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Effect of Natural Coagulants on Solar Water Disinfection

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Abstract: ***Solar water disinfection is the process of treating microbiologically contaminated water in clear plastic bottles through exposure to sunlight. One of the major limiting factors of this treatment is source water quality. This work investigates the impact of source water turbidity on solar disinfection efficiency and evaluates a natural coagulant for turbidity removal. The ability of Strychnos potatoram seed emulsion to both clarify source waters was investigated as coagulation pretreatment for solar disinfection. This coagulant reduced the turbidity by more than two-thirds and achieved up to 1-log10 bacterial removal (90%). The combined Strychnos potatoram coagulation -solar disinfection treatment sequence was tested in highly turbid natural source water and was found to reduce the sunlight exposure time required by up to 2 hours. However, despite being an effective clarification and turbidity removal process, the pretreatment may not shorten the overall treatment time because of its own labor and time requirements, potentially decreasing the treatment compliance rates. In addition, while total coli form regrowth was observed during overnight storage of the treated water, no Escherichia coli regrowth was found to occur.***

1. INTRODUCTION

At least one third of the population in developing countries has no access to safe and reliable drinking water supplies. The lack of adequate water supply and sanitation facilities seriously exposes this unserved population to numerous water related diseases. Lack of public water supply implies that a large part of the rural population is still forced to use contaminated surface water. Unreliable public water supply due to frequent interruptions or breakdowns drives people back to polluted water sources. Public water supply which distributes water unsafe for consumption exposes the supplied population to a considerable health risk.

As a consequence, substantial investments will have to be made in order to achieve full coverage in the near future. Choice of inappropriate technologies, missing operation and maintenance work, difficulties in the procurement of fuel and spare part, and weak management structures often account for the poor performance of many existing public water supplies in developing countries. [4-7]

Self help individual water supply systems operating at household level is certainly one approach that will fulfill these criteria. Boiling of water, disinfection with chlorine and filtration through ceramic filters are treatment methods often propagated at household level.

Boiling of water requires energy which in rural areas is usually supplied in form of firewood. This type of water treatment is no longer a good practice. Disinfection by chlorine compounds is often rejected by the consumers due to the undesirable taste and odor acquired by the water. Filtration through ceramic filters is often an unaffordable treatment method. However, apart from being expensive, ceramic filter candles are subjected to frequent clogging and often leak through fine cracks caused by careless handling. [8-10]

The state problem call for the development of alternative treatment techniques that is effective, practical and simple enough to be applied by individuals or households. Solar water disinfection is considered to be such an alternative. The treatment process is simple technology using solar radiation to inactivate and destroy pathogenic bacteria present in water. [11-14]

However, solar water disinfection has its limits too. Solar radiation in dependent on the geographic location and climatic conditions, and undergoes diurnal and annual variations. The application of solar water purification is simple. However, exposing a small quantity of contaminated water to solar radiation is a complex interaction of physical, chemical and biological processes which are not yet clearly understood. [15-17]

Solar radiation is an ancient disinfection practice used without profound understanding of the process. However, different research groups have recently started to study the process of solar water disinfection.

Under extreme poverty in rural and peri urban communities low cost house hold water treatment solutions are vital for general health and well being of a community. One of these household treatments is solar water disinfection [15], whereby

contaminated water is treated in discarded plastic bottles through exposure to sunlight. It is very cheap method but its efficacy is dependent on numerous factors such as: availability of discarded bottles, suitable weather condition and the source water quality. [18-19]

2. METHODOLOGY

Previous studies have found decreases in effectiveness of solar disinfection with increases in turbidity and sample volume and an increase in effectiveness with increased fluences and higher water temperatures. The experiments conducted for this practical examined these variables and their impact on the inactivation of *E. coli* by solar radiation and heating. By using the same testing, sampling, and enumeration methods for each experiment, the results can be directly compared.

2.1 Coagulants

Natural coagulants were extracted from seed of rural species *Strychnos potatoram* from the rural area of Raipur. Natural coagulant is obtained in the following way: seeds were ground and sieved through the sieve with pore size of 0.4 mm. An amount of a 10 g/L of the smaller fraction is suspended in distilled water. This suspension is stirred 10 minutes on a magnetic stirrer in order to extract active coagulants. After that, the suspension is filtered through filter paper Macherey-Nagel MN 651/120. Obtained filtrates, called crude extracts, are stored in a refrigerator at 258K. [20]

2.1.1 Coagulation test

The coagulation activity is assessed by jar test using synthetic turbid water, with the kaolin concentration of 50 mg/L and turbidity 35 NTU. The pH of the model water is adjusted to pH 9 by adding 1 mol/L NaOH just before performing coagulation test. The jar test is carried out by adding different amounts of extracts to 250 mL of model water. Rapid mixing (200–250 rotation per minute, rpm) for 1–3 minutes and slow mixing (30–40 rpm) for 12–15 minutes and after that the system is left to sediment for 1 h. The same coagulation test is conducted with no coagulant (blank). After sedimentation for 1 h, residual turbidity is determined in 50 mL of upper clarified liquid, using turbidity meter and coagulation activity is calculated:

Coagulation activity (%) = (Mb – Ms) x 100 / Mb [1] were Mb and Ms are the turbidities of the blank and the sample, respectively. [21]

2.2 Jar test experiment

Jar test is the most widely used experimental methods for coagulation-flocculation. A conventional jar test apparatus was used in the experiments to coagulate sample of synthetic turbid water using some coagulants (Figure 2). It was carried out as a batch test, accommodating a series of six beakers together with six spindle steel paddles. Before operating the jar test, the sample was mixed homogenously. Then, the samples ought to be measured for turbidity, coliform count for representing an initial concentration. Coagulants of varying concentrations were added in the beakers. The whole procedures in the jar test were conducted in different rotating speed.

After the desired amount of coagulants was added to the suspensions, the beakers were agitated at various mixing time and speed, which consist of rapid mixing (200–250 rotation per minute, rpm) for 1–3 minutes and slow mixing (30–40 rpm) for 12–15 minutes. After the agitation being stopped, the suspensions were allowed to settle for 20–60 minutes. Finally, a sample was withdrawn using a pipette from the middle of supernatant for physicochemical and bacteriological measurements which represent the final concentration. All tests were performed at an ambient temperature in the range of 26–32^{0}C and for different turbid ranges—higher (90–120) NTU, medium (40–50) NTU, and lower (25–35) NTU. In the experiment, the study was conducted by varying a few experimental parameters, which were coagulant dosage and mixing time in order to study their effect in flocculation and obtain the optimum condition for each parameter.

2.3 Bacterial preparation

An Escherichia coli culture was grown from a seed culture and stored at low temperature with 10% sterile glycerol according to Standard method. The evening prior to an experiment a portion of the stock culture was thawed and cultured in a 1:10 ratio of stock culture to tryptic soy broth (TSB) for 16 h at 37^{0}C. It was assumed that these cells had reached their stationary growth phase after 16 h. The cells were washed in sterile phosphate buffer saline (PBS) solution. (centrifuged at 10,000 x g for 10 min) three times before being added to specific source waters.

The microbial content of water samples was analysed by the membrane filtration method differential coli form (DC) agar in order to monitor the E.coli. and total coliform(TC) concentrations. On the DC agar plates the E.coli forms were observed as blue dot colonies whereas other coliforms were grown as orange/red colonies. The TC concentrations were determined by summing the E.coli and other coliform counts together. All dilutions and plating procedures were conducted inside an operating biosafety cabinate, following standard sterile techniques, in order to prevent sample contamination. [22]

3. RESULT AND DISCUSSION

3.1 Solar disinfection experiments

Natural sunlight has been shown to have germicidal properties.[21] It is found that a fluence of natural light of

approximately 2000 kJ/m^2 or 555 Wh/m^2 resulted in a 3-log inactivation of *E. coli*. Viruses required higher fluences than bacteria for the same inactivation level.

Pasteurization is an effective treatment option for liquids. However, a false sense of security may mislead one to under treat the drinking water. Certain organisms cannot survive temperatures of 55°C while others are still viable at 75°C. [24]

Without knowing the exact composition of organisms in the water, the user may not adequately treat the drinking water before use. There is also a high capital cost associated with purchasing pasteurization equipment if the process is used for a community. However, pasteurization of liquids is independent of turbidity and pH. This, coupled with the fact that solar energy is free and solar disinfection is a simple process to employ, warrants further study for use by individuals or small families in developing countries.

Following 2 h of settling time the six waters were each decanted from the jar tester beakers and placed in three prepared PET water bottles. One bottle of each different test water was included in three sets of water bottles which are herein referred to as 'test bottle', 'control bottles' and 'temperature bottles' for the bottles exposed to the sunlight, the bottles kept in the dark and the bottles used for measuring the water temperature in the sunlight, respectively. [25-26]

Test bottles and temperature bottles were taken to the roof of the Institute and placed horizontally on a southward-facing corrugated metal sheet at approximately 10.00 a.m. for solar treatment. The dark bottles were stored inside a closed cardboard box in the laboratory. [27-28]

Samples were taken before coagulation and after 0, 1, 2, 3, 4 and 6 h of sunlight exposure, and then after a 24 h regrowth period (18 h in the dark at room temperature). After 6 h of exposure, the bottles were brought down from the roof and were placed inside a closed box (with the control bottles) overnight at room temperature. The following morning, 24 h after the solar disinfection treatment was initiated; a 24 h sample was taken from each of the test and control bottles to measure the extent of regrowth of E. coli. Samples for microbial analysis were plated on differential coliform (DC) agar (according to MOE Method #E3407) to monitor the E. coli and TC concentrations. [29-30]

3.2. Heating Only Experiments

Three replicate experiments were conducted to determine the effects of heating on the inactivation of *E. coli*. A control bottle was prepared with PBS and spiked with *E. coli*. The bottle was kept in the dark at room temperature throughout the duration of each experiment. A test bottle was prepared using PBS spiked with *E. coli*. Light interference could possibly affect the inactivation of the bacteria and was therefore eliminated by wrapping the test bottle in aluminum foil. The temperature of the test bottle was controlled using a water bath.

Figure 1 displays the results of these experiments. There was less than 0.5 log inactivation or growth of *E. coli* in each experiment for any given temperature. Therefore, heating the samples to 46°C in the absence of sunlight did not reduce *E. coli* concentrations. Inactivation of *E. coli* when samples were exposed to the effects of solar radiation and heating can therefore be attributed to the bactericidal effects of solar radiation or the synergistic effects of irradiation and heating.

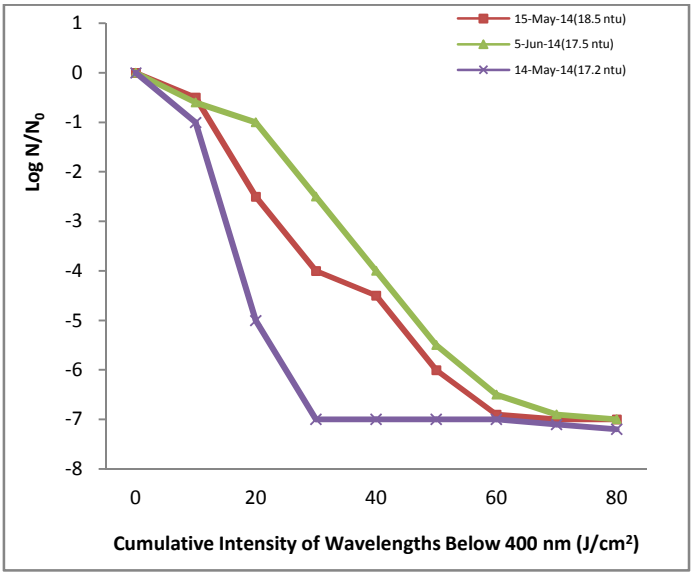

Fig. 1

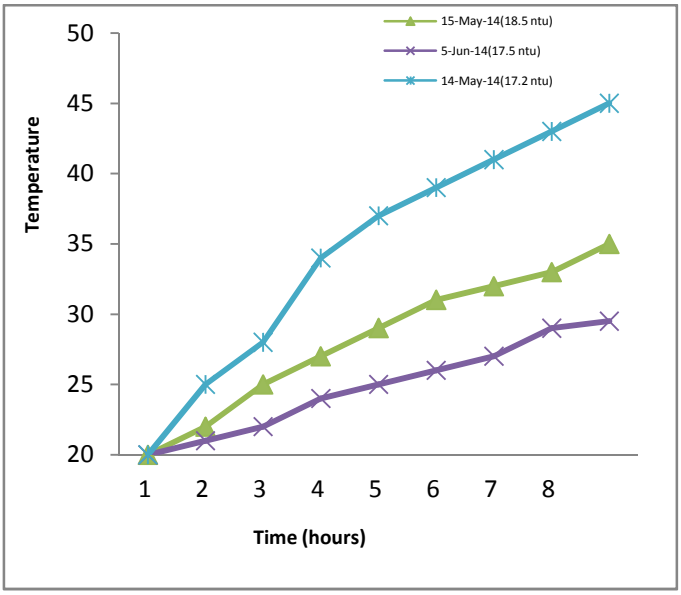

Fig. 2

3.3 Solar irradiance and water temperature

Figure 2 shows the soar irradiance measured on the solar treatment conducted during 3 days experiment. The total amount of solar light is indicative of the amount of $UV_{315-415}$ and visible irradiation available for disinfection and therefore is one of the main factors influencing solar treatment efficiency. On first day the solar irradiance measured was consistently high and on other two days were cloudy which resulted in solar irradiance ranging from 350-750W m^{-2}.

Only one sample (time 2 pm, first day) reached a temperature greater than 45°C. At temperature below 45^0C, the overall disinfection are to be minimal. Waters that have not been pretreated are raised to temperatures approximately 1^0C higher than those waters which have been pretreated and have a 65% lower color.

	Sedimentation only	CFS
Natural E coli	2-3	0-2
Cultured E coli	4-6	2-4
Natural TC	4->6	3->6
Cultured TC	>6	≥6

	Average log reduction achieved by pretreatment		**6 hour of solar exposure**		**Pretreatment + 6h of Solar treatment**	
	SO	**CFS**	**SO**	**CFS**	**SO**	**CFS**
Natural E coli	0.3±0.2	1.0±1.0	2.6±0.2	1.0±0.9	2.3±0.2	2.3±0.2
Cultured E coli	0.1±0.5	0.5±0.5	7.6±0.8	6.2±0.9	7.5±0.3	7.5±0.3
Natural TC	0.1±0.2	0.8±0.1	3.9±0.5	3.2±0.8	3.9±0.9	3.7±1.2
Cultured TC	0.1±0.5	0.6±0.5	6.1±1.7	6.2±1.0	6.0±1.2	6.7±0.5
SO – Sedimentation only CFS – Coagulation Floculation and Sedimentation						

Figures 3-6 show the E.coli and total coliform(TC) removal and inactivation curves of the four different waters tested in the two separate experiments. Waters containing naturally present E.coli and TC bacteria are presented with coagulation treatment prior to solar treatment are presented in the graphs on the left. Waters containing cultured and naturally present E.coli and TC that are pretreated with coagulation prior to solar treatment are shown in the graph on the right.

Cultured E.coli is added to natural source water, already containing native bacteria, in order to increase the E. coli concentration by at least 10^7 CFU/100 mL and, in doing so the disinfection potential of 6 h of sunlight could be better estimated.

Log reduction of E.coli and total coliform by the pretreatment and solar treatment (± standard deviation), and the approximate sunlight exposure time required to reach concentrations below the detection limit

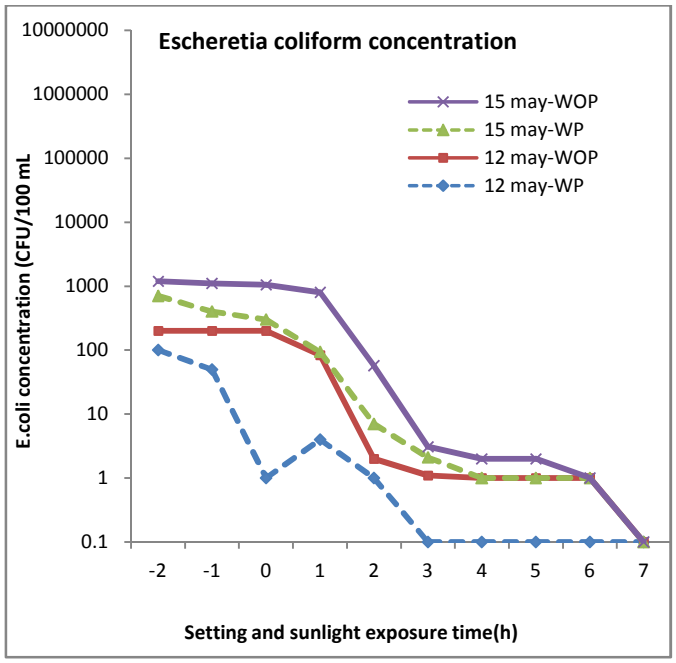

Fig. 3

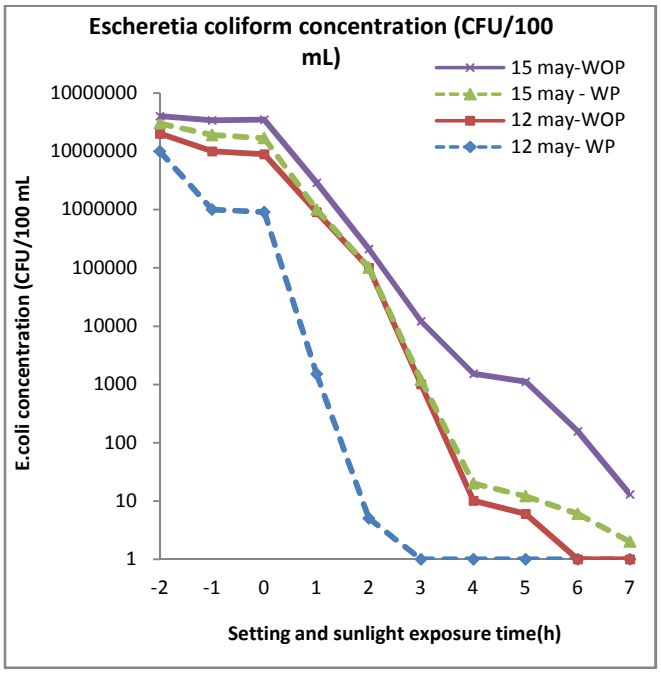

Fig. 4

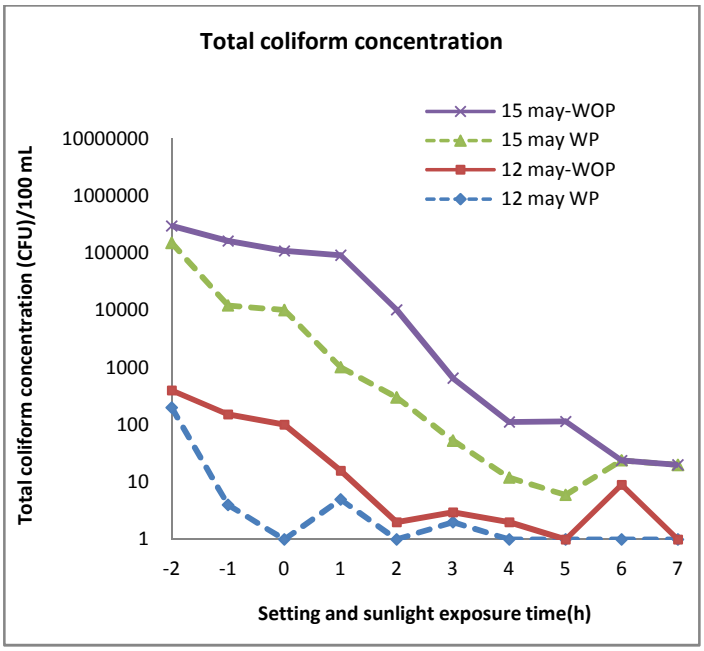

Fig. 5

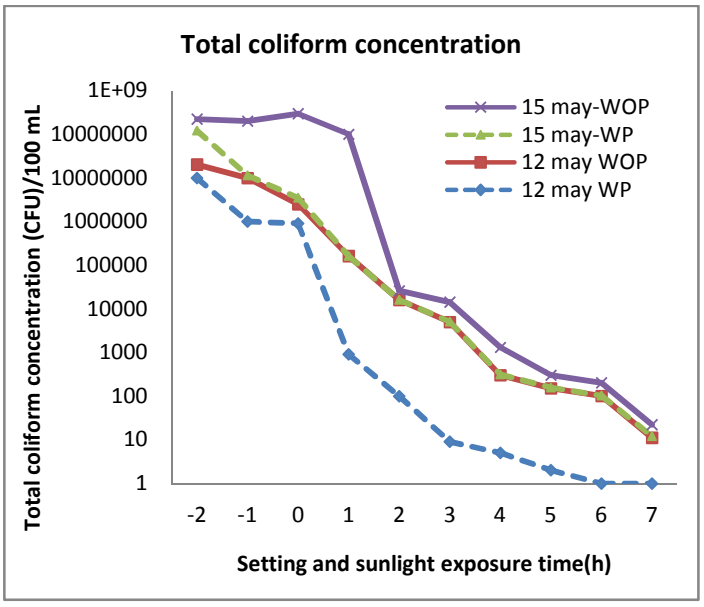

Fig. 6

Sunlight exposure time to reach the detection limit (h)

Figure – Removal and inactivation curves during the pretreatment (CFS or sedimentation only, -2 to 0 h) and solar disinfection (0 to 6 h). Natural bacteria results (for waters A and B) (a) E. coli. (b)TC. Natural + cultured bacteria results. Waters that were pretreated dotted line WP = with pretreatment) and were not pretreated (solid line, WOP = without pretreatment) are presented together for comparison.

Since waters which underwent the same treatment process their result have been arithmetically averaged for each experiment and are shown in the figures as an average line. The natural E. coli makes up 0.05-5% of the natural total coliforms (TCs). Up to 2 h of sunlight exposure was required for the natural E.coli., while up to 3 to 6 h waters required for the natural TCs. Cultured and natural E.coli. reached concentrations below the reported detection limit after 2 to 4 h of sunlight exposure.

The E.coli appears to follow first-order disinfection kinetics, while the TCs tend to follow characteristic decelerating rate kinetics resulting in a tailing region where little further reduction is achieved with additional irradiation. The average reductions (±the standard deviation) of the natural and cultured organisms during the CFS or sedimentation only pretreatments, and during the 6h of solar exposure, are summarized in Table. The reduction is presented on a logarithmic scale. Additionally, the approximate solar exposure time that was required to achieve CFS concentrations below the method detection limit for each tested organism is presented.

Table also shows the log reductions achieved for the full treatment sequence for each type of bacteria (with or without the CFS pretreatment). The log reductions reported are the sum of the pretreatment + solar treatment log reductions reported in Table. While there was no change in the E.coli log reductions with the inclusion of the CFS pretreatment, the pretreatment resulted in a slight improvement in the TC log reduction. The collective measure of the log reduction achieved, after 6 hours of solar treatment, made regardless of the differences in the rates of inactivation between waters and organism types.

Although no E.coli are present after the 18 h storage period for each experiment conducted, substantial regrowth of TCs are found to occur during or some time before the 18 h when the bottles were stored in the dark at room temperature. In Figure some TC bacteria regrowth also observed to occur before the end of the sunlight exposure time. It is suggested that any regrowth during the solar treatment may show natural cellular repair mechanisms or photo-induced reactivation. In waters that had been pretreated (A,B,C and D) TC regrowth was found to occur in the range of a 1.8 to 2.6 log increase. Without the application of the pretreatment, TC regrowth was measured to be in the range of a 0.6 to 3.6 log increase. Therefore, pretreatment aids in improving the stability of the treated water, but not for extended periods of time.

With these different categories of bacteria a final consideration regarding regrowth, is with respect to the health relevance associated with these different categories of bacteria. It is observed that TC bacteria regrow, the health concerns associated with their presence are substantially less

than those of pathogenic bacteria, such as E.coli, which was not observed to regrow.

4. CONCLUSIONS

As the natural coagulant decrease turbidity of the water as well as the amount of sunlight required for disinfection, so it is recommended. In compare to individual treatment combined treatment sequence has been shown to be more effective. However, the time required to perform the Strychnose potatoram)SP- CFS pretreatment is roughly equivalent to the amount of time saved in sunlight exposure during solar treatment. So, the overall treatment time may not be shortened, and the main benefit is improved water clarity. This being said, requiring less sunlight exposure time may allow for disinfection when the CFS pretreatment can be completed before the sunlight is strong enough for solar treatment.

CFS pretreated and unaltered (sedimentation only) waters achieved similar log reductions after 6 h of solar treatment. However, for both categories of bacteria monitored in the pretreated waters the log reduction was approximately 2 h faster.

Whether the water is treated by SP-CFS or solar treatment or these treatments in combination, there is the potential for regrowth of total coliforms bacteria if the treated waters are stored for a period of time. However no E.coli regrowth was observed, approximately 2-log regrowth was found to occur for TC when kept in the dark overnight. While regrowth of natural TC bacteria is less than desirable, there is less health risk associated with their presence relative to that of E.coli.

It should be recognized, despite any potential benefits, that introducing additional steps into any treatment method can cause a decrease in compliance rates because the system being promoted is too complicated, is viewed as unnecessary or is not being explained properly

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