of the SODIS introduction and render it acceptable to the local community [19].

III. THE APPLICATION IN THE FIELD

Many technologies may sound very promising under laboratory conditions, but reveal to be inappropriate or show much lower efficiency at user level. That is the reason why SODIS has been extensively tested for its microbiological efficiency under a wide range of field conditions.

Laboratory research has been conducted under strictly controlled conditions, where the most relevant parameters were exactly defined. Selected strains of bacteria or virus were exposed in quartz tubes to artificial radiation simulating sunlight, while defined temperatures were maintained. The laboratory tests allowed quantifying and understanding the effect of UV radiation and heat in the inactivation process of water pathogens.

To measure the SODIS efficiency at user level is not as simple as during a demonstration workshop. In fact, the inactivation rate of bacteria cannot always be defined accurately, as data on the initial contamination often is not available. Due to operational, logistical or human limitations, a survey of SODIS efficiency at user level is difficult. Current SODIS dissemination projects focus on social and educational aspects, water quality is generally monitored occasionally, mainly with a didactic purpose, to demonstrate SODIS efficiency to the users.

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 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 calculating the SODIS efficiency.

The efficiency of any disinfection process depends upon the water being treated beforehand to a high degree of purity, as disinfectants will be neutralized to a greater or lesser extent by organic matter and readily oxidizable compounds in water. An initial design was done for the manufacturing of a single exploratory demonstration unit. The first improvement made was a change to one large wheel with a spherical shape instead of the two small wheels. It would also reduce the ground pressure, making it easier to push on soft surfaces, and help to prevent soil compaction. This would increase both the manoeuvrability and stability of the device during cartage.

The acceptance of a new technology by a community of possible users depends on several factors. If solar water heating was used by the general affluent society, it would have been something that people would have become used to, and even could aspire to. That proposed a conceptual framework for the adoption of new technologies, and concluded that the adoption decision was heavily influenced by interest and familiarity. For this to happen, a broader framework of social, technological and economic factors first had to be installed. The most important of these were found to be: financial incentives, government led initiatives, reduction of investment costs, and increase in product reliability, dissemination of information, and environmental awareness. All of these factors are represented in the conceptual framework.

Need for Solar Heat Barrow: The need for clean domestic hot water has been confirmed. This water is used for bathing, washing dishes, food preparation, cooking, and sometimes for washing clothes. Access to hot water leads to improved hygienic practices, which in turn lead to a higher quality of life and improved health. A large portion of the Southern African population does not have access to running water in their dwellings. Water has to be carted from communal water sources. Sometimes potable water is available from communal taps. In other cases natural sources of water, not meeting the requirements for human consumption, is the only source available to a community.

People are thus exposed to the ailments caused by a large variety of waterborne pathogens, especially in the case of sewerage contamination of the water source. These people without access to water in their homes normally do not have access to electricity. They use a variety of solid and liquid fuels to, amongst other, heat water. This is expensive in relative terms. The idea thus originated that an affordable multipurpose device could be of use to people living under these conditions. This device should assist them with the carting of water, its disinfection where necessary, and the heating. With the abundant solar energy available in Southern Africa, a solar water heater was the natural choice for the latter function. This, however, added a functional requirement to the device that hot water should be stored until the middle of the evening at any time of the year.

A device, the Solar Heat Barrow (SHB), was conceptualised to fulfil this need. To ensure a high level of disinfection, where required, a second add on device was conceptualised to add a sufficient dose of disinfectant to the water every time it is filled. This device is named the “dispenser”. It must, however, be stressed that the success of the final water disinfection will depend to a large extend on the participation of the community to protect their water sources, and to apply simple additional filtering techniques before filling the SHB.

The Water and the Environment: The water sources are formed through the hydrological cycle of water. This means, water first evaporates from the lakes and seas and it falls as rain to the earth. Part of the rainwater infiltrates the ground to form ground water. The other part flows as surface runoff over the soil to form rivers, streams and lakes.

The Use of Water: It is important, that the water that is consumed during meals or in between is clean and safe. This can be achieved by disinfecting the water. To take care of and protect the water is a task for girls and boys as well as for adult women and men, then without water life would not be possible. It is therefore important that the whole family has a profound knowledge about water.

Consequences of Consuming Contaminated Water: If we do not clean the vessels used for keeping the water, the water will be contaminated even if it was clean originally. Inside the water there are very small microorganisms. These microbes are so tiny that we cannot see them with our eyes. When we see clear water, we therefore believe that the water is clean, but it is not always the case.

Common Methods for Water Disinfection: The most common forms of water disinfection at household level are: boiling the water, chlorination, using SODIS.

Influence of Turbidity and Depth of the Bottle: If the water we are exposing is very turbid, the sunrays cannot penetrate through all the water because they are absorbed by the particles found in the water. In other words, the particles present in turbid water protect the pathogenic microorganisms and the sunrays then cannot kill them. It is scientifically shown that SODIS is a method for disinfecting small quantities of water. For large volumes of water SODIS will not work. Therefore it is recommended to use bottles with a volume of up to 2 litres for the application of SODIS. The depth of a vessel for applying SODIS should be less than 10 cm, if we use vessels with more depth, the sunrays cannot penetrate the profound areas of the vessel with the same intensity. This makes the disinfection process incomplete.

Expose the Bottles to the Sun: The bottles have to be exposed to the sun on the metal roof of the house, on a piece of corrugated zinc sheet put on the floor or on a tile roof if no corrugated zinc sheet is available. The bottles are exposed to the sun in horizontal position, facing towards the sun. It is important that the place of exposition receives sun during the whole time, this means from at least 9 o’clock in the morning until 3 o’clock in the afternoon.

It is recommended to use double the amount of SODIS bottles required for preparing the daily drinking water. While one bottle is being exposed to the sun, the other bottle stays ready for consumption in the house. The SODIS bottle is a clean and safe container, protecting the water against recontamination. Therefore it is the best to store the disinfected water in the SODIS bottle itself and not in a different container which could be contaminated. Use a clean glass to drink the disinfected water. It is recommended to consume the SODIS water within two days after exposing the water to the sun. Finally, it is of advantage for the facilitators using this Posters’ guide to study additional literature and information about SODIS in order to deepen their understanding of technical aspects of the solar water disinfection method. Also, it is a requirement for facilitators to collect their own experiences with the application of SODIS through personal use before they start teaching the application procedure of SODIS to others.

IV. Result And Analysis

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 diarrheal 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. Therefore, this study was aimed at establishing relationships between these variables and the effectiveness of solar disinfection.

In much of the developing world, there are no funds to develop a drinking water system infrastructure. Where treatment systems do exist, there are several issues that often preclude adequate water treatment. These include misemployment, under employment, in operational equipment, lack of spare parts, unavailability or cost of chemicals, inadequately trained staff, and lack of supervision [13].

Solar disinfection offers a worthwhile reduction in disease risk under "real life" conditions, but is not a panacea. A central problem is that people cannot usually be relied on to follow laboratory protocols. In practice they may not leave the water in the sun for long enough before drinking it, and they will probably also drink water directly from water holes or other sources. In addition, contaminated water is only one of the causes of diarrhoeal disease, which is often the main public health problem in areas where solar disinfection offers potential benefits [16].

Other advantages can result from solar disinfection. In endemic areas, schistosomiasis (bilharzia) can be contracted from drinking water containing the cercariae stage of schist some worms, although this is not the most common route of infection. Cercariae lose the ability to penetrate skin or mucosa within 48 hours of being shed by their aquatic snail host. Solar disinfection can therefore remove one transmission route of schistosomiasis if drinking water is allowed to stand for 2 full days before being consumed. Another advantage of storing drinking water in transparent, rather than opaque, containers is that the risk of ingesting leeches is greatly reduced, as it is immediately apparent if they are present in the water.

V. Conclusion

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.

The best solution to avoid secondary contamination of SODIS treated water is to store the water in the same bottle and drink it directly from the bottle (best by using a cup). This handling is very effective in preventing secondary contamination of the treated water. Therefore, a double set of SODIS bottles is required: One for exposure during the day, the other containing the water treated during the previous day ready for consumption.

During the third phase the sociocultural acceptance, applicability and financial viability of SODIS were studied in demonstration projects in local communities in Colombia, Bolivia, Burkina Faso, Togo, Indonesia, Thailand and China. The survey assessing the sociocultural acceptance of SODIS revealed that users appreciate the sustainable and simple water treatment method. An average of 84% of the users stated that they will certainly continue to use SODIS after the conclusion of the demonstration projects. About 13% of the users consider to maybe using it in the future, while only 3% refuse to use SODIS as their health is not affected by the present water quality [1, 5].

At the one end of the scale, there are those countries with highly developed commercial and industrial sectors, well established secondary and tertiary education systems, good communications, and a well developed ability to improvise adequately when apparently essential equipment is not available. At the other extreme, there are countries in which the already minimal economic achievement is totally overburdened by natural or political disasters, where communications are appalling, technical and tertiary education nearly nonexistent, and the agricultural and industrial base so limited that the provision even of the simplest techniques of water supply is only achieved through external aid, and the operation and maintenance of these is a continuing nightmare.

Acknowledgment

I am grateful to Professor Dr. K. Jyrki KAUPPINEN (Physics Department, Laboratory of Optics and Spectroscopy, University of Turku, Turku-Filland) for the oppurtunity to perform this work and his valuable comments on the manuscript.

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