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TREATMENT OF BREWERY WASTEWATER USING AN ADIABATIC FLUIDIZED BED BIOREACTOR

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ABSTRACT

Adiabatic fluidized bed digester treatment methods are most suitable for the treatment of brewery wastewater streams as they offer more attractive operating and maintenance cost. This study is an investigation into the performance of an adiabatic fluidized bed bioreactor (AFBBR) system made of lagged insulating materials of cellulose. The digester was filled with activated carbon of particle size (70-300 µm) and operated at a superficial velocity of 0.00112 m/s, minimum fluidized velocity of 0.00233 m/s, height of 0.025 m and with a voidage of 0.298. At the liquid volumetric flow rate of 0.017361 m^3/s, the system was thermostatically controlled to operate at a temperature range of 35 ^oC- 42 ^oC. The wastewater treatment was conducted at different hydraulic retention times (HRT) of 1-5 hour. Results obtained revealed that chemical oxygen demand (COD) efficiencies reduced from 100% to 25.73% while the corresponding biological oxygen demand (BOD) reduced from 100% to 22.46% for a wastewater of initial concentration 2009.03 mg COD/L and 1719.2 mg BOD/L in 5 hours of HRT. Statistical analysis was carried out on the operation parameters using the Fisher's test and P- value to check the model adequacy. In this system, adiabatic fluidized bed bioreactor (AFBBR) played the most vital role in fulfilling the triple R of reducing, recycling and reusing for effective waste management.

1. INTRODUCTION

Water is one of the most indispensable substances just like air that all living organism cannot do without. The world's supply of freshwater is limited and threatened by pollution from various human activities, and the rising demands of water to supply agriculture, industry and cities are leading to competition over the allocation of the limited freshwater resources (Nyilimbabazi et al, 2011). The pollution of aquatic environment by waste streams from the industries and urban cities is ever increasing throughout the world and government is doing their best to curtail this menace through various environmental regulation agencies. Aluyor and Badmus, (2008) reports that "increasing population and increasing water use has already created pollution problems in many locations", for example, only about one quarter of the Nigerian population is served by well water source (Okonkwo and Okoli, 2013). Water is the largest raw material used in brewing processes. In a typical brewing process, an estimate of 1113 liters of fresh water is required to produce just 159 liters of beer (Ockert and Porter, 2001) and about 65% of the total water used in the brewery process ends up as wastewater (Fang et al., 1990, Mussatto,2009).Brewery wastewater contains high concentrations of brewers' spent grain (BSG) (Tang *et al.,* 2009) and this accounts for 30 to 60% of the biochemical oxygen demand (BOD) and suspended solids generated by a typical brewery (Allyu and Bala, 2011). Therefore, all breweries are significant water consumers and consequently a huge amount of wastewater producers (Ockert and Porter, 2001). In most breweries, there is no provision for the re-use of water within the process operations and so there is no avenue for limiting the quantity of wastewater discharge (Harry, 2008). The untreated effluent discharge from brewery into the natural water body is undesirable as the quality of the receiving water body is compromised (Owabor et al., 2012). Polley and Polley, 2000 reported that the demand for water in a brewery must be both quantity and quality controlled. As a result, the wastewater has to be effectively treated for removal of all hazardous contaminants before discharge to protect the aquatic life in receiving waters (Shoba et al., 2011). Etuk et al. (2009) reported that the cost of treating brewery effluents for example in Nigeria is in order of 120 - 220 million Naira annually. This high cost of treatment coupled with the environmental implication of discharged wastewater from breweries makes it necessaries to reduce water consumption and wastewater generation from the industry.

The principal water treatment unit operations employed to remove pollutants are rapid mix, coagulation and flocculation, sedimentation, filtration, disinfection, softening, ion exchange, adsorption, reverse osmosis etc. Activated carbon is one of the useful materials used to produce high quality water that is safe for human consumption, has aesthetic appeal (clear and colourless), (Eboibi and Eboibi, 2009; Ogunyemi et al., 2015). Fluidized bed reactors (FBR) have been used for more than 30 years for treating industrial and municipal wastewater (Rabah and Dahab, 2004; Jafari et al., 2013). Also some studies have demonstrated the use of up flow anaerobic sludge blanket (UASB) for various industrial wastewater treatments of brewery wastewater (Cronin and Lo 1998), piggery wastewater, pulp and paper mill effluents (Fang et al., 1990). However, long period of time is needed to develop good bacterial floc for successful operation of UASB reactor systems before the treatment begins (Basandorj 2007).Thus, this research was aimed at carrying out treatment and management of the brewery wastewater generated using an adiabatic fluidized bed bioreactor, instead of the conventional ways usually adopted and applied in most brewery industries. Statistical analysis is used to establish the relationship between mass transfer of the pollutants and biodegradation kinetics of the independent variable(s) and dependent (s) variables were also studied. In this context, the relationship between the operating HRT, organic loading rates (V/Q_{50}), COD and BOD was studied by developing a first order regression models.

2. MATERIALS AND METHODS

2.1. Material Collection and Preparation of Samples

Wastewater was obtained from the brewery factory located at Iganmu in Lagos State, Nigeria. Activated carbon of size range 70-300 µm which was procured from a local supplier in Ojota chemicals market, Lagos State, Nigeria, was used for the treatment process. pH was measured by a pH-meter (HANNA pH 211). The reagents used were of analytical grade; NaOH, distilled water were used for sample preparation.

2.1.1. Characterization of the activated carbon

In order to measure the effectiveness of the purchased activated carbon, the characterization was carried out immediately after sample arrived in the laboratory, for the purpose of treatment and the properties include % yield of 16.31, bulk density of 0.508 g/cm^3 and % Ash of 7.0 (Etuk et al., 2009).

2.1.2. Adiabatic fluidized bed reactor

The reactor filtering column was made up of Perspex with height of 50 mm, wall thickness of 3 mm and a working volume of 0.0103 m^3. The column comprised of three sections, which includes liquid discharge, testing and distribution section. The reactor was initially filled with 20 g activated carbon (70-300 microns), and then the 150 hours incubated seed sludge 100 ml was added. The seed used in the work helped to improve heat transfer resulting from the inherent characteristics of the fluidized state when thoroughly mixed with the fluid. The reactor length was lagged to prevent heat loss in temperature which was needed for the work. The water flow to the column was controlled by a pump Bomba (DAB Model). An air vent was also provided at the top of the column to avoid pressure build up within the system. The airline was connected to a compressor through a calibrated flow meter. All readings were obtained at ambient temperature.

2.1.3. Determination of COD and BOD

The fluidized bed reactor was operated continuously for 5 hours by which treatment was achieved at interval of 1hour. The resulting mixture was filtered, to determine the COD and BOD from the filtrate. These samples were analyzed as prescribed by the standard methods for the examination of water and wastewater (APHA et al., 2005).

2.2. Methodology

The methodology adopted for the treatment and chemical analysis on the treated water, according to the “Standard Methods for Examination of Water and Wastewater” (APHA, 2005). The raw wastewater sample was collected from the convergent point of wastewater from different process units in the brewery. The adiabatic system was made by lagging the reactor section with insulating materials of cellulose to maintain steady state. Sodium hydroxide solution (1 M) was added periodically to maintain the pH range of 6.91 to 6.97 in the digester. In the operational period that lasted for 150 hours, the adiabatic fluidized bed reactor was fed with wastewater and acclimatized seed sludge of 100 ml was added to allow for the greatest possible surface area for the reactor to take place. The results for the characterization of the brewery effluent before treatment contained total solid (2507.12 mg/L), dissolved solid (117.53 mg/L), suspended solids (42123 mg/L), pH of the sample was stored at 25 ^{0}C, organic loading rate (1719.2 mg/L), COD (2009.03 mg/L), and BOD (1792.02 mg/L). The AFBBR was operated under five different HRT of 1, 2, 3, 4 and 5 hours at the same initial feed concentration (1719.2 mg/L) and feed flow rate (0.017361 m^3/s). Liquid volumetric flow rate of 0.017361 m^3/s, superficial velocity of 0.00112m/s and 0.000233m/s minimum fluidized velocity, 20 g activated carbon, bed of height 0.025 m and 0.298 voidage were used in fluidized bed reactor.

3. RESULTS AND DISCUSSION

Characteristics of studied wastewater sample from the brewery are presented in Table 1 while Table 2 shows the summary of the investigated parameter values and also expresses the operational parameter values, the BOD reduction efficiency with the corresponding COD reduction efficiency at steady state.

Table 1: shows the characteristic results of raw sample at different HRT

HRT (hr)	1	2	3	4	5
COD, mg/L	2009.3	1719.31	1209.13	859.2	517.07
BOD, mg/L	1792.02	1693.41	1250.3	900.72	402.4
Organic Load mg/L (V/Q_{5O})	1719.21	1253.40	1100.00	900.72	894.7
Total suspended solids, mg/L	2123.4	2068.4	1938.4	1642.0	1790.2
Total solids, mg/L	2507.12	2549.01	2779.01	2871.10	2904.3
Dissolved solids mg/L	117.53	116.23	90.79	85.23	70.9

Table 2: Operational parameter values, reduction efficiency at steady state

HRT (θ_H), hr	1	2	3	4	5
V/Q_{SO}	2.62×10^{-2}	3.59×10^{-2}	4.1×10^{-2}	4.97×10^{-2}	5.03×10^{-2}
% B.O.D	100	94.48	69.77	50.26	22.46
% C.O.D	100	85.56	60.18	42.76	25.73
$\ln (S/S_o)$	0.00	2.28	2.24	2.14	0.09
$(1/S) \times 10^{-4}$	4.71	4.87	5.16	6.09	5.58
$\frac{S - S\theta(HRT)}{\theta H x 10^{-7}}$	1.00×10^{-6}	6.5×10^{-5}	3.3×10^{-4}	1.35×10^{-5}	3.38×10^{-5}

3.1. Modeling and Statistical Analysis

Statistical analysis was carried out on "the parameters obtained for organic loading and economical efficiency using **"**Fit Regression Model" of MINITAB 17.0. Mathematical models were developed (at 95 % level of significance) to describe the statistical relationship between specified predictor values (HRT) and the response variables (COD, BOD and V/Q_{50}) in order to predict new observations. The quality of the fit polynomial models were assessed by the

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coefficient of determination (R^2) and the ANOVA results for the response parameters are shown in Tables 3, 4 and 5.

Regression results indicate the statistical significance of the relationship between the predictor and response. Coefficients represent the mean change in the response for one unit of change in the predictor while holding other predictors in the model constant. P-value for each coefficient tests the null hypothesis that the coefficient is equal to zero (no effect). In order to obtain the optimum V/Q_{50}, COD and BOD (dependent variables) reduction, the responses were studied and interpreted by Minitab 17.0 to generate linear regression models (Equations 1, 2 and 3) and coefficient of determination (R^2) was used to explain the significance of the models.

Organic loading rates (V/Q_{50}) = 0.02202 + 0.006200 HRT (hr) (1)
Chemical oxygen demand (COD) = 120.25 – 19.134 HRT (hr) (2)
Biological oxygen demand (BOD) = 132.6 -19.93 HRT (hr) (3)

The coefficients of determination (R^2) of 94.56% (V/Q_{50}), 99.36 % (COD) and 83.30 % (BOD) respectively show that the models were highly significant with very small errors.

Table 3: Regression Analysis: V/Q_{50} versus HRT (hr)

Source	Df	Adj SS	Adj MS	F – Value	P – Value
Regression	1	0.000384	0.000384	52.16	0.005
V/Q_{50} (hr)	1	0.000384	0.000384	52.16	0.005
Error	3	0.000022	0.000007		
Total	4	0.000407			
S	R-sq	R-sq (adj)	R-sq (Pred)		
0.0027147	94.56 %	92.75 %	77.03 %		
Coefficients					
Term	Coef	SE	T-Value	P-Value	VIF
Constant	0.02202	0.00285	7.73	0.004	
V/Q_{50}	0.006200	0.000858	7.22	0.005	1.00

Table 4: Regression analysis: COD versus HRT

Source	Df	Adj SS	Adj MS	F – value	P – value
Regression	1	3661.10	3661.10	469.40	0.000
V/Q_{50} (hr)	1	3661.10	3661.10	469.40	0.000
Error	3	23.40	7.80		
Total	4	368.50			
S	R-sq	R-sq (adj)	R-sq (Pred)		
2.79275	99.36 %	99.15 %	98.50 %		
Coefficients					
Term	Coef	SE	T-Value	P-Value	VIF
Constant	120.25	2.93	41.05	0.00	
C.O.D %	-19.134	0.883	-21.67	0.000	1.00

Table 5: Regression Analysis: BOD Versus HRT

Source	Df	Adj SS	Adj MS	F – value	P – value
Regression	1	3972.0	3972.0	13.94	0.033
V/Q_{50} (hr)	1	3972.0	3972.0	13.94	0.033
Error	3	854.5	284.8		
Total	4	4826.6			
Model summary					
S	R-sq	R-sq (adj)	R-sq (Pred)		
16.8774	82.30 %	76.39 %	46.03 %		
Coefficients					
Term	Coef	SE	T-Value	P-Value	VIF
Constant	132.6	17.7	7.49	0.005	
BOD	-19.93	5.34	-3.73	0.033	1.00

Figure 1 show plot of B.O.D, C.O.D and V/Q50 versus H.R.T. These plots depict inverse relationships between H.R.T and operational parameters (C.O.D and B.O.D), and proportional relationship between HRT and V/Q_{50}, which implies reduction in the solids at different retention time. The COD decreased from initial concentration of 2009.03 mg/L to final concentration of 517.07 mg/L after 5 hours. This progressive decrease of COD was as a result of increase in rate of hydrolysis and acidogenesis reaction in the reactor. Hydrolysis involves breaking down of complex organic matter and its solubilization by extracellular enzymes produced by the anaerobic microbes in the reactor. A similar observation has been reported by Okonkwo and Okoli (2013). Hence, insoluble solids are made soluble and available for further transformation to product by other sets of anaerobic microbes. High COD reduction efficiency obtained in this work was as a result of completely mixed condition achieved in the fluidized-bed reactor than any other reactor type. There was also reduction in the total suspended particles, total solid and dissolved solid at every hydraulic retention time. The concentration in terms of organic loading (V/Q_{50}), also reduces as the hydraulic retention time increased, which shows a very good treatment of the brewery waste water. From the treatment of brewery wastewater by Okonkwo and Okoli (2013), it was reported that the COD (mg/L) reduced from 6437.8 to 1845.9 from (2 – 9) hours; in the same manner, BOD (mg/L) reduced from 1349.99 (mg/L) to 154.17 (mg/L) within the same time interval. This also agrees with the work of Etuk et al. (2009) and Menkiti et al. (2012)**.**

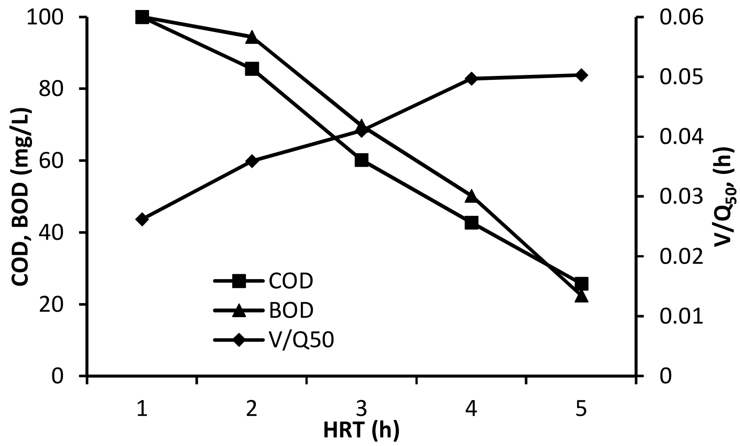

Figure 1: Plots of % B.O.D., % C.O.D. and V/Q_{50} versus HRT

4. CONCLUSION

This study has established the utility of fluidized bed digester system in the treatment of brewery effluent wastewater with high organics content which cannot be treated similar to domestic wastewaters. The application of fluidized bed reactor for treatment of high potency industrial wastewater such as obtained in brewery industry in the case study makes the recycling of wastewater from the process possible. So it is possible to reduce water consumption significantly and activated carbons can be reused after regeneration.

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work

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