Journal of Applied Sciences 5 (1): 108-112, 2005
ISSN 1607-8926

Determination of the Deoxygenation Rates of a Residential Institution's Wastewater

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Abstract: Empirical analysis of a residential institution's wastewater (WW) for the design parameters such as carbonaceous deoxygenation rate (K) and nitrogenous deoxygenation (or nitrification) rate was reported in this study. Standard laboratory procedures were used in analysing the microbial activities in incubated samples in terms of dissolved oxygen requirements for carbonaceous deoxygenation and nitrification using both the daily difference method and the dimension less Fibonacci technique respectively. The BOD removal rate for Obafemi Awolowo University, Ile-Ife's residential institutional waste was found to be 0.23/day with standard deviation of 0.036 day. Mean of the ultimate BOD of the WW was found to be 631.2 mg L^{-1}. Likewise, the nitrification rates were found to be in the range of 0.293-0.443 day with a mean value of 0.34 day. The results show that institutional WWs are stronger than domestic WWs but less strong than some industrial waste waters such as tannery WW.

Keywords: Biochemical oxygen demand (BOD), deoxygenation rate (k), nitrification rate, primary oxidation pond

INTRODUCTION

The biological, chemical and physical characteristics of any given wastewater (WW) such as pH, dissolved oxygen (DO), total dissolved solids (TDS), nitrate, phosphate, chloride and heavy metal (HM) concentrations determine its treatability. The ratio of biochemical oxygen demand (BOD) to chemical oxygen demand (COD) is often used to choose an appropriate treatment regime for a particular WW. The higher the BOD/COD ratio the more amenable the WW is to biological treatment. Although there are conventional treatment facilities such as activated sludge systems, aeration tanks, trickling filters, waste stabilization ponds system has been found to be an appropriate technology for most developing tropical nations where land and labour are still relatively cheap and the climate favours natural operations at tropical temperature. The high ambient temperature encourages the activities of heterotrophic bacteria and algal growth needed for biological treatment of WW.

In biological treatment processes biodegradation of suspended and dissolved solids in WW occurs in two main stages, namely: carbonaceous deoxygenation and nitrification stages[1-3]. Carbonaceous deoxygenation involves symbiotic actions of heterotrophic bacteria and green algae while nitrification requires activities of autotrophic bacteria.

For the design of biological treatment processes such as trickling filters, activated sludge units, waste stabilization ponds such as primary oxidation ponds, facultative anaerobic ponds and maturation ponds, the knowledge of ultimate BOD, the rates of carbonaceous deoxygenation and nitrification are essential and important. To determine these three essential parameters, prolonged (at least 20 days) incubation of the WW samples is usually needed[1,2]. The determination of these three parameters can be achieved using several methods such as Thomas' method, least square method, Fujimoto method, rapid ratio method and moment's method[4] and daily difference method[2]. Thomas' and least square methods are the common methods in use.

Most old Universities in Nigeria (established before 1975) use biological treatment facilities for treating WW generated in their respective community. In spite of having land in abundance, large surface area ponds and favorable temperature, the waste stabilization ponds are apparently not able to produce treated effluents that will meet the minimum standard limits set by Nigeria's Federal Environmental Protection Agency (FEPA)[5]. As a result, most waste stabilization ponds, even in residential academic institutions, discharge their effluents into the environment without adequate treatment and great negative impact on the aquatic life of the receiving streams. There is no evidence that the carbonaceous deoxygenation rate (k), used for the design was based on empirical data nor was the nitrification rate considered in the documents relating to the design and construction of the Obafemi Awolowo University, Ile-Ife, Nigeria (OAU)'s

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primary oxidation ponds. These reasons may account for the poor performance of the ponds.

The Thomas' method for BOD determination is based on the similarity of two series function. It is a graphical analysis based on the function:

$$[t\,y^{-1}]^{1/3} = (2.3kL)^{-1/3} + k^{2/3}(3.43L^{1/3})^{-1}\,t \qquad (1)$$

where:

k = BOD deoxygenation rate in base 10 (day)
L = Ultimate BOD (mg L^{-1})
y = BOD that has been exerted in time interval t (mg L^{-1})
$[t\,y^{-1}]^{1/3}$ = Can be plotted as a function of t, with the slope of the graph being $k^{2/3}(3.43\,L^{1/3})^{-1}$ and the intercept is
$2.3kL^{-\frac{1}{3}}$ = From which k and L will be determined.

Similarly the least squares method involves a fitting curve through a set of data points, so that the sum of the squares of the residuals must be a minimum. Using this method, a variety of different types of curves can be fitted through a set of data points[4]. It is a simultaneous equation based on the function

$$\Sigma y' = na\,b\Sigma y \qquad (2)$$

where:

k = -b (base e)
$y' = y_{n+1} - y_{n-1}(\Delta t)^{-1}$ and
n = number of data points.

However, nitrification kinetic involves at least the following three model components: ammonia - nitrogen, dissolved oxygen and oxidised nitrogen. The generation of oxidised nitrogen is solely related to nitrification and the fate of oxidized nitrogen concentration, S_{NO}, may conveniently be monitored on the basis of the following mass balance Eq (3):

$$S_{NO} = S_{NOo} + \mu_A X_{Ao}[Y_A(\mu_A - b_a)]^{-1} e^{(\mu A - ba)\,t} - \mu_A X_{Ao}[Y_A(\mu_A - b_a)]^{-1} \qquad (3)$$

where:

μ_A = Maximum growth rate for autotrophic biomass (day)
b_A = Specific decay rate of autotrophic biomass (day)
S_{NO} = Oxidised N concentration (mg L^{-1})
S_{NOo} = Initial concentration of oxidised N mg L^{-1} in t = time (d)
Y_A = Overall yield coefficient of autotrophic biomass g cell BOD per g oxidized N
X_{Ao} = Initial concentration of autotrophic biomass (mg L^{-1})

Eq. (3) has been simplified into a simpler linear logarithmic form for the calculation of the corresponding μ_A-b_A value. Orhon *et al.*[6] have shown that the simplified linear expression was not always mathematically justifiable and so proposed a "curve fitting" approach for the same experimental set-up by rearranging Eq. (3) as:

$$(S_{N0} - S_{N0o})\,k + 1 = e^{at} \qquad (4)$$

where:

$k = Y_A X_{Ao}^{-1}(\mu_A - b_A)\,\mu_A^{-1}$
$a = \mu_A - b_A$

This non-linear expression in terms of k is then solved using the dimension less Fibonacci technique, which computes the μ_A-b_A value with the highest correlation coefficient, using all the experimental data and also selecting the optimum k value within a pre-selected interval. Then, the corresponding μ_A value is calculated, using a default value of 0.05 d^{-1} for b_A as no specific procedure has so far been proposed for the experimental determination of the endogenous decay rate of the autotrophs[6].

However, notable references such as[4,7-14] lack data on BOD removal rates, nitrification rate and ultimate BOD of residential institutions' WWs. Adewumi[1] and Onuoha[15] provided data on BOD removal rates and ultimate oxygen demand, but lack data on nitrification of two different residential institutional WWs. This present study is a continuation of Adewumi[1,2]'s study of the treatability of a residential institution's WW in terms of the nitrification rate in particular.

MATERIALS AND METHODS

Samples of waste waters were collected from the influent into the waste stabilization ponds at the OAU. Ile-Ife is on latitude 7.5°N of the equator and longitude 4.5°E of the Greenwich Meridian. It has a humid tropical climate with peak dry and wet seasons around February to April and June to August, respectively[2]. Samples were collected purposively in the second week of each month and on a randomly selected day of the week in February to August inclusive of the same year. Collected samples were serially diluted with aerated dilution water prepared as in APHA[16] and incubated for 20 days in two replicates. The use of buffered aerated water is to ensure the heterotrophic bacteria in the WW would have oxygen that

the green algae would have supplied in the open pond. Average BOD concentrations of the collected samples were determined using the Winkler's modified iodometric method[16].

Monthly averages of the results were used to determine BOD removal rates in the first ten days as established in Adewumi's[1,2]. The BOD values for the subsequent 10 days were used in determining the nitrification rates and ultimate oxygen demand for each month of study. The analyses were replicated in the following year and the average determined. Analysis of BOD removal rate was determined with the least square method. Analysis of the nitrification rate was carried out using the method described in Orhon *et al*[16].

RESULTS AND DISCUSSION

It may be seen from Table 1 that minimum BOD removal rate is 0.15 day, maximum BOD removal rate is 0.27 day with a mean of 0.23 day and standard deviation of 0.036. These results show that BOD removal rate (k) for carbonaceous material in a residential institution's WW is less than that of typical domestic WWs of mean k= 0.30 day[4] but higher than those of most industrial waste waters with 0.08 – 0.12 day[6]. These values of BOD removal rate at 20°C could be said to fall within the range of untreated WWs with 0.15 to 0.28 day[4], higher than high rate filter and anaerobic contact of 0.12 to 0.22 day, high degree bio-treatment effluent of 0.06 to 0.10 day[4].

The average k- value obtained by Adewumi[1,2] for the waste stabilization pond in OAU has not changed. This shows that the quality of the WW has remained within the same strength and characteristics despite changing population. The monthly difference in the laboratory BOD removal rate representing the pond environment may be attributed to any or all of the following reasons:

1. The very low deoxygenation rate in the month of June may be attributable to higher use of toilet facilities during this rainy season, accounting for low strength of BOD and also of expected nitrification rates.
2. Seepage into the sewers from surface runoff may also account for further dilution of the WW into the oxidation ponds.

Also, ultimate BOD as shown in Table 1 is in the range of 364.4 to 769.7 mg L^{-1} with a mean of 631.2 mg L^{-1} and standard deviation of 166.8 mg L^{-1} (Appendices I-II). The mean value shows that ultimate BOD value of institutional WW under investigation is higher than that of typical domestic WW and lower than those of typical industrial WWs[17,18].

However, Fig. 1 and Appx. I -II show the values of nitrification parameters and the mean nitrification rate curve for residential institutional WW. The equation of best fit shows that the mean nitrification rate is 0.33 day which correlates with the value of 0.34 day in Table 2 and is similar to the value obtained by Orhon *et al.*[6] for

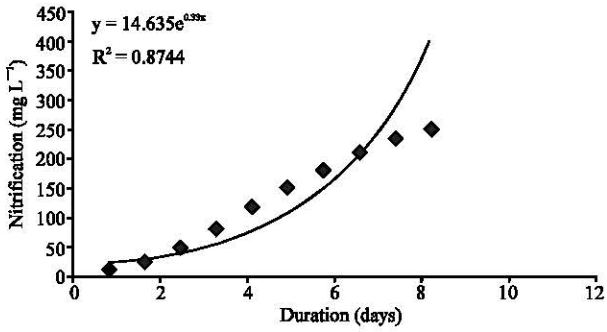

Fig. 1: The mean nitrification rate curve for the Influent WW into the Obafemi Awolowo University, Ile-Ife's primary oxidation ponds

Table 1: The ultimate BOD and BOD removal rate of the influent WW into the Obafemi Awolowo University, Ile-Ife's Primary Oxidation Pond, February –August (2002 and 2003)

	Minimum	Maximum	Mean	Standard deviation
Ultimate BOD (mg L^{-1})	364.40	769.70	631.20	166.800
Carbonaceous BOD removal rate (unit per day)	0.15	0.27	0.23	0.036

Table 2: The nitrification rate of the raw Influent WW into the Obafemi Awolowo University, Ile-Ife's Primary Oxidation Pond monitored in 2002-3

Months	μ_A	Nitrification (μA - bA)	(μ_A - b_A) /(μA)	K	(y_A) /(XoA)
February	0.254	0.304	1.19	20.27	24.26
March	0.292	0.342	1.17	6.16	7.21
April	0.393	0.443	1.13	7.42	8.37
May	0.277	0.327	1.18	12.87	15.19
June	0.244	0.294	1.21	25.69	30.96
July	0.310	0.360	1.16	8.38	9.73
August	0.304	0.354	1.16	9.42	10.96
Maximum	0.393	0.443	1.21	25.69	30.96
Minimum	0.243	0.293	1.13	6.16	7.21
Mean	0.296	0.336	1.169	14.64	17.20
SD	0.049	0.049	0.026	8.44	10.32

Appx. I: The mean monthly BOD data (2002 and 2003) of the influent WW into OAU's primary oxidation ponds and computed values for rate using the Least Square method

Days	BOD (Y)	Y^2	Y'	YY"	BOD (Y)	Y^2	Y'	YY"
February					**March**			
1	150	22500	118.000	17700	150	22500	118.000	17700
2	268	71824	113.000	30284	268	71824	113.000	30284
3	376	141376	91.000	34216	376	141376	91.000	34216
4	450	202500	69.500	31275	450	202500	69.500	31275
5	515	265225	60.000	30900	515	265225	60.000	30900
6	570	324900	47.500	27075	570	324900	47.500	27075
7	610	372100	35.000	21350	610	372100	35.000	21350
8	640	409600	25.000	16000	640	409600	25.000	16000
9	660	435600	25.000	16500	660	435600	25.000	16500
10	690	476100	3.000	2070	690	476100	3.000	2070
Sum	4929	2721725	587.000	227370	4929	2721725	587.000	227370
April					**May**			
1	160	25600	130.000	20800	90	8100	60.000	5400
2	290	84100	110.000	31900	150	22500	55.000	8250
3	380	144400	85.000	32300	200	40000	50.000	10000
4	460	211600	65.000	29900	250	62500	50.000	12500
5	510	260100	45.000	22950	300	90000	45.000	13500
6	550	302500	35.000	19250	340	115600	35.000	11900
7	580	336400	27.500	15950	370	136900	25.000	9250
8	605	366025	22.500	13612.5	390	152100	20.000	7800
9	625	390625	15.000	9375	410	168100	20.000	8200
10	635	403225	1.000	635	430	184900	2.000	860
Sum	4795	2524575	536.000	196672.5	2930	980700	362.000	87660
June					**July**			
1	80	6400	60.000	4800	180	32400	120.000	21600
2	140	19600	55.000	7700	300	90000	115.000	34500
3	190	36100	45.000	8550	410	168100	100.000	41000
4	230	52900	35.000	8050	500	250000	80.000	40000
5	260	67600	27.500	7150	570	324900	57.500	32775
6	285	81225	20.000	5700	615	378225	37.500	23062.5
7	300	90000	17.500	5250	645	416025	25.000	16125
8	320	102400	12.500	4000	665	442225	15.000	9975
9	325	105625	5.000	1625	675	455625	5.000	3375
10	330	108900	0.500	165	675	455625	0.000	0
Sum	2460	670750	278.000	52990	5235	3013125	555.000	222412.5
August								
1	170	28900	125.000	21250				
2	295	87025	112.500	33187.5				
3	395	156025	90.000	35550				
4	475	225625	72.500	34437.5				
5	540	291600	57.500	31050				
6	590	348100	45.000	26550				
7	630	396900	35.000	22050				
8	660	435600	25.000	16500				
9	680	462400	15.000	10200				
10	690	476100	1.000	690				
Sum	5125	2908275	578.500	231465				

Appx II: Monthly average of the BOD removal during nitrification of the influent WW into OAU's primary oxidation ponds

February			March			April		
Days	BOD	Nitrification	Days	BOD	Nitrification	Days	BOD	Nitrification
1	150	15	1	150	-10	1	160	10
2	265	35	2	268	-10	2	290	10
3	345	58	3	376	10	3	380	35
4	395	88	4	450	20	4	460	70
5	435	133	5	515	50	5	510	105
6	470	168	6	570	80	6	550	130
7	500	208	7	610	95	7	580	135
8	527	243	8	640	115	8	605	170
9	547	263	9	660	115	9	625	205
10	562	273	10	690	115	10	635	215

Appx II: Continue

May			June			July		
Days	BOD	Nitrification	Days	BOD	Nitrification	Days	BOD	Nitrification
1	90	10	1	120	20	1	80	15
2	150	20	2	190	60	2	140	35
3	200	40	3	245	80	3	190	65
4	250	70	4	290	120	4	230	100
5	300	100	5	320	180	5	260	140
6	340	120	6	350	220	6	285	170
7	370	150	7	370	270	7	300	200
8	390	180	8	380	320	8	320	225
9	410	200	9	390	360	9	325	250
10	430	220	10	390	380	10	330	270

inhibited synthesis tannery wastewater. This may mean that possible discharge of chemical wastes may have introduced inhibitory chemicals into the institutional wastewater. The determination of such inhibitors is not part of the scope of this present study. Most of the nitrification activity would probably be higher in the sludge formed in the main pond system. Since destruction of the microorganisms in the WW and sludge is part of the object of treatment, it would be necessary to monitor the sludge quality of the pond with a view to reuse or disposal. The accumulation of sludge in the oxidation ponds has reduced the field quality of the treated effluent of the due to reduced detention time capacity.

CONCLUSION

The mean carbonaceous deoxygenation rate of OAU's residential institutional WW is 0.23 day and the ultimate BOD value is 631 mg L^{-1}. This was similar to the findings of an earlier work[1,2]. This implies that the volume of WW may have increased but the activities characterizing the WW has not. The nitrification rate for the WW studied is 0.34 day. The values are slightly higher than for some industrial wastes such as those from tannery WW but less than those of domestic WW. The method used in this study will be very useful to engineers especially in tropical developing countries where the environment and economy of labour and land favours the use of waste stabilization ponds systems.

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