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A Green Approach to Safe Domestic Drinking Water Supply by Using Solar Geyser

Davarkhah Rabbani [1,2], Amir Hossein Mahvi [3,4], Maryam Shaterian [5], Reyhaneh Hesamifard [1], Mohammad Rezvani Ghalhari [3], Morteza Kabiri [1] ,Gholamreza Mostafaii [1,2,*]

[1] Social Determinants of Health (SDH) Research Center, Kashan University of Medical Sciences, Kashan, Iran.
[2] Department of Environmental Health Engineering, School of Health, Kashan University of Medical Sciences, Kashan, Iran.
[3] Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran.
[4] Center for Solid Waste Research, Institute for Environmental Research, Tehran University of Medical Sciences, Tehran, Iran.
[5] Department of Chemistry, Faculty of Science, University of Zanjan, Zanjan, Iran.

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****Corresponding Author:***
Gholamreza Mostafaii

Email:
mostafaii_gr@kaums.ac.ir

Tel:
+989131622128

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ABSTRACT

Introduction: Accessibility to safe drinking water is an important human health issue, so water reuse and water resources management are critical in arid parts of developing regions. This study aimed to investigate the use of a combined simple designed solar geyser/photocell for drinking water disinfection.

Materials and Methods: In this study, a solar geyser with a simple design was combined with a solar cell and its efficiency on the disinfection of contaminated water was investigated. This study was carried out with artificially polluted tap water by a solar geyser joined with a solar photovoltaic cell. The heated water (55°C) was kept for 2 hours using a solenoid valve. The pilot plant was operated and monitored for one year. The volume of the collected effluent was measured every 24 h. The most probably number (MPN) of total coliforms and fecal coliforms in 100 mL of 24-hour composed samples were measured.

Results: The mean volume of disinfected water production was calculated as 2095.74 ± 270.28 mL/day. The strongest correlation was found between disinfected water and the maximum daily ambient air temperature with a linear model (R^2 = 0.9937). The results showed that by increasing the sunny time, the volume of water outlet increased. Therefore, sunny time and UV radiation have direct effect on volume of disinfected water.

Conclusion: The simple designed solar geyser for drinking water disinfection was efficient and recommended for tropical areas, emergency conditions, and farms for agricultural activities.

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Introduction

Population growth and industrialization have caused water shortage and reduced quality of available drinking water [1]. Therefore, water reuse and water resources management are critical in arid parts developing regions [2]. There are many water reuse methods, such as adsorption [3], MBR [4], membrane [5, 6], SBR [7], bio reactor [8], aerated lagoon [9], electro-coagulation[10, 11], and other biological wastewater treatment [12-17], which are expensive and complex. However using simple methods using natural energy is increasing[18, 19]. Sunlight and UV radiation is one of the low-cost water treatment procedures[20]. Due to the limited global resources of fossil fuels and the adverse environmental effects of their increasing use, it is essential to search for new energy sources to replace old ones [21].

The new renewable energy is a set of energy sources, which is expected to play a significant role in providing energy worldwide in the long term [22]. In the meantime, the role of solar energy is more important than the other renewable energy sources [23]. Fortunately, a large part of Iran is among the world's first solar radiation regions, while in Iran, the share of fossil fuels in the energy supply is about 99%, and this consumption is growing increasingly [24].

Today, worldwide attention is focused on the use of renewable energies [12]. Solar active collectors have been widely used in several countries, such as Australia, Cyprus, and Japan; for example, 90% of Cyprus have a solar water heater [25]. The lack of fossil fuels and the high quality of renewable energy dictate the search for more applications of this type of energy [26]. Water is one of the most critical needs of human life after air, and without them, life is impossible for more than a few days. About 60% of a person's body weight is water, and everyone needs about 2.5 liters of safe drinking water every day [27]. With this in mind, the importance of clean and purified drinking water for humans is clear [28].

According to the World Health Organization, about 1.1 billion people do not have access to safe drinking water, and about 4.2 billion do not have any facilities for purifying and providing safe drinking water [29]. The low quality of drinking water is still a severe threat to the deprived inhabitants, with 2 million people every year dropping out due to diarrheal diseases in the world, most of them are children under the age of five [30, 31]. The most important reason for these deaths is living in deprived areas, poverty, and clean water shortage [32].

Pathogens can be transmitted through contaminated drinking water, including bacteria, viruses, protozoa, and microbes, and cause several diseases, such as gastroenteritis, typhoid, shigellosis, cholera, polio, and amebiasis, giardiasis, toxoplasmosis, and ascariasis [33-35].

Diarrhea is the most common illness caused by contaminated drinking water; furthermore, it causes malnutrition and increases sensitivity to other diseases in children [36]. A safe water source, purification and disinfection system, and a proper piping system should be used to prevent water-borne diseases [37]. There are many methods for drinking water disinfection, but the complexity of these methods, the need for high costs facilities investment, operation and maintenance, inaccessibility to energy resources are reasons which need to look for easier ways [38-40]. In the past, many Iranians used direct solar energy to purify their drinking water [41]. Today in rural areas of some countries, such as Brazil, some people use solar energy to disinfect their drinking water [42]. In this method, the unpurified water with turbidity below 30 NTU is poured into the bottle and exposed to sunlight [43]. The temperature of more than 50 ºC and UVC exposure to pathogenic agents for 6 hours cause water disinfection [44]. Cheapness, simplicity, reducing diarrhea, and energy saving are essential advantages of this method, disadvantages of the method are low volume of treated water, inappropriate performance on cloudy days, and the effect of turbidity [45].

Furthermore, numerous studies have been done to find a suitable and inexpensive home water treatment method, especially in developed countries [46]. For example, plastic bottles are used in such a way that at each serving, several bottles are filled manually and exposed to sunlight for a while, and then water is used [47]. Hot box solar cooker (HBSC) system is equipped with a solenoid valve that was placed on the HBSC outlet to ensure that the sterilization temperature was set at the HBSC output. It indicates that these systems have good water sterilization performance [48]. A novel combined solar pasteurizer/TiO_2 continuous-flow reactor was recently studied for decontamination and disinfection of drinking water [49]. In this study, a parabolic solar collector with continuous flow under a natural forced circulation could be used, and simultaneous disinfection and decontamination of drinking water were aimed [50].

The application of solar energy in wastewater treatment for photocatalytic degradation of α-methyl styrene in ZnO presence has been studied [51]. Solar disinfection of drinking water has been claimed as a cost-effective household water treatment method [52]. Also, it is one of the simplest methods for providing an acceptable drinking water quality [53]**.** The use of sunlight to deactivate pathogenic microorganisms in wastewater is another issue that has been considered today [54]. This study was first performed in Kashan, one of the central cities in Iran with a long sunny time. Therefore, this study aimed to investigate using a combined simple designed solar geyser /photocell for drinking water disinfection.

Materials and Methods

Study Area

This study was carried out in Kashan city, located in Esfahan province, Iran, with a hot and dry climate, having 2800 hours sun time per year and more than 2100 kwhm^{-2} year^{-1} UV radiation [55]. Based on the meteorological station reports, the minimum (winter) and maximum (summer) temperature in Kashan is -5˚C and 51˚C, respectively. Figure 1 shows the pilot installation location. Table 1 represents the annual meteorological parameters value in Kashan.

Launch of pilot

The pilot was a simple solar geyser whose schematic is shown in Figure 2.

Figure 1: Location map of the study area and the pilot installation

Table 1: Annual meteorological parameters value in Kashan

Parameters	Sunny time (hours/day)	Minimum temperature (˚C)	Maximum temperature (˚C)	UV intensity (mW/cm^2)
Mean	13.448	20.555	32.33	8.66
SD	0.242	3.244	1.224	0.5

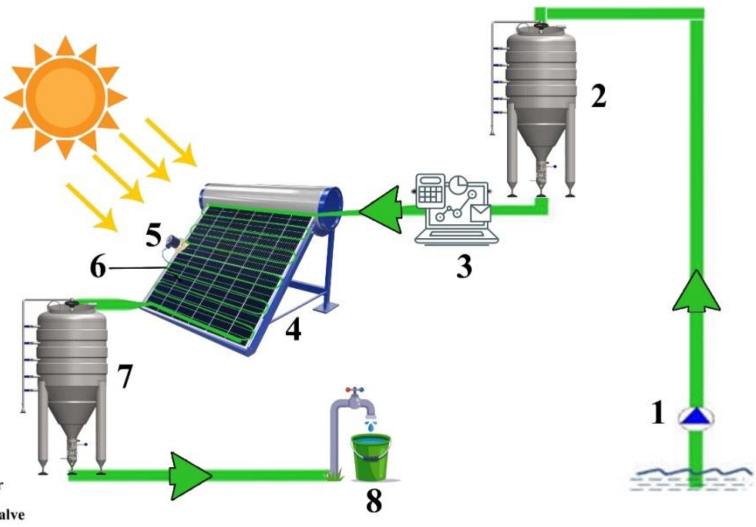

Figure 2: Schematic of the pilot

The pilot was made up of a polyethylene pipe with 10 mm in diameter and 24 m in length which was spirally fixed in an opened galvanized chamber with 0.8 m × 0.8 m dimensions. The chamber interior surface was covered by a black thermal isolating fabric, and a glass plate covered the upper open surface. Artificially contaminated water poured in a 60-liter isolated tank, was entered from the bottom of the solar geyser and discharged from the top after warming.

Operation of pilot

A 55˚C thermostatic solenoid valve powered by a solar photocell was installed in the middle of the length of the spiral tube. A motorcycle battery and an electricity power rectifier were also used.

If the water temperature reached 55 °C, the valve would open and the passed water would be discharged after two hours retention time. Contaminated water was prepared by adding some effluent of secondary sedimentation tank of an activated sludge process to chlorine-free water [39]. The volume of discharged water was measured and recorded during a 24-hour in a cubic centimeter. The most probably number (MPN) of total coliforms and fecal coliforms in 100 mL of the samples were determined according to the 21st edition of book of Standard Methods for Examination of Water and Wastewater (method 9-22) [56]. Exactly 230 composed effluent samples, as well as 230 influent samples, were analyzed. Simultaneously, the maximum and minimum air temperature and UV radiation intensity and the number of sunny hours per day were determined. The data were analyzed using descriptive statistical methods.

On the first of every week, 60 L of chlorine-free well water was purred in a tank and contaminated it by adding 6 mL of active sludge effluent. The total number of coliforms in a domestic wastewater sample ranged 10^4-10^{10} in 100 mL. Also, the efficiency of removing coliforms in the activated sludge system was 99-99.9% [24]. The pilot influent was heated by solar energy; in case of increasing the temperature to 55 °C, the thermostatic solenoid valve opened and passed through the second part of the tube for two hours of hydraulic detention time at this temperature (scheme). The under-process water was discharged to a vessel, and its volume was measured every day. In parallel, two samples were taken from influent and effluent to determine the MPN of coliform bacteria every day.

A total of 460 samples of the influent and effluent of the pilot were examined. Sample

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volume was calculated using the formula of qualitative sample volume and assuming a confidence level of 95% and 50% contamination, an accuracy coefficient of 0.05, and an error coefficient of 10%. The data were analyzed statistically using OriginPro2021 and excel 2013 by descriptive method. All the samples were taken in three seasons and one sample was taken each day.

Ethical Issue

This study has not included human intervention, so there is not any ethical issue.

Results

In this study, 460 samples were taken from the inlet and outlet of the pilot for 229 days during April to November. Table 2 presents the disinfection effect of the pilot-plant on MPN of total and fecal coliform bacteria. As shown in Table 2, the frequency of coliform removal in the summer is more than other season, since in the summer the temperature and sunny time was more than other time. Also, in all samples in all season the complete inactivation of bacteria was observed.

Table 2: The disinfection effect of the pilot-plant on MPN of total and fecal coliform bacteria (n = 229).

Season	Total coliform bacteria (CFU/100mL)		Fecal coliform bacteria (CFU/100mL)	
	inlet	Outlet	inlet	Outlet
Spring	980.23 ± 9.24	Zero	85.36 ± 7.52	Zero
Summer	1021.57 ± 30.18	Zero	97.89 ± 13.65	Zero
Fall	980.23 ± 9.24	Zero	85.36 ± 7.52	Zero

This study showed that in 229 days (0.63 of the year), the pilot had an outlet with acceptable quality, and in the remainder, the system could not raise the water temperature to 55 °C. Thus, the thermal valve did not open, and there was not any outlet. The results showed that the highest pure water volume of the pilot outlet was obtained in August, while the lowest was in November and it was zero at the end of November.

In the days that the pilot plant effluent was less than normal condition, the samples were collected in a sterilized container by using combined sampling for 24 hours. The results of the volume measurement of disinfected water are given in Table 3. The maximum and minimum volume ratio of the disinfected water to its average was 1.19% and 65.4%, respectively. The study showed that designing a pilot which have area equal to 6400 cm² (80 cm × 80 cm), a simple designed solar water heater 2.1 ± 0.3 L per day disinfected water is achievable.

Table 3: The pilot-plant effluent volume (n = 229).

NO.	Volume of outlet water (mL)		
	Fall	Summer	Spring
Mean	1778.668727	2261.353712	2080.143772
SD	246.505475	150.8845316	329.2076664

The relationship between disinfected water volume and the number of sunny hours is shown in Figure 3. As shown in Figure 3, by increasing the sunny time the volume of water outlet increased. Sunny time and UV radiation had a direct effect on volume of disinfected water.

The strongest correlation between the disinfected water volumes with UV intensity is shown in Figure 4 (R^2 = 0.4714).

The maximum correlation between disinfected discharges and the ambient air temperature was observed for maximum daily air temperature in a linear model. This correlation was stronger in comparison with average and minimum daily air temperature (Figure 5, R^2 = 0.9937).

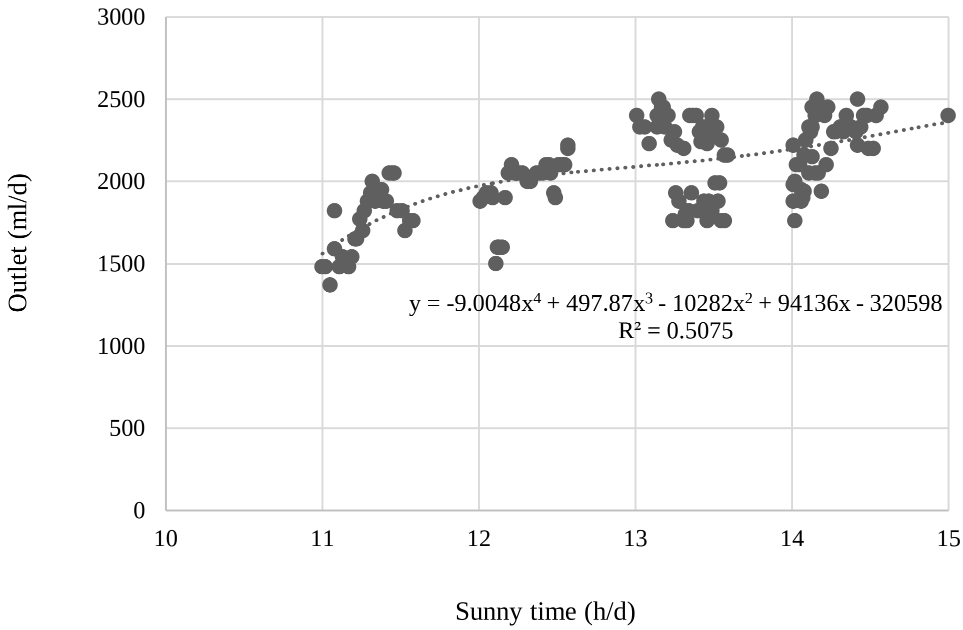

Figure 3: The volume of disinfected water vs. the number of sunny hours in the days

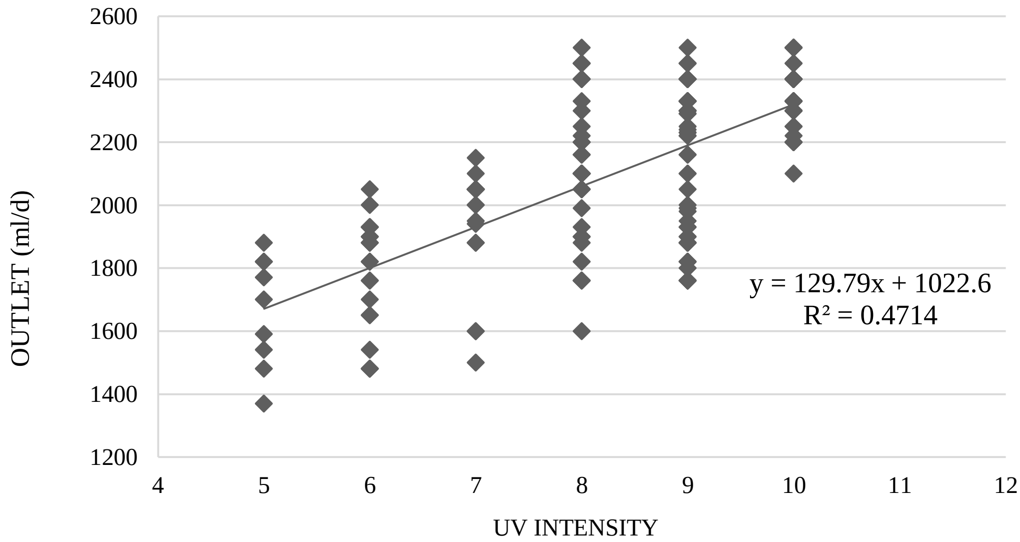

Figure 4: The disinfected volume of discharged water vs. UV radiation

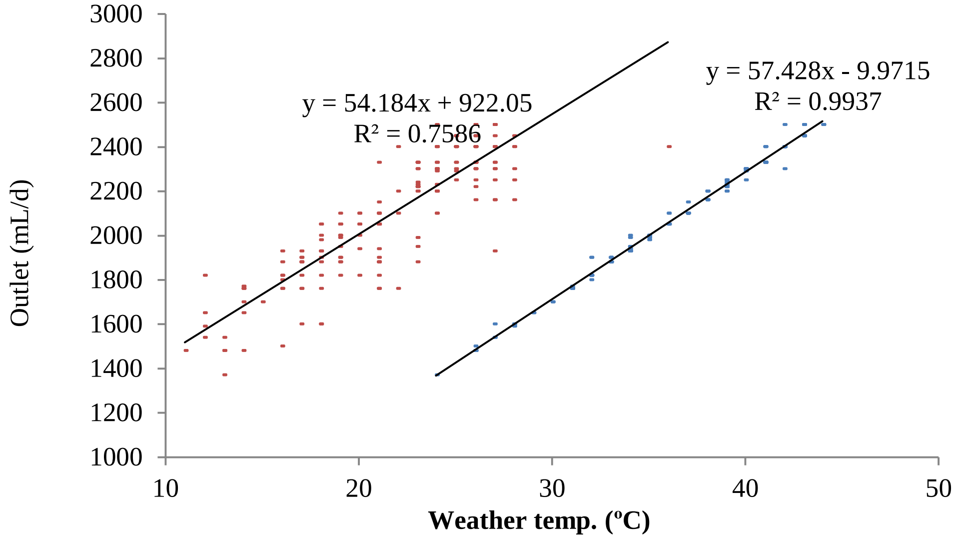

Figure 5: The volume of disinfected water vs. air temperature

Discussion

Based on the results, by increasing sunny time the water disinfection increased. Given more energy was received by the collector, more electricity energy was produced which could help the pilot to disinfect more water volume[45]. Frequency of coliform removal in summer was more than other seasons, since in summer the temperature and sunny time were higher than other seasons. Moreover, Kashan is located in an arid area which is suitable for this pilot; since climatology parameters are important for these pilots. The study results are in line with the study of Ubomba et al. [57]. Moreover, in all seasons the complete inactivation of bacteria was observed in all samples, since in spring, summer, and fall the sun time is adequate for power required for thermostat activity. Daily temperature can affect the fecal coliform and in warm seasons which temperature increases the MPN of total and fecal coliform bacteria decrease. This finding is compatible with the findings of Fisher et al. [58]. Also results shown that the disinfected water was free of coliform and fecal-coliform bacteria, this finding is compatible with the findings of Rabbani and Hooshyar [24] and Sinton et al. [59]. Based on the results, UV intensity had no significant effect on disinfected water volume, since the variation of UV intensity during the day is limited. It had a constant intensity in many times, leading to a constant disinfection rate. This finding is in line with the study of Rabbani and Hooshyar [24].

Conclusion

The highest correlation was found between volume of disinfected discharges and the maximum daily temperature in ambient air, and the UV radiation and sunshine hours had less roles. The design and assemble of the solar collector are very simple and do not require particular expertise and need for any other energy source to provide safe water from contaminated water. The pilot simplicity means that anyone with any level of education with the least facilities can make and use this type of device. The proposed method is cost-free and straightforward and people can easily use it. Therefore, the method is suitable when there is a lack of water treatment facilities, lack of safe drinking water, and high rates of water-borne diseases, especially for people living in rural and remote areas. This device can be used in agricultural fields and orchards from April to November, which is the agricultural activities period.

Credit authorship contribution statement

Davarkhah Rabbani: Funding acquisition, conceptualization, investigation, writing, reviewing, and editing. Amir Hossein Mahvi:

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Conceptualization, investigation, writing, reviewing, and editing. Maryam Shaterian: Methodology, writing the original draft. Reyhaneh Hesamifard: Data collection. Mohammad Rezvani Ghalhari: Validation, visualization, software, writing the original draft. Morteza Kabiri: Data collection. Gholamreza Mostafaii: Project administration, conceptualization, supervision validation, visualization, resources.

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Conflict of interest

The authors declare that they have no conflict of interest.

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