Usage of Combined Solar - Chlorine disinfection process in treating un-potable water for small rural communities in arid or semi arid area of Iran

***Mojtaba Kharazmi*[1]**

Abstract:
A lack of resources and distribution of infrastructure makes the application of the common disinfection procedure extremely limited in small villages, especially those situated in hot weathers where waterborne diseases are prevalent. Solar radiation removes a wide range of organic chemicals and pathogenic organisms by direct exposure, is relatively inexpensive, and avoids generation of harmful by-products of chemically driven technologies. This could be an appropriate method for solving the problem of purification of water or even wastewater in rural communities. The average solar radiation for the Iran as a whole is about 19.23 Mega joules per square meter, and it is even higher in the central part of Iran, so use of solar energy for disinfection is highly suggested for some specific areas. The solar chamber unit, in a pilot plant scale, made up of PLEXY plates or PET plates should be built in order to investigate the effect of solar energy and heat adsorbed by water through UV-A radiation. Further research just focused on the use of solar energy in disinfection by means of batch reactor. It was reported total removal of three orders of magnitude [3log10] for pathogenic organism. The heat increasing due to UV-A radiation helped the removal efficiency greatly. The differences between the previouse researchs and the recent proposal are about the continuity of water flow and the additional chlorine unit following the solar disinfection chamber. The results that is gained from these researchs may guide us to the efficiency of the combined solar-chlorine disinfection process.

Keywords:
Disinfection, un-potable waters, solar – chlorine unit, rural communities

1- Ms Student of civil & environmental engineering, Shiraz University.

Water agenda in small rural communities

At least one third of the population in developing countries has no access to safe drinking water. The main groups of these kinds of peoples are located in small villages far from the cities. The lack of adequate water supply and sanitation facilities causes a serious health hazard and exposes many to the risk of water-born diseases. The main sources of drinking water in small villages are wells, fountains and rivers. Due to lack of sanitation facilities or treatment plants, these water supplies may not pass required standards for drinking water and could be a major problem to spread water-born diseases.

A lack of resources and distribution of infrastructure makes the application of the common disinfection procedure extremely limited in small villages, especially those situated in hot weathers where waterborne diseases are prevalent. In addition these kind of community have small population, so that building acceptable structure for standard treatment is mostly costly than the common cities and town and their implementation could be environmentally unsound. On the other hand, in recent times researchers believe that using common methods of disinfection such as chlorination, without acceptable pre-disinfecting process, produce some harmful byproducts called disinfection byproducts (DBPs) that are carcinogen to human being. So that it is believed that before chemical disinfection of contaminated waters, supplementary treatment units are obligatory.

Solar radiation removes a wide range of organic chemicals and pathogenic organisms by direct exposure, is relatively inexpensive, and avoids generation of harmful by-products of chemically driven technologies. This method could be an appropriate key for solving the problem of purification of water or even wastewater in rural communities.

Water born diseases

The pathogenic organisms found in water and wastewater can be classified into four broad categories, bacteria, protozoa, helminthes, and viruses. Bacterial pathogenic organisms of human origin typically cause diseases of the gastrointestinal tract, such as typhoid and paratyphoid fever, dysentery, diarrhea, and cholera [4]. Because these organisms are highly infectious, they are responsible for many thousands of death each year in areas with poor sanitation, especially in small rural communities and small villages. There are about 4 billion cases of diarrhea per year, out of which 2.5 million cases end in death, mostly among children under the age of five. This is equivalent to one child dying every 15 seconds or 20 jumbo jets crashing every day.

Different methods of disinfection

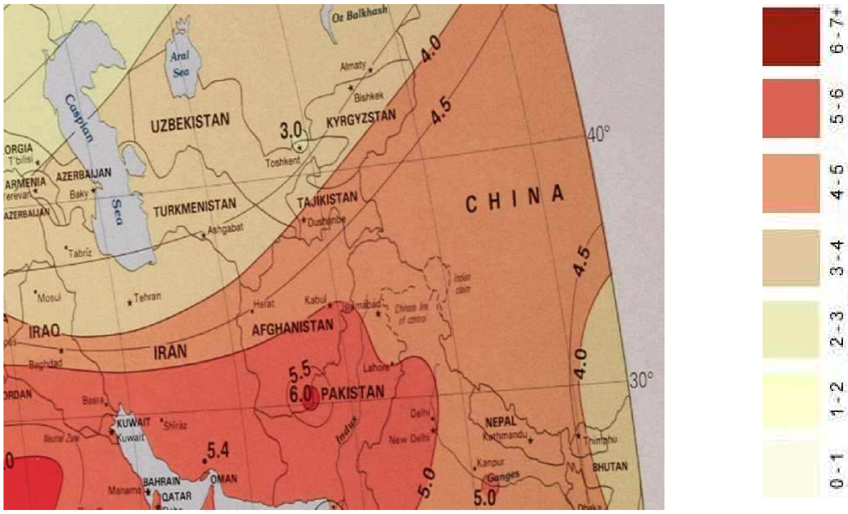
Disinfection refers to the destruction of disease-causing organism. In order to make water safe to drink, further treatment is necessary. The most recognized and established treatment is to boil the water to kill the microorganisms, such as bacteria and viruses, in the water. Conventional technologies used for disinfection of un-potable water include ozonation, chlorination, and artificial UV radiation. These conventional technologies used for disinfecting un-potable waters usually function as a disinfection unit in large water and wastewater treatment plants.

These technologies should be available for large quantities and reasonably priced. They are capital intensive, require sophisticated equipment, and demand skilled operators. They required well established technology because of the hazardous chemical that can be a threat to plant workers and the public, thus strict safety measures must be employed. Some of these methods are unstable and the pathogens can propagate again within time.

Solar energy in Iran

The efficiency of the solar disinfection process is dependent on the amount of sunlight available. Solar radiation however is unevenly distributed and varies in intensity from one geographical location to another depending on latitude, season and the time of the day.

Iran is located between latitude of 25°N and 40°N. This means that the country is in a good position. Besides, sunshine duration is also suitable for solar disinfection, especially in the central and southern parts of Iran, so over 90% of the sunlight directly touches the earth due to the limited cloud cover and rainfall. Figure 1 show the average sun hours in Iran.



Average sun hours in Iran
Unit : kWh/m^2/day

Figure 1: average sun hours in Iran [7]

The average solar radiation for Iran as a whole, is about 19.23 Mega joules per square meter, and it is even higher in the central part of Iran. From image it can be obtained that the variation of daily radiation varies from 2.8 kWh/m^2 in the north part to 5.4 kWh/m^2 in central region [7]. The calculations show that the amount of useful solar radiation hours in Iran exceeds 2800 hours per year. For this reason, the first Photovoltaic (PV) site, with capacity of 5 kW DC was established in the central region of Iran in Doorbid village Yazd in 1993. Following this, in 1998, the second photovoltaic site with 27 kW AC capacity was installed in Hosseinian and Moalleman villages in Semnan 450 Km in land from Tehran.

It is believed that among solar energy potential in Iran, solar disinfection method could be an easy and reliable method for treating un-potable waters in small villages and rural communities, especially places where are located in hot and humid regions.

Application of solar energy in disinfection process

Solar disinfection was first initiated through experiments performed by Prof. Acra at the American University of Beirut. It was further researched with extensive laboratory and field tests carried out by EAWAG-SANDEC, a Swiss Research Center for Water and Sanitation for Developing Countries, based in Switzerland. The field tests of solar disinfection method, completed in several developing countries, have shown it to be an efficient and effective drinking water treatment method, as well as a simple and low cost technology [3].

Ultraviolet radiation is divided according to its biological effects into three major components: 1- UV-C radiation, also called germicidal radiation, which occupies the range up to 280 nm, fortunately it does not reach the Earth, 2- UV-B radiation, also called sunburn radiation, which occupies the range 280-320 nm (Furusawa *et al*., 1990) , and 3- UV-A radiation, referred to as the black light, which occupies the range 320-400 nm (Acra *et al*.,1990) [2].

The solar energy disinfection treatment method based on the synergetic effect of both water temperature and UV-A radiation (wavelength: 320-400 nm). Radiation with longer wavelength (> 400 nm) does not eliminate the bacteria efficiently enough and UV-B (280-320 nm) is only transmitted through special Pyrex glass and does reach the ground level at low intensity only. PET (Polyethyleneterephtalate) shows a good UV-A transmittance and therefore readily available PET-plates are used for the solar disinfection treatment. Application of PET plates with black surface lie down in the bottom will increase the water temperature up to 60 to 70 °C and it can help the pathogen removal efficiency by water temperature multiplication. High temperatures strongly affect all microorganisms; vegetative cells perish as proteins are denatured and their components undergo hydrolysis. Although some bacteria in the water are capable of forming spores, making them particularly heat-resistant, most are generally killed off at between 40 and 100°C, while algae, protozoa and fungi perish at between 40 and 60°C [6]. So that combinations of solar energy with heat in disinfection units can strengthen the eliminations of pathogens.

To ensure safe water disinfection, the raw water should have a low turbidity (less than 30 NTU= Nephelometric Turbidity Units). At a water depth of 10 cm and moderate turbidity level of 26 NTU, UV-A radiation is reduced to 50%. So the water depths play an important role [5]. Using A black surface induces a temperature gradient which cause further elimination of pathogens, in that case further depth of water could be applied. Parameters that could interfere the solar disinfection method with perfect disinfection include geographic latitude and altitude, season, number of hours of exposure, time of the day, clouds, and temperature; volume and material of vessels containing the water; and water turbidity and color.

Disinfection concerning pathogens removal

The damaging effects of UV radiation appears to be largely due to their formation of pyrimidine dimers, thus interfering with, or cleaving of, the nitrogen base sequences of the DNA strands in microbial cells (Muller- Niklas *et al*.,1995). Other mechanisms for UV damage of cellular membranes (Moss and Smith, 1981) or inhibition of tRNA synthesis (Kubitschek and Doyle, 1981) have also been reported [2].

Odeyemi *et al*. (1988) examined the germicidal effects of solar radiation on water samples, using transparent containers and reported total removal of three orders of magnitude [3log10] coliforms within 3 hours exposures. Inactivation of fecal bacteria in drinking water by solar heating has also been reported (Joyce *et al*., 1996). Within 7 hours no viable *Escherichia coli* organisms were detected at either the end of their experiment or a further 12 hour later [2].

As noticed in solar disinfection method, temperature rise could intensify the pathogen removal. Microorganisms are heat sensitive. Table 1 list up the required temperature to eliminate microorganisms within 1 to 60 minutes. It can be seen that it is not required to boil the water in order to kill 99.9% of the microorganisms. Heating up water to 50 – 60 ^{0}C for one hour has the same effect [1].

Table 1: effect of temperature on microorganism removal [1]

microorganism	**Temperature for 100% destruction**		
	1 min	**6 min**	**60 min**
Enteroviruses			62 ^{0}C
Rotaviruses			63 ^{0}C for 30 Min.
Faecal Colioforms	At 80 ^{0}C Complete destruction		
Salmonelae			45 ^{0}C
Shigella		61 ^{0}C	54 ^{0}C
Vibrio Cholera			45 ^{0}C
Entamoeba Histolytica Cysts	57 ^{0}C	54 ^{0}C	50 ^{0}C
Giardia Cysts	57 ^{0}C	54 ^{0}C	50 ^{0}C
Hookworm Eggs and Larvae		62 ^{0}C	51 ^{0}C
Ascaris Eggs	68 ^{0}C	62 ^{0}C	57 ^{0}C
Schostosomas Eggs	60 ^{0}C	55 ^{0}C	50 ^{0}C
Taenia Eggs	65 ^{0}C	57 ^{0}C	51 ^{0}C

It has been widely experimented and established by earlier researchers that at temperature of 50 ^{0}C, pathogenic microbes are inactivated. The temperatures which cause approximately a 1-log decrease in viability with 1 min are 55 ^{0}C for protozoan cysts; 60 ^{0}C for E.*coli*, enteric bacteria, and rotavirus; and 65 ^{0}C for hepatitis A virus [1].

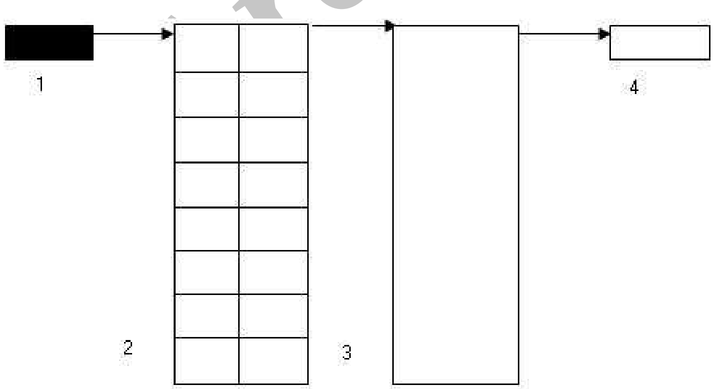
Combined disinfection system: solar - chlorine disinfection in rural communities

In small rural communities, main drinking water resources are wells, fountains, rivers, qanats, reservoirs and cisterns. These water sources have their own specification and limitations in small villages and rural communities. The main problem of these resources is their contamination with different pathogenic organisms that cause water born disease. Rivers, qanats and reservoirs especially are of concern because they are more accessible to highly pollution sources such as sanitary wastewaters and organic contaminations which increase the BOD and pathogenic indexes of water. The villages in tropical and hot weather are more capable of having this problem.

Due to the high price of customary disinfection units for small communities which use these contaminated water resources, an alternative method could be used in order to lower the cost of disinfection process besides maintaining the required standards of drinking water. In this article the combined solar – chlorine disinfection system is suggested for small rural communities which consist of the main rural population in Iran.

Having this system will lower the price of disinfection process in the case of using solar energy and the heat energy gained from the sun. The combine solar – chlorine system first should be examined in pilot scale in order to identify the limitation and specification of the process. The pilot plant can be made up of ordinary glass, plexy glass or PET materials. The PET bottles can be recycled and used in this kind of facilities. Even the real plant could be made up of PET, as it decrease the capital cost, and moreover it is environmentally friend method. Ordinary window glass in thicknesses of 2 mm or more is practically opaque to UV radiation. Certain specific glasses (Pyrex, Corex, Vycor, Quartz Glasses) transmit significantly more ultraviolet radiation than the ordinary window glass. However, for an appropriate technology like solar disinfection, large scale utilization of these special glasses may not be very attractive due to their high costs and rare availability in the rural areas of the country.

The solar chamber unit is made up of PLEXY plates or PET plates, because it shows a good UV-A transmittance. The upper layer should have enough transparency for UV-A radiation and the lower layer should be colored black for temperature increase. Application of PET plates with black surface lie down in the bottom will increase the water temperature up to 60 to 70 °C and it can help the pathogen removal efficiency by water temperature multiplication. Water flows through cells and subject to sunlight and heat. The pathogenic organisms will first disinfected with solar energy and heat energy in solar chamber, afterward they reach chlorine contact basin and the final die-off of microorganisms obtain with chlorine. The schematic flow diagram for this pattern is shown below in figure 2.



1: water supply tank
2: solar disinfection unit with black bottom layer
3: chlorine contact basin disinfection unit
4: storage tank

Figure 2: schematic flow diagram for combined solar – chlorine disinfection process

Factors that affect solar disinfection in solar chamber are time, temperature, UV –A radiation rate, turbidity and inlet of pathogenic organisms.

Advantages and disadvantages of solar disinfection

Table 2 shows the advantages and disadvantages (limitation) of using this process briefly.

Table 2: Advantages and disadvantages of solar disinfection

advantages	disadvantages
Not dependent on conventional energy, whose cost rises with the growing demand	Cannot be used on cloudy or rainy days
Decrease the use of toxic chemicals	The turbidity must be below 30 NTU
Require relatively simple and low-cost equipment	Require complementary disinfection unit for 100% disinfection
Not environmentally damaging	Require enough time
Extremely simple and inexpensive	The plates should clean daily for enough transparency
Easily accepted by the communities	Cannot be used to disinfect large volumes of water
Generate lower DBPs	
The facilities could be designed in movable mode	

Result & discussion

Earlier researchs on disinfection of unpotable water by solar energy was only done with some kind of batch reactors. The differences between the previouse researchs and the recent article are about the continuity of water flow and the additional chlorine unit following the solar disinfection chamber. Bag bottle and PET bottle was investigated formerly. The results that is gained from these researchs may guide us to the efficiency of the combine solar-chlorine disinfection process. Inactivation of microorganism by means of solar energy depends on the UV radiaion rate, turbidity and time. Table 3 shows the relationship between these parameters and table 4 shows the inactivation mode.

Table 3: inactivation of microorgansims [2]

Species	Turbudity NTU	Inactivation with time (hours)			
		1	2	3	4
Staphylococcus spp.	16	99.9998	-	-	-
Salmonella spp.	8.9	99.85	99.9998	-	-
Pseudomonas spp.	2.6	90.0	99.9998	-	-
Streptococcus spp.	5	98.8	99.25	99.9998	-
E. coli	2	90.3	96.1	99.9	99.9998

Table 4: pathogenic inactivation mode [5]

Species	Water born diseases	Inactivation mode
E. coli	Water quality index	3-4 log
Vibrio cholera	Cholera	3-4 log
Salmonella spp.	Thyphoid	3-4 log
Shigella spp.	Dysentery	3-4 log
Giradia spp.	Giardiasis	3-4 log(infectivity of cytes)
Cryptosporidium spp.	Cryptosporidiasis	3-4 log(infectivity of cytes)

Also Temperature rise is the result of using solar energy, especially if the black color on the bottom layer of the solar chamber are used. The effect of temperature rise will increase the pathogen removal and help the operation of solar-chlorine process. Additional chlorine disinfection unit following solar chamber in this method will always be a good assurance for required standard of drinking water, plus the main advantage of applying this unit is dropping off the chlorine usage and reduction in production of DBPs.

References

[1]. A Jagadeesh., Centre for Energy and Sustainable Resources, R.M.K. Engineering College, Kavaraipettai, “drinking water for all”, 2003

[2]. Ali elkarmi., Kh.A.Elteen., “Disinfecting Contaminated Water with Natural Solar Radiation Utilizing a Disinfection Solar Reactor in a Semi-arid Region”, Jordan journal of biological science, Mar, 2008.

[3]. EAWAG/SANDEC, SODIS bulletins. “Bulletins of the Water and Sanitation section of the Swiss Federal Institute for the Environment”, Science and Technology, 1997

[4]. George Tchobanoglous., Metcalf & Eddy Inc, “wastewater engineering, treatment and reuse”, fourth edition, McGraw-Hill series in civil and environmental engineering, 2003

[5]. Swiss Federal Institute of Environmental Science and Technology (EAWAG) and Department of Water and Sanitation in Developing Countries (SANDEC), “Water & Sanitation in Developing Countries”, ISBN Nr.: 3-906484-24-6, SANDEC Report No 06/ 02

[6]. U.S. Environmental Protection Agency, **“**Ultraviolet light disinfection technology in drinking water application: an overview”, EPA 811-R-96-002. U.S. Environmental Protection Agency, Washington, D.C, 1996

[7]. www.solar4power.com, solar power global maps