Computational Research Progress in Applied Science & Engineering
©PEARL publication, 2015
ISSN 2423-4591

CRPASE Vol. 01(03), 83-92, August 2015

Solar Disinfection: An Empirical Study on Karoon River, Khuzestan, Iran

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Keywords:

Solar disinfection,
Water,
UV,
Coliforms.

Abstract

This study has been conducted in three seasons (winter, spring, and summer) using the sample water from Karoon river in Khuzestan, Iran. PET bottles containing the river contaminated water were put under direct exposure of the sun and the amount of Coliforms after the exposure was examined employing MPN method. The study shows that the amount of coliforms is substantially decreased after 4 hours of direct exposure. In turbidities of 25, 35, 49, 55, and 162 NTU the amount of Fecal coliforms were decreased to 0.66, 0, 0, 2 and 14 MPN/100ml respectively. That shows more than 99.9% of bacteria reduces. We also compared the disinfection rate of the UV and sun heat which showed that UV based disinfection was pretty more effective than heating. Finally, we concluded that solar disinfection is a very good alternative in providing remote villages with drinking water and in emergency situations.

1. Introduction

All the ancient civilizations had been established near the water sources and the very need of humans for water is of real importance. In recent years, while the technological developments and population of the world has raised the need for water to its highest value ever, the quality of water has fallen notably. Finding an effective and cost-efficient method for obtaining fresh drinking water without micro-organisms has been an issue for the experts in the field. Every year thousands of people fall in danger of catching diseases or even dying due to lack of access to clean, safe drinking water. Finding an affordable solution to disinfecting drinking water for at household level in remote areas and under-developed villages has always been in primacy for the Health and treatment organizations in the world. According to WHO report , 1.2 billion people are infected by polluted water every year. This figure includes 15 million under 5 children who die out of lack of access to safe water [1, 2]. Every child deserves clean water. However, more than 1,600 children under age 5 die every day from diarrhea caused by unsafe water - that’s more than AIDS and malaria combined. Clean water, basic

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Received: 22 May 2015 ; Accepted: 21 July 2015

sanitation, and hygiene education are some of the most effective ways to prevent child disease and death. It is most commonly caused by gastrointestinal infections which kill around 2.2 million people globally each year, mostly children in developing countries. The use of water in hygiene is an important preventive measure but contaminated water is also an important cause of diarrhoea. Cholera and dysentery cause severe, sometimes life threatening forms of diarrhoea. [3]. Waterborne diseases are caused by pathogenic microbes that can be directly spread through contaminated water. Most waterborne diseases cause diarrheal illness. Eighty-eight percent of diarrhea cases worldwide are linked to unsafe water, inadequate sanitation or insufficient hygiene. These cases result in 1.5 million deaths each year, mostly in young children. The usual cause of death is dehydration. Most cases of diarrheal illness and death occur in developing countries because of unsafe water, poor sanitation, and insufficient hygiene [4].

Drinking Water supplies for most of the developing countries which mostly includes the remote villages are at stake [5, 6]. Meanwhile, contaminated water supplies, poor administration of health foundations and facilities and lack of adequate programmed instructions for the illiterate adds to the issue in Iran. Water disinfection largely reduces the risks of diseases transferred to the humans. Hence, there are a number of available methods to water disinfection most of which require huge budgets, proper educations or would have adverse effects on the environment if practiced [7, 8, 9].

One of those fairly easy and long established methods is boiling. Boiling for at least 3 minutes would eliminate almost all pathogens in the water including Giardia. Heating up the water up to 55◦ C is an effective way to destroy most infectious pathogens. Boiling a liter of water requires a kilogram of wood to be burnt. This is rather too much for the arid or barren lands and villages in which finding a durable energy resource is itself an issue. Furthermore, boiling changes the taste of water and makes it undesirable for people to drink. Disadvantages to boiling are 1- unavailability of woods as the main fuel source 2- destruction of the green vegetation and 3- air pollution that is emitted through the burning process [1]. There are a few methods commonly used for the disinfection of drinking water which include the use of solar radiation. The sun radiation includes ultra-violet which has been proven to be a good disinfectant [10]. Solar radiation consists of visible and invisible components. Of the invisible component, is the Ultraviolet in the 220-230 nm wavelengths which is an effective microbial destructor [11]. It has been established that at the wavelength of 254 nm the nucleic acid for bacteria, yeast, protozoans, and viruses are mostly fragile. [12, 13, 14, 15]. Studies proved the effect of solar energy on bacteria's and protozoa's same as Shigella, fecal coliform, Giardia lamblia, Cryptosporidium parvum, Cyclospora cyatenensis and Entamoeba histolytica [10, 16, 17, 18, 19].

Karoon River has crossed Ahvaz city and it has divided city in two parts of western and eastern. This work has conducted in Ahvaz, capital city of Khuzestan province. In addition to shortcomings in view of safe drinking water, Ahvaz has encountered many problem related to dust storm [20, 21, 22] and air pollution as well [23, 24, 25, 26]. their final.

2. Purpose of the Study

The purpose of this study is to pursue a practical approach to utilization of solar disinfection in the Karoon River and to present alternatives for communities which lack access to water treatment plants and proper water distribution systems. Since the surface water is usually turbid, we have tried to test different turbidity levels in 3 different seasons so that the best values of turbidity and time of year would be evaluated for solar disinfection process in Ahvaz and other places with the same climate. UV radiation creates free radical and H_2O_2 when it is in the vicinity of the dissolved Oxygen in the water and empowers the disinfection process [27]. So we measured the effects of aeration on disinfection process efficiency.

3. Materials and Methods

This paper has been conducted based on empirical studies in which we started our library research in the summer 2003 and continued until winter 2004 and we tested sample water from Karoon River, Ahvaz which is the inlet for Kian Abad water treatment plant. To the test of the water samples, we put them under direct exposure of the sun for duration of 4 hours [10 a.m. To 2 p.m.] This time was selected due to the fact that the highest amount of UV radiation is believed to be exposed during this time [7, 8, 17] for each of the sample bottles of water there was one control group. PET 1.5 liter bottles were used in the whole study. The bottles were about 9 cm in diameter, according to the permeability of UV [27]. To make UV absorption more effective we painted one side of the bottles into black and to undermine the heat variable in the experiment, the study was repeated in the winter where the temperature did not exceed 50◦c. In spring, the highest measured temperature was 49◦c. To remove the UV effect on the disinfection process in this season, we heated up the bottles in incubator to 49◦c and measured the number of bacteria after 4 hours. Likewise in summer one sample was put under direct exposure of sun and the control sample was wrapped in aluminum to prevent UV from permeating to the bottle. The sample under the sun and the one covered were 65◦c and 55◦c respectively.

Firstly, temperature, PH, Turbidity, Total coliforms, and fecal coliforms for the sample and control group were tested which is present in table 1 and 2.To sterilize the bottles, Cetrimide C and alcohol 76◦ were used and they were dried immediately in the temperature of 70◦c. Aeration was done by shaking the bottle up and down for 1 minute every 30 minutes. Turbidity of the water samples were measured by Turbidi meter in the laboratory, which were from 0.3 to 162 NTU. To allow for reduction in turbidity amount, bottles were left still for some time on the ground. Since solar disinfection is more effective in lower than 30 NTU turbidities [27], we chose 0.3 NTU in winter and tested solar disinfection and aeration effect on sample water. In spring, we chose 25, 35, and 49 NTU turbidity and finally, in summer to account for higher turbidities, we chose 55 and 162 NTU. To check for the best time of the day to use solar radiation for the disinfection purpose, most of the samples were put under the exposure during 10 to 14; however, in spring the 35NTU and 25 NTU samples were exposed to sun during 13-15 and 12-16 respectively and finally the differences were captured. To measure the number of coliforms using MPN method with 15 tubes at probably number method [culture medium: 26 gr/lit for concentrated lactose broth and 13gr/lit for diluted lactose broth] validation step [40 gr/lit brilliant green bile broth for the total coli forms] and [37.5gram EC environment to culture fecal coliforms] were used. To reduce inaccuracies, culturing was carried out three times and the average figure was reported. Coliform bacteria represent the existence of pathogens in a solution; hence, inexistence of them can be used as an index to show that no other pathogenic bacteria exists [11, 27].

Because of high level of river pollution, we used sodium chloride 9/1000 sterilized in autoclave to dilute the sample water. The samples' PH was measured before and after the exposure in summer. All the experiments were conducted using Standard Methods [28] then all the data were analyzed using Microsoft Excel & SPSS.

4. Results and Discussions

As the Table 1 show, the total number of coliforms and fecal coliforms are reduced notably after exposure to sun light.

Table 1. comparison of total coliform and fecal coliform in summer, winter and spring, Karoon, Ahvaz

Conditions	Season	Total Coliforms (MPN/100ml)	Fecal Coliforms (MPN/100ml)
Before exposure (Control)	winter	160,000	18,000
	spring	137,333	16,666
	summer	114,666	14,000
After exposure (Experimental)	Winter	20	14
	Spring	1.3	0
	summer	4	2

All the samples were under sun exposure during 10 a.m – 2 p.m for the period of 4 hours. The reduction of the number of microorganisms after UV exposure in the winter is quiet logical, for the temperature of water was measured at 17-18◦c so temperature plays very little role in elimination of microorganisms. According to the table, UV performs more significant role in this respect. All the experiments carried out in the winter were in turbidity of 0.3 NTU.

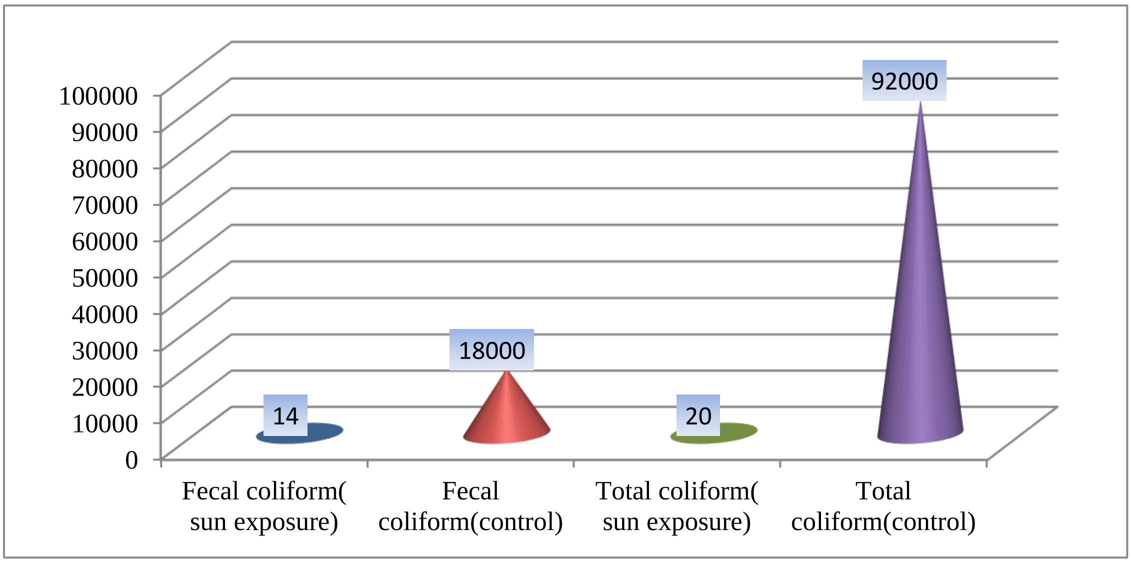

Figure 1. Total coliforms and fecal coliforms in winter (MPN/100ml)

To see how much important aeration would be in decrease of coliforms in the winter, one sample was treated by aeration in laboratory for 4 hours, repeating the process each 30 minutes while one sample was put both under solar exposure and aeration process. Based on the results from Figure 2, there are no significant changes in the number of microorganisms which tells us that aeration is not effective per se. on the other hand; the second sample has only a few microorganisms, confirming that oxygen conjoined with sun light is a strong oxidizer.

$$H_2O \xrightarrow{UV\ \&\ O_2} H_2O_2 \tag{1}$$

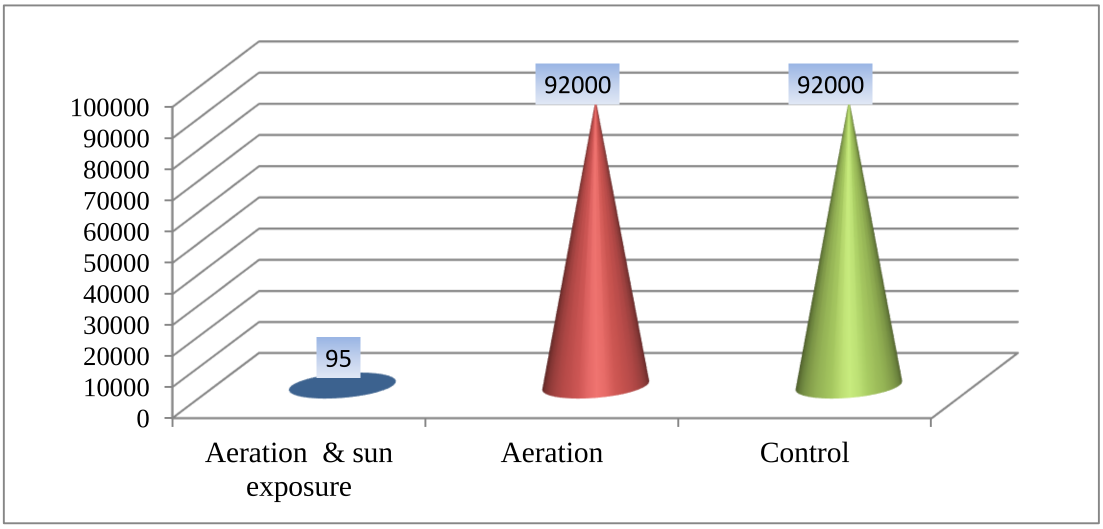

Figure 2. number of total coliforms after aeration in winter (MPN/100ml)

Table 2. Number of coliforms in 3 turbidity levels in spring

	Turbidity / sample	Total coliforms (MPN/100 ml)	Fecal coliforms (MPN/100 ml)
	Control sample	137333	22333
49 NTU	Control sample after 4 hrs.	137333	16666
	Control sample after exposure	1.3	0
	Control sample	137333	19666
35 NTU	Control sample after 4 hrs.	114666	15666
	Control sample after exposure	0	0
	Control sample	114666	12466
25 NTU	Control sample after 4 hrs.	92000	8633
	Control sample after exposure	1.3	0.66

Advanced Oxidization Process (AOP) is the sole reason for notable fall in number of bacteria. Aeration along with UV results in generation of hydrogen peroxide which explains the death of bacteria in the sample bottle of water. Table 2 shows that total number of coliforms in samples with turbidity levels of 25, 35 and 49 NTU drastically decline after exposure. We expected the 25 NTU sample as the lowest turbidity level in this study would be zero, however it reached to 0.66 NTU. Since the highest amount of UV reached to earth is shown to be in 10-14 [8], and this sample was under exposure during 12-16, the reason why not all the coliforms were destroyed becomes simple: it was not the best time for most UV exposure. Why the samples showed decreased number of coliforms after 4 hours without exposure is simple indeed: some bacteria precipitate with suspending materials.

To confirm the hypothesis that aeration adds to the speed and effectiveness of disinfection in spring, all the samples were exposed to sun light air throughout the experiment. Results show a dramatic decrease in number of fecal coliforms.

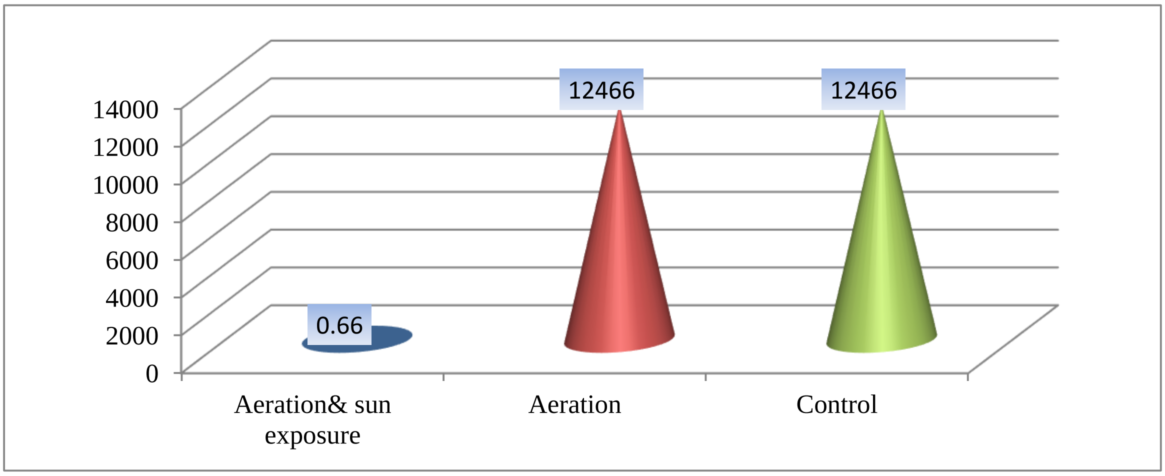

Figure 3. fecal coliforms after aeration and exposure in spring

We also tested to see how important heat could be in disinfection of the bacteria. Figure 4 approves the fact that heat can also facilitate the disinfection process [samples were in incubator for 4 hours at the temperature of 49◦ C]; however the main reason for this radical decrease in total coliform number in the UV.

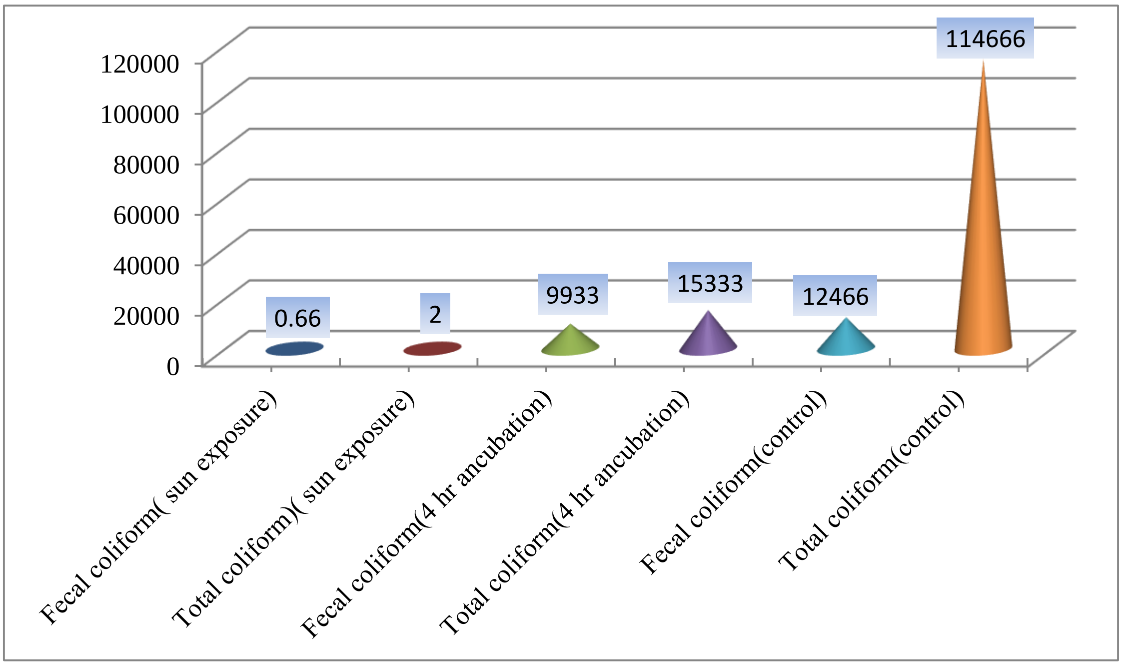

Figure 4. total coliforms and fecal coliforms under aeration and solar exposure in spring (25 NTU)

Table 3. number of coliforms in exposed samples and samples in the shadow in two turbidity levels in summer

Turbidity	Sample	Temperature (Celsius)	Total coliforms (MPN/100ml)	Fecal coliforms (MPN/100ml)
	Control	30	240000	28000
162 NTU	Aluminum covered bottle	60	92000	2300
	Exposed sample	64	27	14
	Control	30	28000	14000
55 NTU	Aluminum covered bottle	59	4900	1700
	Exposed sample	64	4	2

All the experiments which were conducted in winter and spring were repeated in summer to confirm the sun radiation effectiveness in disinfection of highly turbid sample waters.

The findings in this season further prove the results in Figures 1 and 4. Although the temperature difference between the seasons is fairly high, the difference between the numbers of coliforms after solar exposure is not much, confirming that UV plays more significant role in disinfection process.

Figure 5 demonstrates that the PH for samples under sun exposure has risen a little which is accounted for in two reasons. First, according to Henry's law if the temperature of a liquid is risen, dissolved gases like CO_2 escape from the surface of the liquid. CO_2 performs an important role in formation of carbonic acid.

$$H_2O+CO_2 \rightleftharpoons H_2CO_3 \tag{2}$$

After a rise in temperature, H_2CO_3 is decreased to compensate for the fall in dissolved CO_2 in the water, resulting in increased pH level. Second reason is that if there are any algae in the sample water they start photosynthesis process, decreasing the CO_2 level in water resulting to alkaline condition.

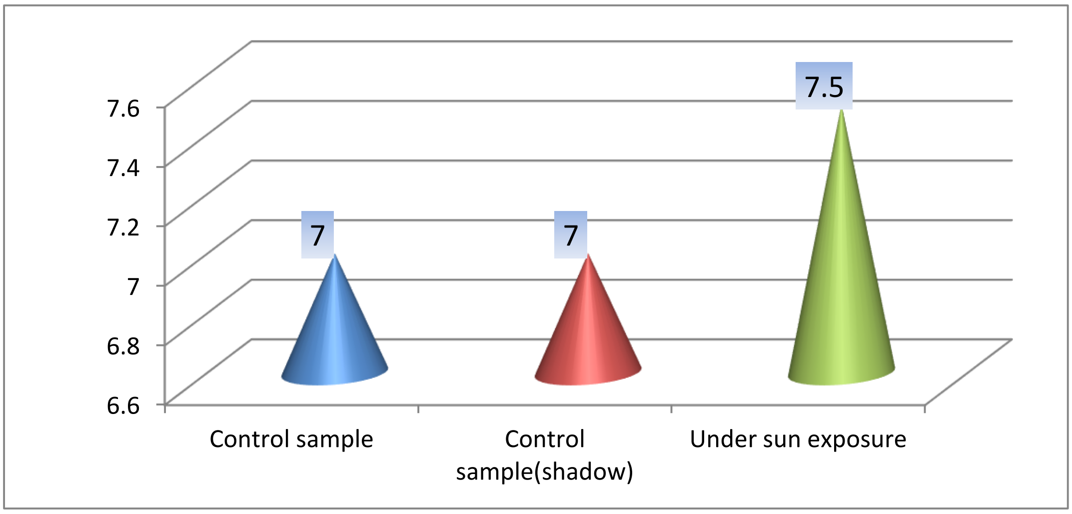

Figure 5. pH levels in samples under exposure and in shadow

5. Conclusions

As the findings show, the total number of coliforms and fecal coliforms were measured after solar exposure, confirming the idea that solar disinfection is a greatly efficient method in remote locations where proper water distribution systems are not accessible or for emergencies when the sky is clear and sunny. It should be noted that the method is only practicable when the pollutants' levels are under the standard limits.

Since PET bottles are widely available with low cost, everyone can use them to keep their water for disinfection under the sun. All the bottles must be clear, transparent and without any labels. [8, 9]

For further research it's suggested that the study be conducted in different hours of the day, more or less than 4 hours. It is possible that spores, protozoans, resistant viruses and forth would live after solar disinfection so the feasibility of this method in destruction of the mentioned pollutants should be analyzed in future research. Since travel of UV rays to the surface of the earth is not blocked by clouds, it is suggested that practicality of the method be tested in cloudy days. Other turbidity levels could also be used in further researches. Researchers can also apply the experiment using a different shape bottle with different measurements and type. Environmental factors like wind speed, strength and angle of exposure, etc. can also be measured in effectiveness of solar disinfection method. As iron and humic materials can absorb UV radiation [11,12] we suggest the role of these parameters be accounted for in the future studies.

Acknowledgements

We would like to thank Dr Jafarzadeh.N, Dr Takdastan. A and Dr Abtahi.M. PHD of environmental health engineering, Faculty of Health, Jundishapour University of Medical Sciences.

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