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Performance Evaluation of Anaerobic Technology in Handling High Strength Effluent of a Brewery

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Abstract: This study examined industrial effluent treatment, from the treatment plant installed at a brewery in Benin city, Edo State, Nigeria. Grab samples were gathered from different phases of the treatment process to determine the efficiency of each phase and its input to the overall performance of the treatment plant. Chemical and biological analyses were carried out on samples collected daily during peak periods of production and analyzed within 24 h. Handling and analysis of samples were done according to standard procedures ISO/IEC 17025. The factors investigated include; Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), total phosphate, total nitrogen, Total Suspended Solids (TSS), sulphate, total coliform and Escherichia count *(E. coli)*. The results showed that the average waste treatment efficiency is about 82% and that the suspended solids removal is made more effective by the DAF clarifier while the CIRCOX reactor enhances nutrient removal. Also, the plant has about 59% Coli form removal and 607% *E-coli* degradation capacities. These results authenticate that the anaerobic technology with an aerobic polishing step is effective for treating High Strength Effluents (HSE) to meet the discharge requirements of effluent into water ways like river accessible to the public. A system efficiency model proposed in this study would assist in effective plant operation planning.

Key words: Anaerobic treatment, industrial effluents, wastewater, aquatic life, biological, analyzed

INTRODUCTION

With enhancement of world economic conditions and increase exploitation of natural resources, water assets are ending up progressively insufficient and the quality of environment in the world is constantly getting worsened in most regions (FAO., 2007). Treatment and administration of effluent, especially, industrial effluent is presently one of the environmental problem contributors of great concern (UN-Water, 2015). Furthermore, the high organic contents of such High Strength Effluents (HSE) make aerobic treatment systems uneconomical. In this way, there is a desperate need to create dependable advancements for wastewater treatment (Stuckey, 2010). Industries consume an immense measure of freshwater and produces organic-rich, HSE which requires suitable treatments before discharge (Oktem *et al*., 2008). In the immediate past decade, population explosion and continued increase in industries have inadvertently brought about the debasement of different biological communities that sustain man existence. Such activities of man have given rise to decrease in the quality of water bodies that serve man. Documented evidence reveals that many of such pollution is essentially, brought about by the discharge of poorly treated domestic, industrial and municipal wastewater (Chan *et al*., 2009; UN WWAP., 2008). However, chief among these are the discharge from industrial activities. Industrial wastewaters display varying high levels of inorganic toxins that have potential negative impacts on the ecosystems. Reviews of contemporary works also indicate that industrial waste water may posses Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD_5) or Chemical Oxygen Demand (COD) in the tens of thousands mg/L (Ng, 2006; Liu *et al*., 2010). Traditionally several methods are utilized to treat HSE, this comprises both physical, chemical and biological treatment of wastewater.

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Physical methods are deployed to eliminate the tangible and coarse matter in the waste water and the chemical treatment is deployed to eliminate the suspended impurities. Also, the biological treatment such as anaerobic and aerobic treatment are targeted at the high COD and BOD which may be present in the effluent (Sara *et al*., 2012; World Bank, 1999). Of a particular interest in this study is the biological treatment system which depends solely on the nature of microorganisms by use Driessen and Vereijken (2003). Anaerobic digestion is described as a designed methanogen anaerobic decomposition of organic matter present in effluents. The process entails varying species of anaerobic microorganisms that are employed to degrade pollutant organic matter (Cote *et al*., 2006).

The anaerobic process is developed to decompose organic and inorganic substrate in the absence of molecular oxygen (Abdurahman *et al*., 2013). In spite of the growing popularity and usage of the biological treatment system, there are scanty information in literature on the evaluation of its efficiency. There is scanty record in Nigeria with high number of beverage industries and huge market potential (Driessen and Vereijken, 2003; Babayemi and Dauda, 2009). This study is therefore, focused on evaluating the efficiency of a selected anaerobic system of a brewery in Nigeria for the treatment of HSE.

MATERIALS AND METHODS

The recently installed effluent treatment plants at a brewery in Benin, Nigeria is used for the purpose of evaluation in this study. It comprises of a BIOPAQ Internal Circulation Reactor (ICR) for anaerobic treatment process, BIOPAQ CIRCOX Reactor (CR) that handles aerobic treatment, the Dissolved Air Floatation (DAF) clarifier and the dewatering systems in the tertiary processes units. The plants design capacity is shown in Table 1.

In operating the plant, other assumptions used include, BOD/COD ratio of 0.5, effluent temperature between 30 and 40°C. Data on the changes in toxic content from the point of loading the treatment plant and at every stage in the treatment process were collected from the relevant authority at the brewery. In the same light, samples were also collected at all these points for independent analyses. Conformity with both international and local discharge limits were examined in this study. Grab samples were collected daily during peak periods of producing at the balancing tank, recycle tank, CIRCOX and the DAF clarifier. At each of these points, 500 mL of sample was collected and analyzed within 24 h following the ISO/IEC 17025 standards. The analyses of the grab samples were performed as specified in the standard methods. The variables monitored are: temperature, pH, BOD, COD, Total Phosphate (TP), Total Nitrogen (TN), TSS and sulphate test. Table 2. presents data on the effluent sources, characteristics and time of collection and the source.

These are important parameters that influence the quality of the effluent. The volume of discharge from each section of the brewery, classified as “High (>1000).” “Medium (500-1000)” or “Low (<500)” is required in this study to evaluate the effect of the wastewater quality viz. the efficiency of the installed brewery treatment plant. The analysed results are presented in Table 3-6. Samples used for both the independent laboratory analysis and the test by the brewery plant were taken from all the major stages of the treatment process. The process performance was evaluated using various parameters. These parameters include:

Table 1: Design data of the effluent treatment plant

Variables	COD (mg/L)	BOD (mg/L)	TSS (mg/L)	SO_4 (mg/L)	P (mg/L)	pH	Oil (mg/L)	Flow (m^3/day)
Max.	4212	-	317	-	-	12	<20	5695
Min.	-	-	61	-	-	6	-	-
Average	2799	1399	211	100	>12	8	17	5040

Table 2: Sources and characteristics of effluent sampled for independent laboratory analyses

Samples	Production discharge	Packaging discharge	Date	Time
A	Low	High	28/02/17	09:15; 15:45; 17:00
B	High	Low	10/02/17	09:00; 13:20; 16:45
C	High	None	11/02/17	09:00; 13:15; 17:45
D	Medium	High	24/02/17	09:00; 13:40; 18:00
E	None	High	03/03/17	09:12; 11:15; 17:48
F	High	High	04/03/17	09:05; 12:10; 18:06
G	Medium	Medium	18/03/17	09:00; 13:25; 18:00
H	High	High	08/04/17	09:08; 15:15; 18:15
I	High	High	21/04/17	09:00; 15:30; 18:00
J	High	High	06/05/17	09:15; 13:35; 18:00

The samples were collected three times a day to analyze temporal variability

Table 3: Discharge limits into river Ikpoba for brewery effluent

Parameters	Units	ESEPA limits	USEPA limits
COD	mg/L	125	120
BOD	mg/L	25	40
TSS	mg/L	35	35
N	mg/L	10-15	10
pH	-	5-9	5-9
Temperature	°C	40	40

Table 4: Comparison of the brewery and independent results of the effluent characteristics-10/02/17

Stages	pH_G	pH_L	Temp. (${}^GC$)	Temp. (${}^GC$)	COD_G (mg/L)	COD_L (mg/L)	TSS_G (mg/L)	TSS_L (mg/L)	TP_G (mg/L)	TS_L (mg/L)	SO_4^- (mg/L)	SO^-_L (mg/L)	TN_G (mg/L)	TN_L (mg/L)
Inlet	10.50	10.22	35.4	36.2	4160	4430	165	151	-	05	-	11	-	12
Balancing tank	5.18	5.41	32.4	32.8	3830	3328	140	133	39	38	29	-	25	21
Recycle tank	6.48	6.66	36.4	32.9	-	-	-	-	-	-	-	32	-	-
ICR	6.93	6.58	35.3	33.2	1296	1184	104	96	18	-	18	-	-	14
CIRCOX	-	-	-	-	-	601	-	-	-	16	1	12	-	-
DAF	7.26	7.11	35.4	35.8	296	260	49	47	09	10	09	04	11	08

Table 5: Comparison of the brewery and independent results of the effluent characteristics-08/04/17

Stages	pH_G	pH_L	Temp. (${}^GC$)	Temp. (${}^GC$)	COD_G (mg/L)	COD_L (mg/L)	TSS_G (mg/L)	TSS_L (mg/L)	TP_G (mg/L)	TS_L (mg/L)	SO_4^- (mg/L)	SO^-_L (mg/L)	TN_G (mg/L)	TN_L (mg/L)
Inlet	12.10	11.01	36.6	38.8	1690	2244	190	243	13	05	-	07	-	10
Balancing tank	6.34	5.44	37.1	32.1	1785	2465	172	171	38	36	33	-	21	32
Recycle tank	6.45	6.53	37.2	33.2	-	-	-	-	-	-	-	28	-	-
IC R	6.82	6.63	33.1	33.4	860	719	-	104	-	-	49	-	2	-
CIRCOX	6.71	-	-	-	-	485	-	-	17	-	-	17	-	-
DAF	6.92	6.55	36.0	35.4	131	120	63	59	10	12	15	09	22	15

Table 6: Comparison of the brewery and independent results of the effluent characteristics – 08/04/17

Stages	pH_G	pH_L	Temp. (${}^GC$)	Temp. (${}^GC$)	COD_G (mg/L)	COD_L (mg/L)	TSS_G (mg/L)	TSS_L (mg/L)	TP_G (mg/L)	TS_L (mg/L)	SO_4^- (mg/L)	SO^-_L (mg/L)	TN_G (mg/L)	TN_L (mg/L)
Inlet	8.40	8.21	35.8	35.5	2810	2245	129	109	-	16	29	03	-	08
Balancing tank	4.59	4.65	32.2	32.8	2240	2020	140	213	47	31	-	-	30	28
Recycle tank	6.17	6.34	32.5	33.2	-	-	-	-	-	-	44	31	-	-
ICR	6.44	6.34	33.3	33.4	775	612	-	105	-	-	-	-	-	-
CIRCOX	-	-	-	-	-	208	-	-	-	-	-	-	-	-
DAF	7.00	7.01	34.5	35.5	122	101	66	64	28	09	16	12	24	11

*$_G$ stands for the brewery laboratory result; $_L$ stands for independent laboratory result

Volumetric Loading Rate (VLR): The daily amount of COD fed into the reactor:

$$VLR = \frac{Q_i \times COD}{V} \quad (1)$$

Where:

Q_i = Flow rate of effluent
COD = COD content in mg/L
V = Volume of reactor

COD removal efficiency of the system:

$$\frac{COD_i - COD_e}{COD_i} \times 100\% \quad (2)$$

Where:

COD_i = COD at the inlet
COD_e = COD at the outlet

The Sludge Loading Rate (SLR):

$$\frac{COD_{ic}}{OS} \quad (3)$$

Where:

COD_{ic} = The daily amount of COD fed to the ICR
OS = The amount of Organic Solid

Hydraulic Retention Time (HRT): The average time the sewage is retained in the reactor:

$$HRT = \frac{V_R}{V_E} \quad (4)$$

Where:

V_R = Volume of reactor
V_E = Volume of effluent (sewage)

Specific Gas Production (SGPR):

$$SGPR = \frac{BP}{COD_R} \quad (5)$$

Where:

BP = The biogas produced in m^3d^{-1}

COD_R = The COD removed in kgd^{-1}

RESULTS AND DISCUSSION

The specified limits for effluent discharge into river Ikpoba by the Edo State Environmental Protection Agency (ESEPA) (Anonymous, 2000; USEPA., 2002) is presented in Table 3, the limits were compared with the national benchmark by the United States Environmental Protection Agency (USEPA) and the international standard and were observed to vary very slightly. The removal of organic compounds COD from the effluent is imperative to prevent the depletion of the dissolved oxygen in the receiving waters. The dissolved oxygen level in the river body largely determines the level of the biological activities in it. Thus, organisms living in the water like fishes, prawn, etc. will be seriously threatened, if the COD in the effluent is not removed to a definite allowable limit.

Comparative results from both the independent analyses and results obtained in the brewery laboratory for some selected dates are presented in Table 4-6. Figure 1 and 2 displays the effectiveness of the effluent treatment plant at various stages in comparison with the Environmental Protections Limit (EPL). Close inspection of the table showed that the results from the independent laboratory analyses and those from the brewery laboratory are very close. The little differences observed from the comparison of the different result for all the thirty samples, suggest that the effluent mix ratios from the production process are very dynamic. Expectedly the effluent characteristics vary with the source of the inflowing wastewater, a factor that depends on the production plan. A quick index of the quality and source of the wastewater is the effluent colour which varies from dark brown to light brown. For example, a light brown effluent showed that the waste consists mainly of straws, waste labels and the brewery solids (Kieselghur sludge and spent grain) while dark brown is an indication of high presence of suspended solids and turbid water.

The temperature of the effluent was observed to be within the range 34.5-38.0°C. Inspection of the results also showed that the incoming temperature is normally high during the day when wastewater from the mash boilers is discharged. The inflow temperature is only slightly reduced during the process. pH value varies as the wastewater treatment proceeds. Specifically, the pH in the balancing tank is brought very low for the pre-acidification process to take place. It increases in the recycle tank to between 6.3-6.8 which are the acceptable levels for the ICR. The effluent is sometimes odourless but at other times had a musty choking smell, depending on the source.

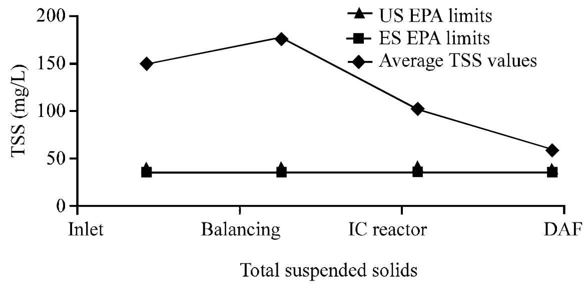

Fig. 1: Trend of TSS in comparison with environmental protections limits

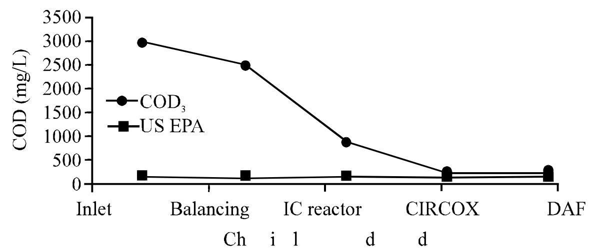

Fig. 2: Trend of COD in comparison with environmental protections limits

The daily flow of wastewater to the plant was within the range of 1, 200-1, 500 m^3/day. The chemical oxygen demand is the major factor used in determining the extent of pollution in the company's industrial waste (APHA, 2012). On the days when the company discharges wastewater from the production area alone, the COD is usually with the effluent characterized by a dark brown colouration. However, when it is dissolved with the wash water from the packaging section, it becomes lower but with significant increase in the nutrient content. The COD removal efficiency of the waste treatment plant for all the sample is between 81 and 96%. This is much higher than the values obtained with from a typical Chemically Enhanced Primary Ttreatment (CEPT) plant (Xu *et al*., 2006). Detailed analysis of the removal efficiency in all the samples showed that it is inversely proportional to the suspended solid content. This apparently is due to the fact that the suspended solids are in their own form of COD. Furthermore, when their quantity in any discharge water is low, the treatment process becomes more efficient, since, the major problem in the process is that of removing solid waste.

Table 7: Biological analysis of the effluent

Variables (cfu/mL)	Rivers	Production	Packaging	Label	Outlet
E. coli	0.12×10^1	-	-	1.11×10^3	0.66×10^1
Coliform	0.20×10^1	-	0.08	1.65×10^3	0.86×10^3

The high amount of coliform, i.e., Escherichia count (*E. coli*) going into the treatment plant as shown in Table 7 is as a result of microbial activities in the drain. Removal efficiency of the microbial content by the treatment plant was about 60%. The removal efficiency of TSS in all the samples on the average is 77%. TSS is related to the turbidity of the sample. It is normally caused by particles larger than 1.2 μm, efficient removal of suspended solids will enhance wastewater reuse (Knapp and Bromley-Challoner, 2003).

The efficiency from this treatment plant is low compared to an average of 90% recorded with the CEPT. It should however be noted that unlike in CEPT, alum is not added, thus, it is more economical to run. Also, the treated effluent will still be discharged into water bodies where natural sedimentation can occur in good time. The increase in the level of nitrogen during the treatment process is brought about by the use of nitrogen and phosphorus in the plant for the sustenance of the anaerobic micro-organism that does the waste digestion. It is suggested that the COD to nitrogen ratio at the balancing tank should not be <350:5 and the acceptable ratio for COD to phosphorus should be 350:1. It should be noted that most of the nitrogen is used in the formation of biogas which is a very good product of this treatment process.

Treated effluent versus discharge limit: Since, one of the objectives of this study is to access the deviation of processed wastewater quality from the stipulated discharge limit, the COD, TSS, TP and the TN levels were compared with the standard set by the ESEPA (Anonymous, 2000). It was observed that in the 10 instances analyzed from independent analysis, the conditions were only met at 4 instances, 28 January 2017, 4 March 2017, 18 April 2017 and 21 April 2017. This is quite challenging, since, it indicates that the conditions were only met at 40% of the time. Critical analysis of the result showed that, managing the plant according to specification is very important in attaining set standard. It was observed that when the design parameters were strictly adhered to, processed wastewater met the stipulated standard, 90% of the times, compared to a low range of 40% of the time, when the specifications were not followed. Furthermore, at the different instances when the discharge limit was met, the COD at the inlet was within the range of the plant design capacity. When the COD level at the inlet increased to 7.000 mg/L, even though the efficiency of the treatment plant was high, the ESEPA discharge limits were still exceeded. The implication of these is that concerted efforts must be applied through management planning to reduce the level of COD at the inlet (Maszenan *et al.*, 2011).

Removal efficiency of microbial content: The end use of the river Ikpoba for community water supply, bacterial analysis was conducted on the effluent before and after treatment. Analysis carried out includes Coliform count and *E. coli*. The result showed that waste water from the production area had a negligible coliform count. Wastewater from the packaging area had an average coliform count of 0.08 cf u/mL. This was as a result of some microbial actions taking place in the used bottles before washing.

CONCLUSION

The anaerobic technology is an effective method of treatment of brewery effluent as well as other biodegradable high strength effluent. Anaerobic technology is as well useful in the treatment of human waste, preventing environmental contamination and the disperse of disease causing pathogens and bacteria (Okunola *et al.*, 2018). It is also imperative to note that the combination of anaerobic and aerobic treatment of industrial effluent posses many advantages over complete aerobic treatment systems still in use in most industries especially in developing countries. The anaerobic technology helps to reduce the total energy requirement of dissolving oxygen in wastewater and leads to a higher amount of COD degradation. Also, excessive sludge production rate is minimized. In contrast, however, the combination of the anaerobic process with an aerobic polishing step, in the recent anaerobic technology as installed at the brewery helps to reduce the disadvantage of the anaerobic process such as low efficiency of nutrient removal (nitrogen and phosphorus). From the result of a stage by stage efficiency model developed in this study, it was shown that the second stage (balancing) contributes the most to the reduction of the toxic content of the effluent while the process of the removal of suspended solid in the last stage helps to increase the efficiency of the whole treatment process. It was shown that the proper functioning of all the stage is very important as no particular stage can give the full efficiency required. The reduction in efficiency of one stage will go a long way to affect the overall efficiency of the plant.

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