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Evaluation of Coliform Removal by the Application of Induced Oxygen and Solar Reflectors

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ABSTRACT

The study focused on the use of an integrated approach in enhancing facultative ponds for the treatment of sewage. Three single-cell ponds of various length-to-width were designed as a complete mix model, which receive induced oxygen and solar energy from a hydraulic flume and solar reflector. The three ponds were operated at a 10 days retention time. Settled sewage was allowed to flow through the individual ponds and samples were collected at three days intervals for laboratory analysis based on standard methods. The result showed that coliform removal efficiencies by the combined effect of induced oxygen and solar energy were 88%, 94% and 90% in ponds A, B, and C respectively. The solar reflectors only contributed 19%, 20% and 19% efficiencies in ponds A, B, C respectively, to the overall removal efficiency of total coliform. The experimental ponds A, B and C had coliform removal that ranges from 0.95 - 1.13 log reduction. This study indicated that minimum solar dose is sufficient to bring about photocatalytic action; any advanced increment produces a corresponding effect on the disinfection efficiency. Hence these findings concluded that coliform bacteria seem to be negatively affected mostly by relatively high dissolved oxygen than by the additional intensity of incident light.

Keywords: facultative pond, coliform removal, induced oxygen, hydraulic flume, synergistic effect, single effect.

1. Introduction

Destruction of pathogens in waste stabilization ponds (WSP) is a complicated phenomenon. In temperate regions, WSP has been found to commonly achieve a 2-6 log unit removal of coliform bacteria [1,2]. However, its performance is affected by extreme climatic conditions such as constant precipitation which are often experienced during rainy seasons. Consequently, leading to low temperature, reduction in sunlight duration, instability in pH of wastewater, low biodegradation and variable organic loading rate [3,4]. Although hydraulic retention time and temperature are seen as having a greater effect, investigation on certain factors is still ongoing [5-8].

In the past, the effort to maintain the benefit of waste stabilization pond (WSP) while abating its disadvantages resulted in its modifications through an integrated approach. Consequently, remarkable enhancement is being observed in conventional ponds design over the years. Research in the hydraulic property of ponds have aided in its upgrade with aeration systems to create an effective pond [9]. Examples of such systems include algae pond systems [10,11] and advanced integrated pond systems [12,13]. These treatment systems achieve high removal efficiency without sludge production. However, they require a similar land area as WSP, high investment cost and expert skills for design and construction.

It is of great interest that solar exposure is considered as being crucial for the elimination of pathogen indicators in waste stabilization ponds [14-17]. Despite its complicated interrelationship with other factors, such as temperature, turbidity, pH, dissolved oxygen and total dissolve solid, the operation of sunlight-mediated disinfections for micro-organism were proved through three distinct paths, which are direct inactivation, indirect endogenous inactivation, and indirect exogenous inactivation [18,19]. Damaging of microbial DNA by endogenous inactivation is direct by the involvement of UVB absorption. Indirect damage involves the presence of oxygen and takes place through the development of reactive oxygen species, either inside (endogenous) or outside (exogenous) the microbial cell.

Moreover, attenuation of downward solar irradiance with penetration depth in WSP has resulted in its demand for a large surface area. Solar radiation is considered only effective at the water surface (less than 10cm) [20]. To enable light penetration beyond that depth, there is a need for an increased light intensity using a solar reflector. This is because concentrated sunlight ($17 \times 10^4 Wm^{-2}$) in comparison with normal sunlight ($850Wm^{-2}$) has reported to cause a decrease in the microorganisms by a 5-log reduction in 3 seconds [21,22]. Furthermore, a study has revealed treatment cost for sewage is lower (77.6%) with solar enhanced facultative pond than the conventional facultative pond [23,24]. Such ponds may be a reliable source of heat to increase the temperature of ponds, upgrade single-cell deep ponds and reduce attenuation of downward solar irradiance. Interestingly, the solar enhanced pond has been found to improve effluent quality and at the same time reduce large land demand by the pond system.

Finally, aeration of ponds has been used to overcome the problem of thermal stratification as a result of inadequate mixing by the wind. This has been accomplished by the use of mechanical aerators which supply the needed oxygen, but demands a lot of energy. Therefore, there is a need for a cost - effective hydraulic mixer with an adequate power supply capable of distributing oxygen throughout the pond depth. Every aeration system transfer oxygen at a rate that depends on certain factors such as contact time between the bubble and the liquid, the size of the bubble, and the turbulence in the liquid. In treatment plants that are designed for BOD removal, dissolved oxygen level is maintained to be either greater than or equal to 2 mg/1 [25]. Thus, this study focuses on the synergic effect of these factors to bring about optimum sewage stabilization in an optimal pond size. In the light of the above circumstance, there is a need to investigate the potential of an integrated system for wastewater treatment.

2. Material and Methods

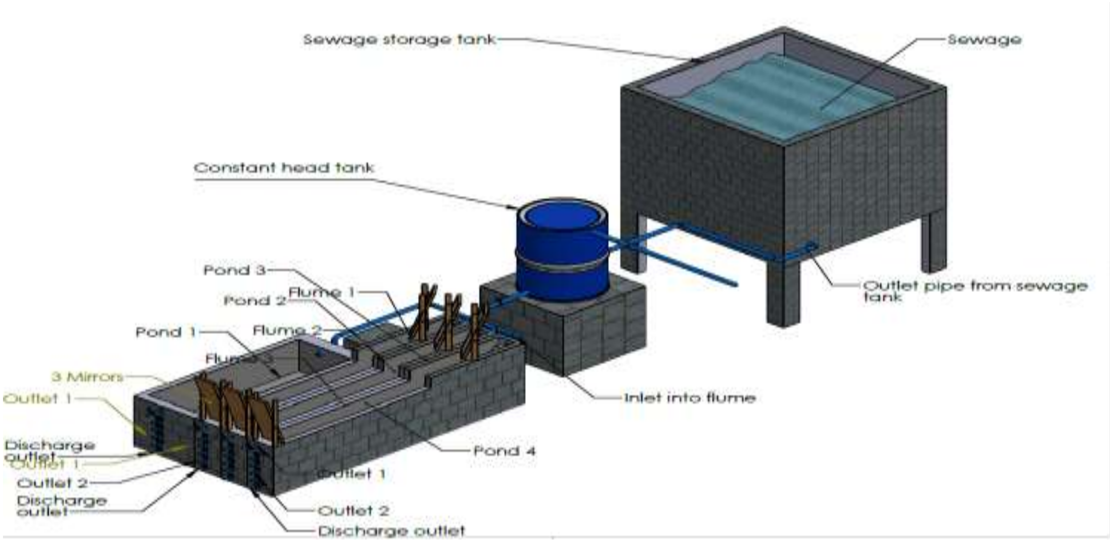
The small-scale pond system was set up with simple devices. The integrated facultative pond is made up of a rectangular concrete chamber with wall partitions into three ponds with different aspect ratios. Three ponds have equal depths of 0.51m. Another run on the three ponds serves as a control. Each pond is designed as an open channel that receives light energy directly from solar radiation and indirectly from a solar reflector. These reflectors are made of mirrors and fixed at both ends to increase light penetration. The ponds are designed as a complete mix model, which receives induced oxygen from a hydraulic jump created by a Parshall flume. The three flumes were made of concrete with a dimension of 0.25 m × 0.076 m × 0.152 m and positioned above the ponds to direct flow into the individual ponds. The flume contains some additional appurtenances to generate turbulence and transfer oxygen to the influent throughout its passage to the ponds. An influent PVC pipe (25mm diameter) was used to direct the sewage to the flume. During the treatment operation, sewage was pumped to the overhead tank and from there, it flows to a storage tank. The influent pipes from a storage tank were connected into four branched pipes. The ends of three branched pipes were further fixed to the flume through holes (25mm diameter) made in them. Through these holes, influents entered and flooded the top of a chute. Then it down the chute (200mm height with a slope of 3:1). The slopes produced supercritical flow conditions within the channel to form depth before the jump. By installing chute blocks, downstream, another jump was formed downstream to produce a high turbulence effect. Then, the sewage flowed down through a Parshall flume that formed the continuous part of the flume to create a mixing effect at a 90mm throat width. Finally, it diverges out and flows down the ponds through an inlet pipe of 25mm.

Hence sewage flow rates of 60.48 m^3/d, 34.56 m^3/d, and 25.92 m^3/d are obtained in ponds A, B and C respectively. The system was then operated at a 10 days retention time. Effluent passed through the three ponds and samples were collected at different retention times. In each sample, the concentration of coliform was constant for twelve weeks. Laboratory analysis was based on standard methods for the Examination of Water and Wastewater, 20th Edition. A model JPB-70 pen-type intelligent dissolve oxygen analyser was used for dissolve oxygen measurement and **a** model pyranometer designed at the national space research and development agency (NASRDA), Nigeria was used for irradiance measurement. DO and temperature profiles were monitored at intervals to determine dissolve oxygen concentration and thus the mixing capabilities of the pond. Profile measuring points were the water surface, mid-depth and 2cm off the pond bottom. Profiles were monitored at one-hour intervals. The flume used in the study is shown in Fig. 1. Pond sizes, aspect ratio and flow area of the model pond are shown in Table 1.

Table 1: Pond sizes, aspect ratio and flow area of the ponds

Experimental Ponds	Aspect ratio	Water Depth(m)	Size(m)	Treatment techniques
A	4	0.51	1.5 × 0.38 × 0.61	Hydraulic flume and solar reflectors
B	5	0.51	1.5 × 0.30 × 0.61	
C	6	0.51	1.5 × 0.25 × 0.61	
A_C	The same size as experimental ponds			Hydraulic jump only
B_C				
C_C				

Note: all the pond has an equal freeboard of 0.10m



3. Result and Discussion:

3.1 Synergistic effect of induced oxygen and solar energy on bacterial removal

To examine the synergic effect of induced oxygen and solar energy on bacterial die-off, samples were taken from ponds A, B and C at two days intervals and monitored for MPN during the experimental period. Another experimental run was done on ponds A, B and C (without solar reflector) which were denoted as Ac, Bc, and Cc. Pond A, B and C had coliform removal that ranges from 0.95 – 1.13 log reduction. While in ponds Ac, Bc, and Cc, the bacterial removal ranges from 0.46-0.58log reduction.

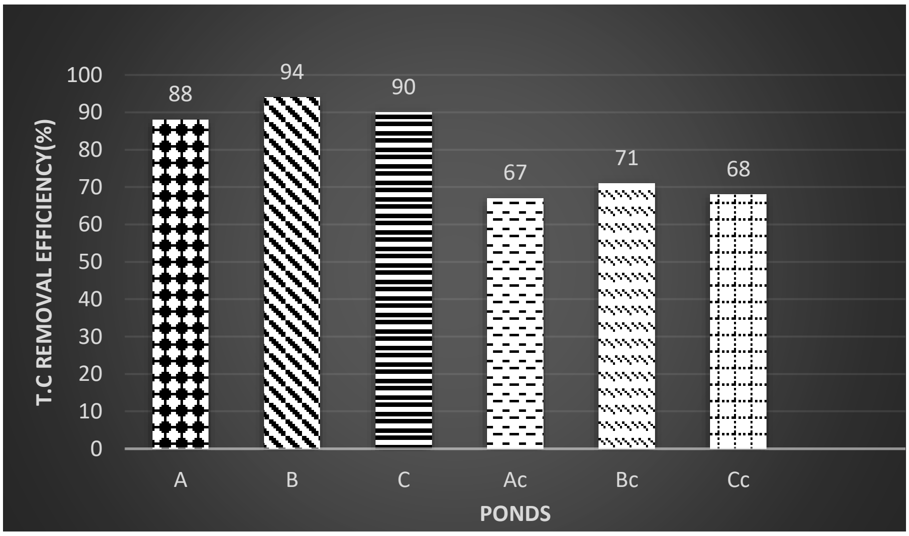


Figure 2: A graph of removal efficiency of Total coliform in experimental ponds.

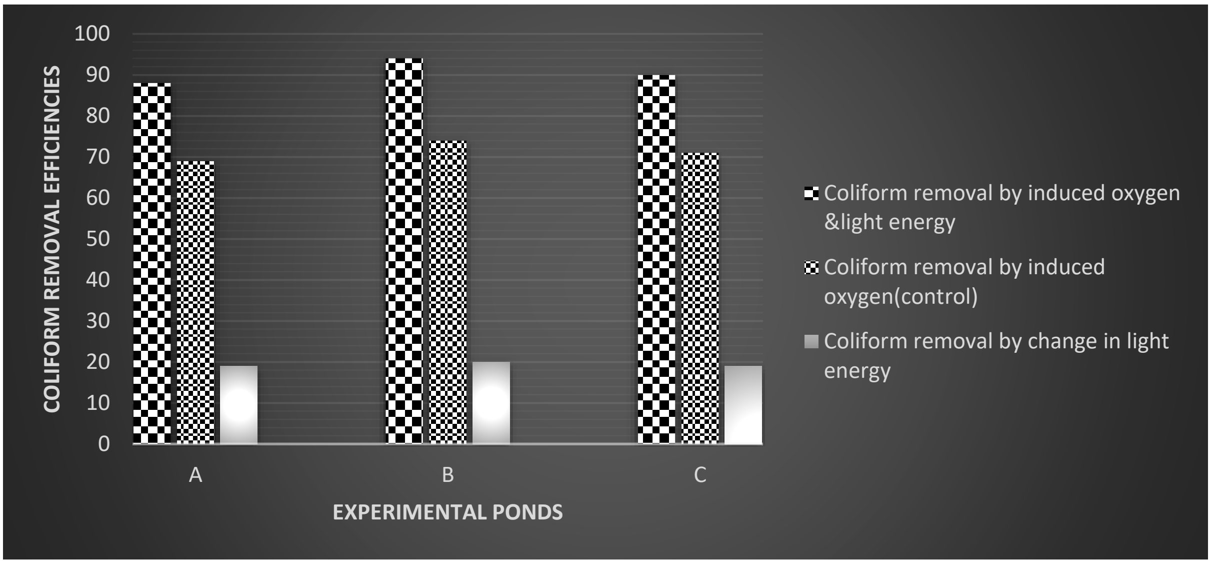


Figure 3: Induced oxygen, light energy and their synergistic effects on total coliform removal.

Coliform removal by a change in light energy = coliform removal by induced O_2 & light energy minus coliform removal by induced oxygen only.

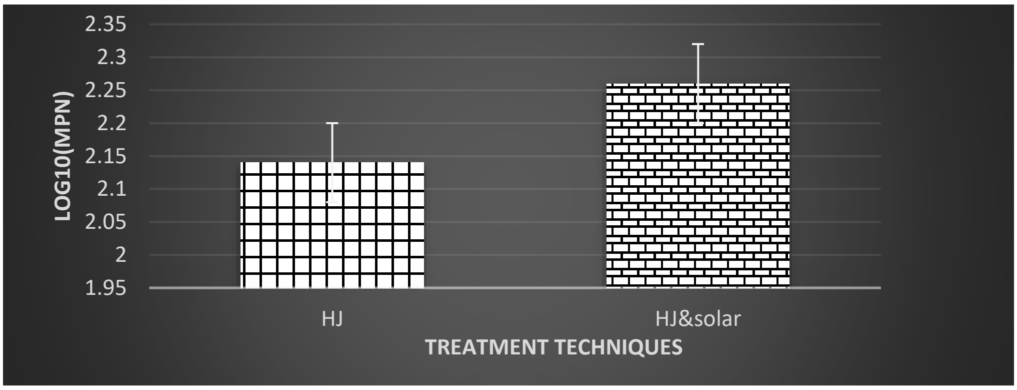


Figure 4: A graph of the standard error of the mean (SEM) between bacteria removal by hydraulic jump (HJ) and HJ & Solar reflector models

Figures 2-3 shows that the removal efficiencies by hydraulic jump and solar reflector had the highest reduction of 79%, 94% and 90% in ponds A, B, and C. The ponds (Ac, Bc, and Cc) with only hydraulic jump gave percentage reduction of 69%, 74% and 71% respectively. induced oxygen and solar energy the removal efficiencies in these ponds were aided by direct sunlight, while increased removal efficiencies in ponds A, B, and C was caused by both direct sunlight and reflected light by the solar reflector. The solar reflectors only contributed 19%, 20% and 19% efficiencies in ponds A, B, C respectively, to the overall removal efficiency of total coliform by the synergistic effect of hydraulic jump and solar reflector. The result proves that a minimum solar dose is sufficient to bring about photocatalytic action; any advance increment produces a proportional effect to the disinfection efficiency. The little effect of the solar reflector can be attributed to the insufficient solar radiation at the time of this study. Hence these findings might indicate that the coliforms seem to be negatively affected more by relatively high dissolved oxygen than by the additional intensity of incident light. The result of this work agrees with [24] on the effective inactivation of coliform by a solar reflector. In their study, the coliform removal efficiency in all their experimental pond was in the range of 56-89%. This research also agrees with the findings of [26] on the impact of solar and hydraulic jumps on facultative ponds. In his study, the highest percentage reduction (96%) of coliform was achieved after 40 days retention time. Although the result of [26] is slightly higher compared with the highest removal efficiency (94%) obtained from this study. Normally, high removal efficiency is expected when the ambient temperature is high and consistent. However, periodic precipitations were experienced during this study, which affected sunshine hours.

Figure 4 shows a graph of the standard error of the mean (SEM) between the ponds A, B, C and Ac, Bc and Cc. Here, the error bars show that the true value indicated in the bar graphs of the latter lies between 2.08 and 2.2 while that of the former lies between 2.20 and 2.3. Hence, the error bars do not overlap, so there is a significant difference between the two different sets of ponds. This implies that the solar reflector contributed to the removal efficiency of the total coliform bacteria.

3.2 Efficiency of hydraulic jump aeration on the ponds.

Settled sewage was allowed to flow through the hydraulic flume into the pond on a daily interval to keep the three ponds aerated. Oxygen transfer from the three individual flumes was monitored for two weeks and the average oxygen concentration in each section of the flume were measured using a dissolve oxygen meter. The inlet and outlets of the ponds were also sampled for insitu reading of dissolve oxygen and temperature. The results of both experiments are presented in Table 3.

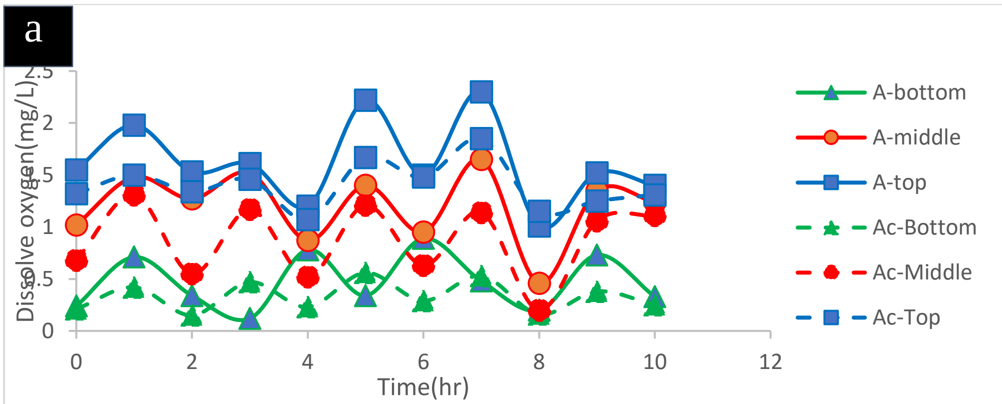
Table 3: Average dissolve oxygen concentration in the flume and experimental ponds

Sampling points of the flume	Dissolve Oxygen in flumes and ponds		
	A	B	C
Inlet of Flume	1.4	1.4	1.5
Chute	2.0	2.0	1.8
Throat of the flume	2.6	2.5	2.5
Outlet of the flume	4.2	4.8	4.0
Inlet of pond	2.54	2.58	2.54
Outlet of the pond	3.20	3.30	3.32

The results from Table 3 shows that DO in ponds A, B, C are 1.4mg/L, 1.4mg/L and 1.5mg/L at the inlet and 4.2mg/L, 4.8mg/L and 4.0mg/L outlet respectively. Hence, there is effective oxygen transfer from the flume to ponds. The flume is a combination of two parts; a stilling basin (at the beginning) and was completed by a Parshall flume (which emptied into the ponds). Hence, oxygen was generated at two places within the flume. Dissolved Oxygen concentrations increased from the flume to the Pond, with pond C having the highest DO. In Table 3, the dissolve oxygen increased from inlet to outlet. Our finding is in support of the view of [27] who reported that the dissolved oxygen in their three experimental ponds increased from the inlet to the outlet of the ponds.

3.3 Dissolve Oxygen variation in the ponds

Comparisons between three layers (water surface, mid-depth and bottom) of the six model ponds are shown in Figure 5 below. It was observed that ponds with both hydraulic jump and solar reflector (A, B, C) had relatively higher DO values at all times than ponds with only hydraulic flumes (Ac, Bc, Cc). This can be attributed to effective oxygen production by algal photosynthesis in the former ponds. The additional solar energy substantially increased the pond's performance via pond reoxygenation. ·



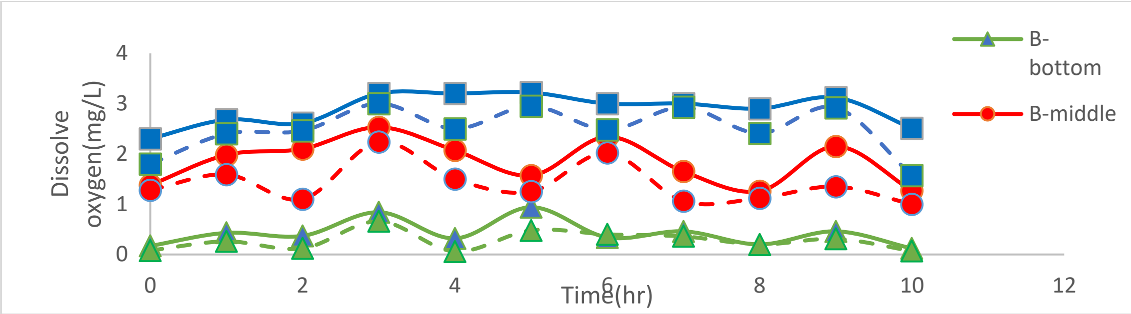


Figure 5: Dissolve oxygen variation with depth in ponds (a) A & Ac (b) B & Bc (c)C & Cc

Figure 5 shows that, out of the six ponds, pond B has the maximum dissolve oxygen concentration of 3.22mg/L, followed by pond C with 2.75mg/L and finally by pond A with 2.3mg/L. This could be resulted from the design of the system and also the positioning of the pond between ponds A and C. Thus, it gives it an edge over others as it tends to receive a greater and constant reflected light from the solar reflectors of others in addition to its solar reflector irrespective of the movement of the sun during the day.

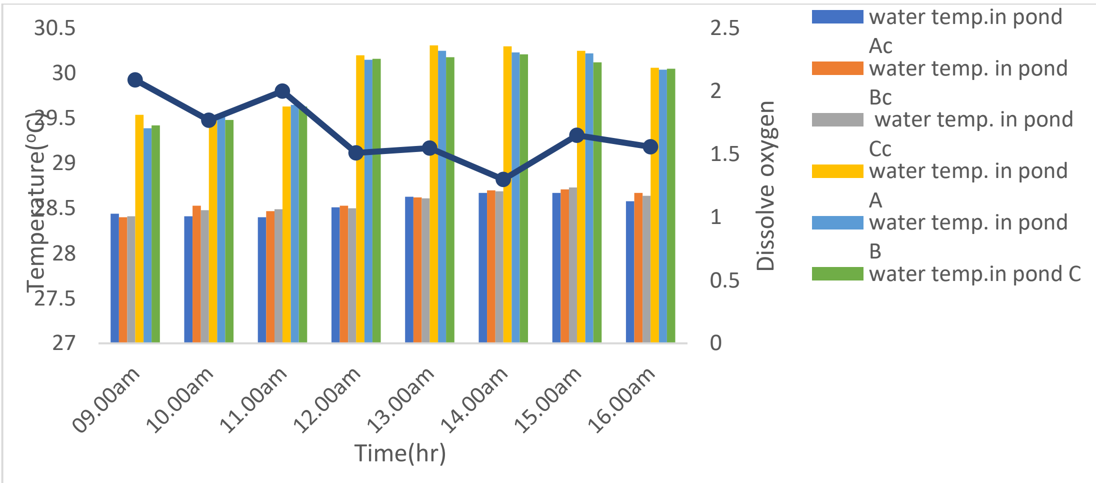


Figure 6: Temperature and average dissolve oxygen variation in all the experimental ponds

The ponds (A, B, C) with both induced oxygen and additional light energy had higher average temperatures throughout the day than ponds (Ac, Bc, Cc) with only induced oxygen. Temperatures in the former were, on average 0.66°C higher than those in the latter. Furthermore, the temperatures for each set of ponds are at the same elevation and had little discrepancies among them. Dissolved oxygen is highly temperature dependent and normally shows an inverse relationship with temperature.

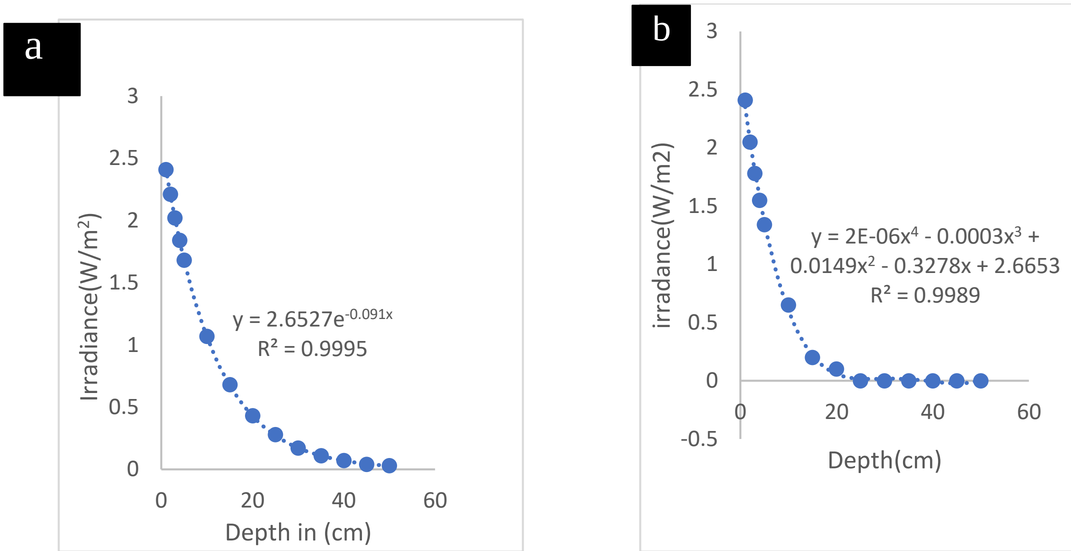


Figure 7: Average light attenuation in (a) ponds A, B, C (b) Ac, Bc, Cc

Figure 7 shows the attenuation of solar irradiance in the pond as a function of depth. In the ponds A,B, C, about 60% of solar was attenuated within the first 10 cm in the water column, and more than 90% was attenuated within the first 30 cm. Solar irradiance was not detected below 35 cm from the water surface. For the pond Ac, Bc and Cc, 80% of solar was attenuated within the first 20cm and irradiance was not detected below 25cm. Hence, as the depth of the pond increases, the portion of the pond that was shaded from sunlight also increases. This reduces the capacity of the pond towards higher disinfection rates through the sunlight-mediated mechanism. Consequently, leading to a decrease in the overall rate. The results do not correspond effectively with the findings of some researchers, where UV light was reported to be attenuated within the first few centimetres of the water column and to be insignificant in overall pathogen indicator removal [28-30]. Moreover, exponential and polynomial models are the best curve fitting with the highest correlation coefficient of 1 and 0.9989 for the experimental and control pond respectively.

3.4 Effect of different Pond Depths on coliform bacterial removal

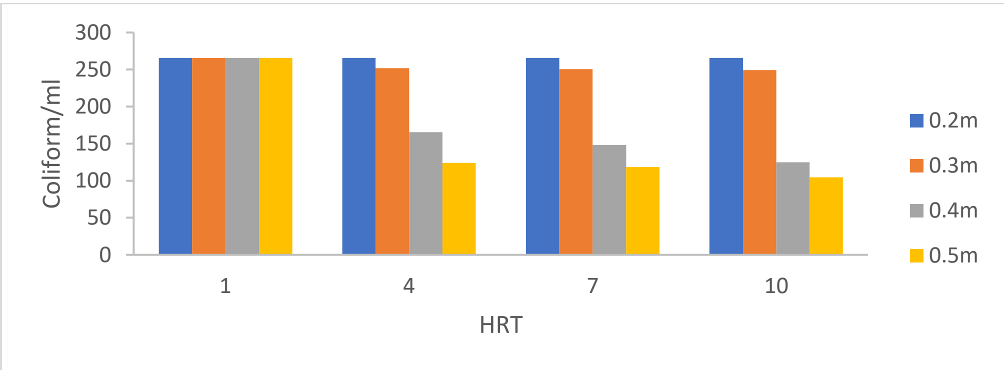


Figure 8: A graph of coliform against time at different depth

In this experiment. a series of different depths 0.2 m, 0.3 m, 0.4m, and 0.5m measured from the bottom of ponds B were examined. Samples were taken at every outlet and total coliform were analyzed. Figure 6 shows that the performance efficiency of the pond was significant, at pond depths of 0.4 m and 0.5 m. The total coliform at the outlet was reduced to 165.661, 148.160, 125.130 coliform/ml for 0.4m and 124.160, 118.26 and 104.721coliform/ml for 0.5m. There was approximately insignificant bacterial removal in both 0.2 and 0.3m depths during the ten-days retention time. Our findings are in conformity with the works of Pearson et al. (1987), who conducted vertical transects on separate ponds at the same site in Portugal and observed that reduced numbers of faecal coliform (FC) were only seen to have happened at the top surface around 0. 4 - 0. 5 m of the ponds. This is attributed to high pH and dissolve oxygen at the topmost layer, enhanced by oxygen-induced aeration, mixing and sunlight penetration.

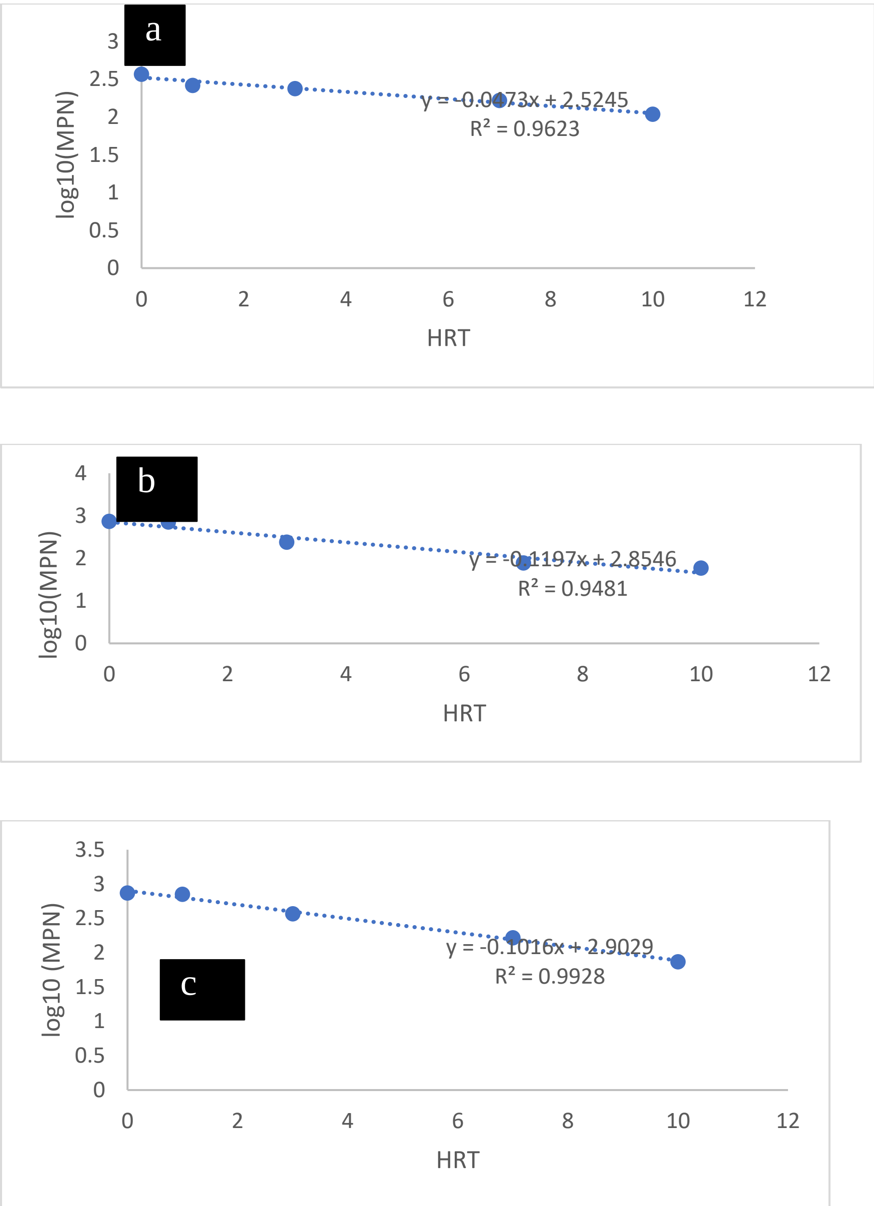


Figure 9: A graph of log10(MPN) bacterial die-off against time in ponds (a) A (b)B (c)C

Figure 9 show the relationship between bacterial die-off and hydraulic retention time (HRT) in pond A, B and C. From the time curve, it can be seen that the model expressing the bacterial die-off is a straight-line equation. A high correlation coefficient of r = 0.9623, 0.9481 and 0.9928 in ponds A, B and C respectively were obtained.

4. Conclusion

This study has shown that solar reflector and dissolve oxygen enhanced ponds treatment performance as the two variables accounted for 88 to 94% elimination of total coliform (TC) in the ponds studied. Results indicated that the coliforms seem to be negatively affected more by relatively high dissolved oxygen than by the additional intensity of incident light. Moreover, the effect of the solar reflector was minimal because of the fewer hours of contact with sunlight at the time of this study. The inclusion of reflectors into the facultative pond substantially increased the pond's performance through reduced light attenuation. This enables optimal use of the pond volume. Though this work has given a level of clear indication of impacts of these induced light and oxygen to total coliform removal in the facultative pond, it has some limitations. Every aeration system transfers oxygen at a rate that depends on certain factors such as contact time between the bubble and the liquid, the size of the bubble, and the turbulence in the liquid.

Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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