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Research Article

Design, Construction and Performance Evaluation of a Model Waste Stabilization Pond

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Abstract: The study aimed at the design, construction and performance evaluation of a model Waste Stabilization Pond (WSP). The WSP comprised of one facultative pond and three maturation ponds all in series. The influent of the WSP after filtration through the lined sandy loam media (obtained from the premises of Federal University of Technology, Owerri, Nigeria) had the BOD reduced to 22 mg/L from 356 mg/L indicating a 93.8% removal level. A faecal coli form count (fc) of the influent sample gave 1×10^8 fc/100 mL, whereas the effluent gave 10 fc/100 mL which was 99.9% fc removal. The value of 150 mg/L of the Total Suspended Solids (TSS) for the influent was reduced to 26 mg/L for the effluent after treatment. It was concluded that the effluent from the WSP was within the limits of Federal Environmental Protection Agency (FEPA) standard of 30 mg/L for TSS, 30 mg/L for BOD_5 and 400 fc/100 mL for faecal coli form thus making the waste water safe for discharge into surface water as well as its use for irrigation after treatment. The sandy loam soil media was found to be non-promising earlier in the removal process until it was lined with polyethylene material. A clay media was therefore recommended.

Keywords: Construction, design, evaluation, model, performance, waste stabilization pond

INTRODUCTION

As urban and industrial development increases, the quantity of waste/water generated also increases. These wastes pose a serious threat to public health when they are not treated and not readily disposed of.

Waste Stabilization Ponds (WSP) often referred to as oxidation ponds or lagoons is a method of wastewater treatment, suitable for use in hot climates. It consists of series of shallow lakes (ponds namely anaerobic, facultative and maturation) through which waste water flows. Treatment occurs through natural, physical, chemical and biological processes and no energy or machinery is required except sun light energy. According to Arthur (1983), stabilization ponds are the preferred waste water treatment process in developing countries where land is often available at reasonable cost and skilled labour is in short supply.

Usually, anaerobic and facultative ponds are designed for BOD removal and maturation ponds for pathogen removal although some BOD removal occurs in maturation ponds and some pathogen removal in anaerobic and facultative ponds (Mara *et al*., 1998).

The most appropriate wastewater treatment is that which will produce an effluent meeting the recommended microbiological and chemical quality guidelines both at low cost and with minimum operational and maintenance requirements (Arar, 1988).

A World Bank report (Shuval *et al*., 1986) endorsed the concept of stabilization as the most suitable wastewater treatment system for effluent use in agriculture.

The choice of a site to construct a pond system requires an area where the water table is deep and the soil is heavy and impermeable. Silt or clay soils are ideal for pond foundations and construction. Building ponds over coarse sands, gravels, fractured rock or other materials, that will allow effluent to seep out of the pond or allow groundwater to enter in, should be avoided (Agunwamba, 2000).

Generally, ponds should be located at least 200 m (preferably 500 m) downwind from the community they serve and away from any likely area of future expansion (Mara *et al*., 1998).

Therefore, the objectives of the study are to design and construct a model waste stabilization Pond and to evaluate its performance.

METHODOLOGY

The study area is the hostels (B, C and D) of the Federal University of Technology Owerri (FUTO) Imo State Nigeria located on longitude 7°E and latitude 5.4°N. The topography of the site varies from 100m to 125 m respectively. The temperature of the area averages around 32°C and rainfall starts in April and ends in October. The heat from the sun is very intense all year round but more during the dry season.

Typical wastewater flow rates (average) for campuses (Schools, Boarding) as stipulated by Qasim

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(1995) are approximately 80% of water demands. The population of students for the design was 1500 with daily water requirement for each student taken as 130 L/day.

The most important design parameter for the facultative and maturation ponds used includes:

- The mean air temperature in the coldest month obtained from the Meteorological Centre in Owerri airport of 28.3°C.
- Wastewater flow rate (q) design value is about 80% of the water consumption with a design population of 1500 and a daily water requirement of 130 L/day per student, total quantity of water used by the population (Qp) is given by:

Qp = 1500×130
Qp = 195,000 L/day
Qp = 195 m^3/day
q_p = 80% of water consumed
q_p = 0.8×195.0
q_p = 156 m^3/day

The Biochemical Oxygen Demand (BOD_5) after a 5 day incubation period at 20°C for the influent wastewater of 356 mg/L was measured.

The wastewater used in the study was obtained from the drainage systems behind hostels B, C and D. The characteristics of the wastewater collected before, during and after treatment in WSP were tested in the laboratory for faecal coliform count, BOD_5 and total suspended solids.

The Federal Environmental Protection Agency (FEPA) Standards for wastewater discharge into surface waters and for irrigation was used to compare with the obtained results.

RESULTS

Design of facultative pond: The equation below was used in determining the area of the facultative pond (Mara *et al*., 1998).

$$A = q_p/DK_T\,[Li\text{-}Le/Le] \quad (1)$$

A = Area of pond
q_p = Wastewater flow rate (156 m^3/day)
D = Depth of pond
Li = BOD of influent (356 mg/L)
Le = Effluent BOD
K_T = Rate constant and is given as:

$$K_T = K_{20}\theta^{T-20} \quad (2)$$

K_{20} = for raw wastewater is 0.3 per day and the Le value should be in the range of 50-70 mg/L for a pond depth, D of 1.5m (Mara *et al*., 1998), T = average temperature of the coldest month (28.3°C); θ = Arrhenius constant and is usually between 1.05 - 1.09 for waste water treatment in stabilization ponds.

Substituting Eq. (2) into (1) and solving:

$$A = 156\ (356 - 60)/60\times1.5\times0.3\ (1.05)^{28.3-20}$$
$$A = 1140.73\ m^2$$

Detention time:

$$t_f = AD/q_P \quad (3)$$

f_t = 1140.73×1.5/156
f_t = 10.96 days
t_f = 11 days

The length (L) and breadth (B) ratio of a facultative pond is usually 3.1.

Area of pond = $3B^2$
1140.73 = $3B^2$
B = 19.5 m
L = 3B = 58.5 m

The dimensions of the pond are length = 58.5 m, Breadth = 19.5 m and depth = 1.5 m

Design of maturation pond: The following design considerations were made:

- The minimum acceptable value of the detention time in maturation ponds (t_m) is 3 days, below which the danger of hydraulic short-circulating becomes too great
- The value of $t_m \leq t_f$
- The surface BOD loading in the first maturation pond does not exceed the surface BOD loading in the facultative pond

The reduction of faecal bacteria for the WSP system is given by:

$$N_e = N_i/(1 + K_bt_a)\ (1 + K_bt_f)\ (1 + K_bt_m)^{\,n} \quad (4)$$

N_e = Number of faecal coliform/100 mL of effluent
N_i = Number of faecal coliform/100 mL of influent
K_b = First order rate constant for removal, (per/day)

$$K_b = 2.6\ (1.19)^{T-20} \quad (5)$$

t_f = Detention time in facultative pond
t_m = Detention time in maturation pond
t_a = Detention time in anaerobic pond
n = Number of maturation ponds

Since use was made of the facultative and maturation ponds, Eq. (4) becomes:

$$N_e = N_i/(1+ K_bt_f)\ (1+ K_bt_m)^{\,n} \quad (6)$$

For the design, $N_i = 1\times10^8$ fc/100 mL; t_f = 11 days and $t_m \geq 3$ days and $t_m \leq t_f$ we assume t_m = 4 days and n = 2; $K_b = 2.6(1.19)^{28.3-20} = 11.02$/day.

Substituting the above values into Eq. (6) gives a N_e = 402.61 fc/100 mL.

The value of N_e = 402.61 fc/100 mL signifies that the two maturation pond and I facultative pond will treat the wastewater but the effluent cannot be safely discharged into the environment (based on FEPA standard at 400 fc/100 mL).

With n = 3 and all other parameters remaining the same, the value of N_e in Eq. (6) is 8.93 fc/100 mL.

The value of N_e = 8.93 fc/100 mL signifies effluent standard that is less than 400 fc/100 mL. Thus, three (3) maturation ponds and one (1) facultative pond are satisfactory for the treatment of the wastewater and safe discharge to the environment.

$$\text{Area of maturation pond} = q_p t_m / D_m \tag{7}$$

Dm = Dept of maturation pond = 1.2 m
Area = 156×4/1.2 = 520 m^2

Each of the ponds will have an area of 520 m^2.
Length (L) to breadth (b) ratio is 3:1

Area of pond = $3b^2$
520 = $3b^2$
b = 13.2 m
L = 3b = 39.6 m

The dimensions of the pond are Length = 39.6 m, Breadth = 13.2 m and Depth = 1.2 m

Modeling of facultative and maturation ponds: The daily flows of wastewater and dimensions in/of the model were computed using dimensional analysis and Froude number method.
By equating Froude numbers, F_r:

$$F_{rm} = F_{rp} \tag{8}$$

where the subscripts m and p are model and prototype respectively:

$$Fr = v/\sqrt{Lg} \tag{9}$$

where,
v = Flow velocity
L = Length
g = Acceleration due to gravity

Thus,

$$\left[\frac{v}{\sqrt{Lg}}\right]_m = \left[\frac{v}{\sqrt{Lg}}\right]_p \tag{10}$$

Since g is constant:

$$\frac{vm}{vp} = \left[\sqrt{\frac{Lm}{Lp}}\right] \tag{11}$$

Using a scale of 1: 30
Area - Length - scale ratio is given by:

$$\frac{Am}{Ap} = \left[\frac{Lm}{Lp}\right]^2 = \left[\frac{1}{30}\right]^2 \tag{12}$$

Length - scale ratio is given by:

$$\frac{Bm}{Bp} = \left[\frac{Lm}{Lp}\right] = \left[\frac{1}{30}\right] \tag{13}$$

Am, Lm, Bm = Area, length and breadth of model pond respectively
Ap, Lp, Bp = Area, length and breadth of prototype pond respectively

Area and dimensions of the model facultative pond:

Am = Ap $(1/30)^2$
Am = 1140.73 $(1/30)^2$
A_m = 1.267 m^2 is the area of the model facultative pond
Lm = Lp (1/30)
Lm = 58.5 (1/30)
Lm = 1.95 m is the length of the model facultative pond
Bm = Bp $(1/30)^2$
Bm = 19.5 $(1/30)^2$
Bm = 0.65 m is the breadth of the model facultative pond

Area and dimensions of the model maturation pond:

am = ap (1/30)2
am = 520 (1/30)2
am = 0.578 m^2 is the area of the model maturation pond
Im = Ip (1/30)
Im = 39.6 (1/30)
Im = 1.32 is the length of the model maturation pond
Bm = bp (1/30)
bm = 13.2 (1/30)
bm = 0.44 m is the breadth of the model maturation pond

Flow rates or discharge (m^3/s) for the model facultative and maturation ponds: The flow rate for waste water in the prototype pond is:

Table 1: Summary of design dimensions and flow for the prototype and model ponds

Parameter	Prototype facultative pond	Model facultative pond	Prototype maturation pond	Model maturation pond
Area (m^2)	1140.73	1.267	520	0.578
Discharge (m^3/s)	1.99×10^{-2}	4.04×10^{-6}	1.99×10^{-2}	4.04×10^{-6}
Detention time (days)	11	4	4	3
Length (m)	58.50	1.95	39.60	1.32
Breath (m)	19.50	0.65	13.20	0.44
Depth (m)	1.50	0.75	1.20	0.60

Table 2: Result of analysis carried out on the waste water treatment in the model WSP

Parameter	Influent waste water before treatment	Effluent waste water after treatment	FEPA standard	Observed percentage removal (%)
BOD_5 (mg/L)	356	22	30	93.8
Faecal coliform count (fc/100 mL)	1×10^8	10	400	99.9
Total suspended solids (mg/L)	150	26	30	82.7

q_p = 156 m^3/day
q_p = In m^3/s for 11 days detention is:
q_p = 156 m^3/day ×11 days ×1/60×60×34 sec
q_p = 1.99×10^{-2} m^3/s

The flow rate or discharge for the model pond is given by the equation:

$$q_m = qp\left[\frac{L_m}{L_p}\right]^{25} = qp\left[\frac{1}{30}\right]^{25} \quad (14)$$

$q_m = 1.99\times10^{-2}\times(1/30)^{2.5}$
$q_m = 4.04\times10^{-6}$ m^3/s

The model dimensions and flow rates obtained for both the facultative and maturation ponds are tabulated in Table 1. The model ponds were then constructed and a performance evaluation conducted whose result is shown in Table 2.

DISCUSSION

The result of the analysis of the influent waste water Table 2, showed that the micro-organisms in the influent wastewater will be harmful to the downstream community if it is discharged without treatment into the surface waters or used for irrigation. The BOD of the influent waste water was 356 mg/L before treatment. The result from the treatment process after passing through the facultative pond and the three (3) maturation ponds reduced the BOD to 22 mg/L (about 93.8% removal rate). This final BOD value of the treated waste water is within the FEPA standard of 30 mg/L and can be safely discharged into surface waters (i.e., streams) and be used for purposes of irrigation.

Similarly the faecal coliform (fc) count and the total suspended solids (TSS) of the influent waste water before treatment were 1×10^8 fc/100 mL and 150 mg/L respectively and this exceeded FEPA standard of 400 fc/100 mL and 30 mg/L respectively (Table 2). The result from the treatment process after passing through the WSP system reduced the fc and the TSS to 10 fc/100 mL and 26 mg/L respectively (about 99.9 and 82.7% removal rate) and this values are within FEPA standard thus making the waste water safe for discharge into surface water as well as it use for irrigation.

CONCLUSION AND RECOMMENDATIONS

The influent of the WSP after filtration through the lined sandy loam media had the BOD reduced to 22 mg/L from 356 mg/L indicating a 93.8% removal level. A faecal coliform (fc) count of the influent sample gave 1×10^8 fc/100 mL, whereas the effluent gave 10 fc/100 mL which was 99.99% fc removal. The value of 150 mg/L of the TSS for the influent was reduced to 26 mg/L for the effluent after treatment. It was concluded that the effluent from the WSP was within the limits of FEPA standard of 30 mg/L for BOD, 30 mg/L for TSS and 400 fc/100 mL for faecal coliform, thus making the waste water after treatment safe for discharge into surface water as well as its use for irrigation.

The sandy loam soil media was found to be non-promising earlier in the removal process due to seepage problem until it was lined with polythene material. A clay media is therefore recommended for use in the construction of WSP as clay tends to have low seepage.

From the performance evaluation of the model WSP, it is highly recommended that a standard WSP be constructed so that the wastewater leaving FUTO hostels are treated before its discharge into the Otamiri River.

It is also recommended that further work on the construction of the WSP should include the construction of preliminary treatment devices such as sedimentation basins and filters so as to remove sediments that may be unsightly on the pond surface.

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