EXPLORE iJET International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 3 No. 2, February, 2013

Evaluation of the Influence of Reactor Design on the Treatment Performance of an Optimized Pilot-Scale Waste Stabilization Pond

David O. Olukanni
Department of Civil Engineering, Covenant University, P.M.B. 1023, Ota, Ogun State, Nigeria

ABSTRACT

Waste stabilization pond (WSP) is globally one of the most popular wastewater treatment options due to its high efficiency and low cost. A field scale prototype was designed and scaled down to a pilot-scale model using dimensional analysis in the development of the foot print size. Pilot-scale reactors were built with the specifications produced from literature suggested reactor geometric configurations and experimental study was conducted to evaluate the performance of optimized pilot-scale WSP configurations. The optimized pilot scale WSPs consisted of an anaerobic, facultative, and a maturation stage with varying baffle orientation, length to width ratio, and depth. Comparisons were made on the optimized pilot-scale WSP reactors. The removal performance of the experimental test was based on a number of parameters (Faecal coliform, pH, TDS, and Conductivity). Results showed that the significantly lower cost design displayed slightly better removal performance compared to other WSP design developed from literature data. This paper covers a relevant subject within the field of waste stabilization ponds, namely the representation of the influence of reactor design on the treatment performance of WSP.

Keywords: *Waste Stabilization Pond, Reactor design, Pond-configuration, Performance and Cost.*

1. INTRODUCTION

The construction cost for a standard wastewater treatment plant has been a major barrier for the implementation of modern technologies by local authorities in many African nations (Agunwamba, 1994 and 2001b; Olukanni and Aremu, 2008, Olukanni and Ducoste, 2011). In addition, these technologies require considerable technical expertise, which is often not available in developing nations to successfully operate these treatment facilities. Consequently, developing nations are unable to incorporate these technologies as part of a wastewater treatment master plan. It is therefore imperative to develop treatment systems that are economical and sustainable.

Among the current processes used for wastewater treatment, WSPs have been identified and consistently selected as the unit process of choice for wastewater treatment in developing nations due to their low cost and efficient operation in tropical regions (Mara, 1997; Agunwamba, 2001a; 2004; Abbas et al., 2006; Kaya et al., 2007; Naddafi et al., 2009; Olukanni and Ducoste, 2011). Agunwamba (1994), Babu et al (2010) and Mara (2004) describe a WSP as a chemical reactor used for the reduction of solids, organic matter, and pathogenic organisms. The WSP system usually consists of a series of continuous flow anaerobic, facultative, and maturation ponds. The anaerobic pond is designed for eliminating suspended solids and some of the soluble organic matter while the facultative pond is designed for further removal of the residual organic matter through the activity of algae and heterotrophic bacteria. The final stage of pathogens and nutrients removal takes place in the maturation pond (Olukanni and Ducoste, 2011; Babu, et al., 2010).

WSPs are most suited for tropical and subtropical countries since the sunlight irradiance and ambient temperature are key factors for the WSP process efficiency (Mara, 2004; Mara 2001; Mara and Pearson, 1998). However, the application of a WSP system is limited by its large area requirement (Agunwamba, 1994 and 2001a). In addition, no rigorous experimental assessment of a WSP system that account for cost along with treatment efficiency has been performed (Olukanni and Ducoste, 2011). The goal of any WSP system designer would be to optimize pond design by minimizing cost and land required while maintaining treatment effluent standards.

The treatment of wastewater through WSPs has been an important research area over the past three decades (Olukanni and Ducoste 2011; Agunwamba, 2001a; Mara, 2004). Oke, et al (2006) assessed the physical and engineering properties of a WSP system in Ahmadu Bello University (ABU), Zaria (Nigeria). The WSP system consisted of facultative and maturation ponds in series with hydraulic retention time of 6- and 24-days, hydraulic loading 10.2 and 15.34 ($m^3/m^2.d$) and BOD loading of 0.75 and 4.59 (kg/ha.d), respectively. Influent and effluent wastewater qualities were monitored from their system for one year. Oke et al.'s results revealed an average fecal coliform removal efficiency of 99% and an average reduction in suspended solids by 66%. The ammonia and phosphate concentrations of the raw influent were reduced on average by 88 and 81%, respectively, and an overall COD reduction of 96%. Oke et al (2006) confirmed that the WSPs are suitable under tropical condition as compared to the modern and mechanized treatment systems such as trickling filters and activated sludge, because of the ease of operation and maintenance. Hodgson (2000) achieved similar results of a biological treatment plant at Akuse (Ghana) where the WSP system produced a 65% BOD reduction, 99.99% fecal removal, 46% reduction of suspended solids, and 92% and 94% of ammonia and phosphate removal, respectively.

Previous studies have shown that the WSP treatment efficiency is often hydraulically compromised (Shilton and Mara, 2005; Shilton and Harrison, 2003a; Persson and Wittgren, 2003). Majority of the hydraulic studies on WSPs have been performed on full-scale field ponds, which have transient flows and large surface areas exposed to wind and temperature variations (Marecos and Mara, 1987; Moreno, 1990; Agunwamba, 1992; Fredrick and Lloyd, 1996). However, it was observed that uncontrolled mixing characteristics due to a number of sources such as operating condition and weather variation limit the applicability of the results generated from full scale WSP experimental studies. Consequently, a more controlled environment is needed to explore the parameters that influence WSP performance (Antonini et al., 1983; Shilton and Bailey, 2006)

Recently, Olukanni and Ducoste (2011) performed a study that utilized CFD coupled with an optimization program to optimize the selection of the best WSP configuration based on cost and treatment efficiency for a pilot scale WSP system. The numerical results of monitoring the fecal coliform concentration at the reactor outlet showed that the conventional 70% pond-width baffle pond design was not consistently the best pond configuration as previously reported in the literature. The study concluded that target effluent log reduction can be achieved by reducing the amount of construction material and tolerating some degree of fluid mixing within the pond. Several other designs generated by the CFD/optimization model showed that both shorter and longer baffles, alternative depths, and reactor length to width ratios could improve the hydraulic efficiency of the ponds at a reduced overall construction cost. Olukanni and Ducoste (2011), however, did not experimentally evaluate the CFD model predictions. The main focus of this study was to investigate with pilot-scale experiment, the influence of reactor design on the treatment performance of a pilot-scale WSP.

2. MATERIALS AND METHODS

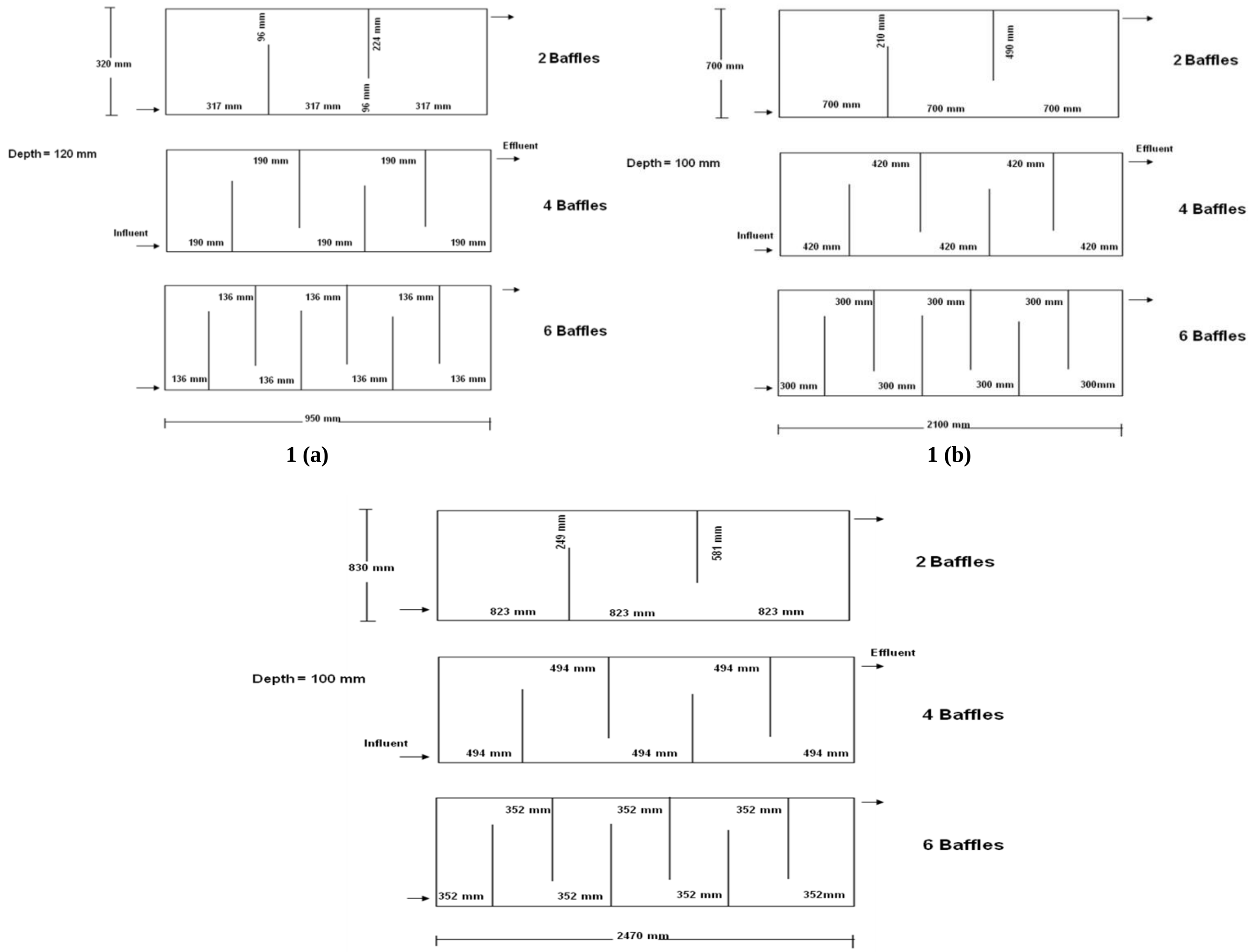
2.1 Study Area

A typical representative community was selected for establishing WSP design parameters that consider the community's population growth and climatic conditions. Covenant University community, within Canaan land in Ota town, is in close proximity to the city of Lagos, Nigeria and was selected in this study. Temperatures are high throughout the year, averaging from 25 ^{0}C to 28 ^{0}C (77–82^{0}F). The institution has undergone an increasing population since its inception in 2002 with a current population of 9114 people and a daily water requirement that was estimated at 136 L/C/day (Olukanni and Ducoste, 2011). Thus, the total quantity of water used by the university community was calculated as 1240 m^3/day. Eighty percent of the household water consumption has been reported as a suitable wastewater design flow and is dependent on the per capita consumption (Mohammed, 2006). This consumption amount produces a wastewater flow rate of 992 m^3/day.

2.2 Design and Construction of a Pilot-scale WSP

A field scale prototype was designed and scaled down to a pilot-scale model using Froude number and dimensional analysis (Bansal, 2003). The WSP system design was based on an expected population growth rate of 4.5% over the next twenty years, which will amount to 17,600 people. The total water consumption for the design period was: 136 L/C/day ×17,600 people = 2394 m^3/day. Thus, the wastewater flow rate used in this study at the pilot-scale was 0.12 m^3/day, which is equivalent to 2394 m^3/day at the full scale. 2 mm galvanized metal gauge plates were used for the design of the reactors including the baffle walls. The cost of material per unit surface area was considered a reasonable way to evaluate the cost since the baffle walls were made with the same material as the reactor and matched the reactor depth. The pilot-scale model was built as a reactor and experiments were performed using raw wastewater from a treatment facility. However, the full scale and consequently pilot-scale design utilize literature data in the development of the foot print size, baffle configuration and length. The initial length to width dimensions of the reactors are (950 mm × 320 mm) ($A_o = 0.3$ m^2), (2100 mm × 700 mm) ($A_o = 1.5$ m^2) and (2470 mm × 830 mm) ($A_o = 2.1$ m^2) for the anaerobic, facultative, and maturation ponds, respectively, as shown in Figure 1.

Table 1 (a-c) displays the configuration of the three sets of pilot-scale reactors for WSP design from Olukanni and Ducoste (2011). It was understood from practice that several other items make up for the construction costs of field ponds such as (land clearing, excavation, leveling, brickwork and masonry etc) that could have been incorporated into the design and construction calculation (Agunwamba, 1991). However, a 2 mm galvanized metal gauge plate was considered for the construction of the pilot-scale reactors including the baffle walls. The cost of material per unit surface area was used as the only measure of the cost since the baffle walls were made with the same material as the reactor and matched the reactor depth. The construction cost excludes labor and other costs associated with the construction of the pilot-scale reactors. The computation of the cost described earlier was sufficient for the study performed.



1 (a)

1 (b)

1 (c)

Figure 1 Different baffle arrangements with 70% pond width anaerobic, facultative and maturation reactors

Three elevated tanks of 1 m^3 each serve as a reservoir for the supply of the wastewater to the pilot-scale reactors in series. These tanks were fed continuously with wastewater from the university wastewater treatment system and a constant head was maintained. The tanks serve the reactors in series at a constant flow rate of 0.12 m^3/day equivalent to 5 liters/hr. The tanks were positioned to supply the wastewater by gravity. The inner walls of the galvanised material were painted with suitable aluminum paint in order to avoid rusting and reaction with the wastewater. Each pond has varying width (w), depth (d) and length (I) based on design. The model was housed within a confined, constant room temperature of 24^0C to minimize temperature changes and exposure to air currents. The sets of reactors in series (anaerobic, facultative and maturation reactors) were sited parallel to each other as shown in Figure 2 (a).

2.3 Design of inlet and Outlet Structures of the WSP

A 25-mm PVC hose was linked with the T-connector that was connected to the raw wastewater holding tank which transfers wastewater into the anaerobic reactor. The inlet and outlet joint was made of ¾ inch socket welded to the designed inlet and outlet position of all the reactors. 25mm PVC hose was used to connect the outlet-inlet of the reactors in series. The sockets were coupled with nipples of their size to allow the fixing of clips in order to make it water tight and also to avoid leakages. Control valves were screwed to position and the inlet and outlet positions were alternated. The outlet structures were connected to two pieces of ½ inch hoses inserted to the mouth of the taps at a vertical height of 1.0 m from the base of the pond to allow effluent to discharge into the effluent tank. The effluent tank has a total surface dimension of 0.64 m long, 0.33 m wide and 0.33 m depth, giving an estimated volume of 0.0697 m^3. The connection of the reactors is as shown in Figure 2 (b).

2.4 Operation of the Pilot-scale Reactors

At the start of operation when the installation was completed, a trial run of the system was conducted. The water holding tanks were filled with fresh water from the tap. This was necessary to ascertain the flow rate of 0.24 m^3/day equivalent to 10 liters/hr for wastewater to flow into the reactors in series as designed. A calibrated bucket was used to determine the volume of water that filled it over a given time. The gate valve from each tank was adjusted until the desired flow of 10 liters/hr was accomplished. This was further divided into two to maintain continuity of flow ($Q = Q_1 + Q_2$) through the Tee-pipe and to allow water to flow into the two series of pond in parallel. The same procedure was followed to have a flow rate of 0.12 m^3/day equivalent of 5 liters/hr flowing simultaneously into the sets of reactors in series by controlling the gate valves. After the trial experiment had been performed, the fresh water was ejected from the tanks and all the reactors. It was at this stage that the raw influent wastewater from the existing wastewater treatment facility of the university was introduced. Figure 2 (a) displays the laboratory set up for the experiment that compares the optimized designs.


2(a) 2(b)

Figure 2 Different laboratory-scale reactors configurations and the inlet/outlet structure of the experimental set up

Table 1a Anaerobic reactor configurations

	Six-baffle 70% pond-width transverse pilot-scale reactor	Four-baffle 70% pond-width transverse pilot-scale reactor	Four-baffle 70% pond-width longitudinal pilot-scale reactor	Type-I pilot-scale reactor	Type-II pilot scale reactor
Cost (₦)	1, 669	1, 582	1, 926	1, 297	1, 234
Area ratio	3:1	3:1	3:1	3:1	2:1
Depth (m)	0.065	0.065	0.065	0.115	0.120
Length (m)	0.950	0.950	0.950	0.717	0.574
Width (m)	0.320	0.320	0.320	0.239	0.287
Baffle length (m)	0.224	0.224	0.665	0.117	0.166
Baffle ratio	70%	70%	70%	49%	58%
Number of baffles	6	4	4	3	2

Table 1(a-c) displays the optimized design for the following 5 WSP designs: 1) six-baffle 70% pond-width transverse, 2) four-baffle 70% pond-width transverse reactor, 3) four-baffle 70% pond-width longitudinal reactor, 4) Type-I pilot scale reactor and 5) Type-II pilot scale WSP designs for anaerobic, facultative and maturation reactors respectively. The naira (₦) cost value, the Nigeria currency was considered in estimating the construction cost of the pilot-scale reactors. This is valued at an approximate rate of ₦160 and ₦220 to one dollar ($) and euro (€), respectively. The price value of galvanized plate in Nigeria for 2mm gauge plate is ₦8,000 which is equivalent of ₦3, 000 per (m) square plate, 4ft by 8ft. The relative low cost is due to the fact that the estimate was based solely on the construction material of a pilot-scale system.

Table 1b Facultative reactor configurations

	Six-baffle 70% pond-width transverse pilot-scale reactor	**Four-baffle 70% pond-width transverse pilot-scale reactor**	**Four-baffle 70% pond-width longitudinal pilot-scale reactor**	**Type-I pilot-scale reactor**	**Type-II pilot scale reactor**
Cost (₦)	5, 563	5, 431	5, 960	5, 091	4, 988
Area ratio	3:1	3:1	3:1	1:1	1:1
Depth (m)	0.045	0.045	0.045	0.048	0.048
Length (m)	2.10	2.10	2.10	1.17	1.17
Width (m)	0.70	0.70	0.70	1.17	1.17
Baffle length (m)	0.49	0.49	1.47	0.97	0.62
Baffle ratio	70%	70%	70%	83%	53%
Number of baffles	6	4	4	2	2

Table 1c Maturation reactor configurations

	Six-baffle 70% pond- width transverse pilot-scale reactor	Four-baffle 70% pond-width transverse pilot-scale reactor	Four-baffle 70% pond-width longitudinal lab-scale reactor	Type-I pilot-scale reactor	Type-II pilot scale reactor
Cost (₦)	7, 360	7, 221	7,772	7, 221	7, 221
Area ratio	3:1	3:1	3:1	3:1	3:1
Depth (m)	0.04	0.04	0.04	0.04	0.04
Length (m)	2.47	2.47	2.47	2.47	2.47
Width (m)	0.83	0.83	0.83	0.83	0.83
Baffle length (m)	0.58	0.58	1.73	0.58	0.58
Baffle ratio	70%	70%	70%	70%	70%
Number of baffles	6	4	4	4	4

3. LABORATORY METHODS

Experimental tests were performed at the Civil Engineering hydraulics laboratory of Covenant University. Grab samples of the wastewater were collected at both the inlet and outlet position of each pond in series for the analysis of Fecal coliform, total dissolved solids, conductivity, and pH. The fecal coliform bacteria for the influent and effluent samples were determined by the membrane filter procedure (method no.: 9222D, APHA, 1998), which uses an enriched lactose medium and incubation temperature of 44.5 ± 0.2°C for selectivity. The total dissolved solid (TDS) and conductivity measurements were performed using the HANNA C99 Multiparameter Bench photometer. The pH was measured using the HANNA Instruments pH meter. The temperature of the laboratory where the pilot-scale experiment was performed was 24^{0}C. The ponds hydraulic retention times were 0.165 day, 0.563 day, and 0.683 day for anaerobic, facultative, and maturation ponds, respectively, based on a flow rate of 0.12 m^3 per day. At this flow rate, the Re number for the three ponds was 304, which suggest that the WSP operates well within the laminar flow regime. The observed influent concentration into the three stage reactors were 59×10^3 per 100 ml for fecal coliform and a mean value of 342 (ppm), 695 (µS), and 7.47 for TDS, conductivity, and pH, respectively.

4. RESULTS AND DISCUSSION

4.1 Evaluation of the Three-Stage WSP Designs

Table 2 displays the comparison of the reactor performance in relation to cost for the fecal log-removal for the following 5 WSP designs: 1) six-baffle 70% pond-width transverse, 2) four-baffle 70% pond-width transverse reactor, 3) four-baffle 70% pond-width longitudinal reactor, 4)Type-I pilot scale reactor and 5) Type-II pilot scale reactor. The 70% pond-width baffle reactor designs was stated by Banda (2007), Shilton and Harrison (2003a), Sperling et al. (2002), Muttamara and Puetpaiboon (1996, 1997) and Kilani and Ogunrombi (1984) as the optimal pond configuration that provides the best WSP treatment efficiency while the Type-I and Type-II are produced from the CFD/optimization model in Olukanni and Ducoste 2011.

It was recognized that the results in Table 2 are almost the same for most of the reactor configurations with little difference in the fecal coliform results. However, the reactor design was able to show how cost could be reduced and still achieve similar effluent quality. The main difference between the three-stage reactors in series is the cost for each of the different set of designs. The Type-1 and Type-II reactors give a lower cost as compared to other literature suggested designs. For the anaerobic reactors, the Type-I design had slightly higher fecal log kill (0.35) as compared to the four-baffle and Six-baffle 70% pond-width lab-scale reactors with fecal log-kill of 0.34 and 0.32, respectively. The Type-II design configuration had a slightly lower fecal log kill as compared to the Type-1 reactor design (0.30 vs 0.35). For the facultative reactors, the same value of log removal was observed for the Four-baffle 70% pond-width transverse reactor and the Type-I optimized design (0.81 log unit). The Type-I design has an additional cost (₦103) over the Type-II design with a fecal inactivation of 0.71 log kill. When investigating the maturation reactor design, the same log removal was achieved for the Type-I, II and four baffle transverse designs with a significant reduction in cost (₦7, 221) over the six baffle 70% transverse and Four-baffle 70% pond-width longitudinal pilot-scale reactors, respectively. The lower cost in the optimized designs was achieved by reducing the baffle length ratio to 50% and reducing the number of baffles to three coupled with using a deeper reactor.

While each design seemed to have produced similar log-inactivation results, Type-I and II configurations led to designs at a reduced cost. A total cost and fecal inactivation results of ₦13, 609 (1.76 log kill) and ₦13, 443 (1.66 log kill) were achieved for the Type-I and II optimized designs as compared to ₦14, 234 (1.75 log kill), ₦14, 592 (1.76 log kill) and ₦15, 658 (1.76 log kill) for other literature arranged designs. It is important to stress that this paper is focused strictly on the evaluation of the influence of reactor design of the treatment performance of an optimized pilot scale WSP with no direct link to its use to field scale WSPs. Model ponds are often subjected to hydraulic flow, operating and boundary conditions that are not encountered in practice. Environmental and flow conditions are critical to the performance of field scale prototype of WSPs (Marcos do Monte and Mara, 1987; Agunwamba, 1992). Hence, the procedures outlined here should be repeated at a larger scale WSP system to evaluate the more complex pattern, this includes additional processes found at field scale WSPs.

The experimental data of the Physico-chemical (PH, conductivity, and Total dissolved solids) parameters in the influent and effluent samples are presented in Tables 3-5 for anaerobic, facultative, and maturation pilot scale WSPs, respectively. The associated cost for each reactor configuration for nutrient removal performance is presented in Tables 3-5. Although the Type-I and II optimized design results and the standard configuration produced similar removal performance, the cost was significantly lower for the Type-I and II optimized systems. Table 3 displays the experimental pH that was measured in all the reactor configurations.

Table 2 Comparison of the reactor performance in relation to cost for the fecal log-removal

Parameter Feacal coliform	Six-baffle 70% pond-width pilot-scale reactor	Four-baffle 70% pond-width transverse pilot-scale reactor	Four-baffle 70% pond-width longitudinal pilot-scale reactor	Type-I pilot-scale reactor	Type-II pilot-scale reactor
Anaerobic reactors					
Experimental Log-removal	0.32	0.34	0.31	0.35	0.30
Cost of construction (₦)	1, 669	1, 582	1, 926	1, 297	1, 234
Facultative reactors					

Experimental Log-removal	0.74	0.81	0.75	0.81	0.76
Cost of construction (₦)	5, 563	5, 431	5, 960	5, 091	4, 988
Maturation reactors					
Experimental Log-removal	0.70	0.60	0.70	0.60	0.60
Cost of construction (₦)	7, 360	7, 221	7, 772	7, 221	7, 221

The measured pH in all the reactor configurations as shown in Table 3 compare well with the expected pH found in the literature (Pearson et al, 1987; Parhad and Rao, 1974). Many chemical and biological reactions in wastewater treatment are pH dependent and rely on pH control. Table 3 shows that as the wastewater moves through the reactors in series, the pH of the effluent from the reactors increases from pH 7.5 to 7.9.

Table 3 Experimental data of PH variation for all the reactor configurations

Parameter pH	Six-baffle 70% pond-width pilot-scale reactor	Four-baffle 70% pond-width transverse pilot-scale reactor	Four-baffle 70% pond-width longitudinal pilot-scale reactor	Type-I pilot-scale reactor	Type-II pilot-scale reactor
Influent pH	7.43	7.47	7.47	7.50	7.50
Anaerobic Effluent pH	7.69	7.54	7.53	7.62	7.58
Facultative Effluent pH	7.81	7.86	7.81	7.80	7.84
Maturation Effluent pH	7.88	7.89	7.85	7.82	7.89
Cumulative cost (₦)	14, 592	14, 234	15,658	13,609	13,443

Table 4 shows that the experimental data of total dissolved solids in the influent was in the range of 340-343 (Avg = 341) ppm while the effluent concentration was in the range of 273-315 ppm, respectively. The Type-I and II configurations performed well when compared to other configurations with a TDS effluent value of 275 ppm for the Type-I and 293 ppm for the Type-II reactors.

Table 4 Experimental data of TDS removal for all the reactor configurations

Parameter TDS (ppm)	Six-baffle 70% pond-width pilot-scale reactor	Four-baffle 70% pond-width transverse pilot-scale reactor	Four-baffle 70% pond-width longitudinal pilot-scale reactor	Type-I pilot-scale reactor	Type-II pilot-scale reactor
Influent TDS	342	340	340	343	343
Anaerobic Effluent TDS	340	334	333	338	338
Facultative Effluent TDS	326	313	309	315	318
Maturation Effluent TDS	302	273	285	275	293
Percentage Removal (%)	12	20	16	20	15
Cumulative Cost (₦)	14, 592	14, 234	15,658	13,609	13,443

Table 5 shows that the anaerobic reactor displayed the least reduction in conductivity values when compared to the performance of the maturation reactors. The low reduction in conductivity in the anaerobic reactor is not surprising since the anaerobic pond is designed to eliminate suspended solids while the final stage of nutrients removal takes place in the maturation pond (Olukanni and Ducoste, 2011; Mara, 2004; Babu, et al., 2010). The four-baffle 70% pond-width transverse pilot-scale WSP system produced the optimal conductivity reduction for the entire configuration (557 µS) followed by the Type-I optimized design with a conductivity value of 562 µS. At present, the conductivity of wastewater is one of the important parameters used to determine the suitability of wastewater for irrigation (Crites and Tchobanoglous, 1998; Metcalf and Eddy 2003).

Table 5 Conductivity experimental data for all the reactor configurations

Parameter Conductivity (µS)	Six-baffle 70% pond-width pilot-scale reactor	Four-baffle 70% pond-width transverse pilot-scale reactor	Four-baffle 70% pond-width longitudinal pilot-scale reactor	Type-I pilot-scale reactor	Type-II pilot-scale reactor
Influent conductivity	700	690	690	697	697
Anaerobic Effluent conductivity	693	682	662	689	691
Facultative Effluent conductivity	656	627	642	653	639
Maturation Effluent conductivity	625	557	581	562	598
Percentage Removal (%)	11	19	16	19	14
Cumulative cost (₦)	14, 592	14, 234	15,658	13,609	13,443

The result of the effluent quality tested for pH, conductivity, and TDS showed that the WSPs performed well with different levels of pollutant removal. The significance of the evaluation is that regulators and designers can consider other options of reactor design configurations with a high degree of confidence to develop an optimal WSP system design that meets the treatment efficiency at a reduced cost. The results showed that the 70% pond-width baffles is not consistently the best pond configuration as previously reported in literature. Also, the Type-I and II reactor results showed that both shorter and longer baffles may improve the process efficiency of the WSP system with different individual pond foot prints. Furthermore, the results of this research will directly impact the possible design decisions that wastewater treatment engineers must make related to WSPs design in developing nations.

5. CONCLUSION

The experimental results have shown that reactor designs can influence the treatment performance of a pilot scale WSP system. The limitation of the entire study is seen in the sence that, though, hydraulic similarity can be achieved in a pilot scale reactors intended to represent a full-scale unit, other physical and biochemical phenomena could not be represented. For instance, sunlight penetration along depth, temperature gradients, algae presence, gas transfer, surface wind shear, variable flow rate, variable climatic condition, sludge deposits, and removal of other nutrient parameters that may impact WSP design decisions. These are also essential items that define pond performance. The incorporation of these parameters depends on various processes such as algae uptake, sedimentation, vaporization, and denitrification which are more complex to evaluate as several other pragmatic steps would be required. In addition, it would also be difficult to test the results of such complexity. However, it is clear that the designs have the potential to predict reasonably well the physics, chemistry, and biological processes occurring in the WSP.

Cost implications have been addressed. While each design seemed to have produced similar results, the Type-I and II designs were significantly lower in cost. In view of the experimental results obtained from the pilot-scale waste stabilization ponds, future research is required:

A similar study of additional physics/chemistry and biochemical components of the process at the full scale needs to be performed. The data obtained from the full-scale construction of WSP would allow the sustainability of the technology to be assessed under real conditions. The full-scale experimentation result would serve as guide to physical planning units of institutions for the design of treatment systems. This type of experience would provide valuable insight on the real investment and operational costs as well as the real requirements of operation and management for this technology that will enhance environmental quality and protection.

ACKNOWLEDGEMENT

The author would like to acknowledge the Management of Covenant University through the Center for Research and Development who provided the platform and part of the grant support for the construction of the pilot-scale pond for the experiments.

REFERENCES

[1] Abbas, H., Nasr, R. and Seif, H., 2006. Study of waste stabilization pond geometry for wastewater treatment efficiency. Ecological Eng, 28: 25-34.

[2] Agunwamba, J. C., 1991. Simplified optimal design of waste stabilization pond, Water, Air and Soil pollution, 59: 299-309.

[3] Agunwamba, J. C., 1992. Field pond performance and design evaluation using physical models. Water resources, 26 (10), 1403-1407.

[4] Agunwamba, J. C., 1994. Capacity expansion of waste stabilization ponds. Journal of Indian association for environmental management, vol. 21(1): 17-23.

[5] Agunwamba, J.C., 2001a. Effect of tapering on the performance of waste stabilization ponds.Wat. Res, 35(5): 1191-1200.

[6] Antonini, G., Brunier, E., Houang, P., Schaegger, M., Zoulalian, A., 1983. Analyse des D.T.S dans les systemes hydrauliques de type lagunaire. Scale-Up of Water and Wastewater Treatment Processes. Schmidtke, N. and Smith, D. (Eds). Butterworth Publishers; Edmonton, Canada; 73-86.

[7] American Public Health Association (APHA), 1998. Standard Methods for the Examination of Water and Wastewater (20th ed.), APHA, Washington, DC.

[8] Babu, M. A., Hes, E. M. A., van der Steen, N. P., Hooijmans, C.M., Gijzen, H. J., 2010. Nitrification rates of algal–bacterial biofilms in wastewater stabilization ponds under light and dark conditions. Ecological Eng, 36: 1741–1746

[9] Bansal, R. K., 2003. Fluid Mechanics and Hydraulic Machines 8th ed., Laxmi Publications Ltd, New Delhi. Pp 524-550.

[10] Crites, R. and Tchobanoglous, G., 1998. Small and Decentralized Wastewater Management Systems. McGraw-Hill Series, San Francisco, USA.

[15] Hodgson, O.A., 2000. Treatment of domestic sewage at Akuse (Ghana), Water SA., 26, 413-416.

[16] Kaya, D., Dilek, F. B., Gokcay, C. F., 2007. Reuse of lagoon effluents in agriculture by post- treatment in a step feed dual treatment process. Desalination, 215: 29-36.

[17] Kilani, J. S., Ogunrombi, J. A., 1984. Effects of baffles on the performance of model waste stabilization ponds. Water Research, 18 (8) 941-944.

[18] Mara, D. D., 1997. Design Manual for Waste stabilization ponds in India. Lagoon Technology International Ltd., Leeds, England.

[19] Mara, D., Pearson, H., 1998. Design Manual for Waste Stabilization Ponds in Mediterranean Countries, Leeds Lagoon Technology International Ltd. Leed, UK.

[20] Mara, D. D., 2001. Appropriate wastewater collection, treatment and reuse in developing countries Proceedings of the Institutions of Civil Engineers, London. Pp. 299-303.

[21] Mara, D. D., 2004. Domestic Wastewater Treatment in Developing Countries. Earthscan Publications, London, England, ISBN 1844070190

[22] Marecos do Monte, M.H.F., Mara, D.D., 1987. The hydraulic performance of waste stabilization ponds in Portugal. Water Science and Technology, 19 (12), 219-227.

[23] Mohammed, B., 2006. Design and Performance Evaluation of a Wastewater Treatment Unit AU J.T. 9 (3), 193–198.

[24] Metcalf and Eddy 2003. Wastewater Engineering: Treatment and Reuse, McGraw-Hill Series in Civil and environmental engineering, 4th ed. New York, USA.

[25] Moreno, M., 1990. A tracer study of the hydraulics of facultative stabilization ponds, Water Research 24(8), 1025–1030.

[26] Naddafi, K., Hassanvand, .A. S., Dehghanifard, E., Faezi Razi, D., Mostofi, S., Kasaee, N.,Nabizadeh, R, Heidari,

[27] M., 2009. Performance evaluation of wastewater stabilization ponds in Arak-Iran, Iran. J. Environ. Health. Sci. Eng., Vol. 6, No. 1, pp. 41-46.

[28] Oke, I. A., Otun, J. A., Okuofu, C. A., Olarinoye, N.O., 2006. Efficacy of biological treatment plant at Ahmadu Bello University Zaria, Research Journal of Agriculture and Biological Sciences, 2(6), 452-459.

[29] Olukanni, D. O., Aremu, S.A., 2008. Water hyacinth based wastewater treatment system and its derivable bye-product. Journal of research information in Civil Engineering, Vol.5, No.1 43-55.

[30] Olukanni, D.O., Ducoste, J.J., 2011. Optimization of Waste Stabilization Pond Design for Developing Nations using Computational Fluid Dynamics. Ecological Eng, 37: 1878–1888.

[31] Parhad, N.M. and Rao, N.U., 1974. Effect of pH on survival of Escherichia coli. Journal of the Water Pollution Control Federation, 46 (5) 980-986.

[32] Pearson, H. W., Mara, D. D., Konig, A., De Oliveira., and Silva, S.A., 1987. Water column sampling as a rapid and efficient method of determining effluent quality and performance of waste stabilization ponds. Water Science and Technology, 19 (12), 100-119.

[33] Persson, J., Wittgren, H. B., 2003. How hydrological and hydraulic conditions affect performance of Ponds. Ecological Eng. 21: 259–269.

[34] Shilton, A., Harrison, J., 2003a. Guidelines for the Hydraulic Design of Waste Stabilization ponds. Institute of Technology and Engineering, Massey University. Palmerstone North.

[35] Shilton, A.N., Mara, D.D., 2005. CFD (computational fluid dynamics) modeling of baffles for optimizing tropical waste stabilization ponds system. Water Science and Technology 51(12) 103-106.

[36] Shilton, A., Bailey, D., 2006. Drogue tracking by image processing for the study of laboratory scale pond Hydraulics. Flow Measurement and Instrumentation, 17 (2006) 69–74.