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The Effect of Hydraulic Jump on the Performance of Waste Stabilization Ponds

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Abstract

One of the simplest forms of biological treatment processes used in the tropics is the waste stabilization pond (WSP). The relative simplicity and low operating cost of the WSP make it the preferred technology for handling, treatment and disposal of municipal waste for small communities. However, its use in urban areas is limited because of its large area requirement. Hence, the research is aimed at investigating if the introduction of hydraulic jump in the Waste Stabilization Pond can increase treatment efficiency and consequently reduce the land area requirement. Thus, WSPs with varying number of hydraulic jumps were constructed using metallic tanks. The hydraulic jumps were created to introduce turbulence thereby adding dissolved oxygen in the pond. Wastewater samples collected from different points (including inlets and outlets) in the ponds were examined for physio-chemical and biological characteristics for a period of ten weeks. The parameters examined were dissolved oxygen, coliform, biochemical oxygen demand (BOD_5), chemical oxygen demand and tracer studies. The efficiencies of the WSPs with respect to these parameters fluctuated with variations in the atmospheric conditions and varying discharge with the highest efficiency obtained from the pond with two hydraulic jumps. The research revealed that the cost of wastewater treatment using hydraulic jump enabled WSP was approximately one and a half times lower than the conventional WSP for the same efficiencies.

Introduction

Waste Stabilization Ponds (WSPs) are popular wastewater treatment system used for the removal of organics and pathogenic organisms. It consists of a large, shallow earthen basin in which wastewater is retained long enough for natural purification processes to provide the necessary degree of treatment. High efficiencies of WSP have been reported with respect to removal of intestinal nematode [1-3], organic compounds and faecal bacteria [4]. In addition, it is also economical [5]. It is simple to construct, operate and maintain and it does not require any external energy input.

However, the main constraint against selecting this technology is not land cost but land availability. WSPs are limited in application by their large area requirement [6]. In the past, researches have been conducted to improve pond efficiency, thereby maximizing land use by solar enhanced wastewater treatment in waste stabilization ponds [7], using optimization techniques [8], using recirculation stabilization ponds in series [9], step feeding [9], incorporating an attached growth system [10] and more accurate estimation of pond design parameters [11-17]. In addition, higher pond depths have been investigated for reduction of the pond surface area [18-21]. Agunwamba (2001) investigated the effect of tapering on WSP performance. However, no work seems to have been done on the utilization of ponds with hydraulic jump.

A Hydraulic jump occurs when flow changes from a high velocity, low depth zone to a low velocity, high depth zone in a short distance. The rapid flowing liquid is abruptly slowed and increases in height converting some of the flow's initial kinetic energy into an increase in potential energy, with energy irreversibly lost through turbulence to heat. A hydraulic jump occurs when the upstream flow is supercritical. There must be a flow impediment for hydraulic jump to occur. The downstream impediment could be a weir, a bridge abutment, a dam or simply channel friction. Water depth increases during hydraulic jump. A common example of a hydraulic jump is the roughly circular stationary wave that forms around the central stream of water. The jump is at the transition between the points where the circle appears still and where the wave is visible.

This study on the effect of hydraulic jump on the performance of waste stabilization pond is therefore undertaken to determine whether the introduction of hydraulic jump would increase the efficiency of the treatment process and hence the reduction in land area requirement of waste stabilization ponds. To this end the specific objectives are as follows:

1. To determine the effect of hydraulic jump on the efficiency of waste stabilization pond for sewage treatment.
2. To determine the effect of hydraulic jump on other pond parameters.
3. To study the hydraulic properties of the ponds using tracer studies.

Experimental Methodology and Set up

Study area

Located at the north-eastern end of the University campus about 800m from the junior staff quarters, the treatment plant at Nsukka consists of a screen (6mm bar racks set at 12 mm centres) followed by two Imhoff tanks, each measuring about 6.667 m x 4.667 m x 10m, and two facultative waste stabilization ponds. Sludge is discarded from the Imhoff tank once every ten days onto one of the four drying beds, so that the beds are loaded at 40 days interval. The beds have a total area of 417 m^2. Although its efficiency has deteriorated, its effluent is used for uncontrolled vegetable irrigation by some village dwellers. The poor effluent quality is also partly attributable to overloading because of population growth.

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Collection of samples and description of experimental setup

Sewage samples were collected from the University of Nigeria, Nsukka stabilization pond for laboratory analysis. Three ponds were constructed with iron sheet for the experiment. Two out of the three ponds were constructed with steps which enabled the introduction of hydraulic jumps. The third pond was without any step hence no hydraulic jump. The setup also included an overhead storage tank (1.2m×1.5m×1.5m) and a sewage storage tank (1.2m×0.5m×0.5m). The detailed description of the various ponds are explained in (Table 1) and graphically represented in (Figure1 and Figure 2)

The first pond was made without hydraulic jump to serve as control while the other ponds were designed and constructed with one and two hydraulic jumps respectively.

Methods of Analysis

All sewage samples collected for laboratory analysis were analyzed

Experimental Pond	Size(m)	Location of Step(s)	Depth of step(s)	Characteristics	Purpose
0	0.4 x 0.4 x 0.8	No step	Not applicable	No hydraulic jump	Control
1	0.4 x 0.4 x 0.8	At inlet	0.4m	One hydraulic jump	Measure the effect of hydraulic jump
2	0.4 x 0.4 x 1.6	At inlet and 0.8m from the inlet	0.4m	Two hydraulic jumps	Measure the effect of hydraulic jumps

Table 1: Detailed Description of the Various Ponds.

Figure 1: Experimental Setup. The overhead storage tank (1.2m×1.5m×1.5m) was usually filled intermittently with sewage from the University of Nigeria, Nsukka, Nigeria facultative WSP through an underground pipe with a pump. The sewage storage tank (1.2m0.5m×0.5m) gets its supply from the overhead storage by gravity flow through a pipe connecting both. Both tanks were usually filled to supply the three ponds with sewage wastewater. The samples were collected at an interval of twice per week from the three ponds for ten weeks. Samples were collected from one pond at a time. For Pond 0, samples (0a and 0b) were collected at both the inlet and outlet. The wastewater flows into the experimental ponds through an inlet (19mm diameter) pipe. The wastewater flows out of the pond through a slit. For Pond 1 and Pond 2, five samples each were collected at intervals of 160mm at different points along the channels. These points corresponded to 1a, 1b, 1c, 1d, 1e, 2a, 2b, 2c, 2d and 2e for Pond 1 and Pond 2 respectively. Thereafter, samples collected from the three ponds were taken for laboratory analysis to determine the concentration of BOD, COD, total Coli form and Dissolved Oxygen. Date of collection of sample was recorded for the duration of the research.

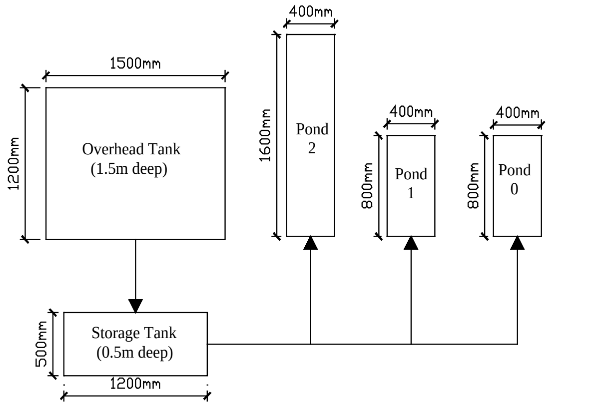

Figure 2: Schematic Diagram of Experimental Setup.

Figure 3: Addition of Commom Salt for Tracer Studies.

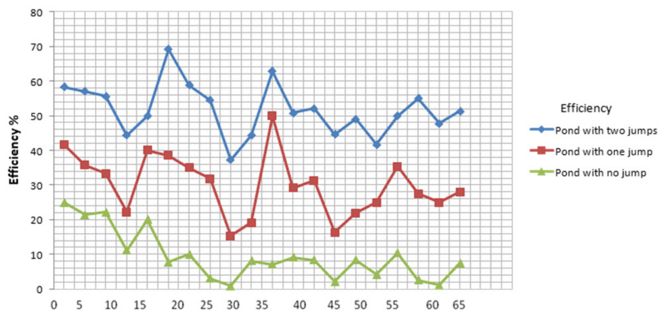

Figure 4: Efficiency of BOD removal versus time.

immediately they were brought into the sanitary laboratory of the University of Nigeria, Nsukka. Owing to time limitation, samples which could not be analyzed on the collection day were preserved in the refrigerator and analyzed the following day. All the analysis was based on the standard methods [22].

Tracers studies

Common salt was used as tracer for this research. 5g of common salt was added to the sewage in the sewage tank and properly stirred. Samples were collected at the outlet of the each pond consequent upon the outflow from the sewage tank. Samples were collected at regular intervals while the first sample was collected just before the

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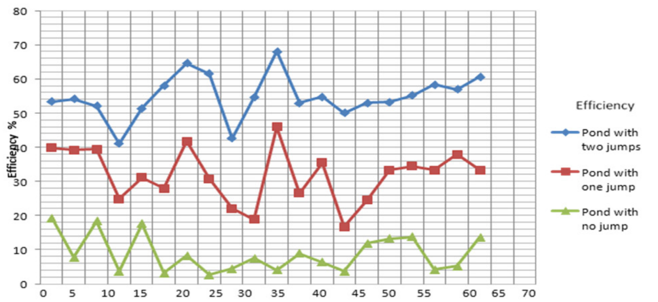

Figure 5: Efficiency of COD removal versus time.

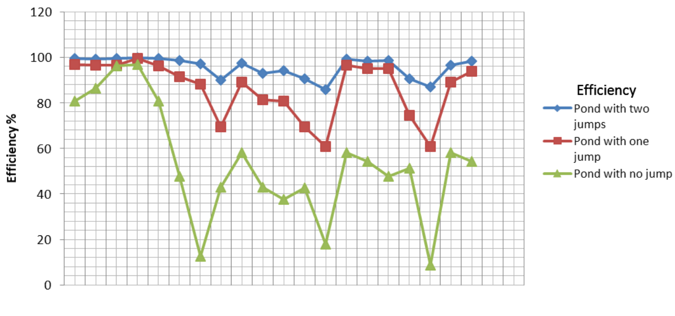

Figure 6: Efficiency of Coliform removal versus time.

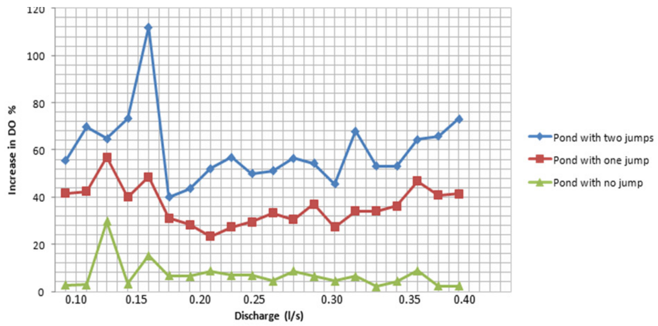

Figure 7: % Increase in DO versus discharge.

theoretical detention time. The process was continuous as equivalent inflow was simultaneously allowed from the overhead tank into the sewage tank. A blank sample was usually collected before the addition of the common salt. The above process was repeated for the other values of discharges studied (Figure 3).

Results

The experimental results are presented in Figures 3 – 8. Figures 3 – 5 depict temporal variations of treatment efficiencies of the control pond and hydraulic jump enabled ponds with respect to coliforms, BOD and COD. (Figure 7) show the effect of the hydraulic jump in the addition of dissolved oxygen. (Figure 8 and Figure 9) shows the variations of treatment efficiencies of hydraulic jump enabled ponds with respect to BOD and COD considering the height of jump.

Effects of hydraulic jump on treatment efficiency

Biochemical oxygen demand: From the results obtained from the laboratory analysis, pond 2 was observed to record the highest efficiency of BOD removal followed by pond 1 and pond 0 as shown in (figure 4 and Figure 8). This was as a result of the two hydraulic jumps in the pond. Though pond 1 and pond 0 have the same geometry, pond 1 shows a higher efficiency of BOD removal than pond 0 due to the single hydraulic jump. All three ponds were exposed to the same discharge per sampling period. The minimum outlet concentrations of BOD in pond 2, pond 1 and pond 0 were 21.6mg/l, 34.8mg/l and 46.8mg/l respectively. Also, the maximum outlet concentrations of BOD in pond 2, pond 1 and pond 0 were 150mg/l, 210mg/l and 240mg/l respectively.

Chemical oxygen demand: From the results obtained from the laboratory analysis, pond 2 was observed to record the highest efficiency of COD removal followed by pond 1 and pond 0 as shown in figure 4 and figure 8. Though pond 1 and pond 0 have the same geometry, pond 1 shows a higher efficiency of COD removal than pond 0 due to the single hydraulic jump. All three ponds were exposed to the same discharge per sampling period. The minimum

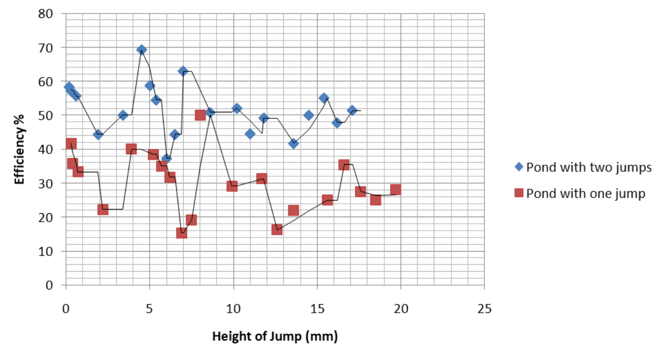

Figure 8: Efficiency of BOD removal versus Height of Jump.

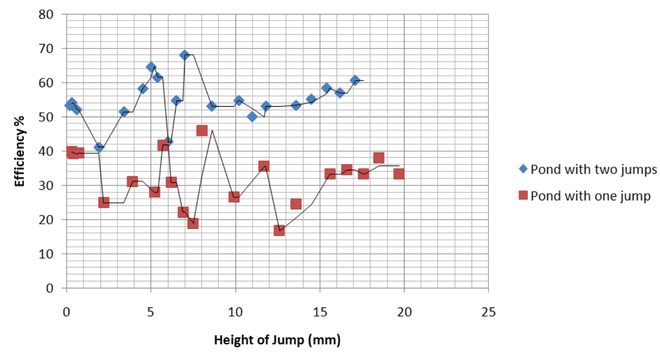

Figure 9: Efficiency of COD removal versus Height of Jump.

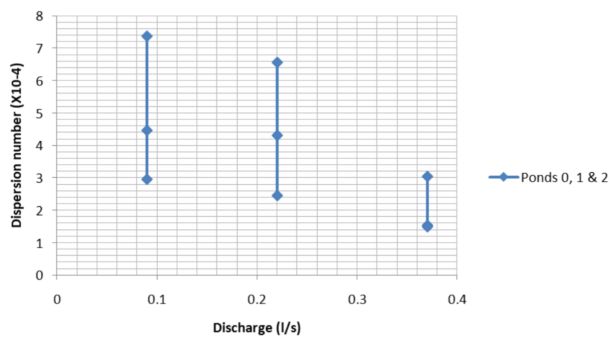

Figure 10: Dispersion number versus Discharge.

S/N	Criteria	Conventional Ponds			Hydraulic Jump Enabled Ponds	
		Pond O (Control)	Pond 1	Pond 2	Pond 1	Pond 2
1	Land Area	0.32 m^2	0.32 m^2	0.64 m^2	0.22 m^2	0.37 m^2
2	Cost of Land	$ 6.26	$ 6.26	$ 12.53	$ 4.24	$ 7.29
3	Area of metal sheet	1.12 m^2	1.12 m^2	2.24 m^2	0.76 m^2	1.30 m^2
4	Total cost of construction with sheet	$ 47.95	$ 47.95	$ 86.55	$ 32.49	$ 50.36

Table 2: Comparison between Pond with Hydraulic Jump(s) and the Conventional Pond that will achieve the same Bacteria Reduction.

outlet concentrations of COD in pond 2, pond 1 and pond 0 were 40.8mg/l, 65.3mg/l and 93.8mg/l respectively. Also, the maximum outlet concentrations of COD in pond 2, pond 1 and pond 0 were 312mg/l, 400mg/l and 512mg/l respectively.

Coliform: After the treatment of wastewater using hydraulic jump ponds, the results obtained from the laboratory analysis were plotted as shown in figure 5. Pond 2 was observed to record the highest efficiency of coliform removal followed by pond 1 and pond 0. Pond 1 and pond 0 have the same geometry, however, pond 1 shows a higher efficiency of coliform removal than pond 0 due to the single hydraulic jump. All three ponds were exposed to the same discharge per sampling period. The minimum outlet most probable number of coliform in pond 2, pond 1 and pond 0 were 3 per 100ml, 9 per 100ml and 21 per 100ml respectively. Also, the maximum outlet concentrations of coliform in pond 2, pond 1 and pond 0 were 43 per 100ml, 150 per 100ml and 1100 per 100ml respectively.

Dissolved oxygen: The dissolved oxygen in the three ponds was found to increase from the inlet to the outlet of the ponds as shown in (Figure 7). However, pond 2 was notably higher than that of pond 1 and pond 0. This increase was observed for all the discharges of the sewage from the inlet to the outlet. This was as a result of the turbulence caused by the hydraulic jump thereby allowing for oxygen transfer between the atmosphere and the wastewater as shown in (Figure 8 and Figure 9).

Dispersion number: From the results obtained from the tracer studies of the three ponds, pond 2 was observed to record the lowest dispersion number for all discharges studied indicating a high degree of axial dispersion. This therefore implies that pond 2 has the highest efficiency of treatment. Furthermore, pond 1 recorded a low dispersion number however; its dispersion number was higher than that of pond 2 indicating a high efficiency of treatment next to pond 2. Pond 0 recorded the lowest efficiency of treatment compared to ponds 2 and 1 (Figure 10). All three ponds were exposed to the same discharge during tracer studies. The minimum dispersion numbers for pond 2, pond 1 and pond 0 were 0.000148, 0.000153 and 0.000305 respectively. Also, the maximum dispersion numbers for pond 2, pond 1 and pond 0 were 0.000296, 0.000447 and 0.000737 respectively.

Cost Benefit Analysis: An analysis was done in order to compare the cost benefit of the hydraulic jump ponds with the conventional waste stabilization pond (Table 2).

Conclusion

From the experimental results obtained from the Water and Environmental Engineering laboratory of the University of Nigeria, Nsukka, it is hereby proved that the introduction of hydraulic jump in the waste stabilization pond has significant effect on wastewater treatment. Results of samples collected from pond 2, pond 1 and pond 0 shows that treatment was higher in pond 2 due to higher oxygen transfer followed by pond 1. Pond 0 had the least treatment due the absence of hydraulic jump.

Also, the cost benefit analysis carried out proved that ponds with hydraulic jumps will require less land area than the conventional pond.

Recommendations

Based on the findings of this research, it is recommended that waste stabilization ponds be constructed with steps in order to increase the rate of microbial activities in the pond thereby increasing the pond performance. This will help to reduce the land area requirement of ponds.

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