Nigerian Journal of Technology (NIJOTECH)
Vol. 43, No. 4, December, 2024, pp.779 - 787
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
https://doi.org/10.4314/njt.v43i4.18

DEVELOPMENT AND EVALUATION OF A COST-EFFECTIVE AERATION-FILTRATION SOLAR DISINFECTION SYSTEM FOR WATER TREATMENT

AUTHORS:
E. J. Nwankwo[1,*]

AFFILIATIONS:
[1]Department of Civil Engineering, University of Nigeria, Nsukka, Nigeria

***CORRESPONDING AUTHOR:**
Email: ekene.nwankwo@unn.edu.ng

ARTICLE HISTORY:
Received: 04 August, 2024.
Revised: 05 December, 2024.
Accepted: 19 December, 2024.
Published: 31 December, 2024.

KEYWORDS:
Continuous flow, Diarrhoea, *E. coli*, Oxygenation, SODIS, Turbidity.

ARTICLE INCLUDES:
Peer review

DATA AVAILABILITY:
On request from author(s)

EDITORS:
Chidozie Charles Nnaji

FUNDING:
None

Abstract
Solar disinfection (SODIS) of drinking water involves storing water in small transparent containers and exposing it to sunlight, but it has not yet gained widespread use despite being simple and low-cost. This study aimed to improve the acceptability of SODIS by developing and evaluating the effectiveness of a pilot-scale, semi-continuous flow, aeration-filtration SODIS (AF-SODIS) system that combines aeration, filtration, and solar disinfection in a single process. Over two weeks, the system was tested with feed water of 100 NTU turbidity and over 1.1 × 10^5 MPN/100 mL of pathogens. The results showed that the system effectively removed over 97% of turbidity and 99.99% of E. coli. When compared to previously developed flow SODIS systems, this new system is more affordable and scalable, which could encourage greater adoption and sustained use. However, responses from potential users suggested that a substantial promotional and educational initiative would be required to establish SODIS treatment as a regular practice in rural areas of developing countries.

HOW TO CITE:
Nwankwo, E. J. "Development and Evaluation of a Cost-Effective Aeration-Filtration Solar Disinfection System for Water Treatment", *Nigerian Journal of Technology*, 2024; 43(4), pp. 779 – 787; https://doi.org/10.4314/njt.v43i4.18

1.0 INTRODUCTION
Numerous studies over the past three decades have shown that microbially contaminated water can be disinfected by storing it in ultraviolet-transparent containers (less than 20 liters) and exposing it to direct sunlight for one to two days in a process known as solar disinfection (SODIS) [1]–[3]. Clear polyethylene terephthalate (PET) bottles are now the favored choice for SODIS reactors because they are readily available, chemically stable, highly effective at transmitting UV light, and durable against scratches over time. SODIS is recommended and promoted in areas with unprotected drinking water sources, especially where these sources are in direct contact with the environment, provided the region's maximum 5-hour average radiation intensity exceeds 500 W/m² [4]. All characterized waterborne bacterial pathogens are susceptible to SODIS treatment under appropriate conditions. Protozoa and viruses tend to be more resilient to sunlight; however, such waterborne species that are not effectively treated under standard field conditions become vulnerable at higher temperatures (exceeding 40 °C). [5], [6]. The World Health Organization (WHO) approved the SODIS method in 2007, and it has since become an essential part of drinking water treatment and diarrhea prevention in pursuit of the water-related objectives outlined in the Sustainable Development Goals

(SDGs) [7], [8]. By 2016, over 5 million people worldwide were using SODIS for daily disinfection of their drinking water [3].

SODIS destroys pathogens through the effects of temperature and the UV components of solar radiation on their key cellular components. Temperature inactivates pathogens by pasteurizing the water, which denatures cellular proteins and inhibits deoxyribonucleic acid (DNA) repair mechanisms [9], [10]. The ultraviolet (UV) radiation that arrives at the Earth's surface are UV-A (320-400 nm) and UV-B (280-320 nm) wavelengths; UV-C (100-280 nm) is totally absorbed by the ozone layer. While UVB can directly cause cell death by attacking DNA and disrupting the cell's ability to replicate [11]–[13], it is of limited significance in SODIS, since only a limited amount of UV-B makes it to the Earth's surface, and most SODIS containers, particularly PET, do not transmit UV-B. The main inactivation pathways are driven by UV-A, which reacts with molecular oxygen in water to generate reactive oxygen species (ROS). ROS target cellular biomolecules, compromise membrane integrity, increase ion permeability, break down proteins, damage DNA and ribonucleic acid (RNA), and disrupt the intracellular oxygen transport system, ultimately leading to cell death [12], [13].

Dissolved oxygen (DO) is essential for the SODIS process, and SODIS is not as effective in water with low DO levels. The DO content of freshly drawn well water can be as low as 13% of its air saturation values [14]. One simple way to improve the DO concentration in SODIS water is to vigorously shake partially filled SODIS containers before filling them to capacity [14]. Mechanical diffusers for bubble-water oxygen transfer are more efficient and serve as the primary method of oxygen transfer in automated industrial systems [15], [16]. In these systems, oxygen is absorbed as bubbles injected from the bottom rise through the water column. In addition to dissolved oxygen, turbidity is another water quality parameter that affects the SODIS process. SODIS is not as effective in very turbid water because the colloidal particles responsible for turbidity can block pathogens from receiving direct sunlight. Multiple studies have demonstrated that the rate at which pathogens die off during SODIS diminishes as water turbidity rises [9], [17]. SODIS guidelines [3] recommend pretreatment to reduce water turbidity to below 30 NTU before applying the SODIS method.

Despite the advantages of low-cost and simplicity the principle of water treatment using SODIS at the household level is not yet a mainstream practice. Factors hindering the acceptance and enduring use of SODIS include the limited volume that can be treated at once and the significant labor required to manage multiple SODIS containers simultaneously, the risk of migration of photoproducts and other toxic compounds from plastic containers during solar exposure, and the potential for underexposure and incorrect application of SODIS protocol. Numerous prototype flow SODIS systems have been created in the past to address these issues and improve the attractiveness and technical effectiveness of SODIS. Flores-Cervantes [18] developed a gravity-fed semi-continuous SODIS (SC-SODIS) system that can be used to treat drinking water at the household level in Nepal. The system comprises a raw water holding tank connected to parallel solar reactors made from PETs by cutting and joining them bottom to bottom using glue. It was allowed to run between 9 a.m. to 5 p.m. producing water of excellent quality. Preliminary feedback suggested high community acceptance. Loux [19] tested the feasibility of a similar setup named Spirasol in the Kibera slum in Nairobi, Kenya and reported microbial removal capacity similar to those recorded in conventional batch SODIS treatment using PETs. The system was assembled using widely available pieces to make it a reproducible technology in rural communities of developing countries. At a slightly higher cost, Rosa e Silva *et al* [20] went a step further and included a slow sand filtration unit before SODIS reactors to enable some form of pretreatment and keep water turbidity within the allowable range of < 30 NTU. The study reported excellent performance with regard to the system's efficiency at turbidity removal and bacterial inactivation.

This study aims to evaluate the viability of a continuous flow SODIS system, which has been developed to enhance cost-effectiveness, simplicity, and sustainability. Additionally, the system is engineered to offer multiple barriers against pathogens and colloidal particles by combining aeration, filtration, and disinfection units into one integrated system. Despite the role DO plays in the pathogen inactivation processes, no studies have found a way of boosting the dissolved oxygen content of SODIS water in a continuous flow system. In this paper, the flow SODIS system is referred to as aeration-filtration SODIS (AF-SODIS) for convenience and to highlight that the water is subjected to aeration and filtration prior to solar disinfection.

2.0 MATERIALS AND METHODS

2.1 Description of Study Area

The study was carried out in Nsukka, located in Enugu State, Nigeria. Nsukka lies between latitudes 6.86° N and 6.83° N of the Equator and longitudes 7.36° E and 7.42° E of the Greenwich Meridian. The area's topography primarily consists of high plateaus and escarpments, with rolling hills of residual mountains, dry valleys, lowlands. This region experiences significant rainfall, averaging about 1500 mm from May to October, followed by a prolonged dry season from November to March. Most households in Nsukka depend on rainwater during the wet season and generally believe that rainwater is of superior quality compared to other sources [23].

2.2 Preparation of Feed Water and Bacterial Enumeration

The feed water for all experiments was obtained from a community hand-dug well. A volume of 500 L was collected in one batch to prevent variations in physicochemical properties. The same water was used for all the experiments. The feed water was sterilized before each experiment using a 50 L industrial pressure pot, which can maintain a pressure of 15 psi for 15 minutes, and then allowed to cool before being contaminated with an *E. coli* stock. To prepare the *E. coli* stock, a naturally occurring strain of *E. coli* was obtained from the wastewater treatment facility at the University of Nigeria, Nsukka and introduced into 200 mL of sterile nutrient broth (Oxoid CM67) and incubated for 24 h at 37 °C under constant agitation to optimize growth conditions.

The cells were harvested after incubation by transferring the culture into sterile cuvette containers and centrifuging at 3000 rev/min (855 g) for 15 minutes. Thereafter, the supernatant was decanted before the pellets were resuspended in sterile phosphate butter saline (PBS) solution prepared with reagent-grade water. The pellets were finally resuspended in 200 ml of sterile water to form the *E. coli* stock. Appropriate dilutions were made directly into the feed water during the refill of the holding reservoir to obtain a reasonable bacterial concentration. The most probable number (MPN) of the inlet (holding reservoir) and outlet (clean water reservoir) water was counted using procedures described in the Standard Methods for the Examination of Water and Wastewater [24]. The target turbidity of 100 NTU for the feed water was attained by adding kaolin (China clay) until the desired level was reached. Water turbidity was measured using a standard turbidimeter (2100N Laboratory Turbidimeter, EPA, 115 Vac).

2.3 Set up and Operation of the AF-SODIS System

Figure 1(a) shows a picture of the AF-SODIS system, while Figure 1(b) shows the schematic illustration of the processes that operate in the system. AF-SODIS consists of aeration, filtration, and disinfection units. The aeration process takes place in the oxygenation tank (which also doubles as the feed water-holding reservoir) by allowing air bubbles to rise through the water column. The tank is made of a 19 L water dispenser container (WDC). To achieve this, the oxygenation tank is turned upside down such that its “shoulder” rests on the tripod frame (see Figure 1). Thus, the outlet/mouth of the oxygenation tank is positioned just below the water level in the funnel, allowing for immediate replenishment of water from the oxygenation tank as the water level in the funnel decreases. As water flows through the oxygenation tank, bubbles of air are entrained and seen rising in the WDC, thereby oxygenating the water. This mechanism enables the water level in the funnel to remain constant as long as there is still water in the oxygenation tank.

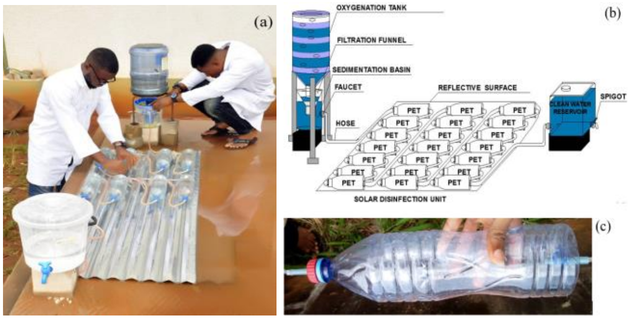

Figure 1: **(a)** A pictorial diagram of AF-SODIS, **(b)** a schematic diagram of AF-SODIS, **(c)** PET bottle perforated and fitted with flow connector a the cork and bottom

The system was designed to create multiple barriers against the colloidal particles that contribute to water turbidity. First, the outlet of the funnel is lined with filter cloth, allowing for filtration before the water enters the sedimentation basin, which is constructed from a 12 L polycarbonate bucket. The outlet valve of the sedimentation basin is positioned higher than the funnel's outlet to enable particles that passed through the filtration unit to settle under the calm conditions of the basin. The disinfection unit comprises eight solar reactors (1.5 L PET bottles) connected in series by a flexible polyvinyl chloride (PVC) hose. The reactors are detachable, allowing the number of reactors and the volume of water treated per batch to be adjusted based on the size and drinking water needs of a household. Additional turbidity removal is expected to occur within the disinfection unit, as the flow velocity decreases below the terminal velocity of the colloidal particles upon entering, allowing them to settle. The hose from the disinfection unit connects near the bottom of the clean water reservoir, which is also made from a 20 L polycarbonate bucket.

The PET bottles were punctured at the bottom and the top cork to facilitate tubing connections, as illustrated in Figure 1 (c). Prior to connecting the tubing, plastic tips or connectors made of silicone rubber were inserted into the openings to prevent leakage. Silicone rubber was selected for its expected thermal and UV stability. Additionally, the top corks of the inlet and outlet PET bottles included catheter connectors to accommodate standard mercury thermometers without leakage. The retention time is regulated by the rate at which water is drawn from the clean water reservoir. During operation, the oxygenation tank, sedimentation basin, and clean water reservoir were all covered in a black polythene sheet to block UV rays so that only the disinfection unit would be responsible for solar disinfection. This is important because similar transparent units may not be available in the field.

The AF-SODIS system can function entirely by gravity as long as the water level in the sedimentation basin remains above that of the clean water reservoir. Flow ceases when the water levels in the sedimentation basin and clean water reservoir are equal, and it resumes when water is drawn from the clean water reservoir. To prevent the undisinfected water in the sedimentation basin from getting to the clean water reservoir, the volume withdrawn was one reactor (1.5 L) less than the total volume of the disinfection unit. Water is usually withdrawn after sunset to provide sufficient time before sunrise for undisinfected water from the sedimentation basin to flow into the disinfection unit as disinfected water flows into the clean water reservoir for another cycle of treatment. Thus, any volume of water collected from the clean water reservoir will be immediately replaced.

2.4 Aeration Experiment

The AF-SODIS features an aeration unit (oxygenation tank) designed to improve the DO content of water before it reaches the SODIS unit. The effect of this process on the dissolved oxygen content was evaluated using two WDCs. The first WDC was turned upside and air bubbles were entrained as water is released and the other was positioned upright and water is released so that no air bubbles are entrained. Water collected from the two WDCs was tested for dissolved oxygen content using a standard dissolved oxygen meter (AZ8403 Dissolved Oxygen Meter®).

2.5 Filtration Experiment

The filtration unit consists of a funnel (height, 12.5 cm; inlet diameter, 12 cm; outlet diameter, 5 cm) and a sari filter cloth (see Figure 1). The filter cloth was tied to the funnel outlet to strain colloidal particles and pathogens out of the water before the water enters the disinfection unit. The filtration was operated using water of the same turbidity (100 NTU) and different number of filter layers which offers different filtration rates. The filtration rate was measured by collecting the volume of water filtered every hour over a 3 h interval to obtain triplicate readings. The filtration was operated under a hydrostatic head of 10 cm, which corresponds with the height of the water column above the outlet of the funnel. For each experiment, a total volume of 19 L (volume of WDC) would be filtered before the turbidity of the filtered water was measured using a standard turbidimeter (2100N Laboratory Turbidimeter, EPA, 115 Vac).

3.0 RESULTS AND DISCUSSION

3.1 Feed Water Quality

The physicochemical and bacteriological parameters of the feed water are shown in Table 1. Besides widespread bacteria contamination, the entire physicochemical parameters measured fell within the WHO's recommended criteria for drinking water [25]. Although physicochemical parameters are not the main focus of this study, efforts were made to include them in the results for the sake of completeness. All tested physicochemical parameters, with the exception of nitrate, do not pose health risks at the concentrations found in drinking water, but they may influence the taste and aesthetic quality of the water, as well as the suitability of raw water for SODIS treatment. Turbidity over 30 NTU interferes with the effectiveness of SODIS processes [3].

Table 1: Properties of feed water

Parameters	WHO (Guidelines)	Well Water
pH	6.5 - 8.5	6.70
Turbidity (NTU)	5	42
DO (mg/L)	None	4.80
Nitrate (NO_3^-) (mg/L)	50	2.82
Sulfate (SO_4^-) (mg/L)	No guideline	1.88
Chloride (Cl^-) (mg/L)	250	11.10
Total Hardness (as $CaCO_3$)	200	15.3
Total Dissolved Solids (mg/L)	600	98.30
FC (MPN/100 mL)	0	26
TC (MPN/100 mL) (× 10^2)	0	9

NTU – nephelometric turbidity unit; DO – dissolved oxygen; $CaCO_3$ – calcium carbonate; FC – faecal coliform; TC – total coliform; MPN – most probable number

3.2 Filtration Capacity of the Filtration Unit

The relation between turbidity removal efficiency, *E. coli* removal efficiency, number of folded layers of filter cloth, and filtration rate is shown in Figure 2. The turbidity of the feed water used for the filtration experiment was set at 100 NTU, which is much higher than the typical turbidity of well water in the region. Water of higher turbidities would foul the system. The results show that the removal efficiencies of the pollutants increased with the number of filter layers at the expense of the filtration rate. As the filter layers were increased from 1 to 10 the removal efficiencies of turbidity and *E. coli* respectively varied from 75.3 to 93.6% and 91.29 to 97.5% (between 1 – 2 log reduction) while the filtration reduced from 2.4 m^3/m^2/day to zero. It can be seen from Figure 2 that five layers of filter cloth correspond to 87.4 % turbidity removal and 96.7% *E. coli*, and further increases in filter layer did not translate to appreciable increases in turbidity and *E. coli* removal but led to a precipitous decline in the filtration rate. The filtration rate reduced to a trickle when the filter was folded more than five times and beyond. For this reason, a five-layer fold was adopted for the AF-SODIS system. The filtration rate through a five-layer sari cloth was also sufficient to enable complete replacement of the water in the disinfection unit before sunrise to enable another cycle of treatment after the water in the clean water reservoir had been collected at night. In all the filtration experiments, water turbidity was reduced below the recommended 30 NTU required of SODIS water.

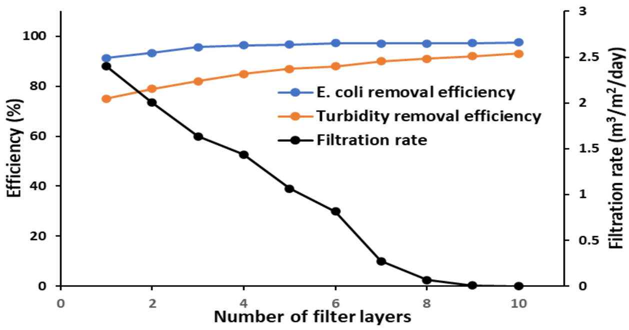

Figure 2: Variation in the efficiency of pollutant removal with respect to the number of folded layers of filter cloth and filtration rate

The bacteria removal efficiency recorded in the present study was found to be lower than those observed by Huq et al. [26] who employed similar filter material (sari cloth) to mitigate endemic *(Vibro) cholerae* in rural Bangladesh. The removal efficiencies of V. cholerae in their experiment varied between 99.21 to 99.44% as the layers of the filter material varied from 1 to 8. The discrepancy could emanate from the fact that Huq and co-workers filtered pond and river water in which V. cholerae are commensally attached to the much larger plankton that can be easily removed by size exclusion while the present study filtered well water which hardly harbours such hosts organisms.

3.3 Oxygenation capacity of the aeration unit

To evaluate the oxygenation capacity of the proposed bubble aeration method, a WDC that was operated upside down to entrain air bubbles was compared with another WDC that did not entrain bubbles while releasing water. The dissolved oxygen content of the water from the WDC that entrained bubbles was consistently found to be about 14% higher than the water from the WDC that did not entrain bubbles after the 19 L WDC volume had been released.

3.4 Variation of Turbidity and *E. coli* Removal Efficiency with Respect to Solar Radiation and Water Temperature

To evaluate the overall variation in turbidity and *E. coli* removal efficiencies of the AF-SODIS with respect to solar radiation and water temperature, the system was run for two weeks, during which the turbidity and the most probable number (MPN) of *E. coli* in the samples collected at the inlet (holding reservoir) and outlet (clean water reservoir) were measured. Table 2 shows the efficiency of AF-SODIS at removing turbidity and *E. coli* together with the daily variation in average 5-h peak solar radiation intensity and maximum water temperature. The maximum water temperatures reported in Table 2 are the averages of the inlet and outlet reactors of the disinfection unit. The water temperatures of the two reactors were within 1 ºC of each other. Only eight out of the 14 days of the experiment exceeded the radiation threshold value of 500 W/m^2. Despite that, no *E. coli* was detected in all the water samples collected from the clean water reservoir immediately after collection and after 3 days of dark storage. Note that a significant percentage of *E. coli* in the holding reservoir must have been removed at the filtration stage before the water enters the disinfection unit where the remaining *E. coli* was inactivated.

Table 2: The efficiency of AF-SODIS at removing turbidity and *E. coli*

Date	5 h peak radiation intensity	Max. water temperature	*E. coli* (MPN/100 mL)			Turbidity (NTU)		
			Inlet (×10²)	Outlet	E (%)	Inlet	outlet	E (%)
8/5/2019	419.4	43	800	< 2	99.998	100	6.6	93.4
9/5/2019	770.1	49	> 1100	< 2	99.998	100	4.4	95.6
11/5/2019	551.5	50	240	< 2	99.992	100	5.7	94.3
12/5/2019	228.1	34	460	< 2	99.996	100	7.0	93.0

13/5/2019	586.3	51	240	< 2	99.992	100	6.1	93.9
14/5/2019	360.1	41	460	< 2	99.996	100	3.2	96.8
15/5/2019	456.9	45	> 1100	< 2	99.998	100	3.4	96.6
16/5/2019	505.3	49	210	< 2	99.990	100	4.3	95.7
17/5/2019	458.0	46	> 1100	< 2	99.998	100	4.1	95.9
19/5/2019	653.6	52	90	< 2	99.978	100	2.2	97.8

E - efficiency

The turbidity of water retrieved from the clean water reservoir was typically below or near the WHO turbidity standard of 5 NTU. The system's impressive turbidity removal capability resulted from its design, which incorporates multiple barriers against the colloidal particles that cause turbidity. First, the funnel's outlet is lined with filter cloth, allowing filtration to occur before the water enters the sedimentation basin. Additionally, the outlet valve of the sedimentation basin is positioned higher than the funnel's inlet to facilitate sedimentation. Any particle whose density is higher than the density of water will not be buoyed up to escape from the outlet valve of the sedimentation basin. Additional turbidity removal occurred within the disinfection unit. As the flow velocity decreases below the terminal velocity of the colloidal particles, sedimentation occurs, leading to further reductions in turbidity. Sedimentation and additional turbidity removal within the sedimentation basin and disinfection unit were evidenced by the accumulation of particles observed at the bottom of the basin and PET reactors over time.

3.5 Cost Analysis

The cost analysis involved comparing the expenses associated with assembling and fabricating AF-SODIS against the costs of two earlier household-scale solar disinfection flow systems: SC-SODIS and Spirasol, developed by Flores-Cervantes [18] and Loux [19] respectively. Table 3 presents a detailed breakdown of the costs for AF-SODIS, Spirasol, and SC-SODIS. The analysis indicated that AF-SODIS is 3.2 times less expensive than Spirasol and 5.6 times less expensive than SC-SODIS. Polyvinyl chloride (PVC) served as the solar reactor in Spirasol, and the cost of PVC is relatively high for a single unit of Spirasol, as it constitutes nearly the entire system. For this reason, increasing the volume of treated water in Spirosol will have significant cost implications when compared to SC-SODIS and AF-SODIS in which increasing the treated volume would require only more PET that cost little or nothing. The multiple fittings in the SC-SODIS system, including hose-to-pipe adapters, ultimately increase its cost compared to Spirasol. However, Spirasol still requires silicone caulk glue. Some components of each system might not need glue and could be secured with tightly wrapped pieces of plastic, rubber, or other watertight materials. While this method may not provide the same seal as a proper sealant, it can be effective when adhesives are not readily available. Using alternative sealing methods will only slightly reduce the cost of the Spirasol system but may enhance the social acceptability of the water. Part of the concerns militating against the successful diffusion of SODIS methods is the leaching or migration of foreign chemicals in the water during solar exposure. Imagining drinking water in contact with glue will heighten such a concern. The use of glue was avoided in the AF-SODIS through the use of watertight connectors. Also, the tubing system of AF-SODIS was much cheaper than the tubing system of the other systems.

Table 3: Cost comparison with previously developed continuous flow SODIS systems

AF-SODIS		**Spirasol**		**SC-SODIS**	
PET Plastic Bottles × 8	Free	PVC Tube (20 ft.) × 1	$21.50	PET Plastic Bottles × 8	Free
0.2 cm flexible tubing × 8	$3.29	$^1/_4$” PVC Ball Valve × 1	$2.94	$^1/_4$” PVC Ball Valve × 1	$2.94
Funnel × 1	$0.82	Silicon Caulk × 1 tube	$2.99	$^3/_4$” PVC Pipe × 10 ft	$7.50
Filter cloth × 1	$1.10			$^3/_4$” PVC 4-way fitting × 2	$1.38
Plastic connector × 24	$3.29			$^3/_4$” PVC T fitting × 1	$0.98
				$^1/_4$” PVC 90^0 bend × 4	$1.56
				$^1/_4$” Zinc pipe-to-hose converter × 8	$28.42
				Silicon Caulk × 1 tube	$2.99
				Plumber’s Tape × 1 roll	$0.99
				Glue sticks × 1Pack	$0.99
Total	$8.50		$27.43		$47.75

Although these prices may differ between countries, the cost ratios are expected to remain relatively consistent. As a result, it is likely that the AF-SODIS system will not only be more accessible for local purchase and assembly but also easier to maintain and operate. Certain components of each system were excluded from the total cost analysis. Containers for holding feed water and collecting clean water were not included, as they are not part of the treatment units. Additionally, a faucet or spigot may be necessary to connect the feed water source to the systems, which could add approximately $10 to the overall cost of each system. The flow rate of AF-SODIS is controlled by adjusting the relative difference in water levels between the inlet and the outlet containers. Given the associated cost and technicalities involved in fabricating, operating, and maintaining both the Spirasol and the SC-SODIS, it is unlikely to represent a groundbreaking advancement for the developing world, as the cost will remain too high for many.

3.6 Acceptability of AF-SODIS

The assessment of social feasibility within the broader AF-SODIS study was derived from informal daily interactions with various individuals across different social, economic, and educational backgrounds in Nsukka and its vicinity during June 2019. The data collected includes firsthand accounts from locals about their genuine concerns and issues regarding the quality of their drinking water sources, information from individuals involved in local health and sanitation initiatives, and observations made by the authors. These findings should not be viewed as formal due to the small sample size and informal methodology, which is subject to the authors' interpretations. Nevertheless, the information offered valuable insights into the potential attitudes and cultural obstacles that AF-SODIS might encounter. A more comprehensive and formal social assessment is recommended for future studies and should encompass health and sanitation, social, and educational survey.

The authors engaged officials from the Enugu State Water Corporation and Nsukka Health Centre to familiarize them with the technology and gather their opinions on the system and its potential for adoption within the community. They reported that the taste of AF-SODIS water was pleasant, with no noticeable flavor or odor. Five individuals who were invited to sample the water were unable to distinguish between bottled water and AF-SODIS water when given them at random. However, the authors encountered persistent concerns that have hindered the social acceptance and willingness to use SODIS: the issue of potentially toxic chemicals leaching from the PET into the water during solar exposure. Another frequently asked question was whether glue was used to prevent leakage, due to concerns that it might leach into the water. This study addressed this issue by using a watertight plastic connector, eliminating the need for glue.

The authors repeatedly answered the question of chemical migration the same way. They introduced them to some of the studies that have been done to provide answers to similar questions [27]–[29]. Toxic chemicals and most photoproducts are generated at the outer surface of the PET reactors [30]. The overall findings from these studies indicated that the risk associated with consuming SODIS water is comparable to the risk of drinking regular bottled water that has not been subjected to solar exposure [3], [5].

After some effort to persuade them, most people were excited about the idea of ensuring their water's safety simply by exposing it to sunlight. Some reluctantly agreed to consider using AF-SODIS to make their drinking water safe. However, the most concerning responses came from a group of women from a nearby village when they were asked for their opinions on AF-SODIS. Upon inquiring about the purpose of the setup, the authors provided an explanation and discussed the issue of diarrheal diseases in children under five. The women downplayed the need for such a system, stating that they do not get sick from drinking water from their village stream, even though they do not use any treatment methods. When the authors tried to link diarrheal deaths in young children to the consumption of microbially contaminated water, the women dismissed the claim, arguing that such deaths were caused by teething-related illnesses. These interactions revealed to the authors that sustained awareness and promotional campaigns will be essential to convey the benefits of AF-SODIS or any other SODIS-based technology.

4.0 CONCLUSIONS

Aeration-filtration solar disinfection (AF-SODIS) presents an effective household water treatment solution that addresses many limitations of traditional batch SODIS methods by significantly increasing the volume of water that can be treated while reducing the labor associated with managing multiple SODIS containers. With its straightforward assembly, operation, and maintenance, along with high effectiveness in removing turbidity and pathogens, AF-SODIS emerges as a more scalable option compared to previous continuous flow SODIS systems. The system operates automatically and is gravity-driven, eliminating the need for a flow control device, and it can completely treat raw water with turbidity levels of up to 100 NTU and $>1.1 \times 10^5$ MPN/100 mL of *E. coli*. Arranging the feed water reservoir to allow bubbles to rise through the water column is a simple method to enhance the dissolved oxygen content in flow systems, while multiple layers of sari fabric can effectively serve as a filtration medium to reduce turbidity and pathogen concentration before solar disinfection. However, the social acceptability of AF-SODIS and SODIS systems in rural communities of developing countries may be hindered by the common misconception that teething, rather than untreated water, is the primary cause of infant diarrhea. Therefore, a comprehensive promotion and education campaign is essential to make the principles of household water treatment a standard practice within these populations.

REFERENCES

[1] Keogh, M. B. *et al.*, "Capability of 19-L polycarbonate plastic water cooler containers for efficient solar water disinfection (SODIS): Field case studies in India, Bahrain and Spain," *Sol. Energy*, vol. 116, pp. 1–11, Jun. 2015, doi: 10.1016/J.SOLENER.2015.03.035.

[2] Polo-López, M. I. *et al.*, "Microbiological Evaluation of 5 L- and 20 L-Transparent Polypropylene Buckets for Solar Water Disinfection (SODIS)," *Molecules* , vol. 24, no. 11. 2019, doi: 10.3390/molecules24112193.

[3] Luzi, S., Tobler, M., Suter, F., and Meierhofer, R. "SODIS Manual: Guidance on Solar Water Disinfection," Swiss Federal Institute of Aquatic Science and Technology (SANDEC) Dübendorf, Switzerland, 2016. [Online]. Available: https://www.sodis.ch/.

[4] Meierhofer, R., and Wegelin, M. "Solar Water Disinfection: A Guide for the Application of SODIS," Dübendorf, 2002. [Online]. Available: www.sodis.ch.

[5] McGuigan, K. G., Conroy, R. M., Mosler, H. J., du Preez, M., Ubomba-Jaswa, E., and Fernandez-Ibañez, P. "Solar water disinfection (SODIS): A review from bench-top to roof-top," *J. Hazard. Mater.*, vol. 235–236, pp. 29–46, 2012, doi: 10.1016/j.jhazmat.2012.07.053.

[6] Davies-Colley, R. J., Craggs, R. J., Park, J., Sukias, J. P. S., Nagels, J. W., and Stott, R. "Virus removal in a pilot-scale 'advanced' pond system as indicated by somatic and F-RNA bacteriophages," *Water Sci. Technol.*, vol. 51, no. 12, pp. 107–110, 2005.

[7] WHO, *Combating waterborne disease at the household level/International Network to Promote Household Water Treatment and Safe Storage*. Geneva, Switzerland, 2007.

[8] WHO, *Safely managed drinking water - thematic report on drinking water 2017*. Geneva, Switzerland, 2017.

[9] K. G. McGuigan, T. M. Joyce, R. M. Conroy, J. B. Gillespie, and M. Elmore-Meegan, "Solar disinfection of drinking water contained in transparent plastic bottles: Characterizing the bacterial inactivation process," *J. Appl. Microbiol.*, vol. 84, no. 6, pp. 1138–1148, 1998, doi: 10.1046/j.1365-2672.1998.00455.x.

[10] S. Samoili *et al.*, "Predicting the bactericidal efficacy of solar disinfection (SODIS): from kinetic modeling of in vitro tests towards the in silico forecast of E. coli inactivation," *Chem. Eng. J.*, vol. 427, p. 130866, 2022, doi: 10.1016/j.cej.2021.130866.

[11] K. L. Nelson *et al.*, "Sunlight-mediated inactivation of health-relevant microorganisms in water: a review of mechanisms and modeling approaches," *Environ. Sci. Process. Impacts*, vol. 20, no. 8, pp. 1089–1122, 2018, doi: 10.1039/C8EM00047F.

[12] S. Pigeot-Rémy, F. Simonet, D. Atlan, J. C. Lazzaroni, and C. Guillard, "Bactericidal efficiency and mode of action: A comparative study of photochemistry and photocatalysis," *Water Res.*, vol. 46, no. 10, pp. 3208–3218, 2012, doi: 10.1016/j.watres.2012.03.019.

[13] R. P. Sinha and D. P. Häder, "UV-induced DNA damage and repair: A review," *Photochem. Photobiol. Sci.*, vol. 1, no. 4, pp. 225–236, 2002, doi: 10.1039/b201230h.

[14] R. H. Reed, S. K. Mani, and V. Meyer, "Solar photo-oxidative disinfection of drinking water: Preliminary field observations," *Lett. Appl. Microbiol.*, vol. 30, no. 6, pp. 432–436, 2000, doi: 10.1046/j.1472-765x.2000.00741.x.

[15] C. D. DeMoyer, E. L. Schierholz, J. S. Gulliver, and S. C. Wilhelms, "Impact of bubble and free surface oxygen transfer on diffused aeration systems," *Water Res.*, vol. 37, no. 8, pp. 1890–1904, 2003, doi: https://doi.org/10.1016/S0043-1354(02)00566-3.

[16] T. Ahmed and M. J. Semmens, "Gas transfer from small spherical bubbles in natural and industrial systems," *J. Environ. Syst.*, vol. 29, no. 2, pp. 101–123, 2002, doi: 10.2190/9402-N69Y-KHGM-YE9N.

[17] H. Gómez-Couso, M. Fontán-Sainz, K. G. McGuigan, and E. Ares-Mazás, "Effect of the radiation intensity, water turbidity and exposure time on the survival of Cryptosporidium during simulated solar disinfection of drinking water," *Acta Trop.*, vol. 112, no. 1, pp. 43–48, 2009, doi:

10.1016/j.actatropica.2009.06.004.

[18] D. X. Flores-Cervantes, "Feasibility of semi-continuous solar disinfection system for developing countries at a household level," Massachusetts Institute of Technology, 2003.

[19] B. M. Loux, "Spirasol: improvements to semi-continuous solar disinfection water treatment systems." Massachusetts Institute of Technology, 2005.

[20] G. O. Rosa e Silva, H. O. Loureiro, L. G. Soares, L. H. de Andrade, and R. G. L. Santos, "Evaluation of an alternative household water treatment system based on slow filtration and solar disinfection," *J. Water Health*, vol. 20, no. 1, pp. 157–166, 2022, doi: 10.2166/wh.2021.211.

[21] J. M. Monteagudo, A. Durán, I. S. Martín, and A. M. Acevedo, "A novel combined solar pasteurizer/TiO2 continuous-flow reactor for decontamination and disinfection of drinking water," *Chemosphere*, vol. 168, pp. 1447–1456, 2017, doi: 10.1016/j.chemosphere.2016.11.142.

[22] B. J. M. Chaúque, A. D. Benetti, G. Corção, C. E. Silva, R. F. Gonçalves, and M. B. Rott, "A new continuous-flow solar water disinfection system inactivating cysts of Acanthamoeba castellanii, and bacteria," *Photochem. Photobiol. Sci.*, vol. 20, no. 1, pp. 123–137, 2021, doi: 10.1007/s43630-020-00008-4.

[23] D. Whittington, A. Okorafor, A. Okore, and A. McPhail, "Strategy for cost recovery in the rural water sector: a case study of Nsukka District, Anambra State, Nigeria," *Water Resour. Res.*, vol. 26, no. 9, pp. 1899–1913, 1990, doi: 10.1029/WR026i009p01899.

[24] APHA, *Standard Methods for the Examination of Water and Wastewater*, 23rd ed. Washington DC, USA: American Public Health Association (APHA), 2017.

[25] WHO, *Guidelines for drinking-water quality: fourth edition incorporating the first and second addenda*, 4th ed + 2. Geneva PP - Geneva: World Health Organization, 2022.

[26] A. Huq, B. Xu, M. A. Chowdhury, M. S. Islam, R. Montilla, and R. R. Colwell, "A simple filtration method to remove plankton-associated Vibrio cholerae in raw water supplies in developing countries," *Appl. Environ. Microbiol.*, vol. 62, no. 7, pp. 2508–2512, Jul. 1996, doi: 10.1128/aem.62.7.2508-2512.1996.

[27] A. Mustafa, M. Scholz, S. Khan, and A. Ghaffar, "Application of solar disinfection for treatment of contaminated public water supply in a developing country: Field observations," *J. Water Health*, vol. 11, no. 1, pp. 135–145, 2013, doi: 10.2166/wh.2012.119.

[28] E. Ubomba-Jaswa, P. Fernández-Ibáñez, and K. G. McGuigan, "A preliminary Ames fluctuation assay assessment of the genotoxicity of drinking water that has been solar disinfected in polyethylene terephthalate (PET) bottles," *J. Water Health*, vol. 8, no. 4, pp. 712–719, 2010, doi: 10.2166/wh.2010.136.

[29] P. O. Diez *et al.*, "In vitro toxicity studies of novel solar water disinfection reactors using the E-screen bioassay and the Ames test," *H2Open J.*, vol. 4, no. 1, pp. 204–215, 2021, doi: 10.2166/h2oj.2021.108.

[30] P. Schmid, M. Kohler, R. Meierhofer, S. Luzi, and M. Wegelin, "Does the reuse of PET bottles during solar water disinfection pose a health risk due to the migration of plasticisers and other chemicals into the water?," *Water Res.*, vol. 42, no. 20, pp. 5054–60, 2008, doi: 10.1016/j.watres.2008.09.025.

.