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Disinfecting Contaminated Water with Natural Solar Radiation Utilizing a Disinfection Solar Reactor in a Semi-arid Region

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Abstract

The present investigation was carried out to assess the efficiency of solar energy in disinfecting contaminated drinking water in a semi-arid region. Distilled water was inoculated with coliform bacteria and exposed to up to 6 hours of ultraviolet radiation using natural solar radiation and UV lamps of 365 nm wavelengths with varying intensities. Total coliform counts were enumerated at intervals to determine percentage inactivation against time. Other factors such as water turbidity, total hardness, chlorine level, pH and temperature were also monitored. The results showed a rapid decrease in microbial counts upon exposure to solar radiation. More than 99.99% reductions were achieved after 6 hours for the bacterial communities tested under different conditions. The rate of inactivation, however, varied and was mainly affected by water turbidity and temperature during the experiments. In addition, a solar flow through reactor for irradiating contaminated water was constructed and tested. The reactor consisted mainly of a disinfection reactor, storage tanks, a submersible pump, and a light activated switching unit. Flow regulation was achieved by a light activated switching unit which controlled the submersible pump. The flow rate was adjusted so that the time it took the water to pass the reactor was sufficient to inactivate the bacteria. The reactor was tested under varying levels of turbidity using coliform bacteria as the source of water contamination and selected bacterial species. The results indicated that turbidity affected the efficiency of water disinfection, and the reactor can be a valuable tool in solar water disinfection technology, especially, for remote and rural areas. Further work is still needed before it can be concluded that solar radiation can be an effective, cost-free, technique for drinking water disinfection.

الملخص

يهدف البحث إلى تقييم كفاءة تعقيم مياه الشرب باستخدام الطاقة الشمسية في المناطق النائية. لتحقيق الهدف تم تلقيح مياه مقطرة ببكتيريا الكوليفورم وتعريضها للأشعة فوق البنفسجية لمدد تصل إلى ست ساعات باستخدام الأشعة الشمسية الطبيعية ومصابيح الأشعة فوق البنفسجية (طول موجة = ٣٦٥ نانومتر وحدة مختلفة). وتم حساب العدد الكلي لبكتيريا الكوليفورم على فترات محددة وذلك لتحديد نسبة تثبيط البكتيريا حسب الزمن وتم مراقبة تأثير عوامل مثل العكارة ومستوى الكلورين والرقم الهيدروجيني ودرجة الحرارة. وبينت النتائج أن هناك تناقص سريع في عدد البكتيريا الكلي مع زيادة مدة التعرض للأشعة حيث وصلت إلى ٩٩,٩٩% تناقص في عدد البكتيريا بعد تعرض للأشعة مدته ست (٦) ساعات. واختلف معدل التناقص في عدد البكتيريا حسب عكارة المياه ودرجة حرارتها. كذلك تم تصميم وتجربة مفاعل لتعقيم المياه مكون من مفاعل تعقيم وخزان ومضخة ووحدة تشغيل باستخدام الإنارة. وتم تحديد معدل التدفق ليتناسب مع المدة اللازمة للتعقيم ، وبعد تجربة المفاعل عند درجات مختلفة من العكارة باستخدام بكتيريا الكوليفورم وأنواع مختارة من البكتيريا، دلت النتائج على أن عكارة المياه تؤثر على كفاءة التعقيم وأن هذا المفاعل يمكن أن يكون مفيدا لتعقيم المياه وخصوصا في الأماكن النائية. مازال هناك حاجة لمزيد من البحث قبل أن يصبح هناك مفاعل عالي الكفاءة وقليل التكاليف لتعقيم المياه.

Keywords: Solar disinfections; Solar radiation; Solar bioreactor; UV radiation; Water disinfection;

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1. Introduction

Securing water supplies suitable for human consumption has become an increasingly difficult undertaking in many parts of the world, particularly for communities in rural areas of less developed countries. A large number of human diseases are water-borne and can cause a variety of illnesses varying from slight discomfort to death. Diseases such as cholera, typhoid fever and shigellosis for example are well-known water-borne diseases, which can cause a staggering number of deaths annually (Mc Donald and Kay, 1988). Although the use of simple technologies, such as boiling of water, can dramatically reduce the number of harmful microorganisms; in many situations the energy necessary to carry out this task may be costly or simply unavailable. In such situations, the availability of a no-cost technique may be the answer. While simple methods are available for water clarification or suspended solids' removal, including sand filtration, it is usually the remaining microbial contamination that lingers. One of the techniques that can meet the no cost requirement is the use of natural ultraviolet [UV] radiation, which are part of natural solar radiation.

Ultraviolet radiation is divided according to its' biological effects into three major components: 1- UV-C radiation, also called germicidal radiation, which occupies the range up to 280 nm, fortunately it does not reach the Earth, 2- UV-B radiation, also called sunburn radiation, which occupies the range 280-320 nm (Furusawa *et al*., 1990) , and 3- UV-A radiation, referred to as the black light, which occupies the range 320-400 nm (Acra *et al*.,1990). There are conflicting reports on the wavelengths of the spectrum of radiant energy responsible for microbial inactivation (Aas *et al*., 1996; Burkhardt III *et al*., 2000; Kapuscinski and Mitchell, 1983; Sinton *et al*., 1994). The damaging effects of UV radiation appears to be largely due to their formation of pyrimidine dimers, thus interfering with, or cleaving of, the nitrogen base sequences of the DNA strands in microbial cells (Muller-Niklas *et al*.,1995). Other mechanisms for UV damage of cellular membranes (Moss and Smith, 1981) or inhibition of tRNA synthesis (Kubitschek and Doyle, 1981) have also been reported.

Studies on the use of solar radiation as a means of water disinfection started early in the eighties (Acra *et al*., 1980). These investigations were developed to determine if the technique is effective in disinfecting small volumes of water for use in the preparation of oral rehydration solutions, used in the treatment of diarrhea. Later, Odeyemi *et al*. (1988) examined the germicidal effects of solar radiation on water samples, using transparent containers and reported total removal of three orders of magnitude [$3\log_{10}$] coliforms within 3 hours exposures. Inactivation of fecal bacteria in drinking water by solar heating have also been reported (Joyce *et al*., 1996). Within 7 hours no viable *Escherichia coli* organisms were detected at either the end of their experiment or a further 12 hour later. Numerous other investigations have also been reported on the use of UV irradiation as an alternative technique for the disinfection of partially treated wastewater (Acher *et al*., 1994; Burkhardt III *et al*., 2000; Dizer *et al*., 1993; Job *et al*., 1995; Meng and Gerba, 1996; Sawai *et al*., 1993) or contaminated fresh and sea waters (Carnimeo *et al*., 1994; Christoulas and Andreadakis, 1995; Elkarmi, 1998; Lund and Hongve, 1994; Mc Guigan *et al.*, 1998). The biodosimetric measurement of the influence of reflection on the reduction equivalent fluence was investigated by Sommer *et al*. (1996) in flow through reactors.

Although the efficacy of using solar radiation for the disinfection of water has been studied by a number of investigators, very few have designed and tested pilot reactors that utilize this method to come up with a simple and low cost system that can be used in places where contaminated drinking water is a health hazard. A model was designed and tested in Thailand, using copper, glass and galvanized steel as tubes for the disinfection process (Koottatep *et al*., 1988). The results obtained from their design showed that the glass tubes provided some disinfection capabilities. Acra *et al.* (1990) designed prototype solar units using serpentine-shaped transparent tube or two Pyrex glass containers and a Pyrex glass helix. The use of an exposure vessel of 1x 2 meters with baffles for directing water flow was also used to design a reactor for water disinfection (Solarte and Dierolf, 1995). They reported that the reactor in which water is heated and exposed to solar radiation produced significant reductions in fecal coliform and *Streptococcus* concentrations under all operating conditions. The Austrian National Standard (Anonymous, 2001) provides biodosimetry as the standard method for type testing of disinfection plants for drinking water (Cabaj *et al*., 1996; Sommer *et al*., 1997; Sommer *et al*., 1999).

In this paper we investigated the use of solar radiation in the disinfection of contaminated drinking water in a semi-arid region and the effects of factors such as turbidity and temperature on the efficiency of UV radiation in the UV- range in the inactivation of contaminated drinking water. In addition, we explored the design and testing of a solar drinking water disinfection reactor which utilize UV radiation as the method of bacterial inactivation taking into consideration the factors that could influence the inactivation process.

2. Materials and Methods

2.1. Phase I: Laboratory Scale "Static System"

Test tubes [25 X 200 mm] with screw caps, borosilicate beakers 2 liters in volume for the preparation of contaminated water, water bath [GFL 1002-1013 series, Germany] and UV lamps and stands with wavelength of 365 nm [Cole- Parmer 9815 series, USA] were used to carry out the tests. The water samples used in the tests were prepared by contaminating distilled water with coliform bacteria. The total coliform count [TCC] was measured [initial count] using the Standard Methods-Microbiological Examination, multiple tube fermentation technique which is based on carrying out the presumptive phase, confirmed phase and completed phase (American Public Health Association,1998). These test samples were either subjected to the UV lamps with UV-365 nm irradiances of 4, 7, and 11 W/m^2 at a distance of 10 cm (according to the manufacturers information), or were subjected to direct sunlight. To test the effects of temperature, the tests were carried out at temperatures of 25, 30, 35, 40 and 45 °C using a water bath to vary the temperature. The test tubes were tilted by 45° angle so that the water in the water bath covered one side of the tubes and the upper sides were subjected to UV. Samples were periodically taken every one hour or half an hour and the TCC was measured using the Standard Methods- Microbiological Examination (American Public Health Association,1998). Furthermore, turbidity, pH, total hardness, and chlorine level were measured at the start of the experiment using the Standard Methods (American Public Health Association ,1998). Tests were carried out at the Hashemite University located in Zarqa city, Jordan (altitude of 600 meters, 31° N and 35° E). At all tests control samples were prepared the same way the test samples were prepared but placed in complete darkness or covered by foil paper.

2.2. Phase II: Pilot Scale "Flow Through System"

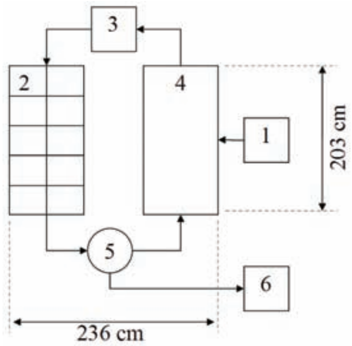
2.2.1. Bacterial species

Distilled water was contaminated with coliform bacteria as described above, and total coliform count (initial count) was also measured (American Public Health Association ,1998). Furthermore, isolated bacterial species of *Staphylococcus* spp., *Salmonella* spp., *Streptococcus* spp., *Pseudomonas* spp. and *Escherichia coli* were used to examine the efficiency of the reactor in inactivating the bacteria. These wild bacterial species were kindly supplied by Jordan University Hospital-Amman, Jordan. These bacterial species were inoculated into a nutrient broth, washed twice with normal physiological saline and finally suspended in 5 ml of nutrient broth before being added to the holding tank of the reactor.

2.2.2. Reactor design

The reactor consisted of an isolated large tank (500 L) connected by PVC (1.25 cm) tubing to a smaller (125 L) tank. The water level in the small tank was controlled by a float valve. A submersible pump (Aqua Clear Power Head 200 - USA) placed in the water holding tank pumped the water to the reactor made of transparent polyethylene terephthalate (PET). The reactor was held by a metal frame similar to that of flat solar water heaters. The frame was tilted by 45 degrees facing south to ensure maximum radiation interception. The reactor was connected to another small tank (125 L) used for the storage of disinfected water. The pump was controlled by a light activated switching unit that utilizes a photovoltaic cell to switch the pump on when light is available dictated by the output voltage of the photovoltaic cell (two hours after sunrise) and off when light is not available (one hour before sunset).

It is worth mentioning that the system was modified to eliminate the need for a pump and to increase the temperature of the water by installing a flat solar water heater which can circulate the water in the reactor as well, and a heat exchanger to regulate the temperature of the water coming out of the reactor and reduce the time needed to heat the water by the solar heater, as shown schematically in figure 1. The solar water heater depends on convective circulation established from solar heating to move the water from one tank to the other. The heat exchanger during the operation of the system will aid in increasing the temperature of the water going into the solar disinfection reactor in order to decrease the time needed to raise the temperature of the water. The system was also equipped with a thermal one-way valve to regulate the flow of water between the solar heater and the reactor. In other words, the one-way valve opens when the temperature of the water reaches the desired temperature and thus starts the whole process of disinfection (in the morning) and closes when the temperature of the water decreases below the limit (close to sunset). This modified system eliminated the need for a pump to circulate the water, a system to switch the pump (or system) on or off and increased the temperature of the water to the required level.



1 Water supply tank;
2 Solar water disinfection reactor;
3 Temperature regulation valve;
4 Solar heater;
5 Heat exchanger;
6 Storage tank;

Fig. 1. Schematic Diagram of the Modified Solar Water Disinfection Reactor

After irradiation of the bacterial suspension in the reactor, aliquots were taken in hourly intervals, and microbiological examination was performed according to standard methods (American Public Health Association, 1998).

3. Results

3.1. Laboratory Scale "Static System"

The effect of turbidity on the inactivation of coliform bacteria by UV-365 nm radiation obtained in the laboratory static system is shown in figure 2. The efficiency is calculated as the semi-log of inactivation of bacterial after 6 hours of continuous exposure to natural UV.

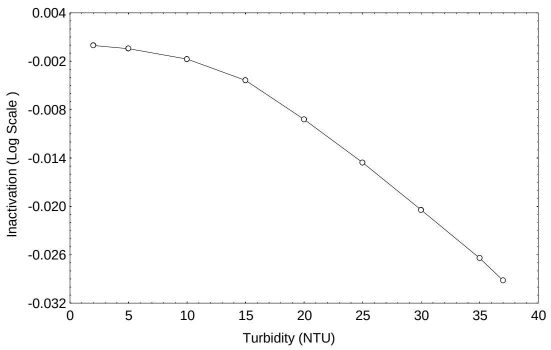


Figure 2. Effect of Turbidity on the Inactivation of Coliform Bacteria Obtained in the Laboratory Static System.

Tables (1-4) show the total coliform counts and reduction percentages after exposure to natural solar radiation under different experimental conditions of various turbidity levels measured as NTU (Nephelometric Turbidity Units), hardness and pH values in the static system. UV irradiances during tests ranged from 4-27 W/m^2.

Table 1. Total coliform counts and inactivation percentages at a 37 NTU turbidity water in a static system.

Exposure time (hours)	Total Coliform counts/ 100 ml	Inactivation %
0.0	1.1 x 10 ^{7}	0.0
1.0	3.0 x 10 ^{6}	72.7272
2.0	1.3 x 10 ^{6}	88.1818
3.0	9.0 x 10 ^{4}	99.1818
4.0	2.4 x 10 ^{4}	99.7818
5.0	5.0 x 10 ^{3}	99.9545
6.0	8.0 x 10 ^{2}	99.9927
Control	5.0 x 10 ^{7}	0.0

Experimental conditions: Water turbidity = 37 NTU, hardness = 273 $CaCO_3$ mg/L and pH = 7.1. Total time in full sun = 7 hours.

Table 2. Total coliform counts and inactivation percentages at a 27 NTU turbidity water in a static system.

Exposure time (hours)	Total Coliform counts/ 100 ml	Inactivation %
0.0	1.7 x 10 ^{7}	0.0
1.0	8.0 x 10 ^{6}	52.9417
2.0	8.0 x 10 ^{5}	95.2941
3.0	2.3 x 10 ^{4}	99.8647
4.0	5.0 x 10 ^{4}	99.7058
5.0	3.0 x 10 ^{3}	99.9823
6.0	5.0 x 10 ^{3}	99.9705
Control	5.0 x 10 ^{7}	0.0

Experimental conditions: Water turbidity = 27 NTU, hardness = 287 $CaCO_3$ mg/L and pH = 7.1. Total time in full sun = 2 hours.

Table 5 shows the results of testing the effect of temperature at UV 365 nm irradiances of 4, 7 and 11 W/m^2. The table shows the time in hours when bacterial inactivation reached a reduction of 99.99% when the starting bacterial count was in the order of 10^5 cells/ ml for all tests.

Table 3 .Total coliform counts and inactivation percentages at a 17 NTU turbidity water in a static system.

Exposure time (hours)	Total Coliform counts/ 100 ml	Inactivation %
0.0	8.0 x 10 ^{6}	0.0
1.0	5.0 x 10 ^{5}	93.7500
2.0	1.1 x 10 ^{5}	98.6250
3.0	2.2 x 10 ^{4}	99.7250
4.0	8.0 x 10 ^{3}	99.9000
5.0	7.0 x 10 ^{2}	99.9912
6.0	3.0 x 10 ^{2}	99.9962
Control	1.3 x 10 ^{7}	0.0

Experimental conditions: Water turbidity = 17 NTU, hardness = 293 CaCO3 mg/L and pH = 7.6. Total time in full sun = 7 hours.

Table 4. Total coliform counts and inactivation percentages at a 10 NTU turbidity water in a static system.

Exposure time (hours)	Total Coliform counts/ 100 ml	Inactivation %
0.0	5.0 x 10 ^{6}	0.0
1.0	8.0 x 10 ^{4}	98.4000
2.0	2.2 x 10 ^{4}	99.5600
3.0	1.1 x 10 ^{3}	99.9780
4.0	2.2 x 10 ^{2}	99.9956
5.0	8.0 x 10 ^{1}	99.9984
6.0	2.3 x 10 ^{1}	99.9995
Control	2.8 x 10 ^{6}	0.0

Experimental conditions: Water turbidity = 10 NTU, hardness = 276 $CaCO_3$ mg/L mg/100ml and pH = 7.5. Total time in full sun = 7 hours.

Table 5. Effect of temperature on the inactivation of coliform bacteria by solar UV-365 nm radiation.

Temperature °C	Hours needed for inactivation of 99.99% by UV 365nm irradiance of		
	4.0 W/m^2	7.0 W/m^2	11.0 W/m^2
25.0	7.0	4.0	2.0
30.0	6.0	3.0	2.0
35.0	5.0	2.0	2.0
40.0	4.0	1.0	1.0
45.0	2.0	1.0	1.0

Each number is an average of three readings. Tests were carried out using distilled water with negligible turbidity

3.2. Flow Through Reactor

Figure 1 show the schematic design of the solar flow through disinfection reactor. The original design and the modified system of the reactor performed adequately switching on and off as planned. The flow of water in the original design was uninterrupted and proceeded continuously between the tanks and the reactor and the desired flow rate was adjusted to ensure that maximum exposure time needed to achieve the desired bacterial inactivation is provided. Water flow in the modified system was also flowing in an uninterrupted manner except at situations where high temperature caused flow problems between the solar water heater and the reactor.

Table 6 shows the inactivation results for coliform bacteria using the solar flow through reactor in the form of reduction percentages and exposure times obtained from using contaminated water with coliform bacteria. Table 7 lists the inactivation results of tests on selected bacterial species by means of the solar flow through reactor, and showing the reduction percentages, exposure times needed to achieve the maximum bacterial inactivation and turbidity of the used water.

Table 6. Inactivation of coliform bacteria by means of solar flow through reactor.

Turbidity NTU	% Inactivation with Time (Hours)			
	3	4	5	6
1.4	98.7	99.9998	-	-
3.0	-	90	99.9998	-
3.5	99.7	99.8	99.9998	-
9.6	92.6	99.8	99.9	99.9998

Table 7. Inactivation of selected bacterial species by means of the solar flow through reactor.

Species	Turbidity NTU	% Inactivation with Time (Hours)			
		1	2	3	4
Staphylococcus spp.	16	99.9998	-	-	-
Salmonella spp.	8.9	99.85	99.9998	-	-
Pseudomonas spp.	2.6	90.0	99.9998	-	-
Streptococcus spp.	5.0	98.8	99.25	99.9998	-
E. coli	2.0	90.3	96.1	99.9	99.9998

The results also indicate that the exposure time needed to reach 99.99% reduction depends on the irradiance of UV radiation and the temperature. The time to obtain this reduction varied between one hour at high UV irradiances, very low turbidity and high temperature to seven hours at low UV radiation and temperature. The average exposure time needed to reach 99.99% reduction at average conditions encountered during testing was six hours. This exposure time decreased rapidly with reduction in the turbidity level and elevation of water temperature.

The results from this study indicate that temperature affects the degree of water disinfection by natural UV radiation. As the temperature of the water increased the time needed to obtain maximum bacterial inactivation is reduced. By increasing the irradiance of solar UV radiation, the time needed to obtain reduction of > 99.99% was reduced compared to a lower UV irradiance at the same temperature. The difference in exposure time required for maximum reductions was not significant for temperatures above 40°C.

4. Discussion

The disinfection of water by UV irradiation has become a credible alternative to chemical disinfection. A number of studies have been conducted to estimate the influence of physical factors, including sunlight and temperature, on the rates of die-off occurring for microbial indicators and pathogens in estuarine and marine waters (Burkhardt III *et al.,* 2000; Davies-Colley *et al.,* 1994; Fujioka *et al.,* 1981; Kapuscinski and Mitchell, 1983; Rippey *et al.,*1987). The results from this study obtained in the laboratory scale indicate that turbidity is a factor that influences the reduction percentage of bacteria and thus the efficiency of UV disinfection of contaminated water. At turbidity higher than 5 NTU, the efficiency starts decreasing rapidly until it reaches approximately 93%. To reach higher efficiency percentages, it is necessary to increase the exposure time. It is worth mentioning that the Jordanian national standards for drinking water state that the acceptable range for turbidity is less than or equal to 5 NTU. Thus, in cases where drinking water exceeds the Jordanian standards, it is necessary to physically treat the water by filtration methods which are efficient in decreasing turbidity levels prior to disinfecting it by ultraviolet. Furthermore, the results indicate that the efficiency increases with increased exposure time, in other words, at high turbidity conditions and severe weather conditions, it is necessary to increase the exposure time to compensate for the effects of these factors. Furthermore, the results were used to adjust the flow rate of water in the reactor to ensure that water in the reactor is exposed to at least five hours of UV radiation before leaving the reactor to the storage tanks.

The effects of solar radiation, temperature, salinity, and other factors on the survival of *Salmonella typhimurium* (Smith *et al*., 2000), *Escherichia coli*, *Clostridium perfringens*, and male – specific bacteriophage in estuarine waters have been studied (Burkhardt III *et al.,* 2000). Temperature influenced the lethal effects from solar radiation only for fecal coliforms and the inactivation of fecal coliforms was significantly and inversely related to temperature and positively related to accumulated light energy (Burkhardt III *et al.,* 2000). Joyce *et al*., (1996) studied water samples heavily contaminated with *E .coli* and heated to temperatures of 50, 55, and 59.5°C and exposed to full Kenyan sunshine (maximum water temperature, 55°C). No cultivable *E. coli* organisms were detected at either the end of the experiment or a further 12 hours later.

There have been several reports about the influence of lamp intensity and water transmittance on the UV disinfection of water ((Blatchley III and Hunt, 1994; Sommer and Cabaj, 1993; Sommer *et al.,* 1997; Sommer *et al*., 1999). The influence of fluence distribution on the result of biodosimetry was investigated by Cabaj *et al.* (1996). In the single lamp pilot system, UV lamp intensity reduced the reduction equivalent dose more than water transmittance (Sommer *et al*., 1999).

The UV irradiance measured during the summer season and between 10:00 A.M. and 3:00 P.M ranged between 23 - 27 W/m^2 indicating an ample level of UV irradiance to carry out water disinfection. The UV irradiance decreases during the winter season and cloudy or rainy conditions to about 4 W/m^2 which is still sufficient to carry out water disinfection at low levels of turbidity. Burkhardt III *et al.*, (2000) showed that light energy was greatest during the summer in Alabama trials and the greatest increase of accumulated light energy occurred between 4 and 8 hours after sunrise [11 A.M-3 P.M.]; this accounted for 55-58% of the total energy observed. The results indicate that *E. coli* needed four hours to reach 99.9998 % reduction, which was the longest time for all bacterial species tested, indicating that it is less sensitive to UV radiation than other tested bacterial types. Thus, it can be used as an indicator for the efficiency of UV disinfection of water. *Staphylococcus* spp. was the most susceptible species to UV disinfection and needed only one hour of exposure time even at high turbidity level (16 NTU). It is worth mentioning that future research should include in the evaluation of the efficacy of disinfection plants using additional test organisms such as bacterial spores or bacteriophages. This is due to the fact that although the more UV sensitive indicator bacteria are no longer detectable, other more UV resistant pathogens could be still present in the water.

The first design of the reactor was successful in inactivating the bacteria tested although it suffered from one drawback, which is the need for electrical power (minimal power to drive a 6 watt submersible pump). Therefore, all rural areas where electricity is not easy available or absent will not be able to use the reactor, which explains the need for the modified version of the reactor. The modification of the reactor to include a flat solar water heater, heat exchanger and a thermal one-way valve eliminated the need for the pump to circulate the water and thus for electrical power. On the other hand, the design faced flow problems specially at elevated temperatures mainly in the form of reduction in flow rates and sometimes back flow problems. Thus, the exposure times needed to achieve the required water disinfection had to be changed slightly by decreasing the flow rate of water through the reactor. This adjustment of flow rate provided additional exposure time. Further modifications of the design are needed to solve the flow problems. Furthermore, the long term stability of the PET used for the first reactor with respect to a sufficient UV transmittance should be the subject of future studies. Another point to be included in future studies is the influence of the spectral UV absorption of the water.

This investigation showed that, based on the bacterial species examined, water turbidity is a major factor influencing water disinfection by natural UV radiation and that on increased exposure time or filtration methods are needed to reach maximum bacterial inactivation. Furthermore, temperature increased the level of bacterial inactivation. It appears that the temperature functions as an accelerating factor in bacterial inactivation when applying UV radiation. Further investigations are needed to determine the exact mechanism of temperature accelerated bacterial inactivation, to improve the design of the solar water disinfection reactor and to test its performance with regard to more resistant microorganisms like bacterial spores and viruses.

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