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Solar Disinfection of Drinking Water Using Flat-Plate Solar Collector

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Abstract

Inaccessibility to steady supply of safe drinking water remains a problem for developing countries like the Philippines. A treatment method that is simple, low-cost, effective, and sustainable needs to be in place as an alternative.

Solar disinfection process for drinking water is a method that is applicable in a household or institutional level. The technology is simple, reliable and operationally cheap for it requires only energy from the sun to run it. Synergetic action of both heat and radiation (UV-A) from the sun is potent in inactivating and destroying pathogenic microorganisms present in water.

This study assessed the local suitability of the solar disinfection process through testing a fabricated Solar Disinfection (SODIS) Plant. The set-up basically consisted of the raw and treated water tanks, solar reactor for combined heating and irradiation, and piping accessories. Tests for thermal and microbiological performance proved that solar disinfection through the SODIS Plant is a viable option for water disinfection. Setting the water temperature to at least 50°C resulted to complete inactivation of Total coliform microorganisms. On an average sunny day, the SODIS Plant is able to raise the water temperature to its minimum effective setting within about 2 hours. Operating at an average of 22% net thermal efficiency, the plant is able to generate 40 liters/m^2/day.

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Introduction

The World Health Organization (WHO) reported that more than one billion people in the developing countries do not have ready access to adequate and safe water supply (WHO, 1998). Among these, 800 million live in the rural areas. Furthermore, included in the report is the three million annual deaths caused by diarrheal diseases, which are closely associated with lack of access to clean water, food and poor personal hygiene.

The booming bottled water business, as can be noticed by a lot of companies venturing into it, indicates public awareness and perception of the unreliability of community water supplies. Reported cases of drinking water contamination through ill-maintained water distribution system raised serious public concern. Like in other developing countries, it shows the prevailing problem of the community water supply systems due to inappropriate choice of technology, unreliable supply and maintenance work, difficulties in procurement of fuel or spare parts and weak management structures (Wegelin 1994). Because of these reasons, most households resort to bottled water, boiling and use of expensive packaged water purifiers, while others simply take the risk from drinking tap water directly. Thus, household spending in ensuring water safety or for medical expenses is increased.

A suggested approach to this prevailing problem involves the increased use of appropriate low-cost disinfection technologies and installation of water supply facilities whose operation and maintenance can be managed and sustained with local resources. It should be simple, effective, and inexpensive and could be used by individuals, families or institutions like hospitals, offices and schools. A promising technology is the disinfection process through solar heating and radiation. The use of renewable energy such as solar energy is the basis of this low-cost and sustainable technology (Wegelin, 1994). It is therefore the intention of this study to investigate the possibility of fabricating locally a solar reactor and to test its performance.

Objective of the Research

The objective of this research is to study the local applicability of the solar disinfection process for drinking water using local materials.

The specific objectives are:

1. to design and fabricate a Solar Disinfection (SODIS) Plant for drinking water application;
2. to determine the thermal performance of the SODIS Plant; and
3. to determine the effective operating parameters of the SODIS Plant for solar disinfection of drinking water that would pass WHO microbiological standards.

Scope and Limitations

This study on solar disinfection process for drinking water application is specifically intended for the Philippine setting and other tropical areas. The treatment process that the SODIS Reactor is designed to accomplish is simply microbiological disinfection; hence, only microbiological parameters and water quality standards were considered. An indicator organism was used to represent the state of microbiological quality of the raw and treated water of the solar disinfection process. The study did not track the fate of every microorganism present before and after the treatment process. Furthermore, the study focused on selected parameters such as temperature, turbidity, exposure duration, solar intensity, and Total coliform count as indicator of treatment effectiveness.

Review of Related Literature

Solar Collector and Thermal Efficiency

A typical Flat-Plate Collector which consists of an optically transparent plate which acts as infrared trap, a space filled with air or vacuum, a heat absorber, and pipes through which air or fluid is circulated. Sometimes, instead of pipes, a sheet of fluid is allowed to flow over the heat absorber plate (Schulert, 1981).

The major constituent of any collector is the absorber. It is a metal, glass, or plastic surface where the absorbed solar radiation is converted to thermal energy and transferred by thermal conduction and convection to the coolant or circulating fluid.

To reduce the irradiative losses from an absorber while at the same time maintaining a high solar absorptance, a selective surface is often applied to the absorber. These surface coatings are composed of specially formulated paints, chemical dips, or electroplated films that have the usual radiative property of high absorptance (Neville, 1995).

Microbiological Quality of Drinking Water

The diverse species of pathogenic agents are impossible to identify and enumerate individually. For this reason, indicator microorganisms are used to indicate their potential presence.

WHO (1993), in its *Guidelines for Drinking Water Quality*, standardized *E. coli*, *Thermotolerant coliform* bacteria, and Total coliform bacteria as indicators of bacteriological quality for drinking water.

WHO Microbiological Standard

The WHO standard for all water intended for drinking says that *E. coli* or *Thermotolerant coliform* bacteria should not be detectable in any 100-ml sample. For treated water entering and within the distribution system, *E. coli*, *Thermotolerant coliform* bacteria or *Total coliform* bacteria should not be detectable in any 100-ml sample (WHO, 1993).

Solar Disinfection Process

Solar exposure is an ancient disinfection practice used without profound understanding of the process. Solar disinfection is the process of inactivating and destroying pathogenic microorganisms present in water through solar exposure. Several experiments conducted reported vulnerability of microorganisms to thermal heat (pasteurization) and radiation from the sun. Furthermore, thermal heat and radiation showed synergetic effect in the rate of reducing microbial population present in water (Wegelin, 1994).

Thermal Effect

More recent studies of Sommer (1997) on Solar Pasteurization (SOPAS) shows that for effective disinfection of drinking water, it is necessary to heat it at 70°C and maintain it at that temperature for at least 15 minutes.

Radiation Effect

The inactivation of bacteria by UV radiation results primarily from the absorption of radiation by the deoxyribonucleic acid (DNA) of microorganisms and subsequent demineralization of thymine bases in DNA. These thymine dimers distort the double helix conformation of DNA and may block replication, which effectively inactivates the bacteria

Because the only ultraviolet radiation effective in destroying bacteria is that which reaches the bacteria, the water should be relatively free from turbidity that would absorb the ultraviolet energy and shield the bacteria. To eliminate failure of the radiation disinfection process due to turbidity factor, thin film approach is being used (Metcalf & Eddy, 1991).

The effective component of solar radiation involved in microbial destruction seems to be the near —ultraviolet (A) band (320-400 nm) and to a lesser extent the visible band of violet and blue light (400-490 nm) (Acra, 1984).

Methodology

Equipment Set-up

The schematic diagram of the SODIS plant is shown in Figure 1. The plant location was at the rooftop of the Solar Laboratory of the University of

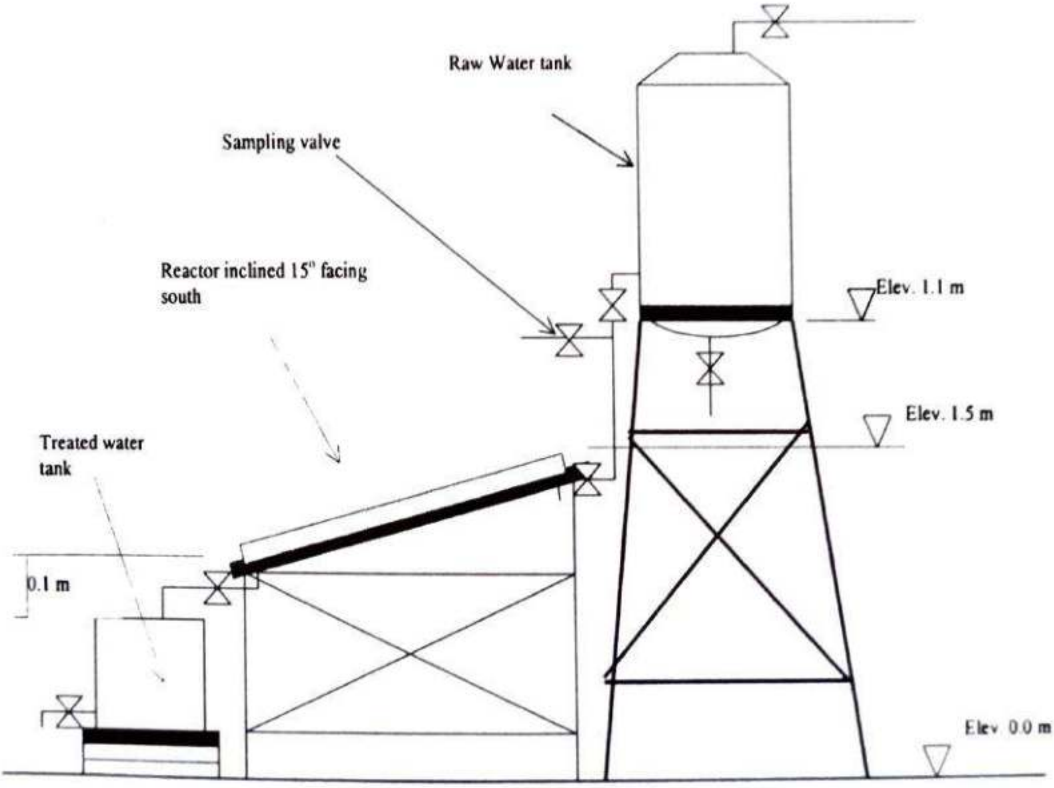

Figure 1. *Schematic Diagram of SODIS Plant*

the Philippines campus in Diliman, Quezon City. Proximity to the UP-Environmental Laboratory eliminated inconvenience of sample handling and delay of laboratory analysis.

SODIS Design and Fabrication

The primary considerations of the SODIS Plant design are transportability, thermal characteristic, operation and maintenance convenience, and as well as economic viability.

SODIS Reactor Details

The heart of the plant is the reactor (Fig. 2). It is where irradiation and heating of the water takes place. It is made of 3-mm thick aluminum plate, which has the advantage over ordinary steel plate in terms of susceptibility to corrosion and weight. It was painted with food-grade black paint (absorptivity = 0.9 to 0.98) on the surface in contact with the water subjected to treatment. Black has the optimum radiation absorptivity property. The dimensions of the single reactor used were 609 mm length x 1219 mm width for transportability and maintenance convenience. A food-grade 18 mm diameter O-ring, positioned on top of the aluminum plate perimeter, was used to both provide the volume space for water to be treated and at the same time to prevent water leakage. It is pressed by a heat-resistant glass (transmittance = 0.79 - 0.85) positioned on its top (see Figure below). Due to the space occupied by the O-ring, the remaining net reactor area is 0.675 m^2, or a volume capacity of 10 liters.

Instrumentation

The plant was provided with on-line sensors (Fig. 3), which were essential during experimentation. PT 100 thermocouple was used for water temperature monitoring, and a pyranometer (Type CM 11 by Kipp and Zonen, Holland with sensitivity of 5.55×10^{-6} V/(W/m^2)) device for the solar intensity. The pyranometer was positioned with the same angular inclination orientation with that of the reactor. It gives output in terms of Watts/m^2. Both instrumentation devices were properly calibrated prior to experimentation.

Thermal Performance Test of the Reactor

This test was incorporated in the microbiological test with considerations only on two physical parameters - water temperature and solar intensity. With the aforementioned parameters, SODIS reactor heating efficiency and rate of temperature increase were determined.

Thermal Efficiency

Thermal efficiency gives the percentage of the amount of solar heat absorbed by water out of the total solar irradiation. It is given by the formula:

$$\text{Thermal Efficiency} = Q/SE * 100\%; \qquad (1)$$

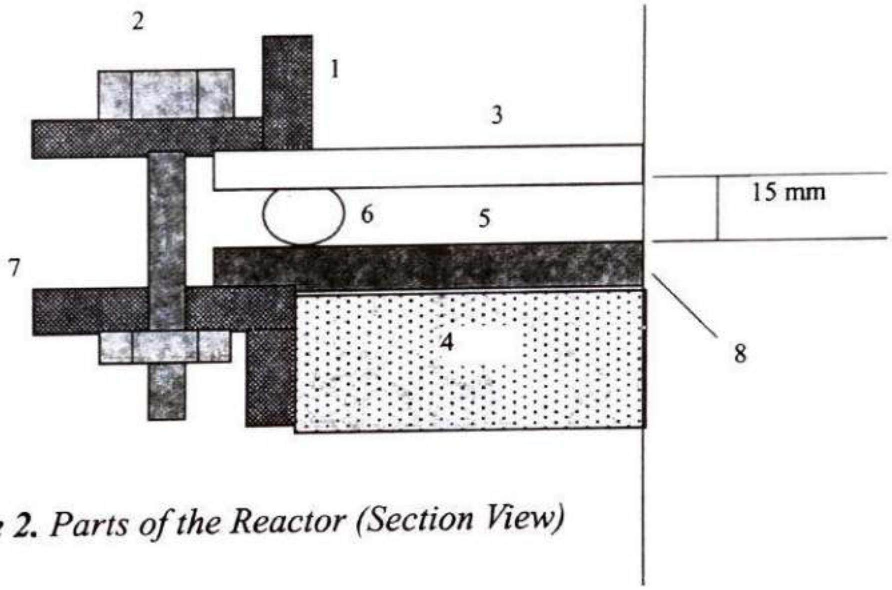

***Figure 2.** Parts of the Reactor (Section View)*

1. Angle Bar (50 mm x 25 mm x 3 mm thick)
2. Bolt (5 mm dia. X 30 mm L)
3. Heat Treated glass (4 mm thick)
4. Insulation (25 mm thick aluminized polyethylene)
5. Water Space (15 mm depth)
6. O-ring (18 mm dia.)
7. Bracket
8. Aluminum Absorber Plate (609mm x 1219mm x 4 mm thick)

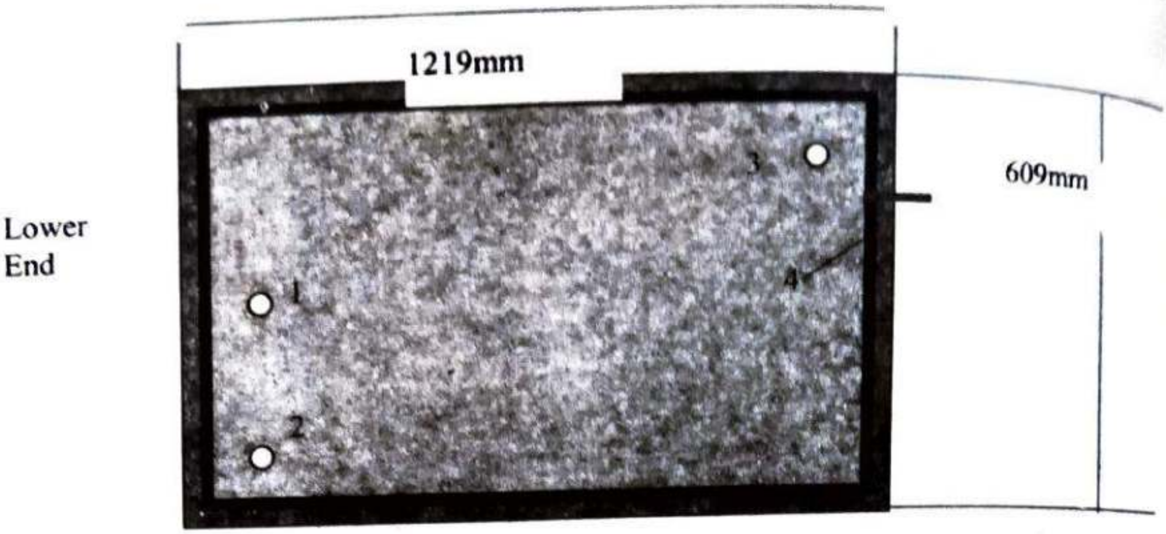

Figure 3. Reactor Plan View

1. PT 100 sensor
2. Exit Hole (12 mm dia)
3. Inlet Hole (12 mm dia)
4. Rubber O-ring
5. Air Ejector (4 mm dia copper tube)

$$Q = m*cp(Tf-Ti); KJ \tag{2}$$
$$SE = ASI*A*te; KJ \tag{3}$$

where:

Q; heat absorbed by water
SE; solar energy exposure
m; mass of water (11 kg)
cp; specific heat constant of water (4.187 KJ/(kg-°C)
Ti, Tf; initial and final temperature of water (°C)
ASI; average solar intensity (KW/m^2)
A; area of reactor (m^2)
te; duration of solar exposure (second)

Rate of Temperature Increase

Rate of temperature increase is the amount of water temperature rise in the Celsius scale for a certain period of time with a determined amount of solar energy exposure. It is determined by the formula below:

$$\text{rate of temp. increase} = (Tf - Ti)/(ASI * t);\ ^{\circ}C/(KW\text{-}Hr/m^2) \qquad (4)$$

where:
Tf; final temperature of water (°C)
Ti; initial temperature of water (°C)
ASI; average solar intensity (KW/m²)
t: duration of solar exposure (hr)

Microbiological Test of Water Quality

Microbiological test was composed of two parts: Group A was aimed to find the minimum temperature setting for effective solar disinfection; and Group B was used to replicate the minimum temperature setting to further validate the findings.

Raw Water Preparation

For conservative experimental results, raw water used for the Group A microbiological test was a mixture of sewage and deepwell water. The sewage was practically intended to be the contaminant or the source of microbiological contamination, while the remaining portion, which is deepwell water, was intended to ensure that the raw water is unchlorinated, which could affect the result of the experiment. Water in the UP Diliman Lagoon at the center of the UP Academic Oval lagoon comes from sewage of dormitories and college buildings, which is contaminated with fecal matters. Proportions of one-fourth Lagoon water and three-fourths deep well water was used to prepare the raw or untreated water for solar disinfection experiment. Deep well water was fetched every morning from Dagohoy Village, UP Diliman, Quezon City, which is about half kilometer away from the reactor site.

Raw water for Group B test, however, made use only of plain deepwell water – this time to fine tune the result to typical deepwell water, which is microbiologically contaminated.

Group A: Finding The Minimum Temperature Setting

Batches were set at different levels of maximum temperature setting. Seven test runs were conducted within the 40 to 65°C range. Finding the minimum setting is essential in optimizing the operation of the solar disinfection process.

Group B: Verification of the Minimum Temperature Setting

Minimum temperature setting result of Group A was replicated twelve (12) times in order to add confidence to the findings.

Temperature and Solar Intensity

Throughout the duration of water exposure to solar radiation, water temperature was logged at 10 minutes time interval together with the corresponding solar intensity.

Turbidity

Turbidity of the raw water was determined prior to treatment, inasmuch as it affects radiation penetration to water depth. Turbidimeter test kit by Cole Parmer was used.

Microbiological Assessment

Raw and treated water samples were analyzed for their microbiological content. Standard procedures for Multiple Tube Fermentation Technique (MTFT) which gives result in Most Probable Number (MPN), was used to determine the initial and final populations of Total coliform present in water before and after treatment (Philippine National Standards for Drinking Water, 1993).

Sterilization

Sampling bottles, tubes and pipettes were sterilized using an autoclave for 15 minutes maintained at 121°C.

Results and Discussion

SODIS Reactor Thermal Performance

Eighteen test runs were conducted for the thermal performance of the reactor. The first set consisting of first seven test runs was conducted on October 1999 while the rest of the test runs were done on June 2000.

Table 1. *SODIS Thermal Performance*

Turbidity	Ave. Solar Intensity	Exposure Time	Final Temp	Initial Temp	Heat Absorbed	Thermal Eff'y.	Rate of Temp Rise
NTU	*KW/m^2*	*Min*	^0C	^0C	*KJ/kg*	%	*$^0C/(kw/m^2$-hr)*
3.50	0.71	110	55.0	38.5	69	20	13
1.80	0.55	140	51.6	36.9	62	18	11
12.00	0.57	180	55.0	36.4	78	17	11
34.00	0.49	90	45.2	34.7	44	22	14
9.00	0.67	190	60.0	33.8	110	19	12
9.00	0.66	130	55.0	33.8	89	23	15
25.00	0.42	180	50.2	34.3	67	20	13
20.00	0.46	180	46.0	35.5	44	12	8
12.00	0.67	50	50.6	41.1	40	26	17
13.00	0.54	100	50.2	36.8	56	23	15
12.00	0.45	100	48.1	36.7	48	24	15
9.00	0.47	140	50.6	31.0	82	28	18
10.00	0.42	160	50.0	35.9	59	20	13
12.00	0.55	110	53.1	36.0	72	27	17
13.00	0.82	60	52.0	37.0	63	29	18
11.00	0.71	70	50.4	38.1	52	23	15
8.00	0.54	90	50.9	36.1	62	29	18
9.00	0.80	70	51.1	38.0	55	22	14
12.41	**0.58**	**119**	**51.39**	**36.14**	**64**	**22.15**	**14.28**

** Highlighted are the average figures for each column*

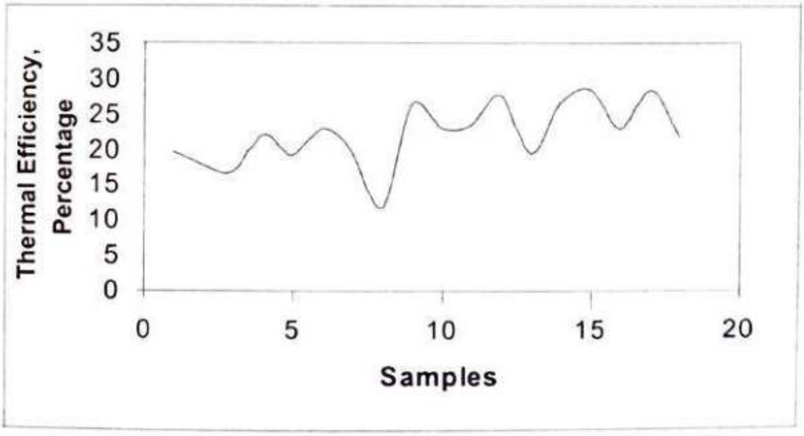

Figure 4. *Reactor Thermal Efficiency*

Thermal Efficiency

Thermal efficiency of the SODIS Reactor as shown in Table 1 falls within the range of 17 – 23 percent, with an average of 22.15 percent. This was based on 90% capacity of a 10-liter reactor amounting to an actual volume of 9 liters and a net surface area of 0.675 m^2. Bansal (1990) generalized the reported thermal efficiencies of low temperature solar collectors as between 20 to 30 percent.

Thermal efficiencies in Table 1 are specific to the water temperature range of 32 - 60°C. Temperature of water heated in the reactor displays a relatively faster heat absorption rate at the start of the heating process, and hence, a higher efficiency for that range. This is explained by the fact that reactor heat loss to the surrounding is proportional to its temperature gradient with the ambient. This temperature gradient (*reactor mean temperature – ambient temperature*) is minimum at the start of the heating process and increases as heating continues. Theoretically, continued heating would reach a maximum level (steady state condition) where heat gain is equal to heat loss (Schulert, 1881).

Turbidity variation of the treated water within the range of 1.5 NTU - 34 NTU does not show significant effect on the reactor thermal efficiency.

Rate of Temperature Increase

Table 1 data too gives the computed rate of temperature increase of water inside the reactor; having a range of 8-18°C/(KW-Hr/m^2) and an average of 14.28°C/(KW-Hr/m^2) for an average solar intensity of 0.58 KW/m^2. It means that some 8.3°C temperature rise is expected per hour when solar intensity is about 0.58 KW/m^2. If raw water inside the tank is initially at 34°C, it would take about 2 hours to reach 50°C for an average solar intensity of .58 KW/m^2.

Microbiological Tests

Group A: Finding the Minimum Effective Temperature Setting
Table 2 shows the microbiological result of the solar disinfection treatment tests when raw water were subjected to different temperature levels for the purpose of finding the minimum temperature setting.

Raw Water

All Total coliform tests on the raw water samples resulted to 5-5-5 positive combinations for 10 ml, 1 ml and 0.1 ml sample dilutions in the confirmative phase of the MTFT. Such combination of positive tubes corresponds to ^{3}1600 MPN/100 ml. This is important to note in order to confirm the extent of contamination of the raw water.

Solar Exposure

Still referring to Table 2, treated water samples which yielded non-detectable Total coliform results indicate a minimum of 4600 KJ/m^2 of solar radiation dose (as white light). Failed sample results (10/13/99 and 10/15/99 data) had radiation doses lower than 4600 KJ/m^2. With a solar intensity of 0.71 KW/m^2, solar dose equivalent to 4600 KJ/m^2 is achieved in 110 minutes and 140 minutes if solar intensity is .55 KW/m^2.

Turbidity

Turbidity of raw water samples ranged from 1.8 - 34 NTU with non-distinguishable effect to the treatment effectiveness. Philippine National Standards for Drinking Water (1993) allows an acceptable turbidity level of 5 NTU, which is lower than the turbidity level of the majority of the raw water used. It is therefore expected that the solar reactor would even perform better microbiologically if raw water used has turbidity within the allowable standard. The raw water used was selected to exceed the normal turbidity level of drinking water so as to come up with a microbiological result that is on the conservative side.

Turbidity's non-distinguishable effect on the solar disinfection performance is attributed to raw water depth setting inside the reactor, which is just 15 mm. Theoretically, turbidity filters off UV penetration to water's depth and in effect hampers the disinfection process. Making water depth considerably shallow, however, compensates the negative effect of relatively high turbidity level of raw water. Data show that 15 mm water depth setting inside the solar reactor can accommodate turbidity variation as high as 38 NTU and still accomplish total inactivation of Total coliform.

Microbiological Assessment:

Table 2 further shows that 51.6°C is the minimum temperature to inactivate Total coliform in the water sample. Test runs 10/13/99 and 10/15/99, with treatment temperatures at 48.6°C and 45.2°C, respectively, yielded complete five tubes positive (^{3}16 MPN/100 ml) results in their treated water samples. Comparative result of experiment as reported by Sommer in 1995 showed complete inactivation of Faecal coliform at 50°C. Wegelin (1994) reported significant synergetic effect on inactivation of bacteria at the same temperature level.

Group B: Verification of The Minimum Temperature Setting

Table 3 shows results of the additional thirteen (13) test runs conducted to further verify the minimum effective temperature setting found in Group A test where 51.6°C was the lowest. Compared to group A test, raw water used for this group test was plain deepwell water. In anticipation of a slightly contaminated state (no sewage component added), five (5) 10-ml sample dilution was used instead of the five sets for each 10 ml, 1 ml, and 0.1 ml dilutions. All test runs

Table 2. *Microbiological Test Group A: Finding the Minimum Effective Temp. Setting*

Raw Water (25%lagoon and 75%deepwell)				Treated Water				
Sampling Date	Temp. ^{0}C	Turbidity NTU	Total Coliform (MPN)	Temp. ^{0}C	Total Coliform MPN	Exposure min	Solar Dose KJ/kg	Solar Intensity KW/m^2
10/8/99	38.5	3.5	≥1600	55	≤ 2	110	4668	.71
10/9/99	36.9	1.8	≥1600	51	≤ 2	140	4636	.55
10/10/99	36.4	12	≥1600	55	≤ 2	180	6115	.57
10/13/99	***32.5***	***3.5***	***≥1600***	***48.6***	***≥16***	***100***	***2924***	***.49***
10/15/99	***34.7***	***34***	***≥1600***	***45.2***	***≥16***	***90***	***2639***	***.67***
10/26/99	33.8	9	≥1600	55	≤ 2	190	7626	.66
10/26/99	33.8	9	≥1600	60	≤ 2	130	5174	.42

Table 3. *Microbiological Test Group B: Verification of the Minimum Temp. Setting*

Plain Deepwell Raw Water					Treated Water				
Sample	Turbidity	Temp.	MTF Result	Total Coliform	Temp.	MTF Result	Total Coliform	Exposure	Solar Dose
No.	NTU	^{0}C	# of tubes positive	(MPN)	^{0}C	# of tubes positive	MPN	min	KJ/kg
1	20	34.3	5	≥16	50.2	0	≤ 2.2	180	4536
2	20	35.5	5	≥16	46.3	***4***	***16***	***180***	***4968***
3	16	31.4	5	≥16	50.7	***1***	***≤2.2***	***180***	***
4	12	41.1	5	≥16	50.6	0	≤ 2.2	50	2010
5	13	36.8	5	≥16	50.2	0	≤ 2.2	100	3240
6	12	36.7	5	≥16	48.1	0	≤ 2.2	100	2700
7	9	31	5	≥16	50.6	0	≤ 2.2	140	3948
8	10	35.9	5	≥16	50	0	≤ 2.2	160	4032
9	12	36	5	≥16	51.3	0	≤ 2.2	110	3597
10	13	37.0	5	≥16	52.0	0	≤ 2.2	60	2938
11	11	38.1	5	≥16	50.4	***2***	***5.1***	***70***	***2982***
12	8	36.1	5	≥16	50.9	0	≤ 2.2	90	2889
13	9	38.0	5	≥16	51.1	0	≤ 2.2	70	3352

yielded all 5 tubes positive in the raw water confirmative test, which is equivalent to ≥16 MPN/100 ml. This confirms that deepwell water source at Dagohoy Village, UP-Diliman, is microbiologically contaminated.

Target temperature for Group B test was at least 50°C. However, test runs which somehow unable to reach 50°C due to weather condition were nevertheless examined. Among the 13 test runs, 10 yielded non-detectable treated water result for Total coliform (0 positive for 5 10-ml samples, equivalent to ≤ 2.2 MPN/100 ml), one (sample no. 2) yielded 4 tubes positive (equivalent to 16 MPN/100 ml), one run (sample no.11) resulted to 2 tubes positive (equivalent to 5.1 MPN/100 ml); and another one (sample no.3) with 1 tube positive (equivalent to ≤ 2.2 MPN/100 ml). Table 3, however, shows that sample which resulted to 16 MPN/100 ml (4 tubes positive) reached only a maximum temperature of 46.3°C. Considering only those samples that were able to reach 50°C, 10 out of 12 test runs or 83.33 percent yielded 0-positive result.

Turbidity

Turbidity of plain deepwell water used for Group B test ranged from 8 to 20 NTU. Consistent with Group A test, turbidity in that range did not show significant interference to the effectiveness of the disinfection process. That of course, as explained in Group A test, was due to the considerably thin depth of water used inside the reactor.

SODIS Plant Capacity

If calculations are based on the average solar data as reported by PAG-ASA for Quezon City Philippines for the year 1995 (average solar intensity of 0.70 KW/m^2 and an effective daily solar exposure of six hours), the solar reactors capacity is about ***40 liters/m^2/day or 13,049 liters/year***. For a 1.5 liters drinking water per person per day consumption, a square meter of reactor could supply to about 27 persons.

Economic Implication

What makes solar disinfection technology attractive is the fact that solar energy is free and renewable. Using (LPG) Liquefied Petroleum Gas (HHV = 1000 BTU/ft^3, boiling thermal efficiency of 70%)) to boil water, and with the current P265/11 kg LPG price, 1 liter boiled water would cost about P0.18. For each 1 m^2 of reactor area, which has about 40 liters a day output capacity, a household is able to save about P7.00 per day. If solar reactor is allowed to operate at 0.90 utilization factor, savings from boiling with LPG is about P2400.00 per year. Such an amount is equivalent to nine (9) 11-kg LPG tanks savings per year.

Savings could more be emphasized if comparison is done with bottled water which costs about P75.00/20 liters (Manila Price, September 2000; 1US$=P45), or an equivalent savings of P150.00 per day. For one year solar reactor production output, equivalent bottled water cost is **P97,867.42**.

Environmental implication of using solar disinfection for drinking water includes mainly the reduction on the utilization of non-renewable sources energy, and the avoidance of combustion products, which contribute to the deterioration of the environment. Calculations show that 98 m^3 of CO_2 could be formed annually if disinfection through boiling is done by means of LPG

Fabrication Cost Estimate and Payback Period

Labor and materials costs incurred in the fabrication of the SODIS Plant amounts to **P6,190.00.** If payback period is computed based on the cost of boiling water through LPG, capital investment is realized within 3.81 years.

Conclusion and Recommendations

The results of the study show that local application of solar disinfection technology is a viable alternative for microbiological treatment of drinking water. The design and fabrication of the reactor, which is a flat-plate solar collector, is relatively simple. It is designed with features making it easy to be transported, ease of operation and maintenance, and of reasonable fabrication cost.

Specific conclusions based on the results of the study are:

1. The SODIS reactor operates at a satisfactory average thermal efficiency of 22 percent.
2. Rate of temperature increase is 10°C per hour based on average solar intensity data of Quezon City, Philippines, which is 0.70 KW/m^2.
3. Effective solar disinfection of drinking water is achieved, passing WHO Microbiological Standard, which is for Total coliform to be non-detectable when water temperature is set to at least 50°C. At 0.70 KW/m^2 solar intensity, exposure duration is about 2 hours.
4. Turbidity as high as 38 NTU did not affect the results with water depth setting inside the reactor which was 15 mm.
5. Shifting from boiling drinking water using LPG into solar disinfection can offer around 4 years payback on the fabrication cost of the SODIS Plant.

Considering the time and financial resource limitations during the course of study, some advantageous features were not tried. Hence, there is still much room for design enhancement for the purpose of performance optimization without compromising the simplicity of the process. The following recommendations are proposed to improve the solar reactor performance:

1. Use of solar reflectors for redirection of solar incident rays to in-

crease solar rays concentration heating the reactor, and hence, greater heating capacity.

2. Development of a device to address the fouling of the reactor glass cover, which can reduce the transmissivity of radiation.
3. Undertaking the study in other areas of the country to further validate the results incorporating thermal design enhancements.

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