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Inactivation of *Escherichia Coli* (*E.Coli*), Feacal Coliform (FC) and Total Coliform (TC) In Grey Water through Batch Solar Disinfection (SODIS) With Reflective and Absorptive Rear Surfaces

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ABSTRACT: *Recently SODIS is looked upon as a potential alternative for disinfecting low strength grey water for inactivation of microorganisms with research mainly focused towards enhancement of inactivation efficiency. The present study was aimed to enhance inactivation efficiency of SODIS through gaining relatively higher temperature by introducing aluminum foil reflectors (reflective rear surface). Investigation were carried out at a constant flowrate 135 ml/min, varying turbidity (30, 25, 20, 15 and 10 NTU) and radiation intensity 550.55 ± 26.55 W/m^2 at glass tubes of SODIS treatment unit inclined at 45^o. At the end of the contact time of 8hours, about average 21.53 % gain of temperature was obtained with reflective rear surface and the inactivation efficiency was about 36.54% for Escherichia Coli (E Coli), 60.62% for Feacal Coliform (F C) and Total Coliform* **(***TC) for 57.58% when absorptive rear surface was kept and 77.54% for E.Coli, 94.79 % for FC and 94.64 % for TC when reflective rear surface was kept. Overall enhancement in inactivation efficiency of 41%, 34.17% and 37.06 % for E.Coli, FC and TC were obtained respectively when aluminum foil was used as reflective rear surface.*

Keywords: *Absorptive rear surface, Inactivation efficiency, Microbial removal, reflective rear surface, SODIS, Solar energy*

I. INTRODUCTION

Natural sunlight is one of the most abundantly available forms of energy in developing tropical countries. Downes and Blunt (1877) [1], reported the bactericidal effect of sunlight. Acra et al. (1984) [2], initiated research practically on solar disinfection for drinking water and oral rehydration solution in late 1970s [3,4]. SODIS technique in drinking water is fed in transparent bottles which exposed to sunlight upto 8 *hours* and there is subsequent inactivation of micro-organisms and viruses [4, 5, 6]. SODIS have advantages simple, no chemical consumption, no harmful by products, low energy requirement, inexpensive and environmentally sustainable method [7, 8]. SODIS application under natural conditions demonstrated that for the inactivation of *E.Coli*, FC and TC temperature is significant [9]. UV-A radiation of the spectrum of sunlight is mainly responsible for the inactivation microorganisms (bacteria and viruses) [4]. UV-A radiation at the same time increased in the mortality of microorganism occurred when temperatures exceeds 45°C [3, 10, 11, 12]. The recorded synergetic effects of solar radiation and thermal water treatment favor a combined use of these two water treatment processes. Another important discovery indicated that a water temperature of at least 50^{o}C considerably increases the inactivation rate of bacteria [4]. Results of the study demonstrated that the importance of temperature in the inactivation of *E.Coli*, FC and TC during application of SODIS under natural conditions [9].

In Kenyan on 2 litres samples containing *E.coli* were completely inactivated at maximum water temperature of 55^{0}C within 7 h [13]. Previous researcher reported that most of the microorganisms get killed when temperature was above 70^{o}C for a certain contact period of time [14]. McLoughlin et al. [15] studied three reflectors V-groove reflector, parabolic and compound parabolic reflector yield a more successful to inactivate *Escherichia coli (K-12)* then other two reflectors. Mani *et al.*, (2006) [16], compared effectiveness of reflective (foil-backed) and absorptive (black-backed) rear surfaces for inactivation of *E.coli* by solar disinfection for small-scale batch reactors, enhancement in performance of reactor was found in an absorptive as well as in a reflective backing surfaces under strong sunlight, but consistent enhancement under low sunlight was found in reflective reactor. Kehoe *et al.*, (2001), [6] studied *E.coli* inactivation efficiency of solar disinfection system was improved with aluminum foil than non-foil-backed bottles total inactivation was achievable in 300 NTU samples within 8 *hours* exposure to strong sunshine. Hipolito Gomez-Cous *et al.,* (2009) [17] studied effect of turbid water samples [5, 100 and 300 (NTU)] for exposure to full sunlight for 4, 8 and 12 h on survival Cryptosporidium resulted that longer exposure time was required for the bacterial pathogens

In recent years, attention has been focused on small-volume (1 to 1.5 L) of batch reactors like UV-light-transparent plastic bottles for domestic treatment of drinking water. This method is effective in areas with high solar intensity [2, 6, 10, 13]. Many researchers focused their studies on varies parameters as SODIS system was affected by ultraviolet solar radiation intensity, turbidity, ambient temperature, quantity of water exposed, wind speed, the contact area between solar disinfectant and the transparent water container and geometrical parameters of the system. [4, 6, 10, 12, 14, 18, 19]. But such arrangement amounts more cost and maintenance with little added advantage in the inactivation efficiency.

Most of above literature mainly reported disinfection through SODIS for drinking water and lesser attention is given for application of SODIS in case of wastewater due to interferences more solids. However, in case of low strength or if solid content is reduced through some pretreatment, then SODIS can be effectively used to treat grey water. In the present research, studies were conducted on application of SODIS on pretreated grey water to assess its feasibility and determine its inactivation efficiency to remove microorganisms from grey water. It investigated comparative effectiveness of the reflective and absorptive rear surfaces for the inactivation of *E.Coli*, FC and TC present in low strength grey water by solar radiation.

II. SODIS FOR GREY WATER

Grey water can be defined as all wastewater flows exiting a building with dish washing, laundry and bathing the exception of toilet waste (black water) [21, 22]. Grey water less polluted i.e low-load grey water in terms of organics and bacteria frequently limited to the bathroom streams of hand basin and shower [23,24,25]. Reuse and recycling of grey water reduces freshwater demand so have sustainable development and water demand management [22, 25]. Grey water is contaminated with feacal contamination and reported presence of pathogenic microorganisms [26,27]. Presence of common pathogens in grey water has also observed [21]. In rural areas also, for private gardens grey water use is practiced during drought periods [28].

SODIS is simple, inexpensive and effective method for disinfection for contaminated water [20]. Few studies were also attempted on application of SODIS on grey water and studied the effect of three important parameters depth, turbidity and container color on TC inactivation [29, 30]. D. Rabbani and H. Hooshyar, (2011) [31] investigated thermal disinfection of the wastewater effluent for 2 hours at 55 ºC using flat plat solar collector. Sanchez-Roman *et al.,* (2007) [32] studied feasibility of solar radiation for the disinfection of treated domestic wastewater for reuse of agriculture. Grey water should not be used for edible crops, but can be reuse for the non potable use with disinfection. As pathogenic microorganisms are present in grey water needs to be disinfected prior to reuse to protect health, water and soil against contamination [33]. Effectiveness of UV disinfection method was found to be suitable for treatment of wastewater.

III. METHODOLOGY

Sample Collection and Pretreatment Unit

Grey water from residential building was collected and subjected to a pretreatment unit so as to remove suspended and dissolved impurities. The turbidity of the influent and effluent of pretreatment unit was measured using turbidity meter (Lamatte 2020e turbidimeter, USA). The effluent from the pretreatment unit was further fed into solar collector (SODIS treatment unit). For maintaining the desire turbidity, the pretreated greywater was diluted adding adequate quality of tap water as and when required. Experiments were carried out at constant flowrate 135 ml/min through a 45^{o} inclined tubes of SODIS treatment unit at varying turbidity (30, 25, 20,15 and 10 NTU). Constant flowrate was maintained peristaltic pump (HBS Technologies, ENERTECH).

A. *Structure of solar collector*

Rectangular solar collector made up of steel body with dimension 70.5 cm X 45 cm with a height of 55.25 cm. A semicircle with radius 25.25cm arrangement was made to accommodate five borosilicate tubes (400ml each, 10 cm apart) placed equidistant along the curved bottom. Whole assembly was mounted on stand of 70.5cm X 1000cm. The space of rectangular box was filled by glass wool for insulation.

B. *Experimental procedure of solar collector*

Experimentations were conducted on the solar collector with borosilicate glass tubes (total illuminated volume 2 litres) placed at angles 45^{0}. The pretreated grey water was recirculated with help of peristaltic pump at constant flowrate of 135 ml/min and 2 l litre bottle reservoir at the bottom. The solar collector placed in such a way that it faces the direction of sun. The period of exposure to solar radiation kept 8 hours (9:00 am to 5:00 pm). Samples for microbial tests were collected in sterile glass bottle (250ml) and analyzed within an hour in the laboratory. Reading of temperatures were recorded in ^{o}C for atmosphere, bottle reactor absorptive (Black paper) and reflective (Aluminum Foil) at 9:00 am, 12:00 PM, 2:00 PM, 4:00 PM and 5:00PM for the each set of experiment. At the same time UV intensity was recorded (First class Pyranometer PM 10 , Sivara Systems and Solutions).

C. Microbial Study

Entire procedure was carried out in sterile condition to determine Most Probable Number (MPN) of *E.coli*, Total coliform and feacal coliform in accordance with Standard Methods for the Examination of Water and Wastewater (1999).

IV. RESULTS AND DISCUSSION

a. Solar Radiations, Temperature and Gain in Temperature with Reflective and Absorptive Surface

Solar radiation and temperature plays a very important role in SODIS. **Fig 1.** showed average variation in temperature of atmosphere, bottle reactor absorptive and reflective rear surfaces. The solar radiation observed as per daily solar cycle in a day is around 625- 668.2 W/m^2 radiation in a morning hours which raises to maximum 834.6 - 854 W/m^2 at noon, little lesser 691.6 – 706 W/m^2 at 2.00 PM and its minimum at 4.00 PM to less than 100 W/m^2 at the location of experimentation. A similar pattern was observed in a temperature in the atmosphere with around 31.42 – 32.88 ºC at 9.00 AM which raise to 35.52 – 37.48 ºC at noon and further rise to around 38.02 – 38.54 ºC and thereafter decrease to 33.02 – 35.06 ºC at 4.00 PM and 28.78 – 29.84 ºC at 5.00 PM. Similarly the temperature of the reservoir bottle in the experimentation setup and on the rear surface was taken which shows again similar pattern but normally more than the atmosphere. It was observed that the temperature at the reflective rear surface was always greater than the absorptive rear surface. This in turn reflected on the temperature in the bottle with absorptive and reflective rear surfaces which can be mainly used towards inactivation of the microorganisms. At every observation taken throughout the day a gain in temperature was always found. A gain of temperature of about maximum 13.1^{o}C was observed in reflective surface as compared to absorptive surface. Whereas maximum 5.04 ^{o}C gain in temperature in water flowing inside the glass tube and bottle reservoir. More temperature gain was observed during in reflective than absorptive rear surface. This is because more heat was absorbed during reflection of radiation on the glass tubes of the SODIS unit. The comparative more gain in temperature helps to improve the bacterial inactivation efficiency.

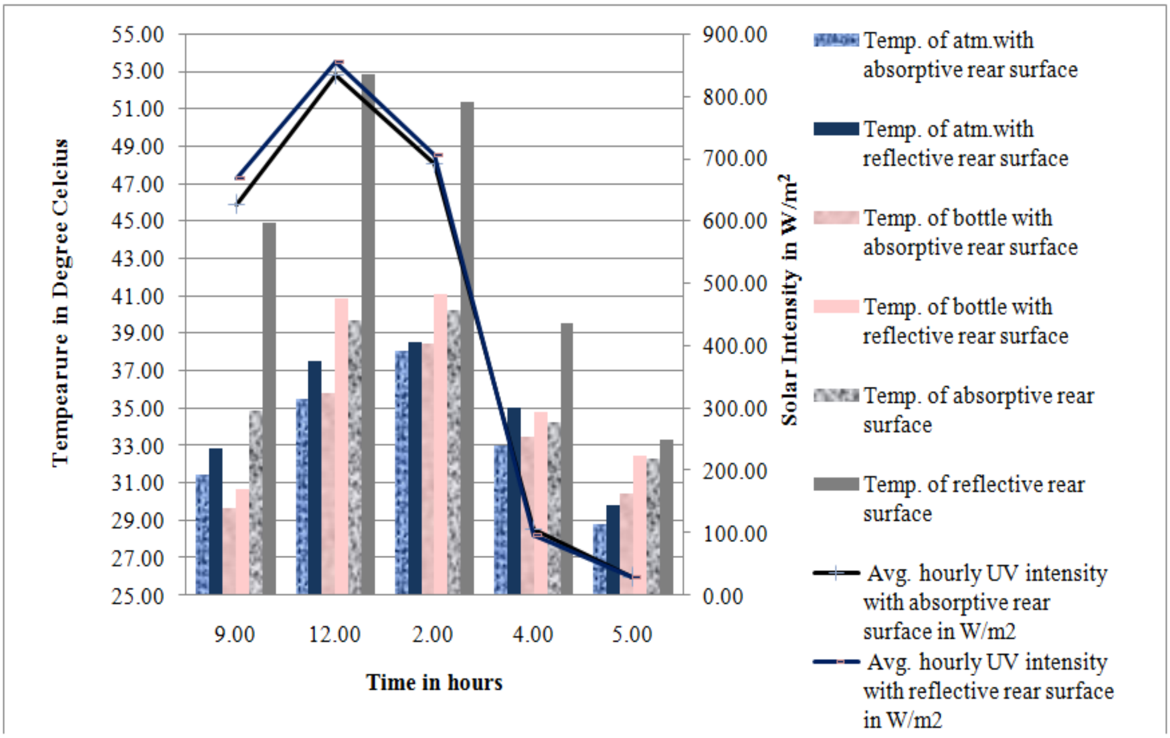

Fig 1: Solar Radiation (W/M^2) and Average Temperature, of Atmosphere, Bottle, Absorptive and Reflective Rear Surfaces in $^{\circ}C$

b. Comparative Inactivation Efficiency with Reflective and Absorptive Rear Surface

Bacterial inactivation efficiency dependent intensity of solar radiation and turbidity. In the present study, considering, natural range of turbidity of grey water with or without treatment and availability of intensity of solar radiation, an effect of reflective and absorptive rear surface on bacterial inactivation efficiency was observed by conducting experimentation at varying turbidity from 30 to 10 NTU with an average UV radiation from 434.4 to 495 W/m^2 and at 8 hours of time of exposure **(Fig 2)** similar to Mani *et.al* (2006) [16]. EAWAG/SANDEC (2008) [34].Further, reflective rear surface was provided to achieve more concentrating radiation available for inactivation. **Fig 2.** showed the comparative bacterial inactivation efficiency with reflective and absorptive surface at varying turbidity and solar radiation. It was found that the bacterial inactivation efficiency increase with increase in intensity of solar radiation and with decrease in turbidity [6, 16]. Both the condition indicates of facilitating availability of more radiation for inactivation.

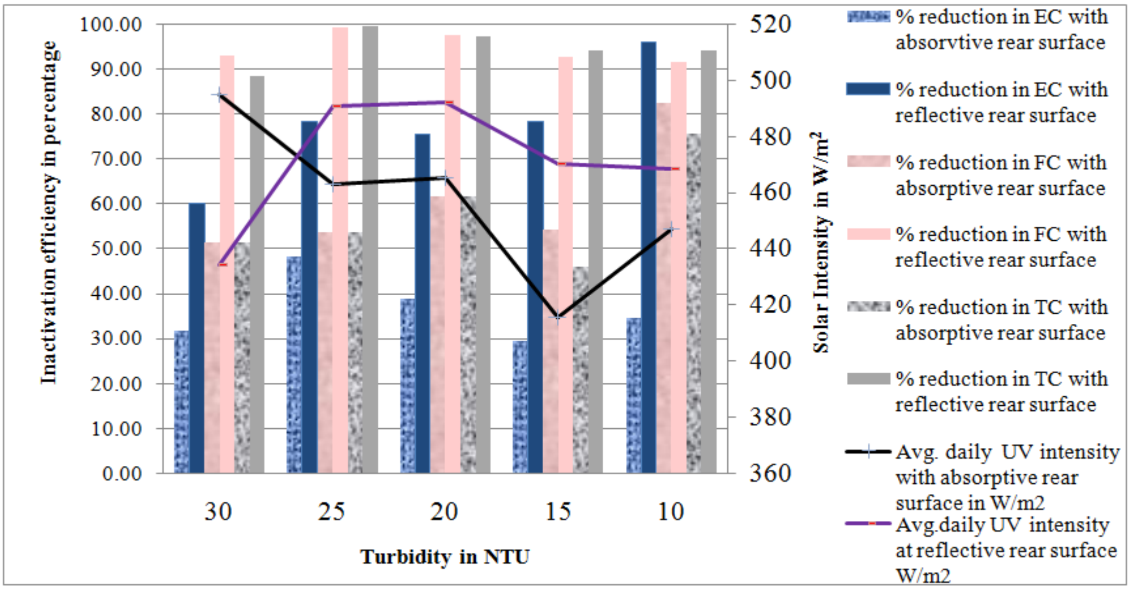

Fig.2: Inactivation Efficiency with Reflective and Absorptive Surface at Varying Turbidity and Solar Radiation

In the present study, inactivation efficiency at turbidity 30 NTU with absorptive rear surface for *E.Coli* was observed 31.58% whereas 60% with reflective rear surface, intensity of solar radiation of 495W/m^2 and 434.4 W/m^2 respectively. For other turbidities of 25, 20, 15 and 10 NTU, the % inactivation efficiency of *E.Coli* was found to be 78.18,75.33,78.26 and 95.92 % at intensities of solar radiations of 490.6, 492.6,470 and 468.4 W/m^2 respectively **(Fig 2)**. The % inactivation efficiency was found to be more as compared to absorptive rear surface where *E.Coli* % inactivation at 25,20,15 and 10 NTU were 48.15, 38.89, 29.41 and 34.67 % at UV intensities 462.8,465.4, 415.4 and 446.8 respectively **(Fig 2)**. This was due to application of reflective rear surface (Al foil), there was gain in bottle temperature which led to thermal enhancement resulted into higher inactivation. Theory of reflectivity holds good [15]. *E.Coli* was less resistant to solar radiation [3] same was reported as there was thermal enhancement happened with reflective rear surface average % increase in *E.Coli* inactivation was 41% compared with absorptive rear surface **(Fig.2)**.

In case of FC reduction, with absorptive rear surface, the % inactivation of FC was 53.53,61.67,54.17 and 82.31 at turbidity levels 25,20,15 and 10 NTU and at average daily intensities 462.8,465.4,415 and 446.8 W/m^2 respectively **(Fig.2).** It was clear from the result inactivation was dependent upon the solar UV intensity and turbidity. At 30 NTU with absorptive surface intensity was 495 W/m^2 but turbidity of 30 NTU so % inactivation was 51.43 % **(Fig.2)**. Turbidity decreased intensity increase inactivation rate also increased [6, 16]. In reflective rear surface inactivation of FC was above 90% which was less dependent upon of turbidity and UV intensity because of thermal enhancement. It was seen from the results at 30 NTU, UV intensity was 434.4 W/m^2 but inactivation was 92.94%. At 25 and 20 NTU intensities were 490.6 and 492.0 W/m^2 inactivation were 99.17 and 97.59 % respectively **(Fig.2)**. As intensity of UV was near to 500 W/m^2 synergistic effect was seen in FC inactivation. At turbidity 15 and 10 NTU with intensity of UV 470 and 468.4 W/m^2 inactivation in FC were 92.59 and 91.64 W/m^2 respectively **(Fig.2)**. It was observed that as UV intensity decrease inactivation in FC also decreases though the turbidity decreases. At turbidity 30,25,20,15,and 10 NTU at UV intensities 434.4, 490.6,492,470 and 468.4 W/m^2 ,% inactivation in TC was 88.94,99.17,97.59,2.59 and 91.64 % respectively **(Fig.2)**. At 30 NTU inactivation in TC was less **(Fig.2)** because of lesser UV intensity and high concentration of bacteria in influent [4].

In general, It was observed that an enhancement of inactivation efficiency in case of *E.Coli*, FC and TC, when reflective surface was kept as rear surface. The reflective rear surface provide more amount of solar radiation on the glass tube of SODIS unit which gave an added advantage of increase in temperature in the running water and thus help in enhancing the efficiency in case of reflective surface then that of absorptive surface. This was mainly due to synergetic effects of solar radiation and thermal water treatment enhanced the efficiency [4]. Similar result were reported in the present study , average % reduction with absorptive rear surface in *E.Coli*, FC and TC were 36.5, 60.62 and 57.58 % and improvement was seen to great extent with reflective rear surface 77.54,94.79, and 94.64 % respectively with different degree of turbidity levels when covering the rear surface of the solar disinfection container with aluminum foil improved the inactivation efficiency of the system and improved bacterial inactivation than of non-foil-backed surface (Kehoe *et.al.*) [6]

V. CONCLUSION

Based on the study, it can be concluded that SODIS can be effectively used for disinfection of grey water with low turbidity. Significant disinfection efficiency is achieved which further enhance when reflective rear surface is used. The enhanced bacterial inactivation efficiency due to the synergic effect.The maximum bacterial inactivation efficiency achieved was 77.54% for *E coli*, 94.79 % for FC and 94.64 % for TC when reflective rear surface was kept. Overall enhancement in inactivation efficiency of 41%, 34.17% and 37.06 % for *E.coli*, FC and TC were obtained respectively when aluminum foil was used as reflective rear surface as compared to absorptive rear surface. Any location where seasonal variations in sunlight are significant or under real sunlight condition when solar disinfection is slow, however it can be enhanced inactivation efficiency of collector by using reflective rear surface. Thus, a SODIS collector designed with thermal reflective rear surface can be easily used to disinfect grey water with low turbidity (< 30 NTU) in the arid and semiarid zones places, where ample sun light is freely available. In case of greywater with higher turbidity, it is recommended to reduce turbidity (< 30 NTU) for better optical penetration by providing pretreatment to get better efficiency of the SODIS collector.

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