
CHIKWUE, M.I\textsuperscript{1}, OKORAFOR, O.O\textsuperscript{2}, OKAFOR, V.C\textsuperscript{3}, DURUANYIM, I.L\textsuperscript{4}, OFOMA, A.N\textsuperscript{5}

\textsuperscript{1,2,3,4,5}Department of Agricultural and Bioresources Engineering, Federal University of Technology Owerri, P.M.B. 1526, Owerri, Imo State, Nigeria

Abstract—The contamination of water bodies by incessant emptying and dumping of refuse, sludge and wastewater into streams and rivers, is not a new observation in our environment, rather it is more like a normal phenomenon. Hence, this research aims at designing a wastewater stabilization pond system (a series or a combination of ponds connected in a defined arrangement or setup to actualize a stepwise reduction of wastewater contamination) that will handle the reduction of the concentration of organic constituents and inorganic pollutants inherent in faecal sludge discharged into Choba river, in Choba community of Rivers State. The waste stabilization pond comprises of two (2) facultative and two (2) maturation ponds arranged in parallel connection, having dimensions of length, L of 112m, and width, W of 37m for the facultative pond, and length L of 56m and width, W of 19m for the maturation pond to handle a daily loading of 308,000 Litres (308m$^3$) with up to 80\%-85\% efficiency under a retention time of about 5-30days, covering a total land area of 10,342m$^2$.

Keywords-- facultative pond, faecal sludge, maturation pond, waste stabilization pond, wastewater,

I. INTRODUCTION

Waste management in the country presently is a challenge, basically because of the absence of stabilization ponds where faecal sludge(according to Heinss, 1998, is a sludge of variable consistency collected from on-site sanitation system and is comprised of varying concentrations of settled solids) can be stabilized or treated before they are disposed. Instead dumpsites and water bodies are used to dispose faecal sludge, without any consideration or regard for the health hazards they portray as well as the contamination of the groundwater which occurs from leachate seepage and percolation into the soil strata. There are several treatment options for faecal sludge of which some include; biogas digestion, drying beds, constructed wetlands, drain fields, endogenous metabolism e.t.c.

The appropriate faecal sludge treatment is that which produce an effluent meeting the recommended microbiological and chemical quality guidelines both at low cost with minimal operational and maintenance requirements, (Mirzadeh et al., 2013).

Biological treatment is the most used technology in wastewater ad sludge purification and management, (Basim et al., 2012) so as to achieve the most minimal hazardous effluent. Waste stabilization pond is a biological treatment method which involves the removal of both organic and pathogenic organisms from faecal sludge, it has been found to be more efficient in destroying pathogenic bacteria and intestinal parasites than conventional treatment plants, (Mara and Pearson, 1998). The purpose of wastewater settling and biological aerations is to remove organic matter and to concentrate it in a much smaller volume for ease of handling and disposal (Hammer and Hammer, 2008). Waste or wastewater stabilization ponds (WSP’s) are large man-made water bodies in which blackwater, greywater or faecal sludge are treated by natural occurring processes and the influence of solar light, wind, micro-organisms and algae, (Mara and Pearson, 1998). Waste Stabilization Ponds are used to treat a variety of wastewater (sewage effluents) from domestic wastewaters to complex industrial waters and they function under a wide range of weather conditions, where decomposition of organic matter processed naturally, (Mara and Cairncross, 1989). However, waste stabilization ponds are economical to construct, operate and maintain. Waste SPs do not rely merely on good design but also on good construction and operation. The activity in the waste stabilization pond is a complex symbiosis of bacteria and algae which stabilizes the waste and reduces pathogens. The result of this biological process is to convert organic content of the effluent into more stable and less offensive forms. The major objectives of this study are;
To design a waste stabilization pond for the treatment of faecal sludge discharged in the study area
- To determine generation rates per day of faecal sludge discharge and provide a standard system approach to stabilize wastes in the study area.

II. MATERIALS AND METHODS

2.1 Study Area description
Choba is located between N4º54’05.2 and E06º54’24.2 to N04º52’47.9 and E06º54’33.4 in the southern part of Nigeria, with a temperature range of 24-27°C, rainfall of about 1500-2500mm per annum and also a relative humidity of over 80%. The area is occasionally flooded so the soil within this area is usually waterlogged and marshy, (Tanimola et al., 2013). The dumpsite for this study is along east-west road, it was a dumpsite for faecal sludge and septic wastewater all situated in Choba community. Data was obtained from the dumpsite managers as regards the capacity of sludge obtained each day which is about 30800 liters of wastewater and sludge generated from 22 tankers per day.

2.2 Methods
A liter of the wastewater and sludge where collected and transferred to the laboratory by the use of vacuum flask from the discharge point of the dumpsite for a period of six (6) weeks. The samples were intermittently stirred over the entire period of analysis because of the presence of suspended solids. The standard method was used in the laboratory to analyze the samples for Dissolved Oxygen (DO) and biochemical Oxygen Demand (BOD) for the first and fifth days respectively. Based on the number and capacity of vacuum tankers discharged on this site the flow rate was obtained for the design process.

2.3 Design Information
The design process for stabilization ponds usually comprises of the combination of either an aerobic, facultative and or maturation ponds. Mostly, anaerobic ponds are used for high strength wastewater above 300mg/(BOD₅) and suspended solids above 300mg/l, (Mara and Pearson, 1998). The facultative pond may be suited to handle waste much below 300mg/L BOD₅; with depths falling between 1-2m. The maturation ponds are placed after the facultative ponds, with the principal aim of removing bacteria at depths between 1-2m. The design was carried out based on this preliminary information.

2.4 Design Procedure
The following procedures are employed to effectively obtain the component of the waste stabilization system;

(a) Anaerobic pond design: from tests carried out on the wastewater and faecal sludge samples, it was observed that the biochemical oxygen demand and suspended solids were less than 300mg/l, so anaerobic pond was not considered in this design. According to Mara and Pearson, 1998, anaerobic ponds are used to treat high strength wastewater having suspended solid and biochemical oxygen demand of above 300mg/l.

(b) Facultative Pond Design: the maximum area of BOD₅ loading (λmax ) which is the area to be occupied by the pond and the design loading area loading rates are given thus by McGarry and Pescod, (1970) and Arthur, (1983) as follows;

\[ \lambda_d = 20T - 60 \]  
\[ = 480 \text{Kg/Ha/Day} \]

where \( \lambda_d \) = design area loading rate (Kg/Ha/Day)

\[ T = \text{Average ambient Temperature which is 27°C for southern Nigeria} \]
\[ A = 10L_1Q/ \]

\[ \lambda_d = 10 \times 128.87 \times 308/480 = 8269 \text{m}^2 \]

We take 8300m²
Where A = surface area of the facultative pond
Q = Flow rate in m³/day
\[ \lambda_d = \text{Design areal loading in Kg/Ha/Day} \]
\[ L_1 = \text{Average maximum observed BOD}_5 \text{ in mg/l or g/m}^3 \]

For efficiency the surface area of the facultative pond will be divided into two ponds connected in parallel arrangement, each covering an area of 4150m² each. The dimensions of the facultative pond are generated from a length-width ratio of 3:1, which is;

\[ L = 3W \]

But A = 3W²; A = 4150; 3W²= 4150
\[ W = \sqrt{\left(\frac{4150}{3}\right)} = 37.19 \text{m} \]

With W = 37m, then L = 3 x 37.19 =111.6m
Take L = 112m and W = 37m
Where L = length of the pond
W = width of the pond

The design criterion of stabilization ponds require a detention time for facultative pond, this falls between 5-30days. Hence as a check;

\[ V = L \times W \times X \times D \]
\[ = 112 \times 37 \times 3 = 4144 \text{m}^3 \]
\[ D = V/Q \]

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(c) Maturation Pond Design: the efficiency of facultative pond in removal of BOD$_5$ is between 80-90%. Assuming that the facultative pond achieves up to 85% removal of BOD$_5$ then we have that 85% of BOD$_5$ will be equal to 109.54 mg/l of BOD$_5$. Thus the remaining BOD$_5$ which finally enters the maturation pond will be 128.87 minus BOD$_5$ achieved by 85% removal which is 19.33 mg/l of BOD$_5$. Maturation ponds are designed to remove faecal coliforms, according to Marais, 1974 we have the following relationship in achieving it;

\[
B_e = B_1 / (1 + K_{b(T)} T_Y) \tag{6}
\]

Where $B_e$ = number of faecal coliform (FC) bacteria/100ml of effluent
$B_1$ = number of faecal coliform bacteria/100ml of influent.

\[
K_{b(T)} = 1^{st} \text{ order rate constant for FC removal}
\]

\[
T_Y = \text{Retention time}
\]

But $K_{b(T)} = 2.6(1.19)^{T_{-20}} \tag{7}$

\[
T = 27^\circ C, K = 8.786 \text{ per day}
\]

The condition of design involves two maturation ponds with retention time of 5 days at a depth of 1.5m in an ambient temperature of 25$^\circ$C and influent faecal concentration of wastewater of $2 \times 10^7$ bacteria/100ml.

Hence the total faecal coliform removal in a complete stabilization pond system including anaerobic, facultative and maturation pond is given by the expression.

\[
B_e = B_1 / (1 + K_{b(T)} T_{Y_A})(1 + K_{b(T)} T_{Y_B})(1 + K_{b(T)} T_{Y_C})^n \tag{8}
\]

\[
= 2 \times 10^7/(1 + (8.8)(27))(1 + (8.8)(5))^2
\]

\[
= 4FC/100ml
\]

Where $T_{Y_A}$, $T_{Y_B}$ and $T_{Y_C}$ are the retention time for anaerobic, facultative and maturation pond system respectively.

N = the number of maturation pond assumed.

Though the maturation pond is specifically designed for coliform removal BOD$_5$ degradation still occurs to a small extent, so the final BOD$_5$ of the effluent discharge into the river can be determined from the expression; (Marais and Shaw, 1961).

\[
K = 0.05(1.05)^{T_{-20}} \tag{9}
\]

Where $T = 27^\circ$C, $K = 0.07$

\[
L_e = L_1 / (1 + K_{Y})^n \tag{10}
\]

\[
= 19.95/(1 + 0.07(5))^2 = 10.9\text{mg/l}
\]

Where $L_e$ = Effluent BOD$_5$

$L_1$ = influent BOD$_5$

The volume of the maturation pond is obtained by multiplying the retention time with flow rate, i.e. $V = \text{retention time} \times \text{flow rate} = 5 \times 308 = 1540\text{m}^3$

Area, $A = \text{volume/ depth} = 1540/1.5 = 1027\text{m}^2$

Also like the facultative pond the dimensions of the maturation pond dimensions are obtained from a length-width ration of 3:1, $L=3W$

But $A = 3W^2$, \tag{11}

\[
W=\sqrt{\frac{1027}{3}} = 18.50m
\]

Therefore $L = 18.50 \times 3 = 55.5m$.

Thus, the length and width of the maturation pond will be taken to be 56m and 19m respectively, so as to maintain proper cross-section.

III. RESULTS AND DISCUSSION

The following are the results of experimental analysis carried out on the samples (42) for suspended solids, dissolved oxygen and biochemical oxygen demand. The dissolved oxygen analysis was done both for the first day and the fifth day. The laboratory analysis done on the samples were carried out consecutively for 6 weeks. The results of the analysis are presented in the tables below;

<p>| TABLE I. FIRST WEEK RESULTS FOR DISSOLVED OXYGEN (DO) AND BIOCHEMICAL OXYGEN DEMAND (BOD) |</p>
<table>
<thead>
<tr>
<th>DAYS</th>
<th>DO(T$^1$DAY) MG/L</th>
<th>DO(&gt;5DAYS) MG/L</th>
<th>BOD$_5$ MG/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.3</td>
<td>133</td>
<td>128.7</td>
</tr>
<tr>
<td>2</td>
<td>4.4</td>
<td>133.5</td>
<td>129.1</td>
</tr>
<tr>
<td>3</td>
<td>4.3</td>
<td>133</td>
<td>128.7</td>
</tr>
<tr>
<td>4</td>
<td>4.4</td>
<td>134</td>
<td>129.6</td>
</tr>
<tr>
<td>5</td>
<td>4.2</td>
<td>132</td>
<td>127.8</td>
</tr>
<tr>
<td>6</td>
<td>4.1</td>
<td>132</td>
<td>127.9</td>
</tr>
<tr>
<td>7</td>
<td>4.5</td>
<td>134</td>
<td>129.5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>30.2</td>
<td>931.5</td>
<td>901.3</td>
</tr>
</tbody>
</table>
From the data presented in the tables above, the average BOD$_5$ for the six weeks for 42 samples collected from the site is equal to the summation of all weeks data/number of samples

\[
= \frac{5412}{42} = 128.87 \text{ mg/l}
\]
TABLE VII
SUMMARY OF DESIGN PARAMETER VALUES FOR FACULTATIVE POND

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>MAXIMUM AREAL LOADING ($\lambda_d$)</th>
<th>SURFACE AREA OF POND, $A$ ($M^2$)</th>
<th>DIMENSIONS OF THE POND (M)</th>
<th>RETENTION TIME OF POND (DAYS)</th>
<th>VOLUME OF THE POND ($M^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VALUE</td>
<td>480Kg/Ha/Day</td>
<td>4144</td>
<td>$L = 112$</td>
<td>27</td>
<td>8288</td>
</tr>
</tbody>
</table>

From the above summary the physical features of maximum areal loading, surface area, retention time, volume and dimensions are specified for two facultative ponds, which are cubic or rectangular in shape.

The pond has been designed for 27 days retention time to remove $BOD_5$ of influent, this falls within design criteria requirements of 5-30 days, for facultative pond design is satisfactory.

TABLE 8
SUMMARY OF DESIGN PARAMETER VALUES FOR MATURATION POND

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TOTAL FAECAL COLIFORM (ML)</th>
<th>EFFLUENT $BOD_5$ ($L_1$) (MG/L)</th>
<th>INFLUENT $BOD_5$ ($L_1$) (MG/L)</th>
<th>DIMENSIONS OF THE POND (M)</th>
<th>VOLUME OF THE POND ($M^3$)</th>
<th>SURFACE AREA OF POND, $A$ ($M^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VALUE</td>
<td>4FC/100</td>
<td>10.90</td>
<td>19.95</td>
<td>$L = 56$</td>
<td>1540</td>
<td>1027</td>
</tr>
</tbody>
</table>

The final effluent $BOD_5$ discharged from the maturation pond into Choba river was determined to be 10.9mg/l which is satisfactory when compared to federal environmental protection authority and department of petroleum resources limit set at 50mg/l. Also in addition the dimensions and features of the maturation pond which are two (2) in number are summarized in the table above.

Therefore the total land area required for the complete waste stabilization pond system is the sum total of the surface areas occupied by both the facultative and maturation ponds which is given by;

$$T = (4144 \times 2) + (1027 \times 2) = 10342m^2$$

IV. CONCLUSION

Through the design process of the waste stabilization pond system the major objective of removal or destruction of excreted pathogens and the oxidation of organic matter is achieved through the reduction of the total faecal coliform to 4FC/100ml. This is lower than the standards of the Department of Petroleum resources (DPR) and Federal Environmental Protection Agency (FEPA) which is 200FC/100ml.

Also in addition the oxidation of organic matter was achieved through 85% BOD removal from the influent in the maturation pond, hence the faecal sludge can be discharged into the river after treatment with the assurance that the public health of the environment is not under jeopardy and the water course is not polluted. All these have been achieved through minimum operating and maintenance requirement.

REFERENCES


