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Evaluation of Design and Operational Parameters of Pilot Single Stage Stabilization Pond for Treatment of Brewery Waste Water Effluent

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Abstract

The suitability of waste stabilization pond (WSP) as a cheaper alternative in the treatment of brewery wastewater effluent was investigated. A pilot WSP was designed and constructed and test run for the treatment brewery wastewater effluent. Wastewater effluents were collected from an operating brewing industry in Kudenda light industrial layout, Kaduna. The influent pond flow rate of 0.2 m^3/day was chosen for the design of the pilot pond. Kinetic model design procedure of a facultative pond was used to design a rectangular shaped pond to reduce the BOD loading by 90%. The pond capacity was 4.7 m^3 (4700 litres) with a retention time of 25 days. The parameters that were analyzed for the raw and treated wastewater include: Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total suspended solids (TSS), Turbidity and Electrical conductivity (EC). It was observed that aerobic degradation occurred at the upper layer of the pond favoring the activities of aerobic bacteria. At the middle layer however favored the activities of the facultative bacteria, while at the lower level where there is virtually little or no presence of dissolved oxygen, anaerobic decomposition of the wastewater predominate. These combined mechanisms yielded the total the total decomposition of the wastewater by the pond. The BOD removal rate constant was 0.088 per day and the BOD-COD correlation was BOD=0.531COD-1.960. The BOD removal regression model was: $BOD=0.0001t^5-0.0034t^4-0.1419t^3+6.6096t^2-102.09t+1114.5$ and the pond performance efficiencies for the reduction/removal of the tested parameters 69% 68.9%, 81%, 67.2% and 71.6% respectively. The pond performance was found to be satisfactory and the kinetic parameter obtained can be utilized in the scale up design for industrial scale WSP.

Keywords: Stabilization pond; Brewery waste water; BOD; COD

Introduction

The world's population explosion has resulted into increase in domestic, agricultural and industrial activities to cater for human needs for survival. This has also led to the increase in generation of wastewater. Although we recognize the fact that water is undoubtedly the most precious natural resource that exists on our planet, we disregarded it by polluting our rivers, lakes and oceans with generated wastewaters. It is therefore the basic duty of every individual to conserve water resources [1]. The construction of cost effective standard wastewater treatment plant coupled with requirement of technical expertise has been a major barrier for the implementation of modern technologies by local authorities in many developing nations [2,3]. Consequently, developing nations are unable to incorporate these technologies as part of a wastewater treatment master plan [4]. It is therefore imperative to develop treatment systems that are economical and sustainable [1]. Waste Stabilization Ponds (WSPs) have been found to be a suitable alternative for wastewater treatment for tropical and subtropical countries since the sunlight irradiance and ambient temperature are key factors for the WSP process efficiency [5,6]. Treatment occurs through natural, physical, chemical and biological processes and no energy or machinery is required except sun light energy. According to [4], stabilization ponds are the preferred wastewater treatment process in developing countries such as Nigeria where land is often available at reasonable cost and skilled labor is in short supply. 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 [7]. The main focus of this study was to investigate with pilot-scale experiment, the suitability of WSP in the treatment of brewery wastewater effluents and the treatment performance of a pilot-scale WSP.

Pond design

Specifications: Design a pilot waste stabilization pond to treat 0.2 m^3 brewery wastewater per day.

- From the analysis of the brewery waste water carried out, the average BOD_5 of the brewery Wastewater is 1135.5 mg/L
- Mean ambient temperature in the coldest season in Kaduna metropolis where the pond is sited is 28 °C
- Pond depth=1.2 m (adequate for aerobic and facultative ponds; Tchobanoglous, 2000)
- BOD removal target is 90%
- For 90% BOD removal the BOD removal is 0.90 × 1135.5=1021.95 mg/L

Therefore:

Effluent BOD=1135.5-1021.95=113.55 mg/L

Kinetic model approach for facultative pond is employed in this design. The values of the design parameters used in the design calculations and the pond configurations obtained are presented in Tables 1 and 2.

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Parameter	Unit	Mean Value
pH	-	3.56
Temperature	°C	29.34
Suspended solids	mg/L	1040
Turbidity	NTU	5.96
Chloride	mg/L	618.2
BOD_5	mg/L	1135.5
COD	mg/L	2134.74
Conductivity	μs/cm	1130
Total Dissolved Solids	mg/L	862
Total Coliform	*E. coli*/100 ml	0.7

BOD: Biochemical oxygen demand; COD: Chemical oxygen demand

Table 1: Analysis of Brewery Wastewater effluent in Kudenda, Kaduna, Nigeria.

Design Parameters	Pond Dimensions
Temperature (28 °C)	Width (1.4 m)
Influent flow rate (0.2 m^3/day)	Length (2.8 m)
Mean Influent BOD (1135.5 mg/L)	Depth (1.2 m)
Net Evaporation (15% of pond Area)	Area (3.91 m^2)
Pond shape (Rectangular)	Volume (4.7 m^3)

Table 2: Design parameters, details and configuration of the Constructed WSP.

Kinetic model design

The simple approach to the rational design of facultative pond assumes they are completely mixed reactors in which BOD_5 removal follows first-order kinetics. The rational equation for the design is given as:

$$\frac{L_e}{L_i} = \frac{1}{(1+k_1 t)}$$

where, L_i is the influent wastewater BOD (mg/L), L_e is effluent (treated) wastewater BOD (mg/L) and t is Retention time; (days).

Rearranging equation (2):

$$t = \frac{L_i}{L_e} - 1\left(\frac{1}{k_1}\right) \tag{2}$$

The area of the pond is calculated using the below equation:

$$A = \frac{Q_t}{D} \tag{3}$$

where, Q is the wastewater volumetric flow rate (m^3/day) and D is the Pond depth (m), and A is the area of pond (m^2).

Substituting "t" from equation (2) into equation (3) the area becomes:

$$A = \left(\frac{Q}{DK_1}\right)\left(\frac{L_i}{L_e - 1}\right) \tag{4}$$

The value of k_1 at 20°C was found to be 0.3 day^{-1}; and its variation with temperature T is described by the Arrhenius equation below:

$$k_T = k_{20}\theta^{T-20} \tag{5}$$

where, Θ is the Arrhenius constant, whose value is usually between 1.01-1.09. The Urban water technology centre, Dundee proposed value of Θ as 1.05 and equation (5) becomes:

$$k_T = 0.3(10.5)^{28-20} \tag{6}$$

Hence from equation (6) above, using the mean air temperature in the coldest season in Kaduna as given in the above data,

$$k_T = 0.3(10.5)^{28-20}$$

$$k_T = 0.4\,day^{-1}$$

Using equation (3), the retention time; t is calculated;

$$t = \left[\left(\frac{1135.5}{113.55}\right) - 1\right]\left(\frac{1}{0.44}\right)$$

t=20.45 days.

This is approximately 21 days.

$$A = \left(\frac{Q}{DK_1}\right)\left(\frac{L_i}{L_e - 1}\right)$$

From equation 4, the pond area is calculated as:

$$A = \left(\frac{0.2}{1.2 \times 0.44}\right)\left(\frac{1335.5}{113.55} - 1\right)$$

A=3.4 m^2

Considering area increase of 15% for net evaporation:

A=1.15 × 3.4

A=3.91 m^2

The Pond Volume for a rectangular shaped pond is given as;

$$V = A \times D \tag{7}$$

V=3.91× 1.2=4.692 m^3 Approximately 4.7 m^3

The length- width ratio for stabilization pond is within the range of 2-3:1;

Taking a length-width ratio; L/W of 2:1

$$\frac{L}{W} = \frac{2}{1} = 2$$

Hence,

$L=2W$

But:

$A=L \times W=2W \times W=2W^2$

Therefore,

$A=2W^2=3.91$

$$W = \sqrt{1.955} = 1.398$$

Hence:

L=2W=2 × 1.398=2.8 m

Conversion of total pond volume from m^3 to liters:

Conversion factor: 1000 liters=1 m^3

4.7 × 1000=4700 liters

The construction and operational stages of the pond are shown in Figures 1-3.

Materials and Methods

The brewery wastewater effluents were collected from a brewing industry at Kudenda industrial layout, Kaduna. The discharge point into the receiving stream is situated at Latitude 10°28.043' N, Longitude 7°23.194' E and elevation 592.3 m above sea level.

The brewery wastewater samples were collected for a period of 27 days analyzed according to the methods of wastewater Quality assessment described in "Standard methods for the examination of water and wastewater of American Public Health Association [8]. The results of the analyses are presented in Table 3 and were considered for the design calculations.

Figure 1: Pond under construction.

Figure 2: Wastewater discharged into the pond.

Figure 3: Pond operated to stabilize wastewater.

Results and Discussion

The results of the analysis of the parameters of the raw and treated wastewater and the performance efficiencies of the WSP are presented in Tables 3-5.

High BOD and COD levels indicates decline in DO because the oxygen that is available in the wastewater is being consumed by the bacteria and this will lead to the inability of fish and other aquatic organisms to survive in the wastewater receiving stream and river. The analysis of the brewery wastewater effluent carried out showed that the range of the BOD_5 and COD of the wastewater are (800-1805) mg/L and (1504-3393.4) mg/L with average values of 1128 mg/L and 2122.1 mg/L respectively as presented in Table 4.

These values are higher than the recommended limits for discharge by NESREA (See Table 4) and this makes the wastewater unsuitable for direct discharge into the receiving water bodies since it may have negative effects on the quality of the stream water and subsequently cause harm to the aquatic life, animals and man [9]. The time profile of BOD_5 and COD for the treated wastewater as fitted on the polynomial curves are presented in Figures 4 and 5.

From these curves, the R^2 values for the BOD_5 and the COD curves are 0.9905 and 0.9728 respectively. The R^2 value is always between 0 and 1. The model is stronger and predicts better response when R^2 value is

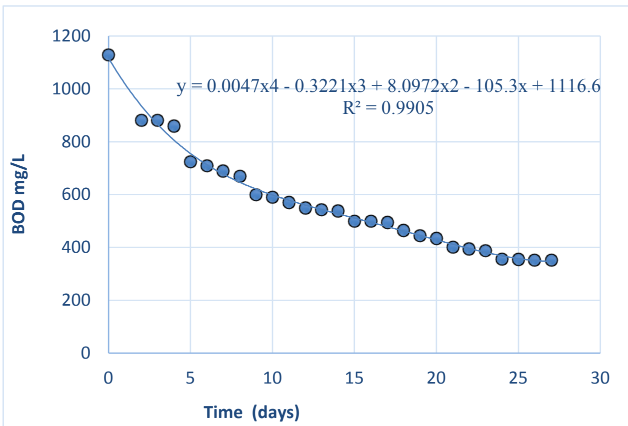

Figure 4: Time profile of BOD.

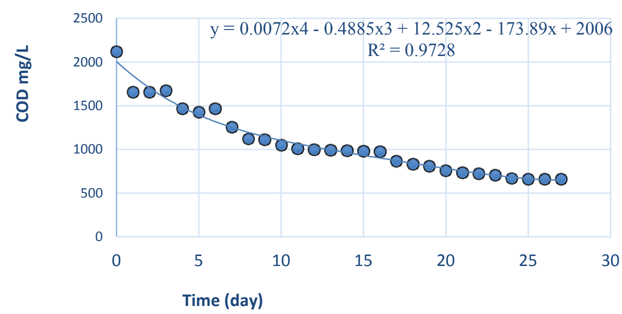

Figure 5: Time profile of COD.

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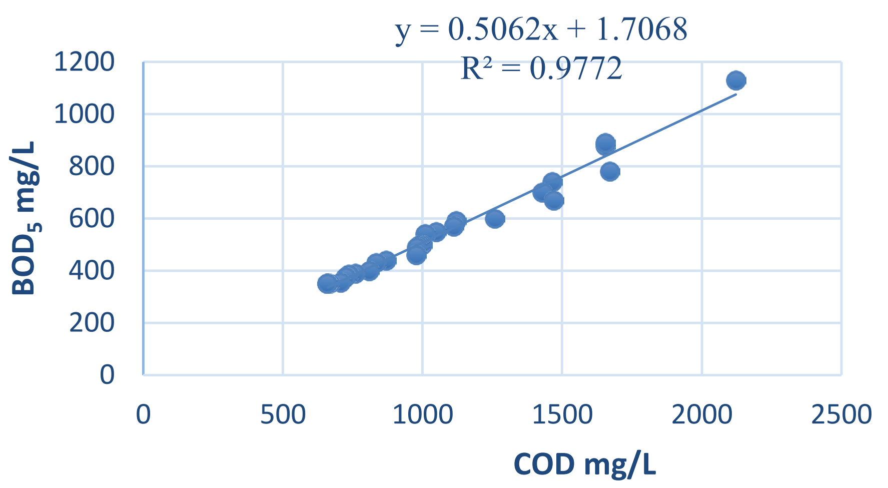

Figure 6: Correlation of BOD_5 and COD.

Ret. time (day)	BOD_5 (mg/L)		COD (mg/L)		TSS (mg/L)		Turbidity (mg/L)		EC (µS/cm)	
	RS	TS	RS	TS	RS	TS	RS	TS	RS	TS
1	1650	880	3102	1654.4	1200	400	7.2	5.0	1470	1280
2	1250	880	2350	1654.4	1200	400	6.5	4.5	1180	1280
3	1805	890	3393.4	1673.2	1000	400	4.6	2.2	1630	970
4	1110	780	2086.8	1466.4	1000	400	5.7	2.3	1120	910
5	1300	740	2444	1430	1000	400	5.0	2.1	960	610
6	990	700	1861.2	1470.4	1000	400	6.2	2.2	1020	610
7	1200	670	2256	1258.4	1000	200	6.1	2.2	1000	700
8	900	600	1692	1122	1000	200	6.0	2.1	1000	695
9	1500	590	2828	1112.8	1000	200	6.2	2.2	940	640
10	900	570	1692	1050.5	1000	200	6.1	2.4	980	620
11	1000	550	1880	1010	1000	200	6.0	2.5	870	410
12	890	540	1673.2	1001	1200	200	6.0	2.2	902	400
13	800	535	1504	990	1000	200	6.2	2.1	890	400
14	1110	500	2086.8	985	1000	200	6.5	2.1	900	370
15	900	495	1692	980	1000	200	6.3	2.1	800	360
16	905	490	1701.4	978	1000	200	6.4	2.0	770	355
17	910	460	1710.8	870	1100	190	6.5	2.0	710	350
18	900	440	1692	835	1100	195	6.5	1.8	715	330
19	905	430	1701.4	810	1120	195	6.6	1.9	716	325
20	906	400	1703.3	760	1200	190	6.6	2.0	700	305
21	1000	390	3102	736	1200	198	7.2	2.1	1470	300
22	1250	385	2350	725.5	1000	198	6.5	2.0	1180	295
23	1005	375	3393.4	708	1000	199	4.6	2.0	1330	290
24	1110	355	2086.8	669	1000	200	5.7	2.0	1120	287
25	1300	350	2444	660	1000	199	5.0	2.0	960	287
26	990	350	1861.2	660	1000	199	6.2	2.0	1050	287
27	1200	350	2256	660	1000	199	6.1	2.0	1000	287

RS- Raw wastewater Sample, **TS-** Treated water Sample

Table 3: Results of the analysis of the raw and treated brewery wastewater.

Parameter	Range	Mean	Treated sample	NESREA limit
BOD_5 (mg/L)	800-1805	1128.8	350	30
COD (mg/L)	1504-3393.4	2122.1	660	80
TSS (mg/L)	1000-1200	1048.9	199	30
Turbidity (NTU)	4.6-7.2	6.09	2.0	25
EC (μS/cm)	700-1630	1011.8	287	Not Specified (900 By WHO)

Table 4: Analysis of Raw and Treated wastewater compared with NESREA Limits.

S/NO	Parameters	Unit	Efficiency (%)/ Rate constant
1	**BOD_5**	mg/L	69
2	**COD**	mg/L	68.9
3	**TSS**	mg/L	81
4	**Turbidity**	NTU	67.2
5	**EC**	μS/cm	71.6
6	**BOD Removal Rate constant**	Day^{-1}	0.088

Table 5: Efficiency and BOD removal rate constant of the Constructed WSP.

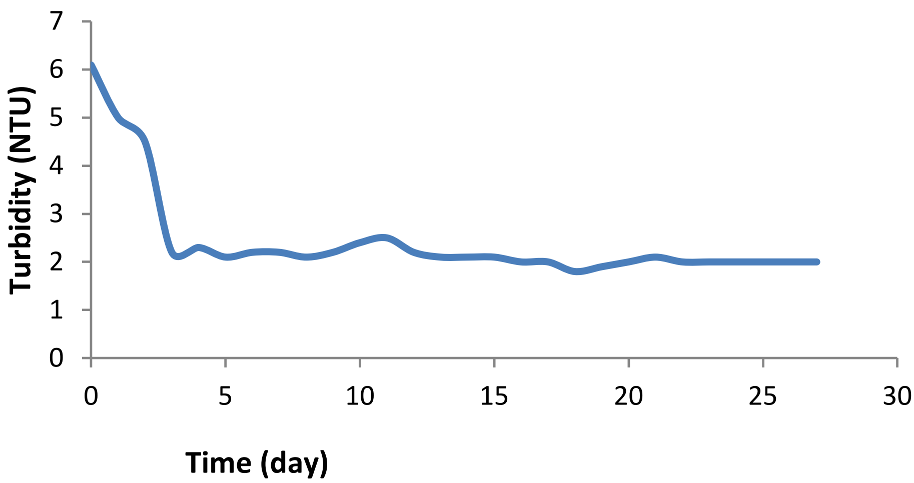

Figure 7: Time profile of Turbidity.

closer to 1, [3]. The plot of BOD_5 versus COD indicated R^2 of 0.9772 as presented in Figure 6 and predicted the correlation between BOD_5 COD as: BOD_5=0.5062(COD)+1.7068. This will be useful for the estimation of COD from BOD data and also ease the calculations of BOD_5/COD ratios in order to predict the biodegradability of the wastewater.

The BOD_5 and COD value obtained for the treated wastewater in the pond at the retention period of 25 days are 350 mg/L and 660 mg/L respectively. Although these values did not meet the NESREA limits for discharge into receiving water bodies, there was a significant reduction in the wastewater pollution loading and further reduction can be achieved with further stabilization in secondary facultative or the maturation ponds.

The turbidity and the total suspended solids of wastewater are indications of the water clarity [10]. The turbidity of the wastewater ranged from 4.6 to 7.2 NTU for the period of the study; and the mean value was 6.09 NTU. Similarly, the range of the TSS measured for the raw wastewater is 1000 to 1200 mg/L and the mean value is 1040 mg/L. The TSS mean value was higher than the NESREA limits [11] for brewery wastewater discharge as presented in Table 4. Excessive turbidity and TSS in water causes problem with water purification processes such as flocculation and filtration, which may increase treatment cost. High turbid waters also affect the sights of most aquatic lives. The Turbidity-time curve for the WSP treated wastewaters is presented in Figure 7. There was a sharp reduction in turbidity in the first 3 days of the retention period and later became gradually steady with little fluctuations over the remaining retention time. The turbidity was reduced from an average value of 5.96 to 2.0 NTU which implied 67.2% reduction (see Table 4). The time profile of TSS presented in Figure 8 have similar pattern which the turbidity curve. The sharp decline in the curves in the earlier days was as a result of high level of suspended solids in the wastewater and hence causing the quick sedimentation of heavier particles due to gravitational pull. Further decline in TSS are as a result of further gradual sedimentation of particles, the activities of algae and bacteria in the decomposition of suspended organic matters.

The range of the electrical conductivities of the brewery wastewater is from 940 to 1630 μs/cm and the mean value was 1130 μs/cm as shown in Table 4. Although there is no specified NESREA [11] limit for EC, this mean value exceeded the World Health Organization (WHO)

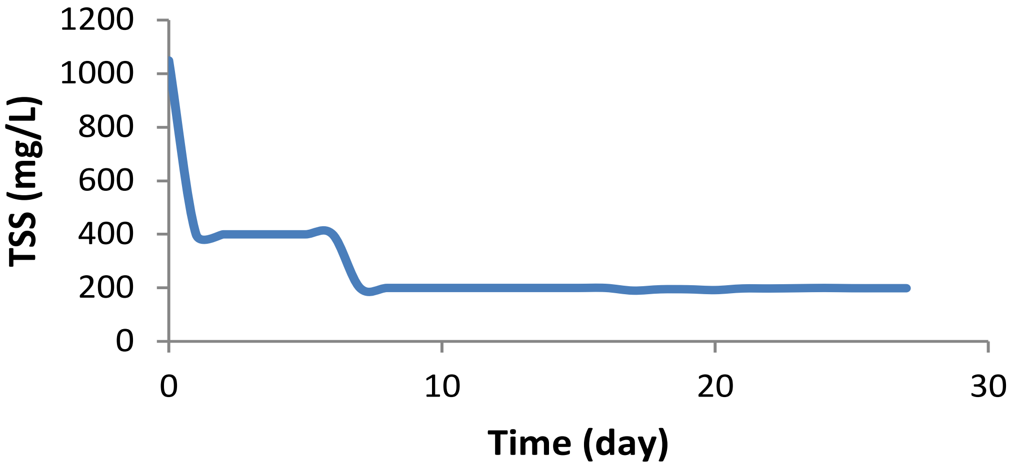

Figure 8: Time profile of TSS.

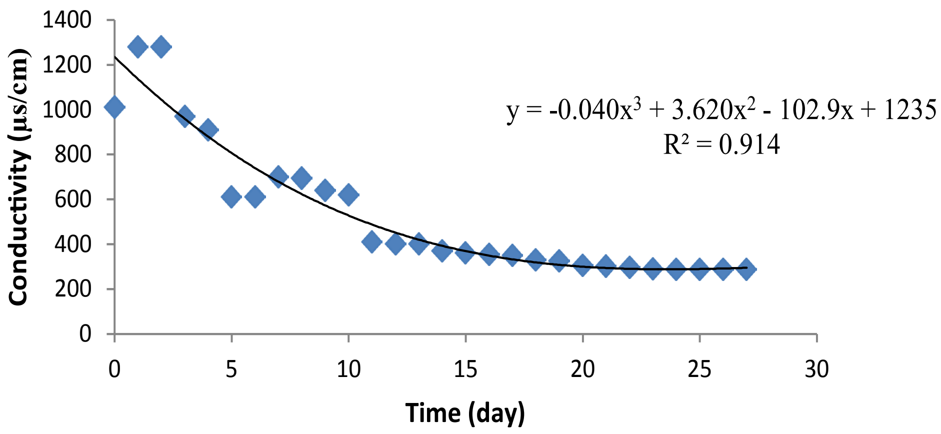

Figure 9: Time profile of conductivity.

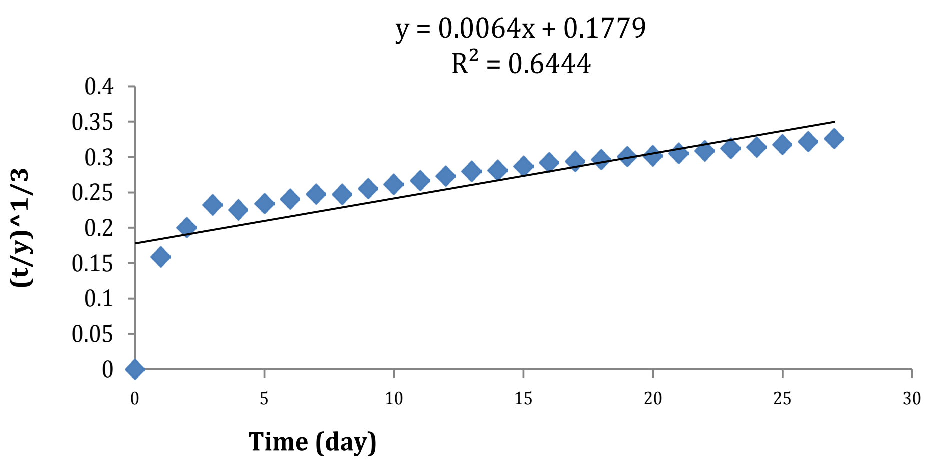

Figure 10: $(t/y)^{1/3}$ vs time.

limit of 900 µs/cm for industrial waste water discharge. Electrical conductivity is a useful indicator of mineralization and salinity or total salt in a water sample. High EC can also increase the corrosive nature of the wastewater. High EC of the wastewater can increase rate of soil erosion. High EC can also increase corrosion rate in metallic tanks/containers and wastewater pipelines. The EC-time profile is presented in in Figure 9. The EC was reduced from mean value of 1130 to 287 µs/cm which is 71.6% EC removal, as presented in Table 5. This value conformed to wastewater discharge limits by WHO [12].

The reaction rate constant for BOD_5 removal was evaluated using Thomas' method. This is obtained by the plot of $(t/y)^{1/3}$ versus time and t is the retention in days, while y is the BOD_5 in mg/L as shown in Figure 10. The BOD_5 removal rate constant k; calculated was 0.088 per day. The reaction rate constant is an important parameter used in the design calculations of WSP. Ref. [13] obtained a BOD_5 removal rate constant of 0.27 per day for WSP sewage treatment in in south eastern Nigeria. The value of the reaction rate constant depends on climatic conditions and type/nature of wastewater.

The performance of the constructed WSP was evaluated in terms BOD_5, COD, TSS, Turbidity and EC removal/reductions. The WSP efficiency based on these measured parameters were 69% 68.9%, 81%, 67.2% and 71.6% respectively as presented in Table 4. The BOD-COD correlation was BOD=0.531COD-1.960. The BOD removal regression model was: $BOD=0.0001t^5-0.0034t^4-0.1419t^3+6.6096t^2-102.09t\ 1114.5$.

Conclusions

It can be concluded from this studies that WSP can be employed as an alternative method for the treatment of brewery wastewater treatment. The performance efficiency of the pilot scale WSP for the removal/reduction of BOD_5, COD, TSS, Turbidity and EC for the wastewater was 69% 68.9%, 81%, 67.2% and 71.6% respectively. The design, operational and kinetic parameters obtained can be employed in the design and construction of industrial scale WSP for brewery wastewater effluents.

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