

Water Purification and Disinfection by using Solar Energy: Towards Green Energy Challenge

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Abstract – The aim of this work was to design a solar water treatment plant for household purpose. Water purification is the process of eradicating detrimental chemicals, biological poisons, suspended solids and gases from contaminated water. In this work we have reported an investigation of compact filter which is cost effective for developing countries and ease of maintenance. We have arranged a solar water disinfection system that improves the microbiological quality of drinking water at household level. We get 14 L pure water and 16 ml water vapour within 240 min by using filtration method. From our work we get hot water up to 49°C. The efficiency of the system at sunny days and cloudy days are 18.23% and 18.13% respectively. This simple solar hybrid system helps to remove turbidity as well as chemical and pathogenic contaminants from water sources in the most affordable, and expedient manner possibly.

Key words: Solar energy, Water filtration, Compact filter; Natural ingredients; Sustainable development.

Introduction

The most important natural resource in the world is water and the safe drinking water availability is a high priority issue for quality of life and human existence. In developing countries water-borne disease leads to millions of deaths and billions of illnesses annually. Water disinfection is one of several interventions that can improve public health, especially if part of a broad program that considers all disease transmissions routes and sustainable involves the community. Unfortunately, water resources are coming under increasing pressure due to population growth, wastage and over use. About 884 million people lack access to improve water supplies is estimated by the World Health Organization (WHO). It is microbiologically unsafe that many more are forced to rely on sources, result a higher risk of waterborne disease transmission, including hepatitis, cholera and typhoid (Jay *et al.*, 1998; Burch and Thomas, 1998; Clasen and Edmondson, 2006). The number of people living in water-stressed or water-scarce countries is estimated to increase from half a billion now to three billion in 2025 (Stikker, 1998).

The reuse of water has been doubled as the greatest challenge of the 21st century (Asano, 2002), and, as such, great emphasis is being put into the development of new technologies for the treatment of wastewater for reuse. In general, the methods used include physical processes such as filtration, sedimentation and distillation, biological processes such as slow sand filters or biologically active carbon, chemical processes such as flocculation and chlorination and the use of electromagnetic radiation such as ultraviolet light. There are many parameters which can be used to measure the quality of water, of which a common one is turbidity, the purpose being to measure impurities in the water. In sense of physical, turbidity is a reduction in the clarity of water due to the presence of colloidal particles or suspended, and commonly it is used as an indicator of the general condition of drinking water. Furthermore, turbidity has been used for many decades as an indicator of the efficiency of drinking water filtration and coagulation processes, so that it is an important operational parameter for this reason. The high turbidity values refer to poor disinfection and possibly to fouling problem in the distribution network, so that it should be minimized (Juntunen *et al.*, 2011).

Another important quality parameter for treated water is residual aluminum, especially when aluminum flocculants are used in the treatment process (Juntunen *et al.*, 2011). It causes turbidity in water networks. Usually the phenomenon can be seen when residual aluminum exceeds 0.1-0.2 mg/L, which are the usual guideline levels for residual aluminum. In addition, metals such as aluminum have been implicated in the pathogenesis of Alzheimer's diseases (Campell, 2006).

Many physical and chemical features of raw water affect the water treatment process. Many inorganic and organic compounds in colloidal, suspended or solved form influence the flocculation process. Organic compounds, which are usually measured by a KMnO₄ test, play an essential role in the process. Furthermore, many inorganic compounds such as the p^H or the silicate of raw water also affect the process (Van Benschoten and Edzwald, 1990; Van Benschoten and Edzwald, 1990; Huang and Shiu, 1996). The one of these is the variation in water consumption, causing changes not only within a day but also within a week and even within a year. Year cycles can be distinguished even more clearly if surface water is treated, because the water temperature is observed to have some effects on the process (Gibbs *et al.*, 2010). Furthermore, successful applications of traditional mechanistic models are limited to idealized, artificial systems (Thomas *et al.*, 1999), so that the correlation between simulated and experimental data from real processes has been poor and expensive in situ testing has been needed (Baxter *et al.*, 2001; Maier *et al.*, 2004).

There are two main types of solar water pasteurization systems: continuous and batch flow. Batch systems usually consist of a simple refillable vessel. It usually takes a full day of sun for a batch system to treat water (Andreatta *et al.*, 1994; Ciochetti and Metcalf, 1984). In a continuous flow system water flows through a solar collector that heats the water to a desired temperature.

Flat plate solar collectors were used by (Jorgensen *et al.*, 1998) to pasteurize water. An adjustable thermostat valve was used to control flow. The effect of the valve set point on the inactivation of microorganisms was studied. With a set point of 75°C the collector treated about 50 L/m²-day. A flat plate solar water pasteurizer with an integral heat exchanger was designed and tested by (Stevens *et al.*, 1998). The system controlled flow with an automotive thermostat and heated water to about 75°C. After a significant warm-up period the system was capable of treating up to 55 L/h-m². (Bansal *et al.*, 1988) conducted experiments with density driven water treatment systems. When evacuated tube collectors were used about 10 L of water was produced per kW h of solar radiation (2.8 L/MJ). Flat plate collectors produced about 3.5 L/kWh (0.97 L/MJ). Both systems heated water to about 95°C. This system is more important because of scarcity of pure drinking water in the remote areas and as a result around 2.2 million people die of basic hygiene-related diseases, like diarrhea, every year. The aim of this study is to design a simple and low cost panel of hybrid technology for utilizing solar energy efficiently towards water purification and disinfection system, and to utilize waste materials for the purification system.

Materials and Methods

Mechanism of water purification and disinfection

The water purification and disinfection system is divided into two steps. First is the compact filter preparation and second is the solar collector preparation. In this system, the water is filtered by using physical process of filtration as well as solar energy. At first the water is filtered by using the compact water filtration. Then the pure water is reserved in an aluminum cylinder surrounding with the square glass, which is connected with the solar flat plate solar collector. The solar collector consists of aluminum cane that absorbs the solar heat energy and passes through the aluminum cylindrical chamber. The solar collector is an air tight chamber in which glass is used as surface cover. Then the reserve chamber obtained heat either directly from the sun or the solar collector so that no significant effect on the disinfection of *E. coli* bacteria. From this, some condensed water is collected from the reservoir which is considered as pure water. There are many parameters of measuring water are tested by different instruments after and before treatment. Finally we not only get the pure drinking water but also hot water from this system.

Preparation of compact filter

Filtration is commonly the mechanical or physical operation which is used for the separation of solids from fluids (liquids or gases) by interposing a medium through which only the fluid can pass. The compact filter is consists 3.00 cm layer of coarse gravel, 2.5 cm fine gravel, 2.5 cm brick chips, 2.5 cm cast iron, 2.00 cm wood charcoal and plastic container. The Figure 1 represents that the schematic diagram of compact water filter.

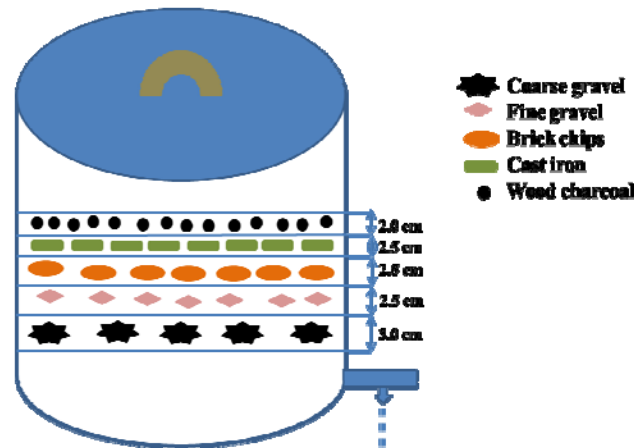


Figure 1. Schematic diagram of compact water filter.

Preparation of solar collector

Solar water disinfection is a type of portable water purification that uses solar energy to make biologically-contaminated (e.g. bacteria, viruses, protozoa) water safe to drink. The filtered water is treated by solar energy in order to remove the rest pathogens, microorganisms, some viruses and bacteria. It also kills germs. Here the water is heated an aluminum cylinder sheet containing 12 inch height with 7 inch diameter and its capacity of containing of 5 liters of water. It is surrounded with the triangle box which is consists of glass sheet containing 9 inch length, 9 inch wide and 13 inch height. The triangle box is attached to the solar collector which is composed of columns of painted black aluminum can, a frame to house the columns and ventilation for the heat transportation. Solar thermal water disinfection uses heat from the Sun to heat water to 40-50 °C for a short period of time. The Figure 2 represents the proposed model of water purification and disinfection system. In the Figure 2, the number 1 indicates the compact water filter.

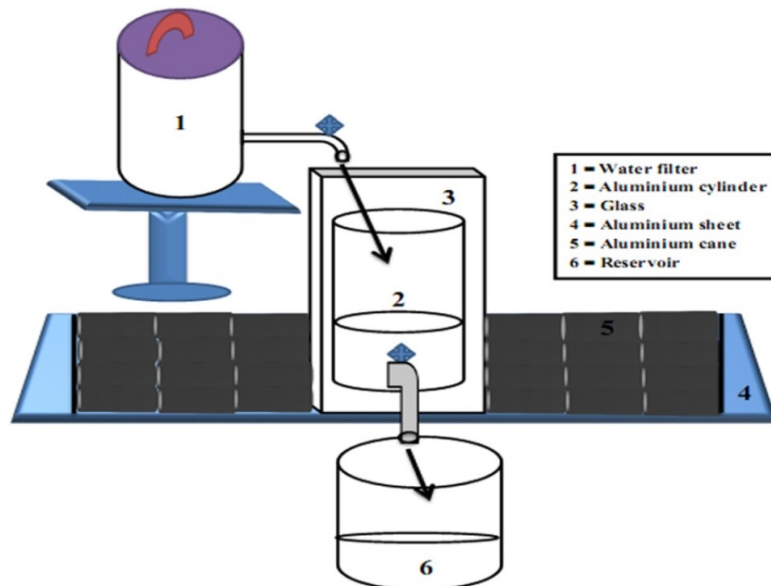


Figure 2. Schematic diagram of water purification and disinfection by solar energy.

Parameters measurement

There are many parameters which can be used to measure the quality of water, some of which are pH , Conductivity, Dissolved oxygen, Chemical oxygen demand (COD_{Mn}), Biological oxygen demand (BOD_5), Color, Turbidity, Phosphate, Sulfate, Nitrite, Ammonia, Fecal coliform, Total hardness, Iron, Manganese and Arsenic. The water quality depends on the above parameters.

$$\text{COD}_{\text{Mn}} (\text{mg/l}) = \frac{(a - b) \times f \times 1000 \times 0.2}{V}$$

Where, a = Volume of Potassium permanganate for sample titration (ml), b = Volume of Potassium permanganate for blank titration (ml), f= Dilution factor, V= Volume of sample (ml).

$$\text{BOD}_5 (\text{mg/l}) = \frac{(D1 - D2)}{P}$$

Where, D1= DO conc. of 1st day analysis (mg/l), D2 = DO conc. of 5th day analysis (mg/l), P = % of dilution.

$$\text{Total Hardness (mgCaCO}_3\text{/L)} = \frac{A \times B \times 1000}{V}$$

Where, A = Volume of EDTA titrated for sample (ml), B = mg CaCO₃ equivalent to 1.00 mL EDTA titrant, V = Volume of sample (ml).

Results and Discussion

Effect of parameters of water purification and disinfection

Water purification is the process of eradicating detrimental chemicals, biological poisons, suspended solids and gases from contaminated water. Drinking water quality standards describes the quality parameters set for drinking water. Water can contaminated by different parameter such as turbidity, dissolved oxygen, suspended solids, nitrates, phosphate, sulfate, ammonia, iron, manganese, arsenic etc. So such kinds of parameter will be present in an acceptable level. These parameters represent the water quality. The desirable level of P^H, iron, manganese, hardness and lead are 6.5 to 8.5, 0.3, 0.1, 300 and 0.05 respectively (Water quality parameters and drinking water standards, IS: 10500-1991).The several researchers have been investigation that the parameters determined before and after coagulation are turbidity, P^H, colour, hardness, iron, manganese and *Escherichia coli*. The result represents that the turbidity is removed of 83.2%, P^H exhibited slight variations through the coagulation, the hardness removal is very low (0 to 15%), high removal of iron (90.4 to 100%), manganese (93.1 to 100%) and the highest *E. coli* is 96.0% (Nkurunziza *et al.*, 2009). In constructed wetland system, 69% of suspended solid (SS) is removed, 86% of biochemical oxygen demand (BOD), and 58% of total nitrogen (TN). Up to 82% of BOD and 27% of TN could be removed in this system (Lin *et al.*, 2015).In the purification stage, with an inlet conductivity of 42.5 µS/cm and a nickel concentration of 10.0 mg/L, the effluent conductivity was 0.3–1.0 µS/cm and the nickel concentration of the effluent was below the detection limit; in the regeneration stage, the average nickel concentration of the concentrate was over 80.0 mg/L, the average pH of the concentrate was 7.4 (Xiaolan *et al.*, 2015).The observation of pure water after treatment, the P^H, iron, manganese, hardness and lead are 7.2, 0.02, 0.071, 200, -0.3162 respectively. All of these water quality parameters are representing the desirable levels. The Table 1 shows that the water quality parameter before and after treatment.

Table 1. Laboratory result of water purification and disinfection by using solar energy

SL. NO.	Water quality parameter	Before treatment	After treatment
1	pH	7.2	7.2
2	Turbidity	0.2 NTU	0.2 NTU
3	Dissolved Oxygen	5.9mg/L	4.8 mg/L
4	BOD	18-19mg/L	16.2mg/L
5	COD	5.1 mg/L	4.6 mg/L
6	Suspended Solid	Not Visible	Not Visible
7	Nitrate	0.8 mg/l	0.075 mg/l
8	Phosphate	0.72 mg/l	0.60 mg/l
9	Sulphate	1 mg/l	0
10	Ammonia	0.01 mg/l	0.02 mg/l
11	Iron	0.03 mg/l	0.02 mg/l
12	Manganese	0.054 mg/l	0.071 mg/l
13	Arsenic	<LOQ	<LOQ
14	Hardness	240	200
15	Electrical Conductivity	372	306
16	Lead	-0.3461	-0.3162

Effect of time at sunny and cloudy days

For reduction of viruses, bacteria, protozoa and diarrheal disease incidence, the solar disinfection system is an ideal. It is mostly depended on the solar energy. Several researchers have been reported that the integrated storage-collector unit is a rectangular galvanized steel box with a total storage capacity of 90 L and angle iron is used to support the edges and prevent buckling and jute fiber was used for insulation. This design achieved a maximum temperature of 45°C by 4.30 PM and provided 30°C water at 5.30 AM the next day (Akuffo and Jackson, 1998). The performance of solar collector is studied under various maximum daily solar intensities, ranging from 1, 2 and 3 on a cloudy day, up to 695 W/m² on a sunny day. The ability of the system in providing hot water suitable for disinfection and the storage tank water temperature reached 52°C just before sunset (Karaghoulis and Alnaser, 2001)

In sunny days, the pure water in the reservoir is heated directly either of the above sun energy or the below solar collector. The solar collector is an air tight chamber that gains large amount of heat energy and flows through the water reservoir chamber. The water temperature is gradually increases and the temperature reaches up to 49°C within 240 min. The solar intensity of sunny days is 700 W/m². At this temperature, the viruses, bacteria, protozoa and diarrheal disease incidence are not alive and for this why they are removed. The Figure 3a shows that the outlet hot water temperature at sunny days.

At cloudy days, due to excessive raining and violent blasts of wind blowing, less amount of solar energy is absorbed. For that time, water temperature is comparatively less increases than sunny days, because of lower intensity of the environment. The solar intensity of cloudy days is 560 W/m². Here the water temperature is also gradually increases and reaches up to 41°C within 240 min. The Figure 3b shows that the output hot water temperature at cloudy days.

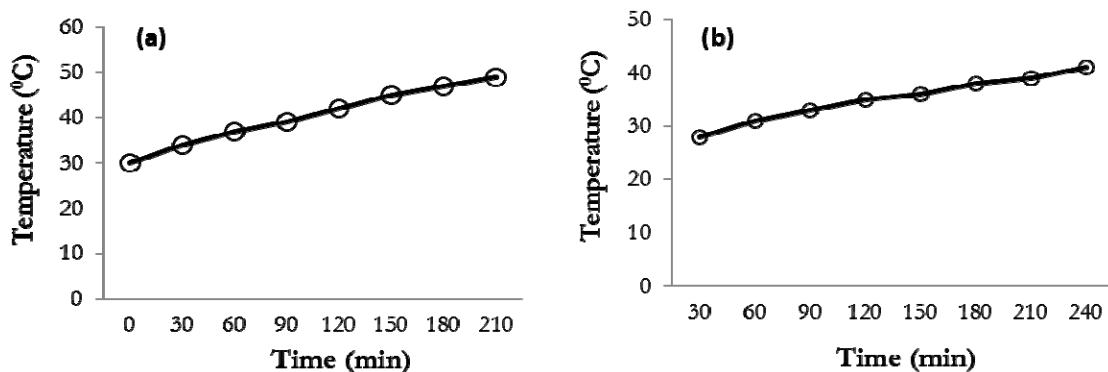


Figure 3. Response of outlet hot water temperature at; (a) sunny days, and (b) cloudy days.

Effect of time in water flow rate

Time is very much important in mass flow rate, because firstly it has low flow rate. After being coagulation and flocculation and sedimentation flow rate increases. The water flow rate mostly depends on the layer of thickness of components in the compact water filter. The larger the thickness of the components, the lower the water flow rate. The screening system also affects the water flow rate. The investigation of solar disinfection unit is tested with both river water and partially processed water from two wastewater treatment plants. The result achieved that the 1 L of pure water in duration 30 minute (Laurie *et al.*, 2004). We use iron net in separation of every layer of components. When time increases mass flow rate increases. We get the output pure water of about 14 L in duration of 240 min. The Figure 4a shows that the output pure water with time.

Effect of solar intensity

When sun shines that time solar intensity increases more than cloudy days. When environmental temperature is almost 30°C that time solar intensity increases whether environmental temperature is at 28°C. The investigation of solar radiation during the three days, the maximum daily solar radiation is 176.3 W/m² on the heavily overcast day, 961.8 W/m² on the clear sky day and 633.4 W/m² on the day with intermittent cloud cover (Ayompe and Duffy, 2013). The Figure 4b shows that the solar intensity is about 700 W/m² at 12.31 pm and average solar intensity is 430 W/m². When sun shines that time solar intensity

is less increase than sunny days. When the environmental temperature is almost 28°C and that time solar intensity increases gradually. It was observed that the solar intensity at 12.25 pm was 560 W/m² and the average solar intensity was about 405 W/m².

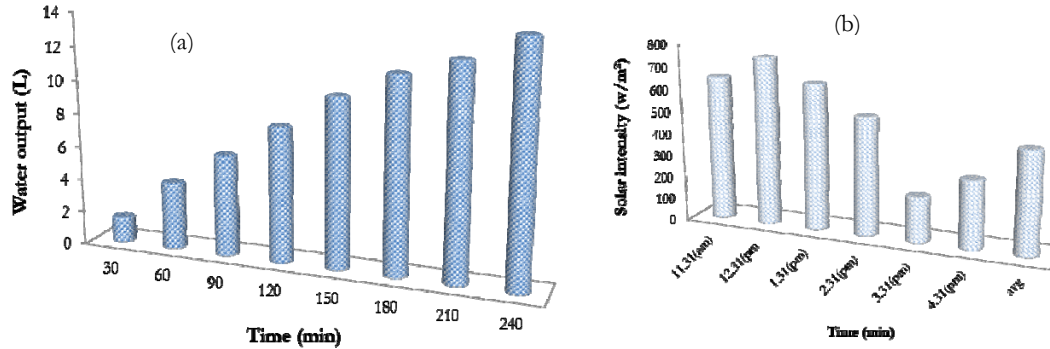


Figure 4. (a)Response of water output with time, (b) Response of solar intensity at temperature (30°C).

Effect of time at vapour

When the water temperature is increases by using solar collector, some of water vapour are produced which is considered as pure water, because of no contamination of viruses, bacteria, protozoa and diarrheal disease incidence. It is mostly depended on time variation and the temperature of the water. The higher the temperature of the water, the larger amount of water vapour is separated. In this system, 16 mL water vapour is produced in duration 240 min. The Figure 5a shows that the outlets vapour.

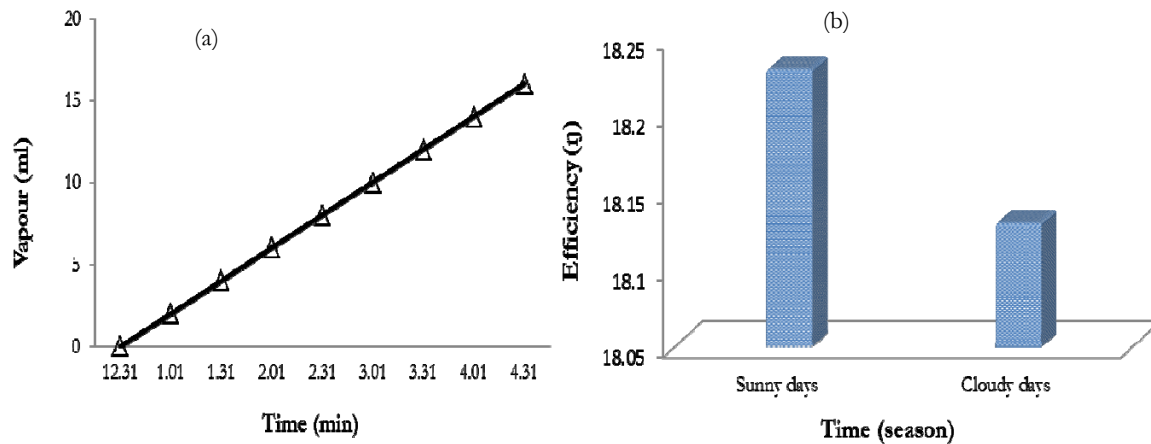


Figure 5. (a) Response of outlet vapour, (b) Efficiency of solar water purification and disinfection system.

Efficiency of the solar water purification and disinfection

At environment temperature 30°C

$$Q = m C_p (T_f - T_i) \dots \dots \dots (1)$$

Where, Q = Net useful heat gained by water, m = Mass flow rate of the water (kg/sec), C_p = Specific heat of water (kJ/kg°C), T_f = Maximum temperature attained by water (°C), T_i = Initial temperature of water (°C), and

Efficiency,

$$\eta = Q/[A_c \times H_b \times R_b] \times 100 \dots \dots \dots (2)$$

Where, A_c = Area of collector (m^2), H_b = Intensity of radiation (W/m^2), R_b = Tilt factor for beam radiation.

Water purification and disinfection by using solar energy plays an important role in modern science. The efficiency of solar water purification and disinfection is mostly depended on climate and season. In this system, we get the efficiency of sunny and cloudy days are 18.23% and 18.13% respectively. The Figure 5b shows that the efficiency of the solar water purification and disinfection system.

Conclusions

Experiments conducted with the simple and effective system presented in this paper show that use of solar hybrid technology for water purification and disinfection is an attractive option to existing solar water filtration approaches. Studies have shown that it is effective in reducing diarrheal illness in children when implemented in field trials. However, the process does have limitations and several variables influence the effectiveness of the process such as solar intensity, temperature, turbidity, container shape, and sample volume. Temperatures up to $49^\circ C$ have no significant effect on the disinfection of *E. coli* bacteria. We get efficiency of sunny days and cloudy days 18.23% and 18.13%. The inactivation properties of solar disinfection are therefore due to its solar radiation component, or the synergistic effects of sunlight and heat. Treatment of treated water with any of the possible options results in higher removal of bacteria and bacteriophages than treatment of tap water with the same treatment options.

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