

## DISINFECTION OF MUNICIPAL WATER USING SOLAR RADIATION: AN ECONOMICAL APPROACH FOR RURAL DWELLERS IN THE COASTAL REGION OF KARACHI

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At present acquiring safe drinking water in rural or remote areas of Pakistan is a challenging task for dwellers. Coast line of Karachi is a sporadic habitat of villages not having access to safe drinking water. Many incidents of waterborne diseases have been reported in that area and attributed to contaminated municipal water supply. Solution of the problem is disinfection however, general methods of water disinfection such as boiling, UV-lamp, ozonation and chemical additive are costly or require skilled manpower. Present study investigates the solar disinfection method to treat municipal water supply at Karachi Institute of Power Engineering (KINPOE) located at the coastal belt of Karachi. Effect of exposure time, bottle material and turbidity of water on the process performance was evaluated. Model indicator bacteria total coliform (TC) was used to evaluate the solar disinfection process. Study revealed that in order to disinfect the municipal water, samples should be filled in PET transparent bottles, having turbidity below 23 NTU, and expose to solar radiation in the study area at least for one hour. Study shows that solar disinfection may provide safe drinking water meeting national and international water quality standards at minimum cost and effort in sunshine rich areas and not having access to other water purification systems.

**Keywords:** Water contamination, Turbidity, Solar radiation, Solar disinfection

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### 1. Introduction

Acquiring safe drinking water is a global issue from health and safety point of view. More than 1.1 billion people do not have access to drinking water supply, which is considered as safe by World Health Organization (WHO) [1]. It is anticipated that the world population will reach to 8, 9, or about 11 billion by the year 2050 according to the low, medium and high variants of the UN projection, respectively [2]. Safe drinking water supply for such a big population is one of the greatest challenges. Consumption of unsafe drinking water is the main cause of diseases like Diarrhea, Hepatitis, Dysentery, Cholera, Typhoid and Gastro [3]. Generally, in Pakistan clean water supply is limited in the low income and rural areas. Water being supplied is contaminated mainly due to leaking pipelines, shallow water tables and cross contamination with sewage lines [4, 5]. Coastline of Pakistan is a sporadic habitat of villages and slumps. Large numbers of waterborne diseases have been reported in the past in these areas [6, 7]. Recently some cases of casualties due to

gastro intestinal diseases caused by the water contaminated with pathogens are reported [8-10].

Obvious solution of the problem is disinfection of water. Disinfection is the process used to eliminate pathogenic microorganisms and is an important step in ensuring that water is safe to drink. Generally, processes used for disinfection are boiling, UV-lamp, ozonation, chemical additive (chlorine) and solar disinfection. Process like boiling requires burning of fossil fuel while chemical addition is expensive. Furthermore, UV-treatment and ozonation are not only expensive but also require skilled personnel for the operation. In major part of rural dwellings where wood is used for heating and cooking, these processes are not feasible.

Researchers are striving to develop low-cost and practical methods to provide safe drinking water in rural and urban areas of developing countries [11, 12]. Solar radiation is a form of renewable energy that is abundant and accessible in most southern countries such as Pakistan. In the

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areas where plenty of sunshine is available, the solar energy may effectively be utilized for disinfecting water. The key to this method lies in the ability of direct sunlight to destroy harmful microorganisms. Use of simple, economical and robust technique of solar disinfection may provide an alternate clean water supply at those areas. The present research focused on providing safe drinking water to small families living in rural areas such as villages in the coastal region of Karachi utilizing solar energy.

## 2. Historical Perspective

In many parts of the world, work is being carried out to use solar energy for disinfecting water and other purposes. Leading work by Gameson in 1967 on the inactivation of coliform bacteria initiated the research in the water disinfection area [13]. Calkins and coworkers were probably the first who initiated a full scale study on the feasibility of using solar energy for water purification in the year 1976 [14]. David and Robert in 1984 investigated the potential of using solar energy to disinfect contaminated water. They heated water to a temperature of 65 °C in a box cooker in order to decontaminate water and encouraging results were obtained [15]. In the following year Razzak and coworkers carried out a direct method for obtaining disinfected water by using solar energy. They designed a concentric solar pipe collector and achieved a temperature of 63 to 78 °C [16]. This work was extended by Joyce and coworkers during year 1996 and they reported the thermal effect of equatorial sunshine on water samples contaminated with high population of coliforms. They also investigated the feasibility of employing solar disinfection for highly turbid contaminated water [17]. A series of experiments were carried out by McGuigan and coworkers in 1998, they identified and characterized the inactivation process in stored water, exposed to sunlight and concluded solar radiation as a feasible source for disinfecting contaminated water [18].

A simple and reliable method was described by Safapour and Metcalf in 1999 that could be used in developing countries to pasteurize milk and water with solar energy [19]. Rijal and Fujioka in 2001 evaluated the effectiveness of combining solar radiation and solar heating to disinfect contaminated water [20]. Later on Salih, during year 2003 formulated a mathematical model to facilitate the prediction of solar disinfection by analyzing the effect of sunlight exposure [21].

Walker and coworkers in the year 2004 constructed a solar disinfection system from commercially available packaging material and demonstrated the disinfection process [22]. A passive solar water pasteurization system based on density difference flow principles was designed, built and tested by Duff and Hodgson in 2005 and they achieved a continuous treated water supply by increasing the temperature upto 85°C using solar radiation [23]. Khaengraeng and Reed explored the effect of oxygen and photo-inactivation of *E. coli* bacteria under sunlight in the same year and reported a synergistic effect of both parameters on *E. coli* inactivation [24]. Berney and coworkers in 2006 reported the effectiveness of solar disinfection method to disinfect water containing *Cryptosporidium* contamination. They achieved 98±1.3 % inactivation of studied microorganism after 8 hours of solar radiation exposure. Their results confirmed that solar disinfection of drinking water can be an effective household intervention against *Cryptosporidium* contamination. [25]. Numerous investigations have demonstrated the effectiveness of solar disinfection of water and established it as an emerging water treatment process of future [8, 13-26].

Investigations of many researchers show that the biocidal effect of sunlight is due to optical and thermal processes, and a strong synergistic effect occurs for water temperature exceeding 45°C [23]. Literature review revealed that sunlight is freely available and has been identified as a potential source to purify microbiologically contaminated water [22, 26]. Boyle and coworkers in recent past studied the bactericidal effect of solar water disinfection process [27]. They reported batch solar disinfection exposure time required for complete inactivation of bacteria is from 20 to 150 minutes. Further research on process efficiency using additives such as hydrogen peroxide and lime juice studied by Fisher and coworkers [28]. They reported that the additives might make the process faster and effective in both sunny and cloudy weather. During year 2009 Malato and coworkers studied various experimental systems for solar disinfection and placing special emphasis on experimental systems to optimize solar disinfection technique due to the potential of research in this area [29].

Present study investigates the solar radiation as a disinfection process for municipal water containing disease causing microorganisms. Effect

of container material, exposure time and water turbidity was studied under local environmental conditions. Study aims to find out optimum parameters suited to local environmental conditions and producing potable water matching the international and national water quality criteria.

### 3. Material and Methods

Disinfection of municipal water using solar radiation was investigated at KINPOE, located at the coastline of Pakistan's largest city Karachi which is the southern coastal region of Pakistan in Arabian Sea. It is situated at 66° 47' 8" East longitude and 24° 51' 15" North latitude. Solar disinfection experimental runs were performed during month of July, 2009 using commercially available (one and half liter) polyethylene terephthalate (PET), and glass bottles. Colored bottles alongwith the transparent bottles were also used. Effect of turbidity in the water samples was investigated by adding laboratory grade Kaolin (K-1020, FISCHER). Turbidity range from 5 to 85 NTU was investigated in this study.

Initial concentration of microorganisms is important in a disinfection process, and if it is desired to carry out an effective study, higher initial concentration of microorganisms is recommended [30]. Municipal water samples were therefore, inoculated by adding 5ml of domestic sewage per liter of municipal water. Inoculated municipal water was exposed to sunlight and samples were collected after 3, 6 and 12 hours of exposure time.

Proper sampling techniques are vital for accurate testing in evaluation studies. Samples were collected in sterilized 300 ml glass bottles. Sodium thiosulfate was used in chlorinated sample collection bottles in order to neutralize the effect of residual chlorine. Similarly separate clean bottles were used for metal analysis. Nitric acid was added to bring the pH of samples below 2 to minimize precipitation and adsorption on container walls [31]. After collection samples were transferred immediately to the lab. in iceboxes within 2 hours and analyzed. Strictly sterilize conditions were maintained throughout collection and transportation of these samples. Analysis of raw municipal water samples was performed in triplicate for various physical, chemical and biological parameters listed in table 1. Analysis of exposed water also carried out for indicator microorganism total coliform (TC) using Multiple-Tube Fermentation Technique [31].

Analysis was carried out at Chemical Monitoring Laboratory, KINPOE and Environmental Engineering Laboratory at NED University of Engineering & Technology, Karachi. All the analysis and sampling procedures were adopted from Standard Methods for the Examination of Water and Wastewater [31]. Details of methods and instruments utilized during analysis are also mentioned in Table 1. Ambient and water temperature was also measured during the study. Solar flux data was taken from alternative energy development board and it is in the range of 4.7-5.4 KWH/m<sup>2</sup>/day in the study area as shown in Figure1 [32].

### 4. Results and Discussion

#### 4.1 Characteristics of municipal water

Characterization of municipal water at KINPOE based on various physical, chemical and biological parameters was made and results of the analysis are presented in table 1. A comparison of results also made with Drinking Water Quality Standards (DWQS) by WHO and National Standards for Drinking Water Quality (NSDWQ) by Pakistan Environmental Protection Authority (P-EPA) and presented in Table 1 [33, 34]. Results of total coliform analysis show a significant counts of indicator microorganisms present in raw municipal water supply (93±1 MPN/100ml) indicate the presence of disease causing microorganisms in the supply. Similarly value of zinc is slightly exceeding the WHO limit of 3 mg/l by 0.2 mg/l. However, it is within the permissible limit of NSDWQ standard (5 mg/l). Results show that water could be utilized for drinking purposes however, proper disinfection is required to bring the biological quality of water within the permissible limits of WHO and NSDWQ which is 0 MPN/100ml.

#### 4.2 Variation in temperature

Variation in ambient and water temperature (present in transparent PET bottle) is shown in Figure 2. It can be seen from Figure 2 that the water temperature is increased from 35 °C (at 9:00 am) with the exposure time and reached to 55.5 °C at noon. Later, temperature reduced to 48 °C at 3:00 pm. Reading of ambient temperature showed some variation and remained between 35 to 39.5 °C. It shows that solar energy was increasing the temperature of water by accumulating solar energy in the bottle which is consequently responsible for disinfecting water.

Table 1. Comparison of results of raw municipal water analysis with national and international water quality standards [33, 34].

Parameters	KINPOE	WHO (2006)	NSDWQ (P-EPA) (2008)	Instruments/ Method Used
p <sup>H</sup>	7.3±0.2	6.5-8.5	6.5-8.5	pH meter/Mi-151/Italy
Electrical Conductivity	243±6	250	--	HACH/ 51800-10
Color	12±1	≤ 15	≤ 15	Pt-Co-Hazan Kit
Turbidity	1.1±0.2	< 5	< 5	HACH/ 2100p
Hardness	118±5	--	< 500	Titration
Total dissolved Solid	410±12	< 1000	< 1000	Gravimetric
Chloride	148±7	250	< 250	Titration
Manganese	0.2±0.08	0.5	≤ 0.5	Spectrophotometer/HACH/USA/Dr-2800
Sulfate	68.9±1.8	500	--	Spectrophotometer
Residual Chlorine	<0.2	--	0.2-0.5	DPD Colorimetric
Fluoride	0.3±0.01	1.5	≤ 1.5	Spectrophotometer
Nitrate (as NO <sub>3</sub> <sup>-</sup> )	17±0.9	50	≤ 50	Spectrophotometer
Nitrite (as NO <sub>2</sub> <sup>-</sup> )	1.2±0.03	3	≤ 3.	Colorimetric-Spectrophotometer
Chromium	< 0.02	0.05	≤ 0.05	Atomic Absorption Spectrometer/ Perkin Elmer-AS70
Sodium	105.3±2.7	200	--	Flame Photo Meter
Arsenic	0	0.01	≤ 0.05	Spectrophotometer
Zinc	3.2±0.1	3	5	Spectrophotometer
Lead	0	0.01	≤ 0.05	Atomic Absorption Spectrometer
Cadmium	0	0.003	0.01	Atomic Absorption Spectrometer
Total Coliform (without inoculation)	93±1	0	0	MPN Method/ Multiple-Tube Fermentation Technique
Total Coliform (with inoculation)	8750±12	--	--	MPN Method

\*All units are in mg/l, except pH, color TCU, conductivity ( $\mu$ -Siemens/cm), coliform MPN/100ml, and turbidity (NTU).

#### 4.3 Effect of exposure time and bottle material on solar disinfection of municipal water

Water samples were filled in transparent PET and glass bottles alongwith colored PET and glass bottles. All samples were exposed to solar radiation at least for 6 hours. Samples from each bottle were collected after predetermined time intervals and analyzed for total coliform (TC). Ambient temperature and water temperature were also monitored during experimental runs. Results of TC analysis using above said bottles for exposure are shown in Figure 3. It can be seen from Figure 3 that the TC counts are decreasing

with exposure time in all types of bottle materials. One may see that significant reduction of TC achieved within one hour of exposure. However, standard of 0 MPN/ 100 ml of TC achieved in all samples in 3 hours. Furthermore, value of zero count was achieved within 2 hours while using transparent PET and glass bottles. Figure 3 also shows that solar disinfection is more efficient when sample is exposed to solar radiation using transparent PET bottle. It is to be noted that these results are obtained in the morning time (from 9:00 AM) and more efficient disinfection may be achieved when sample exposed to solar radiation during mid day when solar radiation may be higher

and water temperature achieve higher value in shorter time. Results reported by Boyle *et al.*, also showing 90% inactivation of E-coli (which is a sub group of total coliform group) within 33 min of solar radiation exposure [27]. It can be seen from figure 3 that in the present study similar degree of disinfection achieved within 35 min of exposure in all containers.

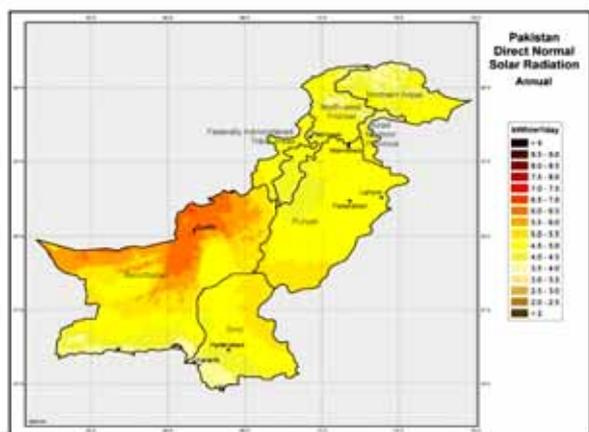


Figure 1. Annual direct normal solar radiation in Pakistan [32].

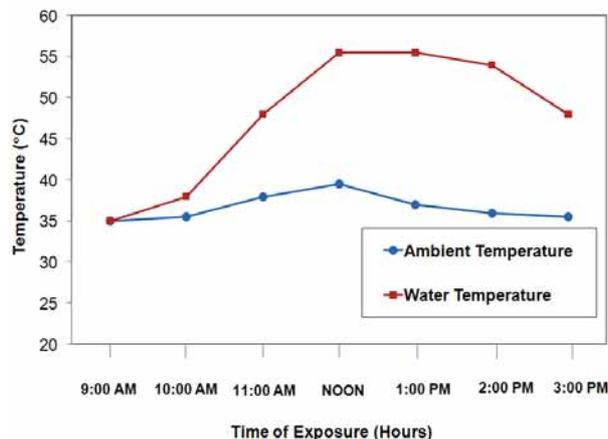


Figure 2. Variation in ambient and water temperature during experimental runs (mean of three readings).

#### 4.4 Effect of turbidity present in water

Turbidity is a measure of degree of cloudiness and has an impact on water disinfection. Effect of turbidity present in water samples was studied and its effect on disinfection efficiency was noted by measuring the reduction of TC in studied water. Transparent PET bottles were used to treat turbid water samples. Percent removal of TC after 6 hours exposure time at various turbidity values is

shown in Figure 4. Results of study show that disinfection efficiency is reducing with increasing turbidity from 5 to 85 NTU. It can also be seen from figure 4 that the effect of turbidity on the removal efficiency reduction is insignificant upto 23 NTU and a prominent decrease in disinfection efficiency observed after this value. As generally municipal water supply contain turbidity less than 5 NTU the solar disinfection is suitable to treat such water.

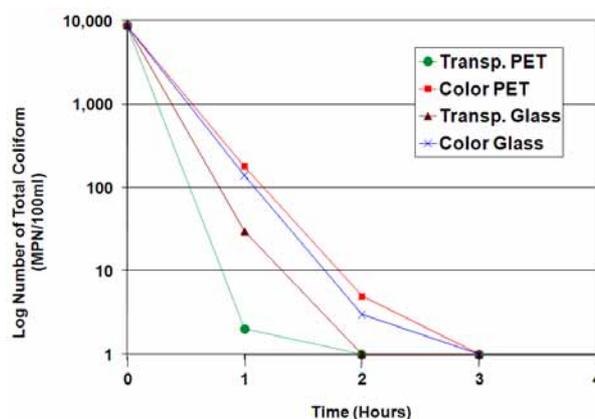


Figure 3. Temporal variation in total coliform (TC) counts in different bottle materials.

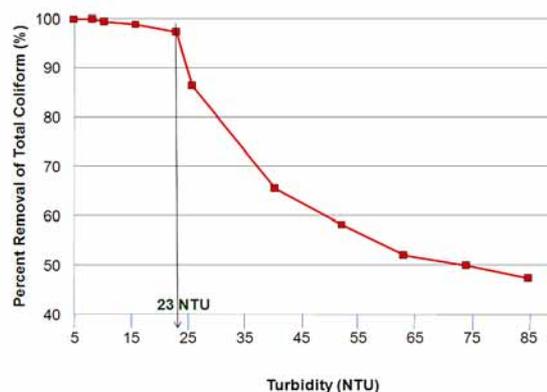


Figure 4. Effect of water turbidity on total coliform removal during solar disinfection.

#### 5. Summary and Conclusions

In this work solar disinfection method was used to treat municipal water supply at KINPOE located at the coastal belt of Karachi. Effect of exposure time, bottle material and turbidity of water on the process performance was evaluated. Model indicator bacteria TC, classified as a 'primary' standard, was used to evaluate the solar disinfection process. Following conclusions are

drawn on the basis of results obtained during the study;

1. Exposure time is a significant factor in solar disinfection. Total coliform are completely inactivated within three hour of solar radiation exposure in all transparent as well as colored bottles.
2. Transparent PET bottle found to be better as compared to other studied bottle materials for solar disinfection purposes because complete inactivation of TC was achieved in this bottle within two hour of solar exposure.
3. Inactivation of TC has direct relation with the water temperature which is the result of accumulated solar energy in tested container.
4. Water turbidity has inverse relation with the inactivation efficiency of solar radiation. However, this relation holds good above 23 NTU. Thus making solar disinfection a feasible method for disinfecting water having turbidity below 23 NTU.

Finally, it may be concluded that in order to disinfect municipal water, samples should be filled in PET transparent bottles, having turbidity below 23 NTU, and expose to solar radiation in the study area at least for one hour (for one and half liter bottle). Study shows that solar disinfection may provide safe drinking water meeting national and international water quality standards at minimum cost and effort in sunshine rich areas and not having access to other water purification systems. In addition to that this method is also suitable for medical facilities and schools operating in rural areas.

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