Research Journal of Agriculture and Biological Sciences, 2(4): 142-146, 2006

Utilization of a Mathematical Analysis in Sizing a Biological Treatment Plant

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Abstract: As a follow -up of an earlier study, in which treatment of wastewaters biologically in an economic size waste stabilization ponds were presented. This paper presents a report on a practical application of mathematical analysis to determine the size of a domestic-institutional waste stabilisation pond. Wastewaters were collected at an influent into Obafemi Awolowo University, Ile-Ife waste stabilisation pond. BOD concentrations of the wastewater were determined using standard method. Kinetic parameters of the BOD and nitrification were determined using non-linear regression and Fibonacci methods respectively. Results of the BOD kinetic parameters were substituted into equations documented in literature to obtain surface area and costs (total and operational). The results of the study revealed that surface area of an economic size waste stabilization pond is proportional to the square of initial cost per unit area and the total annual cost varies partly as the initial cost per unit area and inversely as the square of the area. Also, it revealed that BOD removal of the pond could be as high as 58.8% for a retention time of 2.25 days.

Key words: Mathematical analysis, BOD removel. biological treatment process, wastewaters, economic size, total cost.

INTRODUCTION

Biological treatment of wastewaters have been defined as those processes used in the treatment of wastewaters in which changes are brought about by means of natural conditions such as introduction of air and microorganisms[1-5]. Literature[6-9] reviewed biological treatment processes and dealt with effectiveness of biological treatment processes in treating industrial and domestic wastewaters. Viessman and Hammer[10], Tebbutt[11], Ogunfowokan *et al*.,[12] and Martins *et al*.,[13], just to mention a few state disadvantages of biological treatment processes as follows:

- Requires a large area of land; and
- Produces odour and vectors.

Oke and Otun[5] states a step to overcome the former disadvantage, which is to design for an economic size pond. The main objective of this study is to design an economic size pond for a domestic-institutional wastewater by applying a mathematical analysis as stated in literature[5].

MATERIALS AND METHODS

Wastewaters were collected weekly as specified in APHA[14] for six months at the influent into Obafemi Awolowo University, Ile-Ife waste stabilization pond. BODs removed were determined daily for 20 days using BOD meter method (CAMLAB HACH, model number 2173B BOD manufactured by Hach Chemical Company) and application of equation 1(a). BOD and nitrification kinetic parameters in equations (1) and (2) were determined using non-linear regression and Fibonacci methods respectively. Weekly averages were used in the computations of BOD removed. BOD removed for the first 10 days were used for the determination of ultimate BOD (L_o) and rate of BOD removal (k,), while BOD removed for the last 10 days were used for maximum growth rate for autotrophic biomass and specific decay rate of autotrophic biomass (nitrification kinetic parameters). The values of K_1 and K_2 were obtained from maximum BOD concentration (C_1,) and expected effluent BOD concentration (C_o), BOD removal rate (k), expected depth of the pond (D) and velocity of flow (all symbols are as stated in Oke and Otun[5].

$$BOD_t = \frac{(D_1 - D_2) - (B_1 - B_2)f}{p} \tag{1a}$$

$$BOD_t = L_o\left(1 - e^{(-kt)}\right) \tag{1}$$

$$S_{N0} = S_{N0O} + \frac{\mu_A X_{AO}}{Y_A(\mu_A - b_A)} e^{(\mu_A - b_A)t} - \frac{\mu_A X_{AO}}{Y_A(\mu_A - b_A)} \tag{2}$$

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RESULTS AND DISCUSSIONS

Results of the BOD kinetic parameters for the first 10 days are shown in Table 1. The average values of k, L_0 and their standard deviation show that these parameters are similar to BOD kinetic parameters for domestic wastewaters[1], but slightly different from values stated in Adewumi *et al.*,[15] and Adewumi[16]. These differences might be attributed to method used for the determination of the kinetic parameters and the equipment used. Table 2 shows BOD (nitrification) kinetic parameters for the last 10 days, which gives the values for m_A and b_A. Table 3 shows the values for K_1, K_2, A, C_1, C_2 and T obtained from equation (3), (4), (5), (6), (7) and (8) respectively.

$$K_1 = \frac{0.95\mu_A C_i Q}{b_A} \quad (3)$$

$$K_2 = \frac{V}{D^*k}\left(\frac{C_i}{C_o} - 1\right) \quad (4)$$

$$C_1 = K_1 A^{-1.5} \quad (5)$$

$$C_2 = K_2 A^{-1.0} \quad (6)$$

$$T = C_1 + C_2 \quad (7)$$

Figures 1 and 2 show relationship between discharge, costs, economic surface area of the ponds and K_1. From these figures expected surface area of the pond is 450 square meters. The result shows that the size of the pond is economical when compared to surface areas of similar ponds documented in literature (Table 4).

Checking the application (design): Tebbutt[11] reports that surface BOD loading of a given pond can be determined using equation (9)

$$\lambda_s = \frac{Q\,BOD_5}{A} \quad (8)$$

Using this equation (9) surface BOD loading of designed economic size waste stabilization pond for Obafemi Awolowo University, Ile-Ife is 0.50 kg of BOD per unit square meter day (with Q = 300 m^3/d, maximum BOD_5 = 750 mg/l and expected surface area from Figure 1 is 450 square meters). This value of surface BOD loading is less that permissible surface BOD loading specified in literature such as Tebbutt[11], which can be obtained by using equation (10).

$$\lambda_s = 20T - 120 \quad (9)$$

The value of surface BOD loading indicates that the design is adequate interm of surface BOD loading.

Table 1: Parameters for BOD kinetic for the first 10 days

Description	Parameter	Estimate	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
Sample 1	K	0.218	0.0022	0.213	0.223
	L	969.08	4.581	958.55	979.61
Sample 2	K	0.218	0.0034	0.210	0.226
	L	1112.37	7.921	1094.10	1130.64
Sample 3	K	0.270	0.00408	0.261	0.280
	L	790.8	4.75	779.8	801.7
Sample 4	K	0.253	0.0053	0.240	0.265
	L	775.0	6.848	759.2	790.8
Sample 5	K	0.163	0.0081	0.144	0.181
	L	1207.0	32.80	1131.4	1282.7
Sample 6	K	0.246	0.0040	0.237	0.256
	L	905.4	6.234	891.0	919.8

Table 2: Parameters for BOD kinetic for the last 10 days

Description	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
b_A	0.05	0.05	0.05	0.05	0.05	0.05
m_A	0.25	0.28	0.32	0.26	0.24	0.30

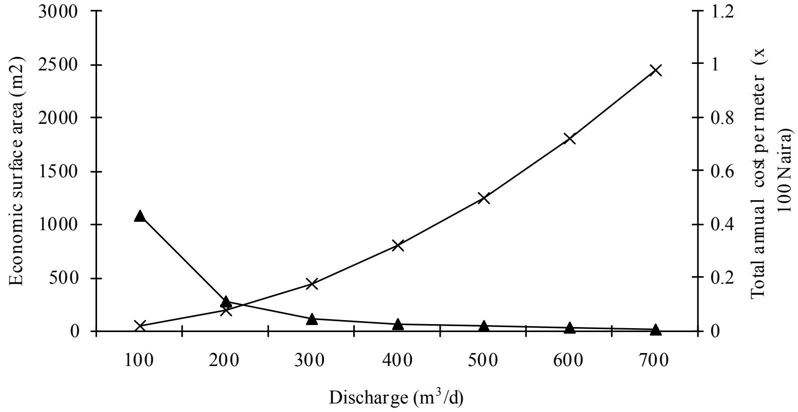

Fig. 1: Relationship between discharge, economic surface area of the pond and total annual cost.

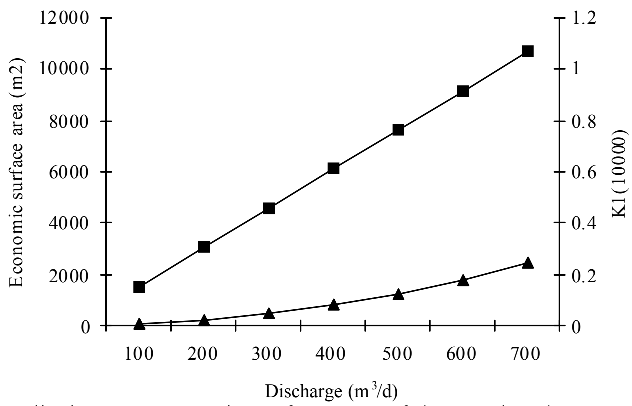

Fig. 2: Relationship between discharge, economic surface area of the pond and K1.

Table 3: Design Parameters for economic size pond

Discharge (Q, m^3/d)	100	200	300	400	500	600	700
K_1 (x 1000)	1.528	3.055	4.583	6.110	7.638	9.166	10.693
K_2 (x 1000)	3.244	3.244	3.244	3.244	3.244	3.244	3.244
Surface area (m^2)	49.9	199.6	449.1	798.4	1247.5	1796.4	2445.1
C_1(x 1000 Naira)	4.334	1.083	0.482	0.271	0.173	0.120	0.088
C_2(x 1000 Naira)	6.500	1.625	0.722	0.406	0.260	0.181	0.133
Total Cost (T, x 1000 Naira)	10.834	2.709	1.204	0.677	0.433	0.301	0.221

Table 4: Surface areas of similar ponds (source: Mara[20])

Description	Flow rate (m^3/d)	Surface area used (m^2)	Expected surface area for 300 m^3/d (m^2)	Economic surface area (m^2)
Auckland, New Zealand	210000	5300000	7571.4	450
Melbourne, Australia	350000	3100000	2657.14	450
Stockton, California	250000	2500000	3000	450

Although the value is higher than specified surface BOD loading for aerobic, facultative and aerated ponds in literature (Table 5) but the same for anaerobic ponds, classified as anaerobic pond which are known for BOD reduction at lower oxygen consumptions and at high BOD concentration to nutrient ratio. Also, anaerobic ponds are known for odour generation thus

Table 5: Design parameters for ponds (Source: Tebbutt[11])

Description	Ponds			
	Aerobic	Facultative	Aerated	Anaerobic
Depth (m)	0.5 – 1.0	1 – 2	2 – 4	3 – 5
Surface BOD loading (kg of BOD/ m^2.d)	0.15	0.05	0.20	0.50
Retention period (d)	2 – 20	5 – 30	2 – 10	30- 60
Percentage BOD removed (%)	80 - 90	75 – 85	50 – 90	50 – 70

there is a need to check for odour production using a known expression (11)

$$\lambda_v = \frac{Q\ BOD}{V} \quad (10)$$

Tebbutt[11] reports that volumetric BOD loading of any pond greater than 400 g of BOD per unit volume per day the pond must generate odour. Substituting the values (Q = 300, V = 450 x 1.5 and BOD = 750 mg/l) the volumetric BOD loading of the designed economic pond is 333.33g of BOD per unit volume per day. The result shows that the pond is not likely to produce serious odour as normal anaerobic pond will do. BOD removal of anaerobic ponds is known to be lower than BOD removal of aerobic ponds. BOD removal by ponds can be determined using equation (12).

$$\lambda_{sr} = 20\lambda_s + 10.75 \quad (11)$$

Substituting these values minimum BOD removal of the designed pond is 11.11 %, which is low as usual, but using equations (13) and (14), retention period and the BOD removed by the pond are 2.25 days and 58.28% respectively. This result shows that the pond is effective in BOD removal and classification of ponds according to depth and surface BOD loading is not applicable to economic size ponds using these derivations indicated in Oke and Otun[5]. Mara[20] reports that ponds operated with retention time greater than 5 days have been found to be facultative ponds rather than anaerobic and that ponds with retention period of less than 5 days are possible but, they are not recommended because of the risk of odour release to the environment. This reason although it is general but it cannot be applied to the designed pond as the volumetric BOD loading is less than 400g of BOD per unit volume.

$$t = \frac{A\ D}{Q} \quad (12)$$

$$BOD_t = L_o\left[1 - e^{(-kt)}\right] \quad (13)$$

Conclusions: It can be concluded based on the result that:

- Design of ponds using economic sizing approach is practicable and really economical in size.
- In the provision of the pond the number in series should be greater than 1 to increase effectiveness of the ponds and to create rooms for maintenance.

Abbreviations:

X_{OA}	initial concentration of autotrophic biomass (mg/l)
Y_A	overall yield coefficient autotrophic biomass cell BOD per unit mass of oxidised nitrogen compound
S_{NOO}	initial concentration of oxidised nitrogen compound (mg/l).
S_{NO}	concentration of oxidised nitrogen compound (mg/l).
m_A	maximum growth rate for autotrophic biomass (/d)
b_A	specific decay rate of autotrophic biomass (/d)
L_o	ultimate BOD concentration (mg/l)t and k time and rate of BOD removal respectively (d,/d)
BOD_t	BOD removed at time t (mg/l).
A	total surface area (m^2)
C_1 and C_2	maintenance and operational and equivalent annual initial cost (in Naira).K_1 and K_2 constant that relate cost and area together.
D	expected actual depth of pond (m) = 1.5 m[11].
C_i	Expected influent BOD concentration (kg/m^3).
C_o	expected effluent BOD concentration = 20 mg/l[17].
V	velocity of flow = 0.3m/s = 25920 m/d[18,19].
T	temperature (35°C, Adewumi[16]).
D_1 and D_2	initial and final dissolved oxygen of the sample respectively (mg/L)
f	ratio of seed in the sample to seed in the controlp decimal volumetric fraction of sample used.
B_1 and B_2	initial and final dissolved oxygen of the seeded control respectively (mg/L)

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