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DESIGN OF WASTEWATER STABILIZATION POND FOR THE UNIVERSITY OF MAIDUGURI

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Abstract

The objective of this study was to design a wastewater stabilization pond for the treatment of wastewater in the University of Maiduguri. Relevant design parameters viz: flow, Biochemical Oxygen Demand (BOD), faecal coli forms, temperature, permissible volumetric BOD loading, hydraulic retention time, particle size distribution, optimum moisture content, maximum dry density and saturated hydraulic conductivity of the soil were determined. The projected population of the design area is 48,590. The calculated BOD of the wastewater is 196 g/m^3, since this value is greater than 25 g/m^3, it has to be treated before discharge as specified by the Council for the European Communities. Permissible volumetric loading of 350 g/m^{3}d corresponding to the designed temperature (31.8 ^{0}C) was used. The designed anaerobic pond volume and area are 8,778 m^3 and 2,949 m^2 respectively. The designed surface BOD loading and the hydraulic retention time for the facultative pond are 467 kg/ha/d and 4 days respectively. The effluent BOD of the maturation pond with an area of 23408 m^2 is less than the 25 g/m^3 maximum standard required by Council for the European Communities, thus it is safe. The quality of the final effluent in terms of BOD and faecal coliform (8.3 g/m^3 and 16 FC/100ml) are within the World Health Organisation standard which indicates that the design is satisfactory to meet the specified objective.

1. Introduction

The scarcity of fresh water is one of the most pressing problems facing the developing world. Some 1.3 billion people in developing countries lack access to safe drinking water, another 2.9 billion lack adequate sanitation. Four million children die each year from water related diseases (IHP, 1999). Population growth, urban development, excessive pumping, deforestation and irresponsible use of water by many has resulted to unavoidable water shortages and the likelihood of replenishing the water resources to adequate levels becomes very difficult and the longer the period, the harder it will become. Hence there is need to use the limited supply as efficiently as possible and to recycle the wastewater for re-use so as to meet the increasing demand. One way to achieve this objective is to use Waste Stabilization Pond.

Wastewater stabilization ponds are shallow man-made basins into which wastewater flows and from which, after a retention time of several days, a well treated effluent is discharged (Mara and Pearson, 1998). According to Pope and Taylor (1996), stabilization ponds have been in use in the United States since 1901. A World Bank report (Shuval 1986) endorsed the concept of stabilization pond as the most suitable wastewater treatment system for effluent use in agriculture.

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The primary treatment takes place in the anaerobic pond; this is mainly designed for removing suspended solids and some other soluble elements of the organic matter. Effluent from first-stage anaerobic ponds will overflow into secondary facultative ponds, which comprise the second-stage of biological treatment. Following primary or secondary facultative ponds, if further pathogen reduction is necessary, maturation ponds will be introduced to provide tertiary treatment. Many characteristics make waste stabilization pond substantially different from other wastewater treatment techniques. These include design, construction and operation simplicity, cost effectiveness, low maintenance requirement, easily adaptive for upgrading and high efficiency (Ramadan and Ponce, 2005). The earlier technologies adopted were power intensive and capital intensive, technologically more complicated and difficult to maintain. Powell et al. (1997), described wastewater stabilization pond among the least expensive onsite treatment options and maintenance is not expensive.

The objective of this work was to design a wastewater stabilization pond in the University of Maiduguri for the treatment of wastewater that can be used for domestic and agricultural purposes.

2. Methodology and data collection

2.1 Site description

The design was carried out for the University of Maiduguri in the year 2005. The university is located along Bama road in Maiduguri, the capital of Borno State, Nigeria. It lies between the latitude 11048'N and longitude 13021'E with an altitude approximately 590m with a relatively flat surface. The pond should be located at least 200 m away from residential/academic areas. This is in conformity with the standard, that waste stabilization pond should be located away from residential areas so as to discourage people from visiting the area and odour release. Necessary data needed for the design of a wastewater stabilization pond for the study were obtained viz: population figures, water supply, meteorological (latitude, longitude, altitude and temperature). Soil samples were collected in different locations at a depth approximately 1 m from the proposed site for subsequent laboratory analysis.

2.2 Water supply

The university has two sources of water supply. Boreholes drilled at different locations within the university and the metropolitan water supply scheme. There are eight boreholes drilled in the university. Out of these, five are fully functional while three are broken down. The discharge of these boreholes varies from 5 to 22l/s which continuously pump water as long as electricity is supplied. The metropolitan water supply scheme has an average daily supply of 100,000 litres to the university (University of Maiduguri Works Department, 2005).

2.3 Population of the study area

The population of the university was used as one of the parameters for the design flow. In the design of waste stabilization pond, the future population covering the design period is considered rather than the present population. Therefore, the population projection over the design period is estimated using the Equation 1.

$$PN = (1 + r)NP0 \quad (1)$$

Where:

PN is the population of Nth year
r is the rate of population growth
N is the period.
P0 is the present population (base population).

If the population exceeds 10,000, two or more stabilization ponds should be designed in parallel (Mara and Pearson, 1998).

2.4 Design assumptions

For the purpose of this design, the following assumptions are made:

a. Seepage and evaporation losses are negligible
b. The entire pond works as a mixed system
c. Organic matter degradation follow first order kinetics that is the rate of treatment of the contaminants at any time is proportional to the contaminant remaining at that time.

2.5 Design parameters

The following equations, estimates and tables from Mara and Pearson (1998) were used in the design.

Flow

A suitable design wastewater flow (Q) value is 85% of the total water consumption.

Biochemical Oxygen Demand (BOD)

The *BOD* can be estimated from the following (Mara and Pearson, 1998):

$$Li = 1000B/q \quad (2)$$

Where:

Li is the wastewater *BOD*, mg/l
B is the *BOD* contribution in g/Ca/d
q is the wastewater flow, 85% of water consumption l/Ca/d

The value of *B* varies between 30 and 70 g/Ca/d with a richer community producing more *BOD* than poor community. As suggested by Mara and Pearson (1998), the value of *B* is taken as 50 g/Ca/d. The quality requirement for effluent discharge should have a *BOD* of less than 25 mg/l.

Faecal Coli forms (FC)

The usual range of faecal coli forms is $10^7 – 10^8$ per 100 ml, and a suitable design value is 5×10^7 per 100 ml.

Design Temperature

The usual design temperature is the mean temperature in the coolest month of the year.

Anaerobic Pond

The anaerobic pond volume can be calculated from (Mara and Pearson, 1998)

$$Va = LiQ/\lambda v \qquad 3$$

Where:

Va = anaerobic pond volume, m3

L_i = influent BOD, mg/l = g/m^3

Q = flow, m^3/d

λv = a volumetric BOD loading, g/m^{3}d

The permissible design value of λv decreases with temperature. Mara and Pearson (1998) recommended the values given in Table 1.

Table 1: Design values of permissible volumetric *BOD* loading and percentage *BOD* removal in anaerobic ponds at various temperatures

Temperature ^{0}C	Volumetric loadings(g/m^{3}d	BOD Removal %
<10	100	40
10 – 20	20T- 100	2T + 20
20 – 25	10T + 100	2T + 20
>25	350	70

Source: Mara and Pearson (1998)

The hydraulic retention time can be calculated from (Mara and Pearson, 1998):

$$\theta_a = V_a/Q \qquad 4$$

Where:

θ_a is the hydraulic retention time, d

V_a is the pond volume, m^3

Q is the flow, m^3/d

If the above equation gives the value less than 1 day, then θ_a should be taken as 1 day (Mara and Pearson, 1998).

Hence, $a = Q^* \theta_a$ 5

The performance of anaerobic pond increases with temperature. Table 2 shows the design assumption for BOD removal and permissible volumetric BOD loading at various temperatures.

Facultative Pond

The facultative pond area can be calculated from (Mara and Pearson, 1998):

$$A_f = 10L_iQ/\lambda s \qquad 6$$

Where:

A_f = facultative pond area, m^2

L_i = influent BOD, g/m^3

Q = flow in m^3/d

λs = surface BOD loading, kg/ha d

A global design equation for determining λs is given by

$\lambda s = 350(1.107 - 0.002T)(T - 25)$ 7

Where T is design temperature, ^{0}C

The retention time can also be calculated from:

$\theta_f = DA_f / Q_m$ 8

Where:

θ_f = retention time, d

D = design depth, m

A_f is the facultative pond area, m2

Q_m= mean flow, m^3/d

BOD removal in facultative pond ranges between 70 – 80%

Maturation Pond

The pond area can be calculated from (Mara and Pearson, 1998):

$A_m = Q\theta_m/D$ 9

Where:

A_m = maturation pond area, m^2

Q = the flow, m^3/d

θ_m = the retention time, d

D = the pond depth, m

The number of FC per 100 *ml* of the final effluent can be calculated from Equation 10 below:

$$N_e = \frac{N_i}{[(1 + K_T\theta_a)(1 + K_T\theta_f)(1 + K_T\theta_m)^n]} \quad 10$$

Where**:**

N_e is the number of *FC*/100 ml of effluent

N_i is the number of *FC*/100 ml of influent

K_T is the first order rate constant for *FC* removal per day

θ is retention time, d

n is the number of maturation ponds in series.

Subscripts *a*, *f* and *m* refers to anaerobic, facultative and maturation ponds respectively.

The value of K_T is temperature dependent. It is given by

$K_T = 2.6(1.19)\ T\text{-}20$ 11

where: T is the design temperature, ^{0}C

Particle Size Distribution

The particle size analysis was carried out using the hydrometer method. The percentage of silt and clay were determined using the following equations:

$A = Sand = 100 - R_1 - R_o + r/W \times 100$ *12*

$B = Clay = R_2 - R_1 + r/W \times 100$ *13*

$C = Silt = 100 - (\%\ of\ sand + \%\ of\ clay)$ *14*

Where:

R_o is blank hydrometer reading

R_1 is hydrometer reading at 40s

W is mass of sample, g

T_1 is temperature at 40s
T_2 is temperature at 2 hrs
R_2 is hydrometer reading at 2 hrs
r = temperature = 0.36 (T – 200C), ^{0}C

Optimum Moisture Content and the Maximum Dry Density Needed for the Compaction
As recommended by Mara and Pearson (1998), the standard proctor test method was used in determining the optimum moisture content and the maximum dry density. The graph of dry densities against moisture contents was then plotted so as to determine the optimum moisture content and the maximum dry density.

$$\gamma d = \gamma/(1 + m) \quad 15$$

Where:
γd is the dry density
γ is the bulk density
m is the moisture content

Saturated Hydraulic Conductivity
The hydraulic conductivity of the soil is determined to ascertain if the pond requires lining or not. Mara and Pearson (1998) suggested that the permissible hydraulic conductivity of the soil after compaction should be less than 107 mm/s. If the permissible hydraulic conductivity of the soil is greater than 107 mm/s, the pond should be lined in order to maintain the water balance in the pond. The hydraulic conductivity is then obtained using the formulae:

$$K = a/A.\ 1/t.\ 2.3 \log 10\ H_1/H_2 \quad 16$$

Where:
K is the hydraulic conductivity, mm/s
a is the cross sectional area of the tube, mm^2
A is the cross sectional area of the mould, mm^2
L is the length of the mould, mm
H_1 is the initial water level in the tube, mm
H_2 is the final water level in the tube after time t
t is the time interval for the water level to fall from H_1 to H_2

3. Results and discussion

3.1 Population

According to the Works Department of the University, the population for the year 2004 was 36,307 residents. The projected population of the University of Maiduguri for the design period of 10 years is 48,590 based on Nigeria's annual population growth rate of 2.37% (CIA World Book of Fact, 2004). In the design of waste stabilization pond, the future population covering the design period is considered rather than the present population. Since the population exceeds 10,000, four wastewater stabilization ponds in series were used in the design, each being designed for a population of 12,148 as suggested by Mara and Pearson (1998).

3.2 Water Consumption

According to the Works Department of the University, the average daily water demand per capita is 300 litres. This implies that the average daily water demand of the university is 14,577m^3. Thus, the design water consumption is 3,644 m^3 daily per stabilization pond.

3.3 Flow

The design wastewater flow is three times the dry weather flow. Using Q = 85%, the calculated value of dry weather flow is 3097 m^3/day. This implies that the design waste water flow is 9292 m^3/day.

3.4 Biochemical Oxygen Demand (BOD)

The calculated *BOD* of the wastewater is 196 g/m^3. Since this value is greater than 25 g/m^3, it has to be treated before discharge as specified by the Council for the European Communities.

3.5 Faecal Coliforms (FC)

The faecal coliform, *FC* of the influent was taken as Ni = 5 x 107 /100ml as recommended by Mara and Pearson (1998).

3.6 Design Temperature

The mean temperature of the coolest month in the year 2004 was 31.8^{0}C as obtained from the Nigerian Meteorological Agency.

3.7 Anaerobic Pond

Permissible volumetric loading of 350 g/m^{3}d corresponding to the design temperature (31.8^{0}C) was used for this study as shown in Table 1. The calculated value of anaerobic pond volume (V^a) and hydraulic retention time (θ_a) are 4916 m^3 and 0.56 days respectively. However, Mara and Pearson (1998) recommended a minimum retention time of 1 day. Therefore, the re-calculated anaerobic pond volume using Equation 5 equals 8778 m^3 taking retention time as 1day. Taking depth of the pond as 3 m, the pond area (A_a) is 2949 m^2. Since the design temperature exceeds 20^{0}C, the percentage *BOD* removal on the anaerobic pond is taken as 70% (Table 1). Thus, the *BOD* of the anaerobic pond effluent will be (1- 0.7)196 = 59g/m^3.

3.8 Facultative Pond

The designed surface *BOD* loading, pond area of the facultative pond are 467kg/ha/d and 11,090 m^2 respectively. The hydraulic retention time (θ_f) was 2.5 days. For temperatures above 20^0C, Mara and Pearson (1998) recommended 4 days minimum retention time for facultative pond. The retention time is taken as 4 days. Therefore the re-calculated pond area is 17,557 m^2. The percentage *BOD* removal of the pond was taken as 75%. Hence the *BOD* of the effluent is (1 – 0.75)59 = 14.75g/m^3.

3.9 Maturation Pond

The maturation pond reduces *BOD* by 25%. Taking two maturation ponds in series, each having a retention time of 2 days, the effluent of the second maturation pond will have a filtered *BOD* of 8.3g/m^3, which is safe for domestic and agricultural uses. Taking depth as 1.5 m, the designed pond area is 23,408 m^2. The value of first order rate constant for *FC* removal was obtained as 20.25/d. The number of faecal coliforms /100ml of the final effluent was 16 *FC*/100ml. The effluent *BOD* of the maturation pond is safe as it is less than the 25 mg/l standard required by EU (Council for European Community, 1991). In the United States of America, irrigating with water containing up to 1,000 FC/100ml is allowed (EPA, 1973), while in Europe, swimming with waters containing up to 2,000 FC/100ml is permitted (Council for European Communities, 1976). This implies that the faecal coliform of the effluent is safe for both irrigation and domestic uses. The faecal coli form content of the effluent also complies with WHO guidelines for effluent to be re-used in fish pond fertilization as it contains less than 1,000 *FC*/100ml.

3.10 Soil Particle Distribution

The soil particle distribution obtained using the hydrometer method is shown in Table 2 below.

Table 2: Soil particle distribution

Sample	% Sand	% Clay	% Silt
A	71.65	8.8	19.55
B	69.15	8.8	22.05

The soil having the above distribution is classified as sandy loam by the USDA soil classification. Waste stabilization can be used in an area with a sandy loam soil type.

3.11 Dry Density and Optimum Moisture Content

A graph of dry density against moisture content was plotted so as to obtain the maximum dry density and optimum moisture content needed for compaction. The values obtained in the graph indicated a maximum dry density and optimum moisture content of 1,740 kg/m^3 and 12% respectively.

3.12 Saturated Hydraulic Conductivity
The saturated hydraulic conductivity of the soil samples ranges from 2.93 x 10^{-4} mm/s to 6.25 x 10^{-4} mm/s with an average value of 4.90 x 10^{-4} mm/s. Mara and Pearson (1998), suggested that, for soils having a hydraulic conductivity greater than 10^{-4} mm/s, some seepage may occur but not sufficient enough to prevent the ponds from filling. The pond may be lined with the cheapest available lining material. Clay soil which is readily available at low cost can be used for the lining.

3.13 Pond Geometry and Maintenance
In general, an aerobic pond and facultative pond should be rectangular so as to avoid sludge banks forming near the inlet. Mara and Pearson (1998) suggested a length to breadth ratio of 2 to 3:1. The maturation pond can be rectangular or square. Figure 1 shows the plan of the stabilization pond. The inlet and outlet can be located diagonally at opposite corners. The longest dimension of the pond should lie in the direction of wind to facilitate wind induced mixing of pond surface layer. Free boards should also be included to prevent the overtopping of the embankment. A freeboard of 0.5 to 1 m is normally sufficient.

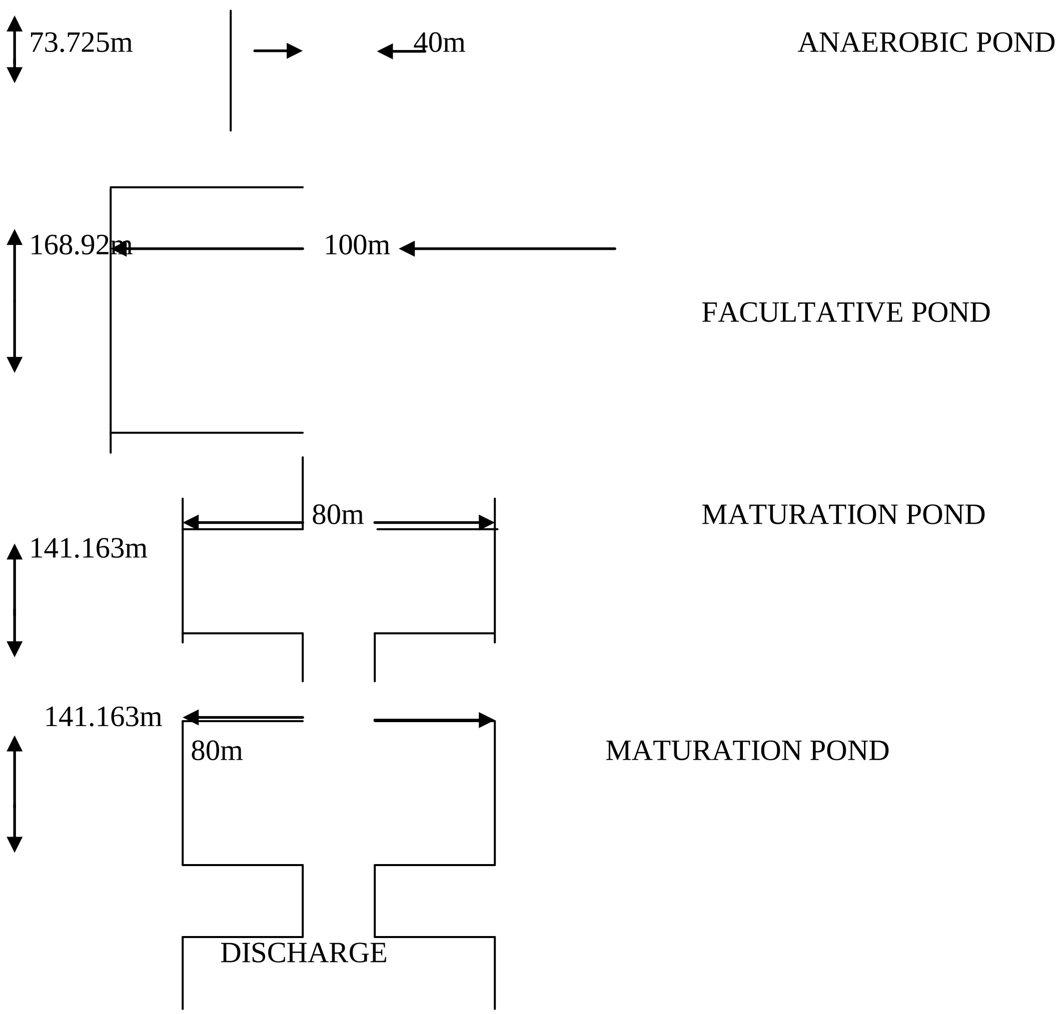

Figure 1: Waste water stabilization

For the effective performance of the pond, proper maintenance is necessary. Efforts should be made to prevent the growth of vegetation. The growth of vegetation on the embankment will attract animals that might feed on the vegetation thereby destroying the embankment. The area should be fenced and if possible de-sludging exercise should be carried out when necessary. Ponds should be located at a distance of 200 m or more from the community.

3.14 Preliminary Treatment

The preliminary treatment involves the removal of large floating objects such as rags, maize cobs, pieces of wood etc. It can be done mechanically or physically. The materials are removed to reduce unnecessary loading on the ponds. It comprises of screening and grit removal. The screens are to be placed across flow so that floating materials can be trapped and removed.

4. Conclusions

The projected population of the design area is 48,590. The calculated *BOD* of the wastewater is 196 g/m^3, since this value is greater than 25 g/m^3; it has to be treated before discharge as specified by the Council for the European Communities. Permissible volumetric loading of 350 g/m^{3}d corresponding to the design temperature (31.8^{0}C) was used. The designed anaerobic pond volume and area are 8,778 m^3 and 2,949 m^2 respectively. The designed surface *BOD* loading and the hydraulic retention time for the facultative pond are 467 kg/ha/d and 4 days respectively. The effluent *BOD* of the maturation pond with an area of 23408 m^2 is less than the 25 g/m^3 maximum standard required by Council for the European Communities, thus it is safe. The quality of the final effluent in terms of *BOD* and faecal coliform (8.3 g/m^3 and 16 FC/100ml) are within the World Health Organisation standard. It is recommended that after the establishment of the waste stabilization pond, periodic assessment of some strength properties; pH, turbidity, conductivity, total suspended solids, dissolved solids, *BOD*, *COD*, phosphates, nitrates and iron should be carried out for possible quality interference. Pond area should be cleared periodically and fenced so as to avoid undue external interference and reduced maintenance cost.

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