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The effect of variation of dimensions of solar reflectors on solar enhanced model pond

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Waste water stabilization pond is a simple way of treating waste water but one of its limitations is that it requires large area of land to be efficient. This study employed the use of solar reflectors to improve the efficiency of waste water stabilization pond by investigating the effect of variation of solar reflectors on the physical, chemical and biological properties of the pond. To achieve this, three model ponds were constructed, arranged in parallel and were supplied waste water by an overhead tank. Different sizes of reflectors varying along its height and width were installed at the effluent side of the pond. Effluent samples were collected and tested for BOD, total coliform, temperature, pH, algal count, total suspended solids and dissolved oxygen. The findings showed that when the width of the reflector is longer than the height of the reflector, it was observed to favor increase in pH, decrease in total coliform and total suspended solids while reflectors with longer height than width were observed to favor increase in algal count, temperature, dissolved oxygen and decrease in BOD.

Key words: Waste water stabilization pond, waste water, solar radiation, solar reflectors.

INTRODUCTION

Waste water stabilization pond (WSP) is a basin dug on the earth for removal of organic and pathogenic organisms (Agunwamba, 2001). Not only has it been found to be one thousand times better in destroying pathogenic bacteria and intestinal parasites than the conventional treatment plants (Mara et al., 1983), but also more economical (Arthur, 1983). It is simple to construct, operate and maintain and it does not require any input of external energy (Agunwamba, 2001). However, one of its limitations as stated by Agunwamba (2001) is that WSP system usually requires large area of land which is attributable to its complete dependence on natural treatment process. Therefore, this research is aimed at enhancing the efficiency of WSP without increasing area requirement of the pond by incorporating solar reflectors.

Due to large area requirement of WSP, researchers has been working on this area of study to improve the efficiency of ponds using attached growth system (Shin and Polpraset, 1987; Saidam et al., 2000), step feeding (Shelef et al., 1987), water hyacinth (Mumtaz and Hashim 2012), hydraulic jump (Agunwamba and Ogarekpe, 2010), hydraulic jump and solar reflectors (Agunwamba et al. 2013) and solar reflectors (Agunwamba and Utzev, 2012). Agunwamba et al. (2013) investigated if a solar-enhanced WSP (SEWSP) can increase treatment

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Table 1. Detailed description of ponds and the corresponding size of solar reflectors.

Experimental pond	Size of Pond (m)	Size of Reflector (m)
A	2 × 0.5 × 0.3	0.4 × 0.1(wxh)
B	2 × 0.5 × 0.3	0.3 × 0.1(wxh)
C	2 × 0.5 × 0.3	0.2 × 0.1(wxh)
D	2 × 0.5 × 0.3	0.1 × 0.1(wxh)
E	2 × 0.5 × 0.3	0.1 × 0.2 (wxh)
F	2 × 0.5 × 0.3	0.1 × 0.3 (wxh)
G	2 × 0.5 × 0.3	0.1 × 0.4 (wxh)

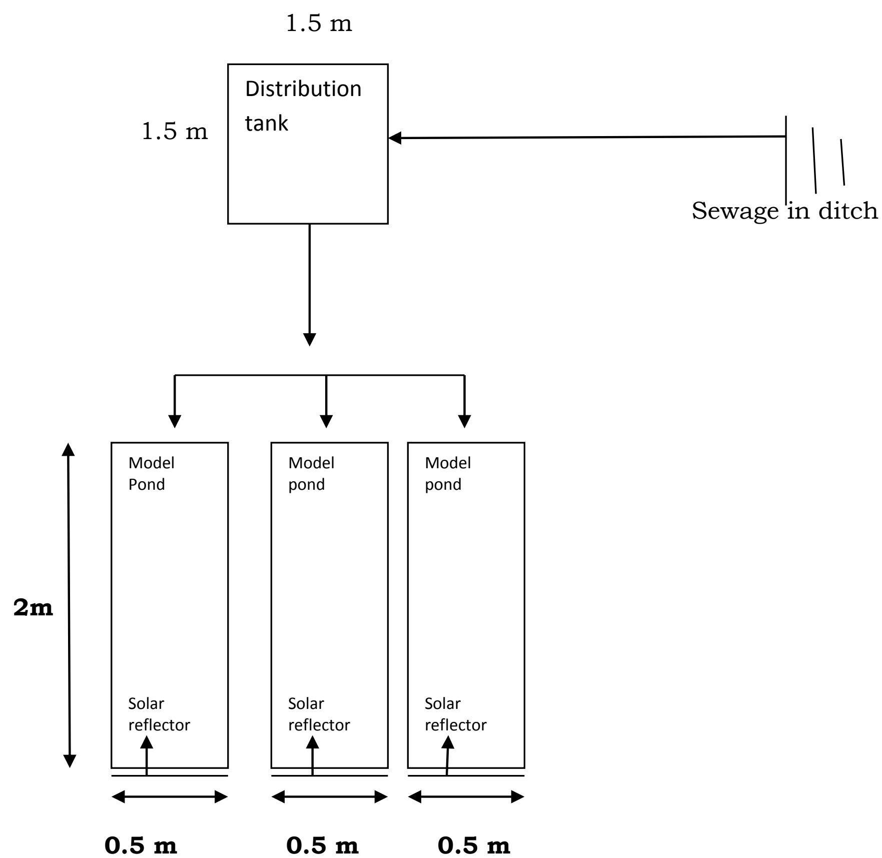

Figure 1. Schematic diagram of experimental setup due to dimension variation of the solar reflectors.

efficiency and consequently reduce the land area requirement. Their study involved installing reflectors at the sides of the pond and it revealed not only that SEWSP improves treatment efficiency and reduces land area requirement but also reduces the cost of treating wastewater approximately two times lower than the conventional WSP for the same treatment efficiencies.

Therefore, the main objective of this research is to increase the efficiency of treatment of waste stabilization pond with solar reflectors by studying the effect of variation of sizes of solar reflectors in the pond.

MATERIALS AND METHODS

Experimental set up

Different sets of solar enhanced ponds with dimensions are shown in Table 1 and Figure 1. It has a sewage tank (1.2 m ×1.2 m ×0.6 m) that receives its influent from sewage that diverted temporary to a ditch. The tank distributes the sewage to the model ponds with the help of control valves and half inches diameter pipes. Each set contain three ponds which are connected in parallel. The inlet and outlet pipes were fitted centrally in the experimental ponds. This setup was situated in the university sewage plant.

Table 2. Sample definition.

S/N	Sample	Characteristics of reflector (HxW)
1	A	No reflector
2	B	0.3 × 0.1
3	C	0.1 × 0.1
4	D	Influent (A, B & C)
5	E	0.4x0.1
6	F	0.2x0.1
7	G	Influent (H, E & F)
8	H	No reflector
9	I	No reflector
10	J	0.1 × 0.3
11	K	0.1 × 0.4
12	L	Influent(I,J,K)
13	M	0.1 × 0.2
14	N	0.1 × 0.1
15	O	Influent (M,N,P)
16	P	No reflector

Solar reflector setup

The set of three ponds in parallel were constructed with frames at the outlet side of the pond to carry reflector of varying length fixed at angle 90° to horizontal plane. For each set, two different sizes of reflectors are inserted at the outlet side of the first two ponds and the third pond has no reflector (serves as control test). The test is run in batches of three ponds per set. The reflectors are made of a flat ceiling board wrapped with foil paper. The foil paper was used as solar reflector.

Sample collection

Influent and effluent samples were collected weekly from the inlet and outlet of the experimental tanks in batches to examine physio-chemical and biological characteristic within a period of 4 months. The influent and effluent samples were collected after 6 h detention time. Table 2 shows the samples with regard to their respective characteristics and the sixteen samples were divided into four batches. The parameters that were examined are pH, dissolved oxygen, algal count, total suspended solids, total coli form and biochemical oxygen demand (BOD_5). All the analyses was done using appropriate water testing meters and in accordance with the standard methods (APHA, 1998).

RESULTS AND DISCUSSION

pH

As shown in Figures 10 to 13, sample D, G, L and O have the lowest value of pH in this study and are the influent. Sample B, E, K and M are from ponds with highest area of reflector in their respective batches. It is obvious from the graphs that increased area of reflector increased the respective effluent pH values. It is an established fact that photosynthesis activities in ponds increase pH values in ponds. In fact, high values above 9 in pond due to rapid photosynthesis by the pond alga which consumes CO_2 faster than it can be replaced by bacterial respiration as a result carbonate and bicarbonate ions dissociate (Mara and Pearson, 1998; Kamyambo et al., 2005). It appears that the higher the intensity of sunlight, the higher the pH values in the pond as values of pH up to 11 were recorded in WSPs in the afternoon (Kamyambo et al., 2005). Therefore, increased pH value in sample B, E, K and M is due to increased photosynthesis activities as a result of increased reflected solar radiation in the model pond from the increased area of reflector.

The percentage increase in pH of sample B, C, E, F, J, K, M and N with their respective influent is 2.6, 1.9, 2.5, 1.8, 2.2, 3.3, 3.3 and 2.6, respectively. Figure 31 shows that samples with breadth wise varied reflectors (JKMN) have higher pH value than longitudinal varied reflectors (BCEF). However, apparently, increase in breadth of reflector seems to favor increase in pH value than increase in its height.

Plate count

As shown in Figure 6 to 9, sample B, E, K and M have the highest value of plate count algae throughout the weeks, while sample D, G, L and O (influent of different batches) have the least values of plate count algae. The results show that plate count algae increases with increase in size of the reflectors. The reflectors increase the solar radiation by reflecting solar radiation in the pond. Oswald (1977) reported that 90% of solar radiation is converted into heat and less than 10% to chemical energy. Increase in temperature has been found to favor increase in algal growth (Marvis, 1970). Therefore, increased area of reflector increased the temperature of the pond which favoured the increase in plate count algae.

The increase of plate count alga in percentage of the sample B, C, E, F, J, K and M and N is 168, 137, 86, 63, 33, 48, 104 and 42, respectively. In average, as shown in Figure 30, longitudinal varied reflectors (B, C, E and F) have higher increase in plate count algal than the breadthwise varied reflectors (J, K, M and N) when compared with their respective control test. This indicates that the longer the reflector longitudinally, the higher the plate count algal in the effluent of the pond.

Total coliform

As shown in Figures 18 to 21, sample D, E, L and O are the influents and have the highest total coliform count. Samples B, E, K and M have the lowest total coliform count. These are the samples with the largest size of reflector in their respective batches. It is a wellestablished fact that sunlight reduces the number of bacteria in a medium. In Portugal, it was found that statistically significant relations existed between solar radiation and die off of *Pseudomonas aeruginosa*, *Clostridium perfringes* and fecal streptococcus (Nascimento et al., 1991). Mancini (1978) reported that about half of the lethal effect of light was due to wavelengths below 370 nm and one quarter to wavelengths between 370 and 400 nm (U.V. radiation). Inhibition of Nitrosomonas was achieved by light exposure for 10 min, with the near U.V. range of 410 to 415 nm being particularly effective for this purpose (Alleman et al., 1987). In a more recent study, it was discovered that wavelength above 500 nm damage faecal coliform and this process is enhanced at higher pH values and in the presence of oxygen (Curtis et al., 1992). Hence, increased size of reflector in this study increased the reflected solar radiation in the pond. This resulted to both direct reduction of total coliform by solar radiation of wavelength below 500 and above 500 nm.

The percentage decrease in total coliform of sample B, C, E, F, J, K and M is 82, 79, 86, 74, 81, 86, and 95 respectively. From Figure 32, samples with higher width of reflector seem to reduce total coliform more than samples with higher height of reflectors. It therefore appears that reflector with higher width reduces total coliform than reflectors with higher height.

Temperature

As shown in Figures 22 to 25, sample D, G, L and O have the lowest temperature and are the influents of the ponds. Samples B, E, K and M have the highest values and the highest size of reflector in their respective batches. In the aforementioned figures, sample with larger reflectors gives higher temperature. The reflector increases the solar radiation in the pond and the higher the increase in size of the reflector, the higher the increase in solar radiation in the pond. According to Oswald (1977), 90% of solar radiation is converted to heat energy and the remaining chemical energy. The solar radiation converted to heat increases the temperature of the pond.

The percentage increase in temperature of sample (B, C, E, F, J, K and M is 14.5, 10.9, 6.8, 2.5, 8.7, 11.4, 11.9, respectively. Comparing sample BJ, EK and FM with their respective no reflector samples, it appears that reflectors with higher height increases the temperature of effluent of pond more than reflectors with higher width (Figure 33).

Total suspended solids

From Figures 14 to 17, samples D, E, L and O have the highest TSS and they are the influents. Samples B, E, K and M are samples with the largest size of the reflector in their respective batches and showed the least value of total suspended solids. In the above mentioned figures, samples with larger reflectors appear to show lower suspended solids. However, the difference in total suspended solids among samples with reflectors and no reflector appear small, whereas, the difference between samples effluent and influent is high. It appears through observation that majority of the suspended solids were removed by sedimentation. Then, minority of the total suspended solids was removed through biochemical reaction. This biological reaction that reduces organic content is supported by solar radiation (William et al., 1852). Consequently, the higher the solar radiation in a pond, the higher the biochemical process which reduces the organic matters in the waste water. Sample B, E, K and M appear to have the least suspended solids in the model pond because they have the highest reflected radiation in their individual batch.

The percentage decrease in suspended solids of sample (BCEFJKM) is 92.5, 86.9, 75.7, 52.9, 73.4, 77.4, and 80.9 respectively. From Figure 34, comparing samples BJ, EK and FM with the respective control test samples, it appears that reflectors with higher height reduces the suspended solids more than reflectors with higher width.

Dissolved oxygen (DO)

As shown in Figures 2 to 5, sample B, E, K and M has the highest DO content and are the samples that have the highest area of reflector in their respective batches. Sample D, G, L and O are the influents of the pond and have DO content of least value in their respective batches. From the above mentioned figures, it appears that samples with larger reflector have higher dissolved oxygen content despite their slight disparity. The main mechanism of oxygenation in pond systems is the oxygen provided by the algal population (Shilton and Harrison, 2003; Mara and Pearson, 1998). After sunrise, the dissolved oxygen level gradually rises in response to photosynthetic activity, to a maximum in the mid-afternoon, after which it fails to a minimum during the night when photosynthesis ceases and respiratory activity consumes oxygen (Mara and Pearson, 1998). This suggests that increase in solar radiation increases dissolved oxygen content in the pond. Pattamapitoon et al. (2013) showed that dissolved oxygen increase with radiation in a quadratic relationship. Sample B, E, K and M have higher values of dissolved oxygen because their reflectors reflected more radiation in the pond which increased the algal activities in the pond and subsequently increased dissolved oxygen content in the pond.

The percentage increase in dissolved oxygen of sample (BCEFJKM) is 28.3, 25.5, 37.3, 13.2, 120, 170 and 130 respectively. In Figure 35, comparing sample BJ,

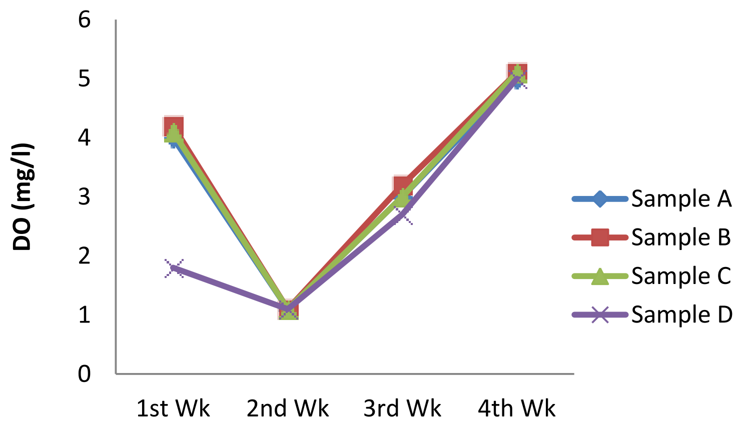

Figure 2. Variation of dissolved oxygen of sample ABCD with time in weeks for first batch.

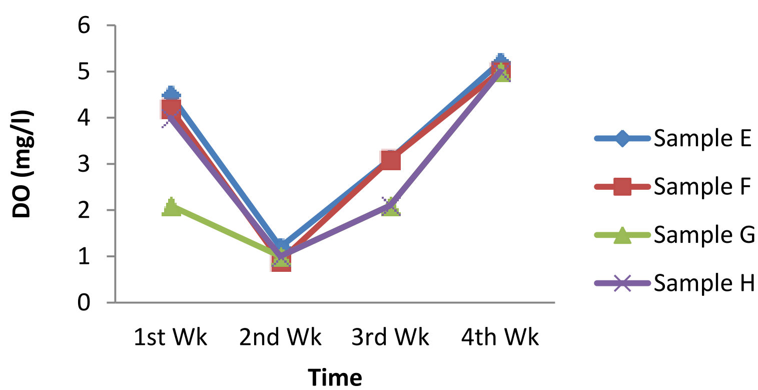

Figure 3. Variation of dissolved oxygen of sample EFGH with time in weeks for second batch.

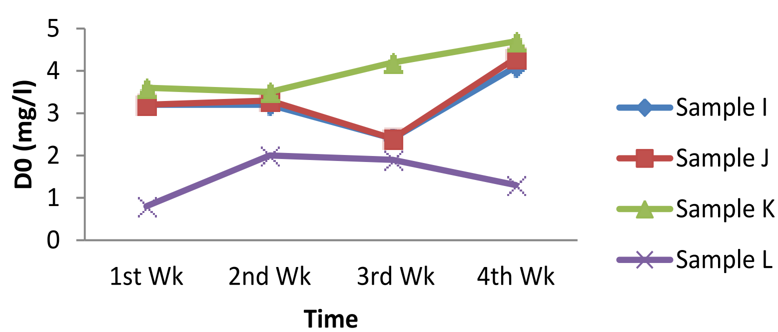

Figure 4. Variation of dissolved oxygen of sample IJKL with time in weeks for third batch.

EK and FM with its respective control test samples, it appears that reflectors with higher height increases the dissolved oxygen in the pond more than reflectors with higher breadth.

Biological oxygen demand (BOD)

From Figures 26 to 29, samples B, E, K and M have the least value of BOD content. And they are samples that

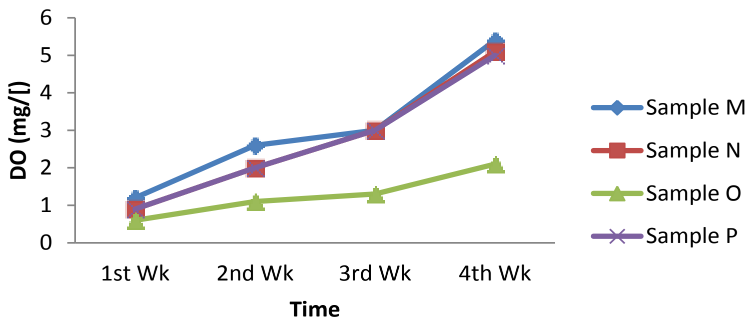

Figure 5. Variation of dissolved oxygen of sample MNOP with time in weeks for fourth batch.

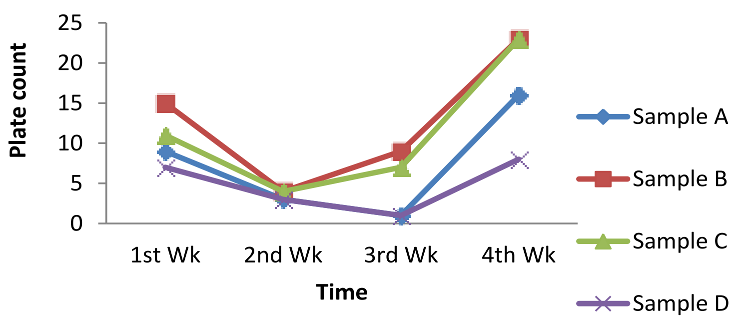

Figure 6. Variation of plate count algae of sample ABCD with time in weeks for first batch.

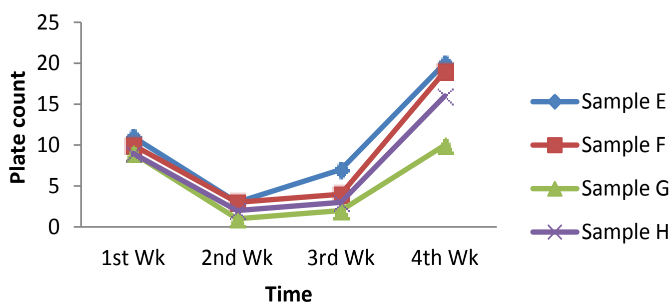

Figure 7. Variation of plate count algae of sample EFGH with time in weeks for second batch.

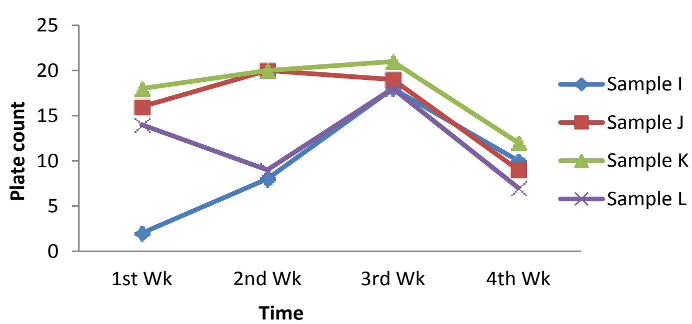

Figure 8. Variation of plate count algae of sample IJKL with time in weeks for third batch.

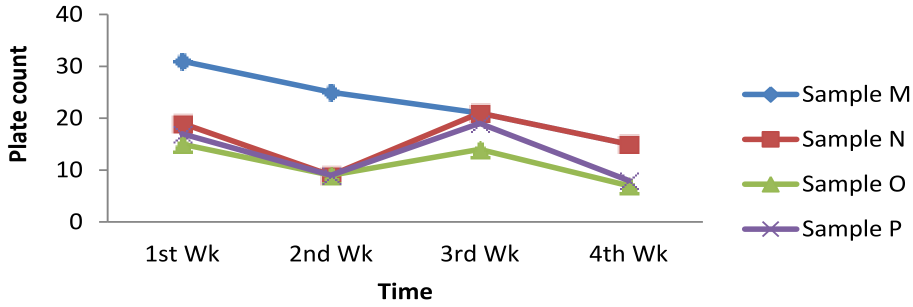

Figure 9. Variation of plate count algae of sample MNOP with time in weeks for fourth batch.

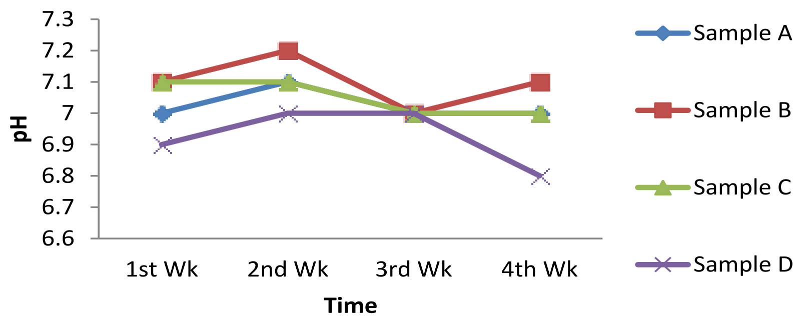

Figure 10. Variation of pH of sample ABCD with time in weeks for first batch

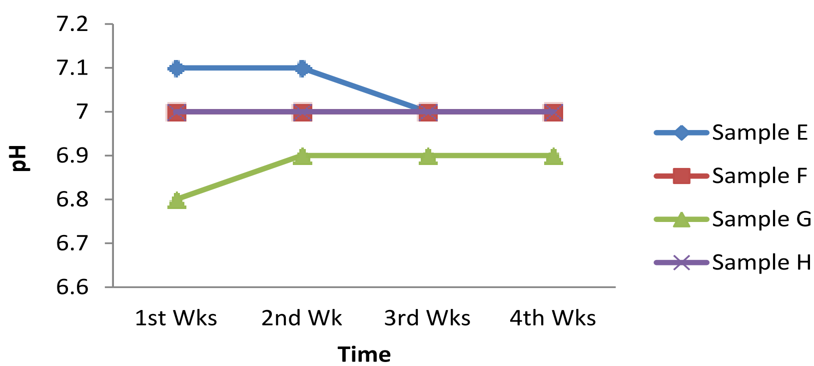

Figure 11. Variation of pH of sample EFGH with time in weeks for second batch.

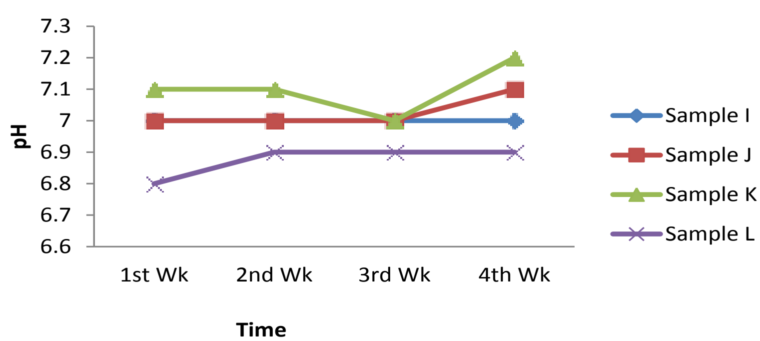

Figure 12. Variation of pH of sample IJKL with time in weeks for third batch.

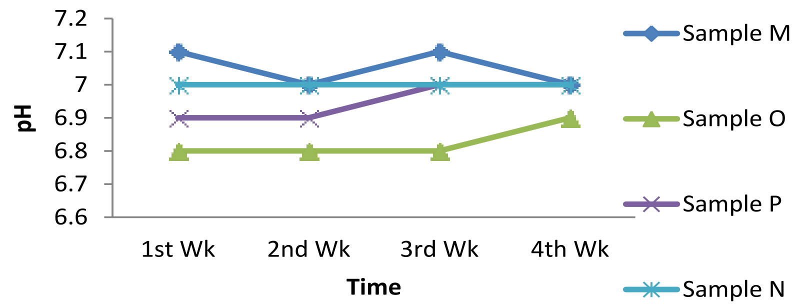

Figure 13. Variation of pH of sample MOPN with time in weeks for fourth batch.

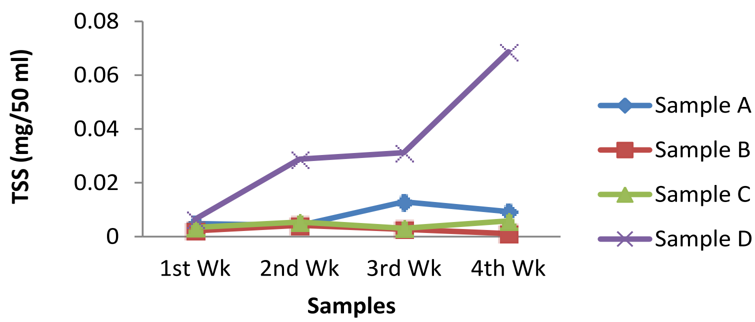

Figure 14. Variation of total suspended solids of sample ABCD with time in weeks for first batch.

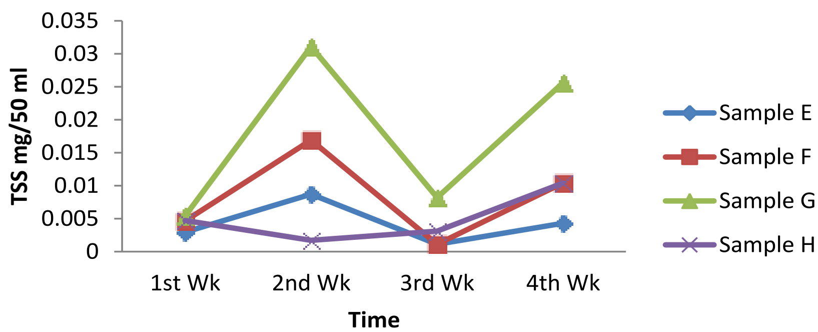

Figure 15. Variation of total suspended solids of sample EFGH with time in weeks for second batch.

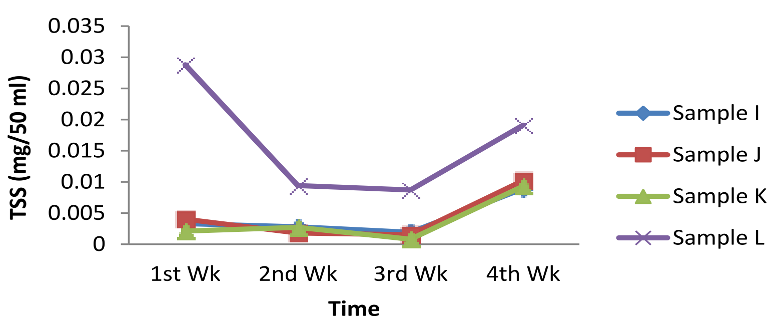

Figure 16. Variation of total suspended solids of sample IJKL with time in weeks for third batch.

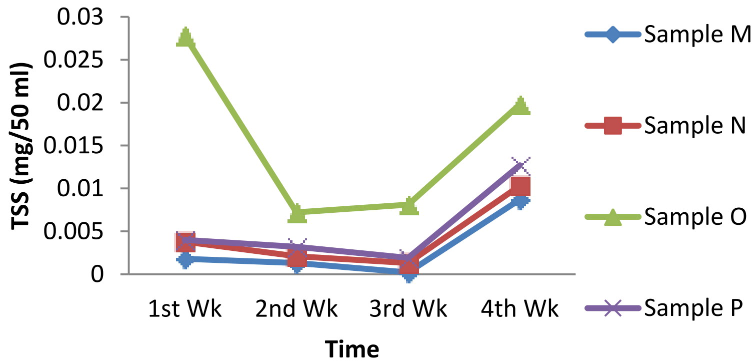

Figure 17. Variation of total suspended solids of sample MNOP with time in weeks for fourth batch.

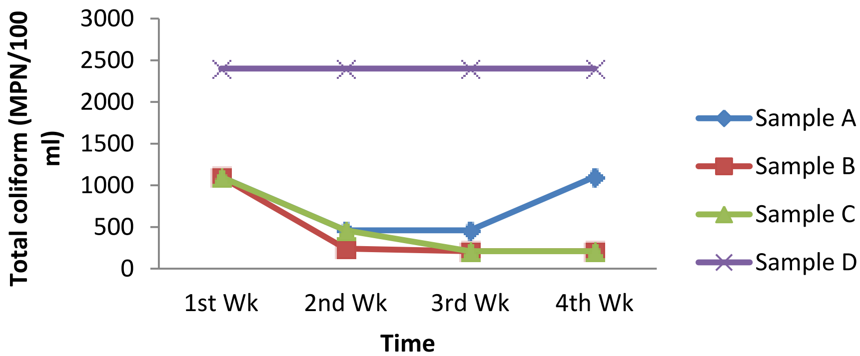

Figure 18. Variation of total coliform of sample ABCD with time in weeks for first batch.

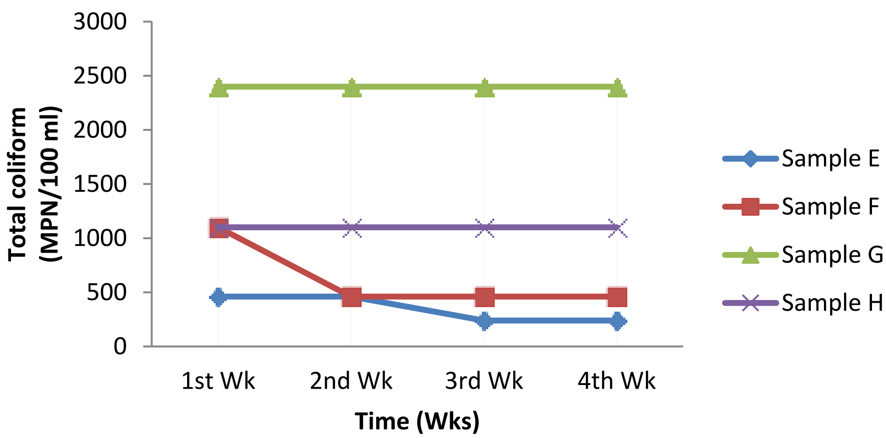

Figure 19. Variation of total coliform of sample EFGH with time in weeks for second batch.

have the highest area of reflector in their respective batches. Samples D, G, L and O are the influents of the pond and have the highest value of BOD content. From Figures 26 to 29, it appears that samples with higher area of reflectors have lesser BOD than samples of lower area of reflector though the disparity is slight. Since organic

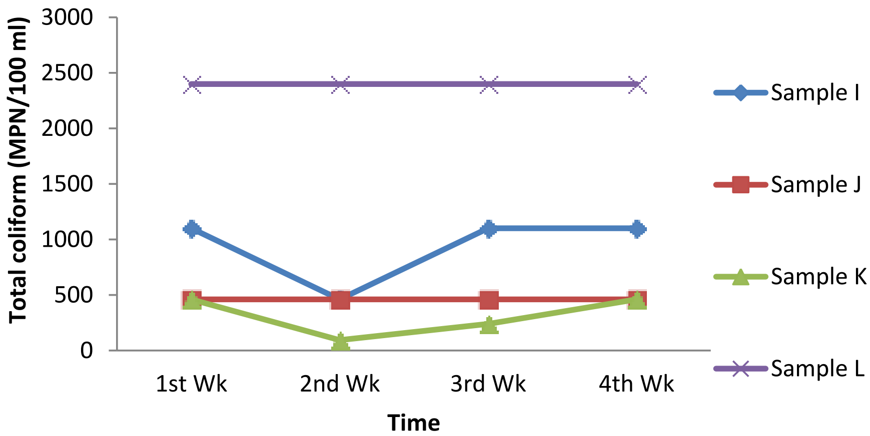

Figure 20. Variation of total coliform of sample IJKL with time in weeks for third batch.

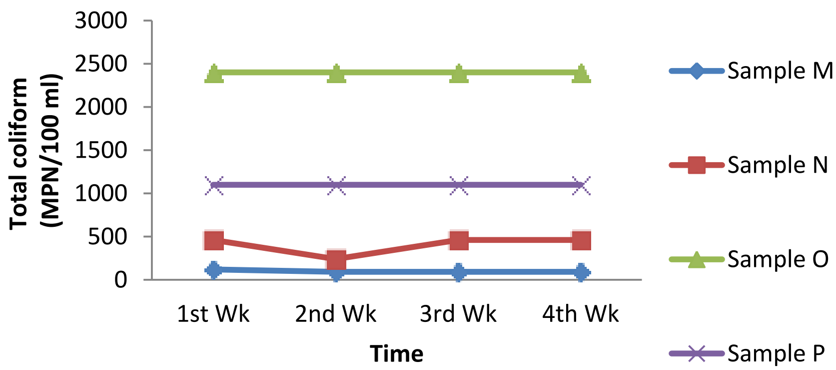

Figure 21. The Variation of total coliform of sample MNOP with time in weeks for fourth batch.

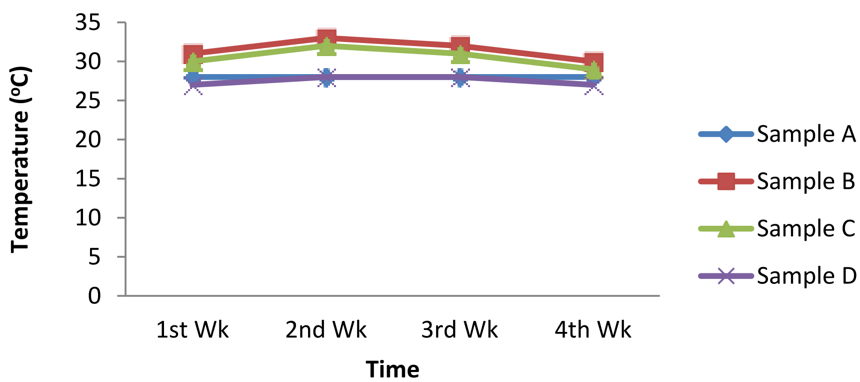

Figure 22. Variation of temperature of sample ABCD with time in weeks for first batch.

content in water determines the value of BOD, most of BOD through observation was removed through sedimentation. That was why there is slightly higher disparity between the influents and effluents of the pond. As mentioned earlier, increase in temperature increases biogradation of organic materials in ponds. The samples

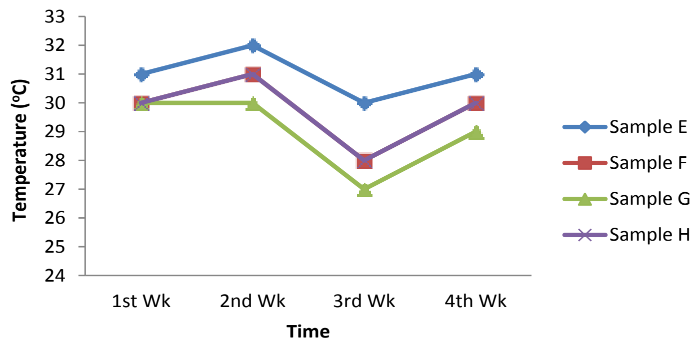

Figure 23. Variation of temperature of sample EFGH with time in weeks for second batch.

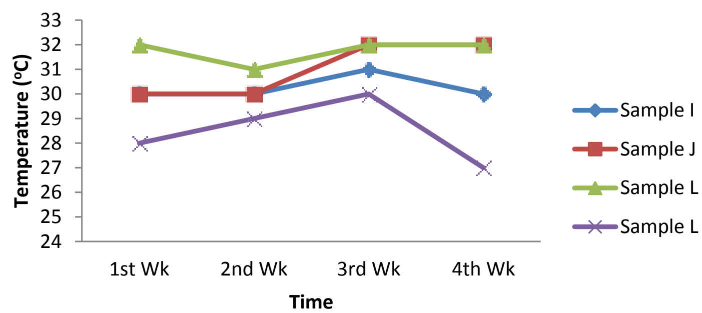

Figure 24. Variation of temperature of sample IJKL with time in weeks for third batch.

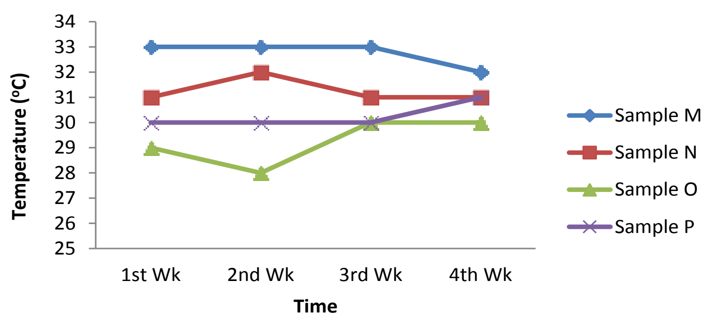

Figure 25. Variation of temperature of sample MNOP with time in weeks for fourth batch.

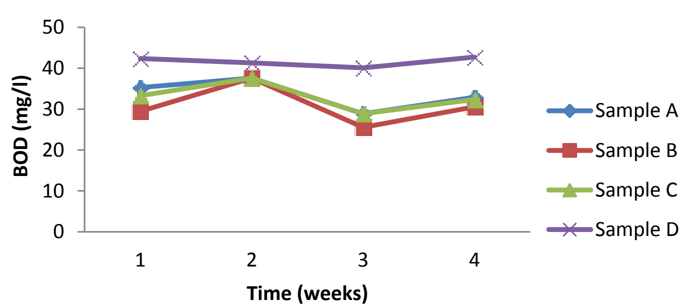

Figure 26. Variation of BOD of sample ABCD with time in weeks for first batch.

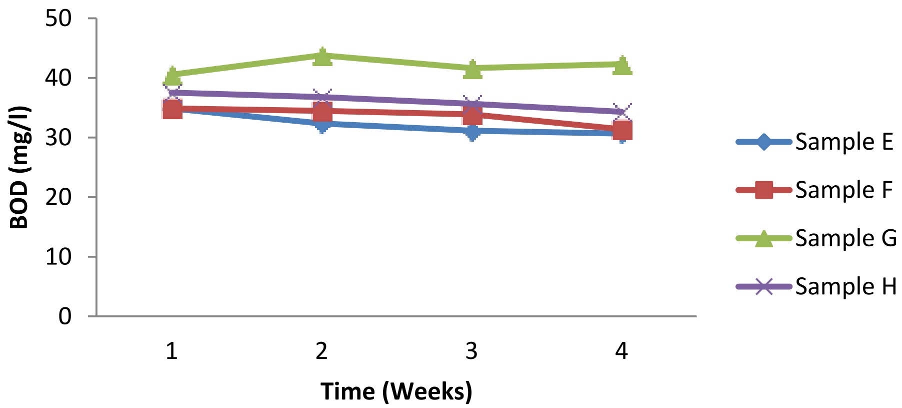

Figure 27. Variation of BOD of sample EFGH with time in weeks for second batch.

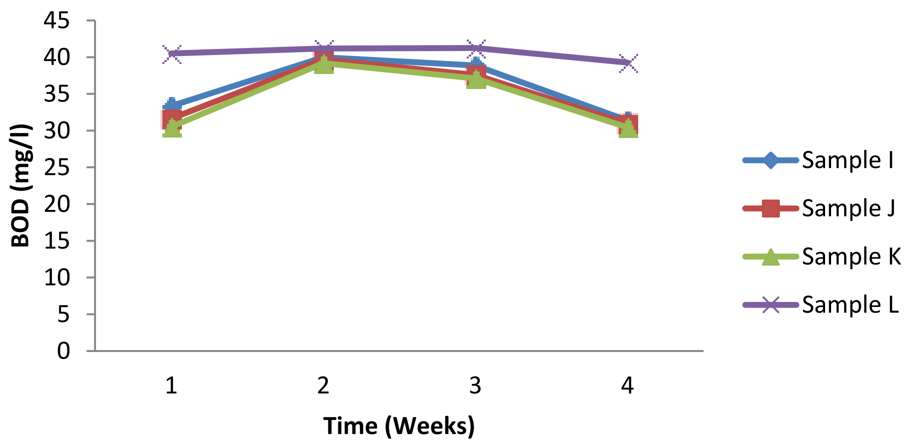

Figure 28. Variation of BOD of sample IJKL with time in weeks for third batch.

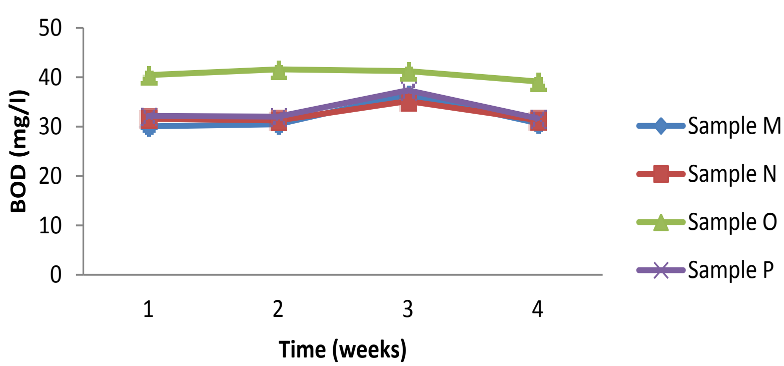

Figure 29. Variation of BOD of sample MNOP with time in weeks for fourth batch.

with higher area of reflectors reflect more solar radiation in the pond and the increased solar radiation in the pond raised the temperature of the pond. The increased temperature increased the rate of degradation of organic content and consequently reduced the BOD in the samples of larger reflectors.

The percentage reduction in BOD of samples BCEFJKM is 19.2, 14.5, 23.3, 20.0, 13.7, 15.3 and 21.3,

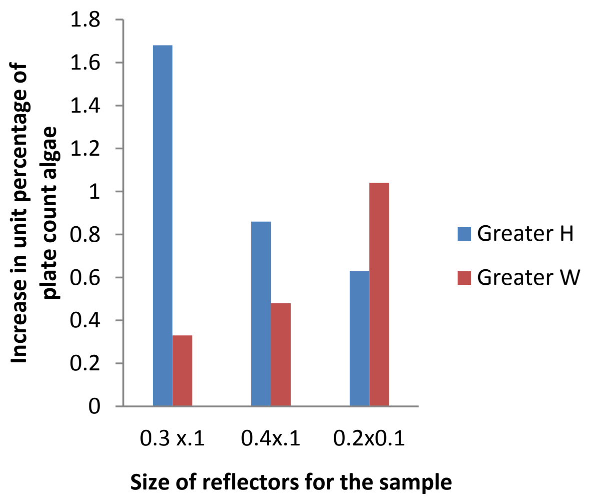

Figure 30. Comparison of increase in the plate count algae for different aspect ratios of the reflectors.

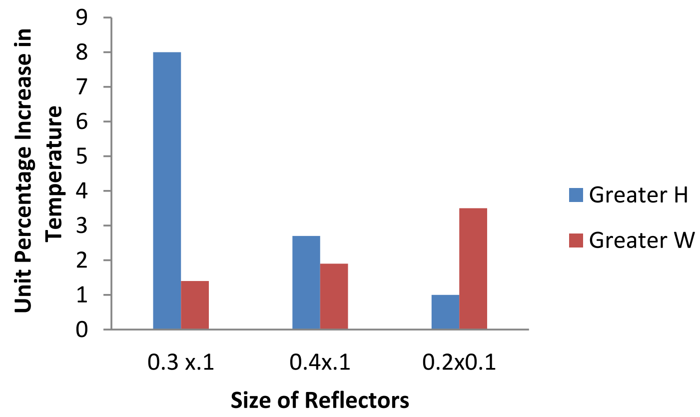

Figure 33. Comparison of increase in temperature for different aspect ratios of the reflectors.

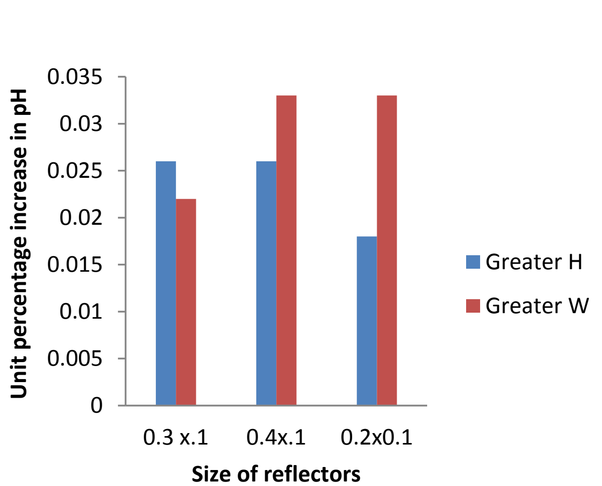

Figure 31. Comparison of increase in the pH for different aspect ratios of the reflectors.

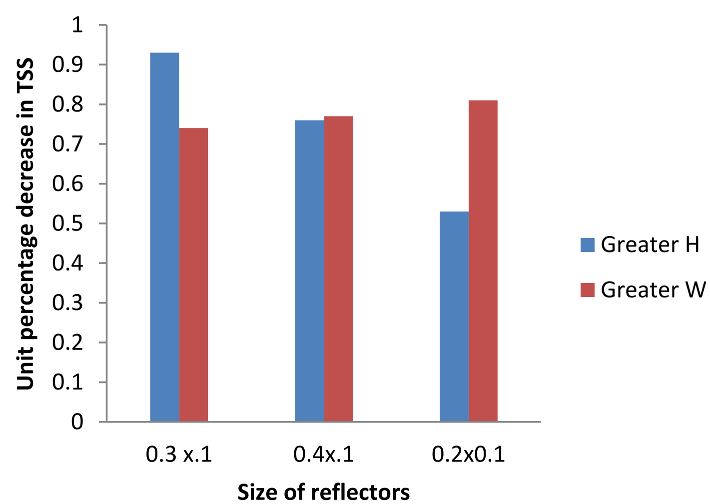

Figure 34. Comparison of decrease in total suspended solids for different aspect ratios of the reflectors.

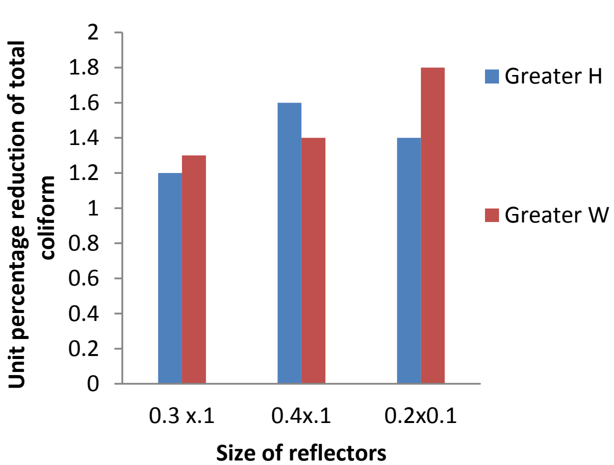

Figure 32. Comparison of decrease in total coliform for different aspect ratios of the reflectors.

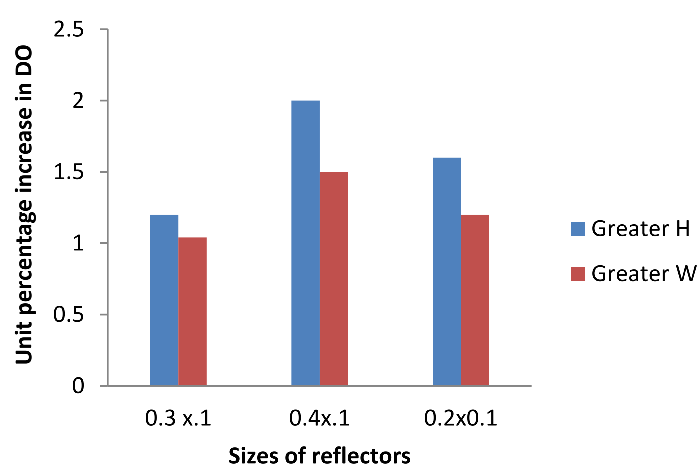

Figure 35. Comparison of decrease in dissolved oxygen demand for different aspect ratios of the reflectors.

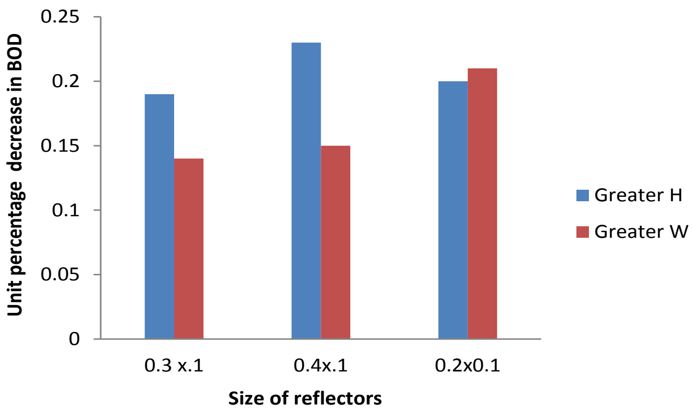

Figure 36. Comparison of decrease in the BOD for different aspect ratios of the reflectors.

respectively. As shown in Figure 36, by comparing samples BJ, EK and FM with the respective control test samples, it appears that reflectors with higher height favours the decrease in dissolved oxygen in the pond more than reflectors with higher breadth.

Conclusion

Waste stabilization pond is a simple way of treating waste water, but its limitation is that it requires large area of land to operate effectively. As such, this research employed the use of solar reflectors to enhance the efficiency of waste stabilization pond. To achieve this, this study varied different sizes of reflector installed at the effluent side of the pond and studied its effect on the physio-chemical and biological properties of the pond. When the influent and effluent respective parameters of SEWSP were observed, the results showed reduction in BOD, total coliform, total suspended solids and increase in temperature, dissolved oxygen, plate count algae and pH. The observations also showed that variation of the dimension of the reflectors affects the properties of the solar enhanced pond. When the width of the reflector is longer than the height of the reflector, it was observed to favor increase in pH, decrease in total coliform and total suspended solids, while reflectors with longer height than width, were observed to favor increase in algal count, temperature, dissolved oxygen and decrease in BOD.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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