Low Cost Water Disinfectant System Using Solar Energy

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Abstract: Solar disinfection unit is unsophisticated, efficient and reasonably priced water treatment process appropriate for use in developing countries. Water was filtered through cloth, net and coconut husk to remove any suspended particles in water which would directly increase the efficiency of solar disinfection. The filtered water is then transferred in solar disinfection unit. Water with Escherichia coli as indicator organism was filled in the solar disinfection unit comprising of four polyethylene terepthalate (PET) plastic bottles joined together with PVC pipes. These bottles were kept in direct sunlight for 12-48 hours. Weather conditions and solar radiation were obtained using different programs. Solar radiations and elevated temperature destroyed the indicator organism efficiently. Health peril of chemical released in water was well thought-out and was determined to be safe with respect to human consumption. The efficiency of solar disinfection was augmented by use of semi-conductor titanium dioxide (TiO2) which reduced the time for exposure up to 90%. The temperature increase and dissolved oxygen decrease in the disinfection process which was overcome by retaining this water in traditional earthenware water storage vessels (*mutka*). Allowing accessibility to better life through improved quality of water.

Keywords: Solar disinfection system, *E. coli*, drinking water.

INTRODUCTION

For better quality of life water is good quality is essential. According to an estimate made by WHO 1.1 billion that is 17% of world population do not have availability to sufficient quantity of water and a lot more consume microbiologically contaminated water. In such situation chances for water borne diseases like diarrhea, cholera, typhoid fever [1], hepatitis A, amoebic and bacillary dysentery increases. According to an estimate by WHO [2], 2004 among 1.8 million people dying of diarrhea 90% are children less than Age of five mostly in developing countries when is equal to about 4500 kids every day.

Public water supplies in our country are unsuccessful to supply safe drinking water. It is an individual's chore to get safe drinking water at household. To reduce the high rate diarrheal diseases one of the options available is to treat it at point of use (WHO/UNICEF 2005) [3], which saves financial resources for medical care and have a prominent positive impact on financial condition of household and increases productivity Health agencies recommend boiling of drinking water since decades but where there is scarcity of fire wood and fuel it is hard to practice and it increases the risk of respiratory diseases due to contact with smoke. Boiling water can increase up to 11% of budget of poorest part of populace [4]

Filtration is dependent on pore size of filtration medium and those with small pore size are considerably expensive like reverse osmosis. One of the drawback of chlorine is that trihalomethanes (THMs) and haloacetic acids (HAAs), which are carcinogenic are produced in enormous quantity when chlorine from any source reacts with organic compounds in water and is regulated by the United States Environmental Protection Agency (EPA) [5]. Ozone escapes from water during the disinfection process, threatening the health of operators and environment at concentration as low as 0.03 gm-1 [6].

It may also increases bacterial growth after treatment because ozone oxidizes neutral organic matter to produce smaller organic matters which are usually biodegradable and has potential to increase bacterial growth after treatment. UV damage done to bacteria has been survived by them through different repair system of genetic material [7] UV in certain range do not have long term effect on their survival instead transiently reduces the ability to form colonies [8].

Solar water disinfection is one of the methods used for treating small amount of water at point of use. There are three potential elements participating in pathogens elimination [9-15]. The first is through heating, second through the effect of natural UV radiation and third through a mixture of both thermal and UV effect. Solar disinfection (SODIS) is included in the techniques reviewed by WHO for household water treatment and storage (World Health Organization, 2001). In SODIS water require several hours of exposure to strong sunlight to obtain the advantageous synergy between UV dose and temperature rise [15, 16]. In cloudy weather much longer level of exposure is required

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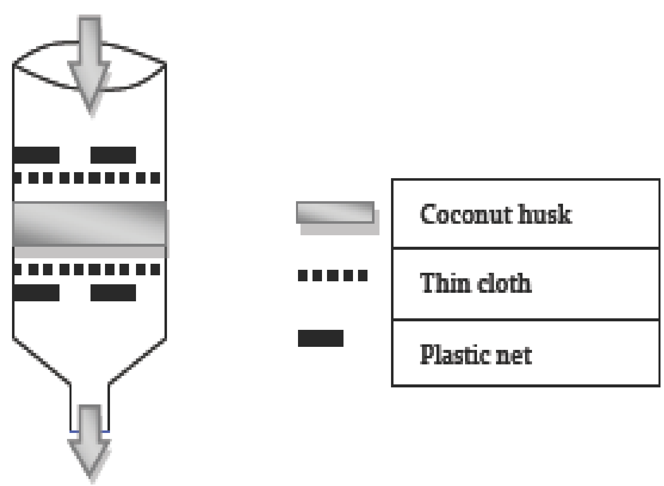
because of lower level of UV radiation and reduced likelihood of temperature of water exceeding above 50^0C. The goal of this work is to overcome possible disadvantages of solar disinfection i.e.; low storage, long exposure, time and weather dependency. A solar disinfection unit was constructed which is simple, efficient and reasonably priced water treatment process appropriate for use in developing countries. Water was filtered through cloth, net and coconut husk. Water with *Escherichia coli* as indicator organism was filled in solar disinfection unit comprising of four polyethylene tetrapthalate (PET) plastic bottles joined together with PVC pipes.

MATERIALS AND METHODS

Initially a pilot plant study was conducted to examine the effect of color on solar disinfection of water. In this study two batches of bottles were made each containing five colored bottles red, green, blue, yellow and transparent [9]. Bottles of batch one were filled with tap water and their initial bacterial count was taken by membrane filter technique (MF) and by pour plate method. The bottle were then inoculated with 0.1 ml of 24 hours grown pure culture of Escherichia coli the bottles containing 2litres of sample was kept in direct sunlight in garden of Institute of Environmental Studies in upright position and readings were taken at different intervals (0, 6 hours, 12 hours, 24 hours, and 48 hours). Same was done with batch2 except they were filled with sewage water taken from sewage line of Karachi University. Then a solar disinfection plant was constructed this plant consists of four parts (a) filtration assembly, (b) disinfection assembly, (c) condensation tank, (d) supply tank.



Diameter: 16.5cm/6.5 inches, Length: 32 cm/12.8 inches, Outlet diameter: 4cm/1.6 inches

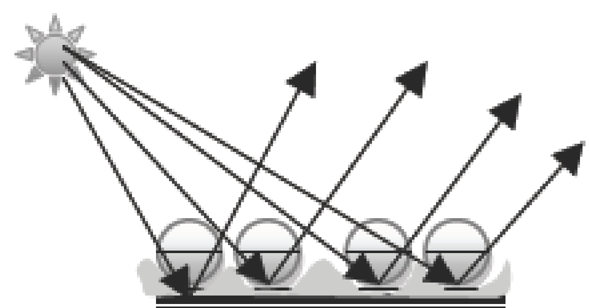
Figure: View of filtration assembly.

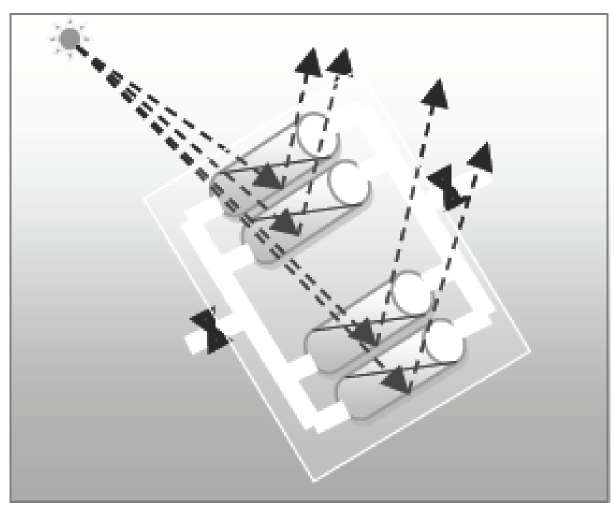
(A) Filteration Assembly

It lining is made from transparent plastic. The filtration material used is coconut husk with one layer of plastic net and other layer of muslin cloth before and after it made in the form of bed which is easy to remove and clean. This is used to remove large particles and to reduce turbidity from water before it enters the process of solar disinfection.

(B) Solar Disinfection Assembly

It is consist of four transparent PET bottles linked together with PVC pipes with one inlet and one outlet for water. The outlets and inlet consist of screw gauge valves. Cemantex sealant where used to join the ends and further plaster of Paris was applied on joint to avoid leakage. Here TiO_2 was added to increase the efficiency when it gets excited under light exposure and produce OH^- responsible for bacterial disinfection [17-26].





SIZES: Diameter of inlet (Internal): 1.0 inches, Diameter of inlet (External): 1.1 inches, Diameter of outlet (Internal): 1.4 inches, Diameter of outlet (External): 1.7 inches CAPACITY: Can hold water of volume = 4 liters

PLACEMENT: Assembly is placed on the roof of solar park of Institute of Environmental Studies, University of Karachi. It was placed in slanted position with an angle of 45° with the roof. It is positioned with its face towards north and south so that it would receive maximum duration of sunlight [11].

(C) Condensation Tank

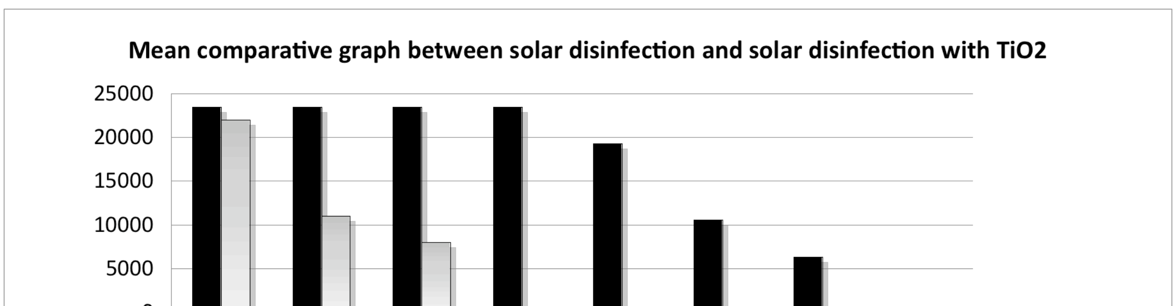
After passing through the process of solar disinfection the temperature of water increases and dissolved oxygen (OD) decreases (Reed 1996), to overcome these changes the water is placed in condensation tank which is an earthen pot. Here the water is condensed and further transferred to supply tank. The presence of this tank increases the capacity of the plant which is very useful for the times of rainfall or bad (cloudy) weather conditions and further decreases bacterial count [25].

(D) Supply Tank

Finally the water is transferred into the supply tank which is also an earthen pot. Here the water is ready for human consumption.

Pure culture of <u>*Escherichia coli.*</u> was isolated, by placing EMB agar plate in open in room for 20 minutes and then incubating it for 24 hours at 37°C. Colonies of E.coli was isolated. Water was initially sterilized by placing water filled assembly in direct sunlight for 48 hours and checking coliform by MPN technique before and after placement. This water was inoculated with pure 48 hours grown *E. coli* culture (1 test tube of 10ml). Sampling was done in sterilized bottles (autoclaved) at the intervals of 0, 3, 6, 21, 23, 25, 27, 48 hours according to feasibility. These samples were examined for *E. coli. E. coli* was examined by pouring 0.1ml of sample on solidified and 24 hours incubated (37°C) EMB agar plate and was spread with spreader. The initial samples were diluted upto10^{-3}, 21 and 23 hours with 10^{-2}, and 25, 27, 48 hours with10^{-1} dilutions. These EMB agar plates were incubated for 48 hours and the number of colonies were counted and then multiplied with dilution factor to get total number of colonies. Each reading was taken in triplicate and average was taken later.

(**a**)



	0	3	4	6	24	27	48	50
without TiO2	23428.5	23428.5	23428.5	23428.5	19285.7	10542.8	6285.7	297.14
with TiO2	22000	11000	8000	0	0	0	0	0

Figure 1a: showing mean average bar graph between simple solar disinfection and disinfection with the use of photcatalyst TiO_2.

(**b**)

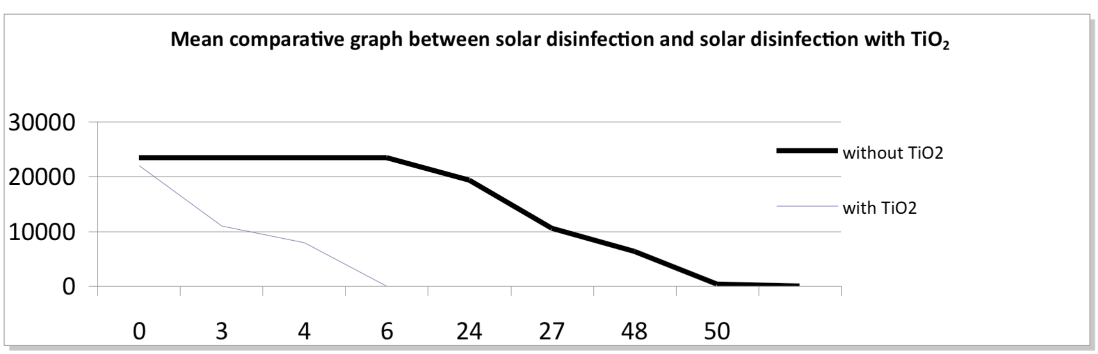


Figure 1b: showing mean average line graph between simple solar disinfection and disinfection with the use of photcatalyst TiO_2.

When the weather conditions were not suitable (weather underground web: http://weatherunderground.com.) i.e.: the solar intensity was low in the month of November and December. TiO_2 was added to water to enhance the solar disinfection 1mg/L of TiO_2 was found appropriate for this purpose increase in quantity decreased the efficiency of disinfection. The addition of photocatalyst increased the efficiency of unit with decrease in the exposure time required for disinfection.

The software STATISTICA5.5 was used to have multiple regression of the observation. Through the programme the regression summary was obtained and matrix plot was taken.

$$Correl(X,Y) = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}}$$

David M. Lawrence's computer software for solar radiation at the Earth's surface (http://www.fuzzo.com) was used to predict the amount of solar radiation at earth surface [27].

RESULTS

Statistical Analysis (statsoft, inc.1995. STATISTICA 5.5 for windows (computer program manual), web: http://www.statsoft.com.)

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	Y
X1	1	-0.81848	0.029812	0.115316	0.120181	0.704295	-0.07407	-0.10614	0.287396	0.040724	-0.05381	-0.92233
X2	-0.81848	1	-0.16297	1.12E-16	-0.0152	-0.76104	0.050096	0.201587	-0.07828	0.102054	-0.22953	0.934439
X3	0.029812	-0.16297	1	0.30697	0.386961	-0.14397	-0.82345	0.097838	0.047606	-0.46416	0.358142	-0.07559
X4	0.115316	1.12E-16	0.30697	1	0.86008	-0.46809	-0.17759	-0.22208	0.302003	-0.61028	0.206995	-0.01472
X5	0.120181	-0.0152	0.386961	0.86008	1	-0.48635	-0.17877	-0.28147	0.21726	-0.81238	0.359779	-0.00495
X6	0.704295	-0.76104	-0.14397	-0.46809	-0.48635	1	0.109377	0.030799	-0.04037	0.391957	-0.0335	-0.79547
X7	-0.07407	0.050096	-0.82345	-0.17759	-0.17877	0.109377	1	-0.28835	-0.15404	0.038844	0.225084	0.037971
X8	-0.10614	0.201587	0.097838	-0.22208	-0.28147	0.030799	-0.28835	1	-0.22324	0.400763	-0.33098	0.157578
X9	0.287396	-0.07828	0.047606	0.302003	0.21726	-0.04037	-0.15404	-0.22324	1	-0.02778	-0.16281	-0.13771
X10	0.040724	0.102054	-0.46416	-0.61028	-0.81238	0.391957	0.038844	0.400763	-0.02778	1	-0.72065	-0.01039
X11	-0.05381	-0.22953	0.358142	0.206995	0.359779	-0.0335	0.225084	-0.33098	-0.16281	-0.72065	1	-0.09692
Y	-0.92233	0.934439	-0.07559	-0.01472	-0.00495	-0.79547	0.037971	0.157578	-0.13771	-0.01039	-0.09692	1

Correlation summary statsoft, inc.1995. STATISTICA 5.5 for windows (computer program manual), web: http://www.statsoft.com.)

	X1										
X1	1										
X2	-0.81848	1									
X3	0.029812	-0.16297	1								
X4	0.115316	1.12E-16	0.30697	1							
X5	0.120181	-0.0152	0.386961	0.86008	1						
X6	0.704295	-0.76104	-0.14397	-0.46809	-0.48635	1					
X7	-0.07407	0.050096	-0.82345	-0.17759	-0.17877	0.109377	1				
X8	-0.10614	0.201587	0.097838	-0.22208	-0.28147	0.030799	-0.28835	1			
X9	0.287396	-0.07828	0.047606	0.302003	0.21726	-0.04037	-0.15404	-0.22324	1		
X10	0.040724	0.102054	-0.46416	-0.61028	-0.81238	0.391957	0.038844	0.400763	-0.02778	1	
X11	-0.05381	-0.22953	0.358142	0.206995	0.359779	-0.0335	0.225084	-0.33098	-0.16281	-0.72065	1
Y	-0.92233	0.934439	-0.07559	-0.01472	-0.00495	-0.79547	0.037971	0.157578	-0.13771	-0.01039	-0.09692

Regression summary

Regression Summary for Dependent Variable: Y

R= .97884582 R^2= .95813915 Adjusted R^2= .93895292

$F(11,24)$=49.939 $p<.00000$ Std.Error of estimate: 10.081

	BETA	St. Err. of BETA	B	St. Err. of B	t(24)	p-level
Intercpt			-368.082	1239.823	-0.29688	0.76911
X1	-0.5422	0.131128	-0.0021	0.000509	-4.1349	0.000374
X2	0.40423	0.115295	0.83656	0.238605	3.506046	0.001815
X3	0.304084	0.455453	6.828084	10.22704	0.66765	0.510726
X4	-0.11378	0.095718	-4.85522	4.084339	-1.18874	0.246172
X5	0.156586	0.166644	0.148573	0.158116	0.939644	0.356762
X6	-0.09408	0.139255	-4.04486	5.986932	-0.67562	0.505743
X7	0.305847	0.433059	1.636003	2.316468	0.706249	0.486834
X8	0.028387	0.053452	0.074765	0.140779	0.531084	0.600242
X9	0.053936	0.051141	4.508439	4.274825	1.054649	0.302088
X10	0.040713	0.146784	0.297291	1.071841	0.277365	0.783875
X11	-0.19947	0.260286	-7.68802	10.03197	-0.76635	0.45094

DISCUSSION:

As from the result obtained for solar disinfection without TiO_2 it was evident that water disinfection can be achieved through exposure of water to natural solar energy. The efficiency of disinfection is dependent on various environmental factors like atmospheric temperature is major among these. The second factor on which it was dependent is the exposure time and requires an exposure of about 50 hours to direct solar radiation to have complete solar disinfection. The major drawback of this technology was need of long exposure time which hinders it usage. There was no significant change in exposure time among the month except in July and rest there was a two hours difference in exposure time. Filtration of water before disinfection was also found successful to increase the efficiency of disinfection. The condensation of water in earthen pot was also successful to restore the aesthetic quality of water. Solar disinfection is appropriate invention for developing countries during endemics.

But the use of TiO_2 was found advantageous with comparison to simple disinfection. With use of TiO_2 there is a 90% decrease in exposure time. The decrease in exposure time will increase the efficiency of solar disinfection. This is dependent on the amount of TiO_2 added to water. Best disinfection was achieved with addition of 1g/litre of water.

CONCLUSION:

The solar disinfection unit has been designed and successfully tested for disinfection of contaminated water under natural solar light. The unit destroyed more than 99% of bacterial colifoms in both with and without TiO_2. In case of without photocatalyst solar disinfection the exposure time required for complete bacterial killing was two days. Simple solar water disinfection has been reported and its possible application has been suggested [21, 28-31]. The use of just the sunlight posses many difficulties mainly the long exposure time. With the use of photoctalyst TiO_2 the exposure time reduce to six hours causing an 88% decrease in the time for exposure. With using different concentration of TiO_2 the best result was obtained with addition of 1gm/litre of water.

Cause for Bacterial killing

Complete bacterial killing was observed in solar disinfection with only exposure to direct solar radiation. The disinfection was found to be dependent on temperature. It can be concluded from the statistical data that in this simple solar water disinfection the atmospheric temperature increases water temperature causing the bacterial killing. According to Brock *et al*., temperature greater than the maximum growth value causes denaturation [14], which impedes protein function and kill the organisms Synergistic UV and thermal effects are observed at water temperature of 45^{o}C [11, 15]. In comparison to lower water temperature only one-third of the UV-A fraction was required to inactivate *E. coli* at 50^{o}C [15]. No appreciable difference in the rate of bacterial inactivation at temperature 12 to 40^{o}C is observed, but when the temperature increases to 50^{o}C there was a threefold reduction [13, 15, 31].

Precautions

It is applicable and effective in less turbid water. Visible turbidity should be removed before solar water disinfection through filtrations because turbidity will interfere with the disinfection efficiency [32].

Vigorous shaking of water is important before disinfection of water, in order to dissolve and disperse the diffuse DO throughout the volume of water.

The TiO_2 powder must be stored in air tight container and dispersion of granules must be prevented. Exposure through inhalation must be prohibited.

It must be emphasized that no residual disinfection powder is available after photocatalyst disinfection. Education of the user is imperative for successful application. Good hygienic practices will prevent or minimize secondary contamination of disinfected water.

Solar Disinfection *vs*. Solar Disinfection with Photocatalyst TiO_2

The solar irradiation was nearly the same and experiment conduction was with same time of exposure of the day that was around midday. There was an 88% reduction in exposure time in solar disinfection with $TiO_{2.}$ It was concluded that solar disinfection with the addition of photocatalyst TiO_2 is more efficient than without $TiO_{2.}$ TiO_2 available in market and it is easy to use. It has not been found to cause any adverse health effects.

Benefits

The use of titanium dioxide can help in the times of high scarcity of water. In the past our country went through a disastrous earthquake in Balochistan and NWFP and high scarcity of water supply was faced by people of those areas. Technology like this can be effective in these conditions and can reduce the rate of death after catastrophes.

Cost Effective

The results are encouraging and it is strongly recommended that solar disinfection be further investigated for Pakistan. The point-of-use treatment option could provide a safe source of water at a very low cost. As large area of Pakistan is benefited with the gift of high intensity of solar energy by nature. Use of solar energy for water treatment will not only reduce the disease exposure but it will also save the non-renewable resources of fuel. A large amount of household budget is used for water treatment like wood or natural gas or might be electricity this amount can very easily be saved through the use of solar water disinfection.

The solar water disinfection unit is very low cost and the material required for its construction is easily available. The amount required to construct this unit is only Rs.1000. A common man can easily construct and operate this unit. The maintenance of this unit is also easy and can easily be done.

The unit is portable and cost effective and can produce 4litres of treated water on a sunny day. It has a storage capacity of 12 liters of water. It also condenses water to a temperature which is aesthetically acceptable. The major application of solar water disinfection unit can come in areas rich in sunshine but distant from reliable water purification system.

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