研究論文

SOLAR WATER DISINFECTING SYSTEM USING COMPOUND PARABOLIC CONCENTRATING COLLECTOR

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ABSTRACT

Solar water disinfection is an alternative technology using solar radiation and thermal treatment to inactivate and destroy pathogenic microorganisms present in water. The Compound Parabolic Concentrating, (CPC) collector can be used as an efficient key component for solar disinfectanting system. Two types of the CPC collectors are studied, namely the transparent-tube and the Copper -tube CPC collector. It is found that after 30 minutes of exposing the water sample to solar radiation or heating it up to 65°C for a few minuets all the coliform bacteria present in the contaminated water sample were compeletly eliminated. In this article, the effect of water temperature on the disinfecting process was presented. Thermal and micro-biological measurements were also made to evaluate the system performance.

I. INTRODUCTION

It is desirable to deliver energy at temperatures higher than those possibles with flat plate collectors. Decreasing the area from which heat losses occur can increase energy delivery temperatures. Interposing an optical device between the source of radiation and the energy-absorbing surface does this, Duffie and Beckman[3]. The small absorber area will have smaller heat losses compared to the flat plate collector at the same absorber temperature. The nonimaging concentrators have the capability of reflecting to the receiver all the incident radiation on the aperture over ranges of incidence angles within wide limits. The limits define the acceptance angle of the concentrator. As all radiation incident within the acceptance angle is reflected to the receiver, the diffuse radiation within these angles is also useful input to the collector. The higher the temperature at which energy is to be delivered, the higher must be the concentration ratio and the more precise be the optics of both the concentrator and the orientation system. In order to achieve higher temperature in a small period of time, the CPC collector can be used efficiently in the solar water disinfecting system.

In recent years, many research studies have been conducted in the field of solar disinfection of water. The earlier findings of Acra et al.[1] obtained that the solar radiation has been proven to inactivate and destroy pathogenic bacteria present in drinking water.

David et al.[2] found that, it is not necessary to boil water to make it safe to drink. Heating water to 65 °C for a few minutes or at a higher temperature for a short time will make the water safe from pathogenic activity.

Saitoh T.S. and ElGhetany H.H[5] studied the various parameters that affect the performance of the solar water disinfecting system.

The objectives of the present study are to experimentally verify (thermally and biologically) the CPC collector as a solar disinfectant device under the environmental conditions of Sendai city, Japan (38° 15 N latitude, 140° 51 E longitude), and to evaluate its performance criteria.

II. EXPERIMENTAL SET-UP

The layout of the CPC solar water disinfecting system is shown in Fig. 1 while the CPC solar energy collector configuration is shown in Fig. 2. The system consists of a contaminated water tank followed by a

5-micron-meter-cartridge type water filter (65-mm diameter, 250-mm height, 10-l/min.-flow rate, and 2-kg/cm^2-water pressure). The filter cartridge is placed inside a rigid housing (115-mm diameter, 316- mm height, and 8.8-kg/cm^2 durable pressure) with 0.75-inch inlet and outlet ports diameter. This filter provides preliminary filtering and sedimentation of any impurities. The water, outlet from the filter, is introduced to the CPC collector through a silicon braid hose (that can withstand temperature up to 200°C) and remained for a certain period of time. In this period, the water temperature is increased because it is placed in the line focusing of the CPC collector while the water sample is exposed to solar radiation. The disinfected water is taken out from the clean water tank through a silicon braid hose 5-cm above the bottom of the tank. A 0.5-inch gate valve controls the water flow. The water samples are taken periodically to count their bacterial content. The water heating process up to temperature 65°C and exposing to solar radiation for a certain period of time make this system worked well in the solar water disinfecting process.

It CPC collector is insulated with a 0.1 m thick insulation (Urethane foam and glass wool) to reduce heat loss. It is also covered by double glazing (single glass and polyethylene film) and tilted by an angle of 15° from the horizontal for receiving normal solar radiation through the glass cover. The solar radiation pyranometer is tilted to the same angle as the glass cover of the CPC collector to measure the solar radiation falling on the tilted surface.

For the sake of verification of the present system for water disinfection using solar energy, the water samples were taken periodically from the CPC system through the day of experiment usually from 10:00 a.m. to 2:00 p.m. The sample bottles are covered by aluminum foil and placed in a refrigerator. Microbiological analysis initiated as soon as possible after collection to minimize changes in bacterial population (maximum elapsed time between collection and analysis not exceed 3 hours). In this study, the pour plate method is used to count the bacterial content. The warm agar culture medium is poured over the water sample and mixed thoroughly in a Petri plate. If the sample is so contaminated, it should be diluted first to obtain countable plates. As an example, if 1 ml of the original sample is added to a blank containing 99 ml of sterile distilled water and mixed many times or placed on a magnetic stirrer to make sure that a complete mixing is happened. Then if 1 ml from the diluted bottle is placed into a Petri plate, it means that the original sample is diluted 100 times and so on, lot of dilutions can be made depend on the degree of contamination of the water sample. The coliform group of bacteria is defined as the principle indicator of suitability of water for domestic, industrial or other uses. This is assayed for viability using Desoxycholate lactose agar. Coliforms are grown on this differential and slightly (special) selective medium forming red colonies upon incubation at 37°C for 24 hours. After incubation the colonies that developed are counted. The bacterial count of the original sample is then determined by multiplying the number of colonies that developed by the dilution factor of the sample in the plate.

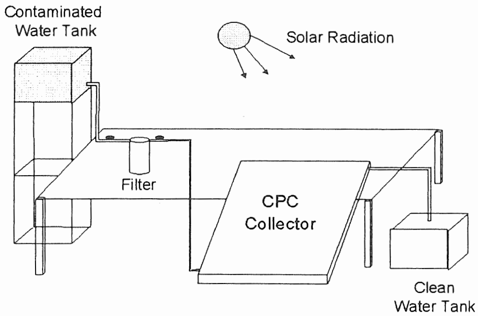

Fig. 1 Solar water disinfecting system using CPC collector

In the present study, two types of the CPC collectors are used depending on the type of receiver (absorber) i.e. the transparent glass-tube and the copper-tube receivers.

III Transparent Glass-Tube CPC Collector

In order to achieve higher temperature than the conventional collector in a small period of time, a CPC collector is introduced to the solar water disinfecting system instead of the Hot Solar Box[4]. The black copper tube with

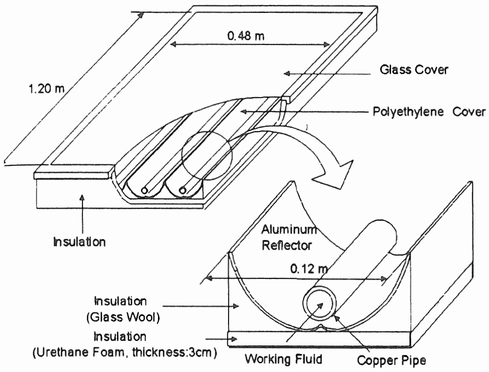

Fig. 2 Layout of the CPC collector

selective surface, which represents the absorber, is replaced by a transparent pyrex glass tube (borosilicate type) to make the contaminated water expose to solar radiation. The transmissivity of this glass in the wavelength bactericidal effect area, near Ultraviolet UV-A (320-400 nm), is in acceptable value. At 320 nm it is about 70% and increased to 90% at 360 nm and keep constant value (90%) from 360-400 nm as shown in Fig.3.

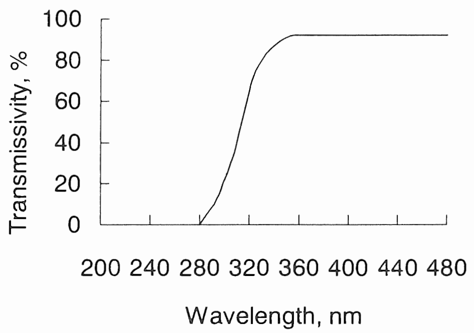

Fig.3 Transimissivity-Wavelength relation for the Pyrex glass tube used

The water samples are taken periodically to count their bacterial content. Different experiments are made to test the water sample thermally inside the solar disinfecting system. As an example, the water sample is placed in the transparent glass tube, which represents the receiver, inside the CPC collector for a certain period of time. The water temperature is recorded as well as solar radiation and the ambient temperature. The experimental measurements of solar radiation, ambient temperature and water temperature inside the CPC collector for a test run on June 10th 1999 is obtained in Fig.4. It is clear from the figure that the water temperature reached 65°C in 30 minutes and reached the maximum value of 76.5°C. This is because a good weather condition (clear sky, non-windy and average ambient temperature (27°C) which represents the optimal case for CPC operation where the heat loss is at minimal and consequently higher thermal performance is achieved.

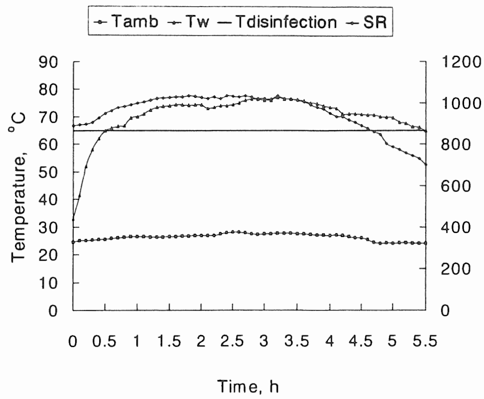

Fig. 4 Experimental measurements of solar radiation, ambient temperature and water temperature inside the CPC Collector for a test run on June 10th 1999

Microbiological Analysis:

The contaminated water sample is placed inside the CPC Solar Water Disinfecting System in the same day of experiment. During exposure to ultraviolet solar radiation and water heating process, water samples are taken periodically at fixed time intervals (30 minutes). Six water samples are collected and their bacterial content is counted. The survival rate of coliform bacteria in the water sample for a test run on June 10th 1999 is obtained in Fig. 5. It is clear from the figure that the number of coliform bacteria per ml at the beginning of experiment is about 178,333 Col/ml and after 30 minutes exposure to solar radiation and increase with its temperature this number is sharply decreased to 1158 Col/ml. After that the number is continue to decrease until it reach 6 Col/ml after one hour and completely eliminated after 1.5 hours. The last three samples after 1.5, 2, and 2.5 hours, the number of coliform bacteria is zero. It can be concluded that the 90% of the UV solar radiation that transmitted through the tube surface has the bactericidal effect beside the water heating process which reflects the importance of using the transparent CPC solar collector in the solar disinfecting system. It can be said also that the 65°C is considered as thermal disinfecting index in the solar water decontamination process.

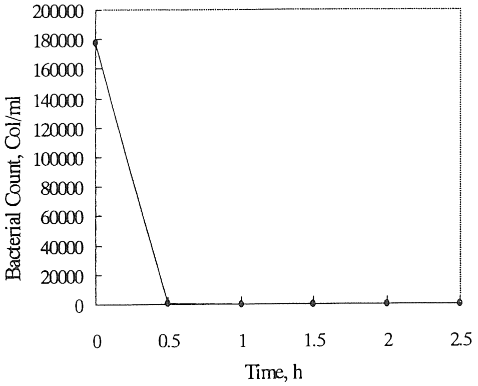

Fig. 5 Survival rate of coliform bacteria in contaminated water for a test run on June 10th 1999 using CPC collector

IV Copper-Tube CPC Collector

In order to obtain the effect of water temperature on the solar water disinfecting process, a Copper tube CPC collector as a solar disinfectant is placed instead of the transparent glass-tube CPC collector in the solar water disinfecting system. The water sample is placed inside the copper tube CPC Solar Water Disinfecting System in the same day of experiment (July 7th, 1999). During water heating process, water samples were taken periodically at fixed time intervals (30 minutes). Six water samples are collected and their bacterial content is counted. The survival rate of coliform bacteria in the contaminated water samples for a test run on July 7th 1999 is obtained in Fig. 6.

It is clear from the figure that the number of coliform bacteria per ml at the beginning of experiment is about 167,350 Col/ml and after 30 minutes, it is sharply decreased to 30,000 Col/ml. After one hour, the coliform bacteria are completely eliminated (the last four

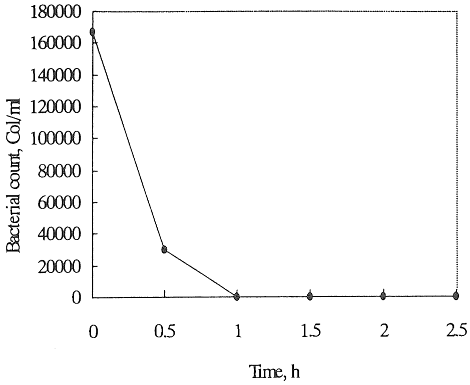

Fig. 6 Survival rate of coliform bacteria in contaminated water for a test run on July 7th 1999 using copper tube CPC collector

samples after 1, 1.5, 2, and 2.5 hours, the number of coliform bacteria is zero). It can be concluded that the water temperature is playing an important role in the solar water disinfecting system. According to the system layout, the copper tube CPC collector obtained higher output temperature than the glass-tube one. The experimental measurements of solar radiation, ambient temperature and water temperature inside the copper tube CPC collector for a test run on July 7th 1999 are plotted in Fig. 7.

It is clear from the figure that the water temperature reached only 63.4 °C within 30 minints because there was some cloud periods at the beginning of experiment. When the solar radiation became in its good conditions (approx. clear sky model), the water temperature reached the maximum value of 93.5°C and the average ambient temperature was 22°C in non-windy conditions that minimize the heat loss and increase the water temperature.

To experimentally verify the effect of water temperature on the disinfecting process, another experiment was made on September 27th, 1999. During water heating process, water samples were taken periodically at fixed time intervals (30 minutes) like the previous experiment (July 7th., 1999). Six water samples are collected and their bacterial content is counted. The survival rate of coliform bacteria in the contaminated water samples for a test run on September 27th, 1999 is obtained in

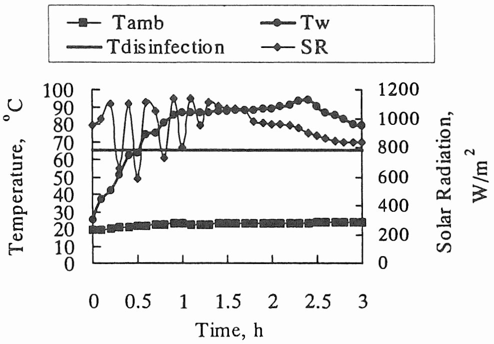

Fig.7 Experimental measurements of solar radiation, ambient temperature and water temperature inside the copper tube CPC collector

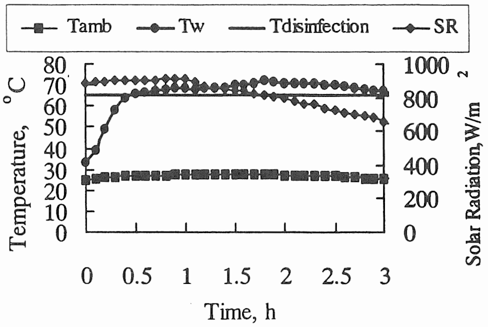

Fig.9 Experimental measurements of solar radiation, ambient temperature and water temperature inside the copper tube CPC collector for a test run on September 27th 1999.

Fig.8. It is clear from the figure that the number of coliform bacteria per ml at the beginning of experiment is about 266,217 Col/ml and after 30 minutes, all the coliform bacteria are completely eliminated. It can be concluded that the water temperature is playing an important role in the solar water disinfecting system. The experimental measurements of solar radiation, ambient temperature and water temperature inside the copper tube CPC collector for a test run on September 27th 1999 are obtained in Fig. 9.

It is clear from the figure that the water temperature reached 66°C within 30 minutes due to good environmental conditions (sunny weather, high ambient temperature, and low wind speed)

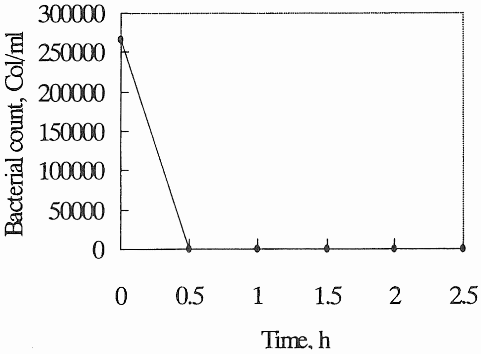

Fig. 8 Survival rate of coliform bacteria in contaminated water for a test run on September 27th, 1999 using copper tube CPC collector

The water temperature reached max. value of 72°C and the average ambient temperature was 26°C in non-windy conditions that minimize the heat loss and increase the water temperature.

The thermal disinfecting index in the solar water disinfecting system (up to 65°C) is verified in both types of the CPC collectors (glass and copper tube). A comparison between the last two experiments using Cu-tube CPC collector (July 7th and Sept. 27th, 1999) is shown in Fig.10. It is clear from the figure that the coliform bacteria are completely eliminated when the water temperature reach 65°C or higher.

The process of milk pasteurization is well known. This is a heating process that is sufficient to kill the most heat resistant disease causing microbes in milk, such as the bacteria which cause tuberculosis, undulant fever, streptococcal infections and Salmonellosis. Most milk is pasteurized at 71.7°C for only 15 seconds. Alternatively, 30 minutes at 62.8°C can also pasteurize milk. Some bacteria are heat resistant and can survive pasteurization, but these bacteria do not cause disease in people. They can, however, spoil the milk, so pasteurized milk is kept refrigerated. There are some different disease microbes found in water, but they are not unusually heat resistant. The most common causes of acute diarrhea among children in developing countries are the bacteria Escherichia coli and Shigelia SD. and the Rotavirus group of viruses. These are rapidly killed at temperatures of 65°C or greater.

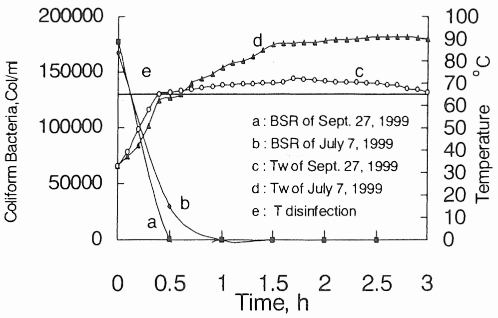

Fig.10 Measurements of temperature distribution and bacterial contents in the water sample inside the copper tube CPC collector.

Heating water to 65°C in the CPC solar water disinfecting system will provide enough heat to pasteurize the water and kill all disease causing microbes. The fact that water can be made safe to drink by heating it to this lower temperature, only 65°C, instead of 100°C (boiling), presents a real opportunity for addressing contaminated water in developing countries.

The transparent glass tube CPC collector is working well in the solar water disinfecting process because it uses the two methods of disinfection heating and exposing to solar radiation. On the other hand the black copper tube CPC collector which represents the thermal model in the disinfecting process, is working efficiently. As a comarison between them, one can find that the black copper tube CPC collector is appeared better than the transparent one due to some reseons, as an example

1- The black copper tube CPC system can produce higher water temperature than the transparent tube CPC system under same weather conditions which consequently produce larger amount of disinfecting water in the same experiment.
2- The life time of the black copper tube CPC system is larger than the transparent tube CPC system due to its good durability. This is because the glass tube may be broken easily if it is not fixed well especially in windy areas.
3- From the economic point of view, the black copper tube CPC system is cheaper than the transparent tube CPC system due to the higher price of the Pyrex glass tube.

V. CONCLUSION

Solar water disinfection inactivates or destroyes most pathogenic microorganisms present in the water through solar radiation and thermal treatment. The thermal disinfecting index in the solar water disinfecting system (up to 65°C) is verified in both types of the CPC collectors (glass and copper tube) where the coliform bacteria, which are considered as an indicator of fecal pollution, are completely eliminated. Among the solar energy facilities that can be applied for heating the water, the CPC collector is appeared more efficient than other solar energy devices, due to its high energy delivered and consequently high output temperature. In the clear sky conditions, the Copper-tube CPC collector can be worked well as a solar disinfectant apparatus beside the transparent-tube CPC collector.

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