PERFORMANCE OF ANAEROBIC DIGESTER-CONSTRUCTED WETLANDS SYSTEM FOR BREWERY WASTEWATER TREATMENT

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ABSTRACT
The study examined the performance of an engineered system designed and constructed with anaerobic digester in treating brewery effluent. The pilot treatment system consisted of two 0.25 m$^3$ digesters and four Constructed Wetlands (CW) with each pair of CW connected in series. The CW consists of 1200 × 1000 × 1000 mm plastic tanks, filled with 500 mm deep, 10-15 mm size granite overlaid with 150 mm thick sand ($C_u = 1.15$ and $C_c = 6.8$) substrate. The pilot CW was planted with Phragmites Karka Retz. at 200 mm centres. Effluent collected from the brewery was analysed for physico-chemical parameters using standard procedures. Performance evaluation was carried out at 2, 5, 7 and 10 days retention periods in both the digester and CW. Results showed that the brewery effluent is characterised by high organic content with a Biochemical Oxygen Demand (BOD$_5$) of 1630 mg/l, which was reduced by 95.82% in the Anaerobic Digester-CW System combination, with about 60% of the BOD$_5$ reduction occurring in the Anaerobic Digester. The nitrate, phosphate and TSS were reduced by 80.96, 82.73 and 96.31% respectively in the CW. The study showed that Anaerobic Digester-CW combination has a high potential in brewery wastewater treatment.

KEY WORDS
Industrial Wastewater, Constructed Wetland, Anaerobic Digester, Brewery Wastewater, Phragmites Karka.

1. INTRODUCTION
The processes involved in brewing use large volume of water and involve the mingling of extracts of malt, hops, sugar with water and fermentation with yeast. Several batch-type operations are involved in processing raw materials to the final beer; the operation uses large quantities of water coupled with water required for washing, cleaning and sterilizing the various units after completion of each batch (Olajire, 2012). Mashing, boiling, fermentation and maturation are some of the chemical and biochemical reactions that are involved in beer production coupled with three solid-liquid separations which are wort separation, wort clarification and rough beer clarification (Fillaudeau et al., 2006). Other areas of water use in beer production include water used in product vessel washing, general washing and cleaning in place (Simate et al., 2011). There are stringent regulations expected from the Federal Environmental Protection Agency (FEPA) before this large quantity of water ultimately finds its way into water courses.

Wastewater management constitute a practical problem in the brewing industry. Almost every stage of the brewing processes use water according to Olajire, (2012). Breweries try as much as possible to keep wastewater disposal costs low while adhering to the stringent regulations imposed for wastewater disposal by regulatory authorities (Fillaudeau et al., 2006). Breweries have been shown to have water consumption ranging from 4 to 11 litres of water per beer. This consumed water could be divided into 2/3 used in the process and 1/3 in the cleaning operations. This water load has been shown to be similar to the effluent load since most of it ends up as effluent (Perry and De Villiers 2003). Brewery effluent has been shown to be one of the major contaminant of streams in South-Western Nigeria (Ipeaiyeda and Onianwa, 2009); this causes public health problems and hinders economic development. Brewery effluent affects water quality in several ways, including increase in organic matter and resultant increase in the Biochemical Oxygen Demand (BOD$_5$) and Chemical Oxygen Demand (COD). This increase in organic load in the wastewater arises from dissolved carbohydrates, alcohol and high Total Suspended Solids (TSS) content. The capacity of municipal treatment plant is always reduced and the treatment plant is even overloaded if brewery effluent is discharge into them. In order to preserve natural ecosystem and the health of the community, there is need for an appropriate Effluent
Treatment Plant (ETP) that maximises removal efficiency and minimises investment and operation cost.

Biological treatments and membrane filtration have been employed in brewery wastewater treatment (Fillaudeau et al., 2006). Anaerobic Sequencing Batch Reactor has been proved to be a potential alternative as ETP in Brewery wastewater treatment; effective for COD removal and energy production (Shao et al. 2008). Simate et al. (2011) emphasised the importance of an integration of different treatment processes in order to remove impurities present in brewery wastewater efficiently; thereby forming the basis for a combination of two treatment alternatives.

Anaerobic digestion requires no form of energy, as it does not require aeration. During anaerobic digestion of wastewater, organic pollutants are degraded by the microbial populations through several degradation steps like hydrolysis/fermentation, acetogenesis and methanogenesis (Shao et al., 2008). Anaerobic digestion also enables industries to comply with the stricter pollution control regulations and brings about greater efficiency. There has been an increasing interest in the use of anaerobic digestion in the treatment of brewery wastewater in recent times because brewery wastewater often provides ideal conditions for the operation of the digester.

Constructed wetlands have gained popularity as alternative treatment systems for wastewater (Badejo et al., 2013, Badejo et al., 2012, Vymazal, 2009). These are natural wastewater treatment systems composed of one or more treatment cells in a built and partially controlled environment designed and constructed to provide wastewater treatment (Kadlec and Wallace, 2009). CWs are specifically constructed at a location other than the existing natural wetlands for the purpose of pollution control and wastewater management (Badejo et al., 2013). It also involves a complex integrated matrix of substrate and locally available macrophytes at minimal cost (Aluko et al., 2003; USEPA, 1999).

CW is designed to take advantage of many of the processes that occur in natural wetlands but do so within a more controlled environment. These are artificial wastewater treatment systems consisting of shallow (usually less than 1 m deep) ponds or channels, which have been planted with aquatic plants. They rely upon natural microbial, biological, physical and chemical processes to treat wastewater. A typical CW is constructed to exploit and improve the biodegradation ability of plants (Shutes, 2001).

CW system operates on naturally occurring integrated and interdependent biochemical processes, which basically operate by solar and microbial processes. Constructed wetland systems have some benefits over conventional treatment systems in that they require relatively low running costs, can be maintained by low skilled personnel with lower energy requirements (Younger et al., 2002). CWs have also been reported to have the potential for the treatment of tannery wastewater as an alternative to conventional biological systems (Calheiros et al., 2008). These may also be employed in treating wastewater for the removal of both biological wastes and non-biological wastes like heavy metals (O’Sullivan et al., 2005).

Nitrate can have serious health effects when it enters drinking water sources and is consumed. Excessive accumulation of nitrogen in surface water results in ecological imbalances; this imbalance causes overgrowth of plants and animals, leading to water quality degradation through eutrophication. Some bacterial species present in CW are facultative anaerobes functioning under both aerobic and anaerobic conditions in response to changing environmental conditions. These are useful in nitrate removal. Emergent plants like Phragmites karka have been shown to have major impact on nitrate removal in CW (Bastviken et al., 2009). Phosphorus is removed in CWs by a series of methods among which are plant uptake, assimilation by microbes and physico-chemical processes involving the wetland soil. The physico-chemical processes include sorption by soil and precipitation reaction (Bubba, et al, 2003). The major mechanism for Phosphate removal is adsorption and precipitation. Its removal efficiency is predominantly affected by the porous media size (Badejo et al., 2013).

Conventional wastewater treatment systems utilize various mechanical processes to treat the waste constituents and bring them within acceptable levels. Reliability features of importance may include: alarm systems, standby power supplies, treatment process duplications, emergency storage or disposal of inadequately treated wastewater, monitoring devices and automatic controllers. All these features bring about complexity in design as well as operating processes and cost of conventional ETP. However, constructed wetlands and anaerobic digestion rely almost entirely on natural processes to treat the wastewater with relatively very little operation and maintenance cost. This study examined the performance of an anaerobic digester combined with a CW in treating brewery wastewater so as to meet the discharge requirement standards by Federal Environmental Protection Agency (FEPA).

2. METHODOLOGY

Brewery wastewater was collected from a local brewery situated in the industrial district of Ogun State, Nigeria. The anaerobic digester was constructed with a 0.25 m³ PVC drum with the inlet at the top and the outlet near the bottom of the drum. The inlet and outlet were made of 12.5 mm diameter PVC pipe with valves to ensure airtightness. The digester system was placed on a higher elevation relative to the surface of the bed to allow for flow under gravity from the digester into the CW. The digester was fed with 0.2 m³ of brewery wastewater through the inlet pipe. The digester was made air-tight using low viscous coal tar to ensure an anaerobic condition. The brewery wastewater had a retention period of 10 days inside the digester and effluent samples were...
taken after 3, 5, 7, and 10 days for analysis in the laboratory.

The pilot CW studied was located at the Civil Engineering Building of the Federal University of Agriculture, Abeokuta, Nigeria. The pilot CW bed consisted of four 1m$^3$ plastic tanks with surface area of 1.2 m$^2$ each. The CW consisted of 500 mm deep 10-15 mm diameter granite with 150 mm thick overlay of well graded sand ($C_u = 1.15$, $C_c = 6.8$). The hydraulic conductivity of the substrate was 0.002 m/s. The four beds were planted with transplanted rhizomes of *Phragmites karka*. Each bed was equipped with drain outlets at the base of the tank for effluent collection. The macrophyte (*Phragmites karka*) was planted at a distance of 200 mm apart to produce a high density bed. It was initially irrigated with clean water in order to allow the stabilisation of the plants prior to the use of the effluent from brewery wastewater.

2.1 Sample Analysis

All the samples were analysed according to internationally accepted procedures and standard methods (APHA, 1994). The physico-chemical parameters analysed in situ at the brewery, at the CW site, from the digester and from the CW include pH, Electrical Conductivity (EC), nitrate, phosphate, TSS, Total Dissolved Solids (TDS), Dissolves Oxygen (DO) and BOD$_5$. The results obtained from the analysis of the brewery effluent were compared with the discharge criteria into streams by the Federal Environmental Protection Agency (FEPA, 1991).

3. RESULTS AND DISCUSSION

The wastewater collected from the local brewery consisted of a combined discharge of organic load from the production processes. Sanitary wastewater from toilet and kitchen were passed into a septic tank. It also included weak wort and residual beer. The concentration of nitrate is mainly from the malt, adjuncts, yeast and cleaning agents. BOD$_5$ has traditionally been used to measure the strength of effluent released from wastewater to surface waters or streams: the observed value of BOD$_5$ revealed a high strength of wastewater. This is due to the fact that beer is regarded as a fermented beverage characterized by low alcohol content which is produced using various grains. Wastewater high in BOD$_5$ depletes oxygen in receiving waters due to bacteria that breaks down organic materials, causing fish kills and ecosystem imbalance (Ogunfowokan *et al.*, 2005). The result of key parameters obtained in the raw wastewater fed into the digester in comparison with Federal Environmental Protection Agency (FEPA, 1991) standard is shown in Table 1. The organic load obtained agreed with Luqiong and Kwang (2001). The high pH obtained was as a result of the alkaline cleaning agents used.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Brewery Effluent</th>
<th>FEPA Standard</th>
</tr>
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<tbody>
<tr>
<td>BOD$_5$ (mg/l)</td>
<td>1630</td>
<td>50</td>
</tr>
<tr>
<td>Ph</td>
<td>11.63</td>
<td>6 – 9</td>
</tr>
<tr>
<td>TDS (mg/l)</td>
<td>2000</td>
<td>2000</td>
</tr>
<tr>
<td>EC</td>
<td>3999</td>
<td>-</td>
</tr>
<tr>
<td>Nitrate (mg/l)</td>
<td>24.6</td>
<td>20</td>
</tr>
<tr>
<td>Phosphate (mg/l)</td>
<td>8.59</td>
<td>5</td>
</tr>
<tr>
<td>TSS (mg/l)</td>
<td>522.44</td>
<td>30</td>
</tr>
</tbody>
</table>

3.1 BOD$_5$ reduction in Anaerobic Digester

A 3-days retention period in the digester produced 60% reduction in the BOD$_5$ content and 72% reduction after 10 days in the anaerobic digester. The rate of BOD$_5$ reduction was observed to increase with time as shown in Figure 1. The relationship between loading rate and removal rate of BOD$_5$ in CW was reported to be linear and the correlations between loading and removal rate were strong for BOD$_5$ (Ayaz, 2008). However, in order to obtain good performance efficiency for the CW, it is always desirable that the BOD$_5$ may be reduced to a level that will not adversely affect the growths of the macrophytes (Badejo *et al.*, 2012).

The mechanism of BOD$_5$ removal in CW involves flocculation, settling and filtration of suspended and large colloidal particles; but actual BOD$_5$ removal may occur when the material causing the BOD$_5$ is completely converted by anaerobic biological processes such as methane fermentation and sulphate reduction to gaseous end products as was observed in the digester.
3.2 Performance Evaluation of the Constructed Wetland in Brewery Wastewater Treatment

3.2.1 Nitrate and Phosphate

After a 10-day retention period in the CW, the nutrient in the brewery wastewater was considerably reduced. This further confirmed Bastviken et al., (2009) where a two day retention period in CW for nutrient removal was proposed. Nitrate and phosphate were reduced by 80.96 and 82.73% respectively as shown in Figure 2. The use of a pilot CW was able to reduce the concentration of each of these nutrients to the permissible limit recommended by FEPA (1991) for wastewater discharge into streams.

The result agreed with Luederitz et al., (2001) who reported that depending on the organic loading regime, all wetlands types have good nutrient processing efficiency under temperate climatic conditions. Transformations by microorganism in CW are either aerobic or anaerobic.

3.2.2 Total Suspended Solids (TSS)

A reduction of 96.31% in TSS was observed in the CW as in Figure 3. This shows that appropriate design of CW can help in reducing the TSS from a brewery wastewater in line with acceptable specification by FEPA (1991). The TSS present in brewery wastewater caused the formation of sludge deposits, and also resulted in anaerobic conditions when discharged into the aquatic environment. In CW, TSS is removed by natural and physical wetland processes. The result shows the physical process of sedimentation and filtration in suspended solids removal in CW as expressed by Brisson and Chazarenc, (2008).

3.2.3 Biochemical Oxygen Demand

The BOD₅ content of the effluents was reduced from 456 mg/l to 68 mg/l with about 50% reduction occurring in the first 2 days. After 10-day retention period, a percentage reduction of 85% was observed as seen in Figure 4. This high removal rate agreed with Xiaoli et al., (2010) where an average removal of 80% was observed in a modified cycle batch of CW. This was also opined by Ayaz (2008) that the relationship between loading and removal rate in CW is linear.
4. CONCLUSION

The study showed the efficacy of an anaerobic digester - CW combination in treating brewery wastewater. The anaerobic digester was observed to reduce the Biochemical Oxygen Demand to a level that could be passed through the Constructed Wetlands without affecting the performance of the macrophytes. The Constructed Wetland was also shown to be effective in nitrate, phosphate, total suspended solids and BOD removal. Therefore, it is apparent from the study that anaerobic digester combined with a CW is a good alternative for treating brewery wastewater so as to meet the discharge requirement specification by FEPA.

ACKNOWLEDGEMENT

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REFERENCES

[27] USEPA A handbook of Constructed Wetlands for Agricultural Wastewater, Domestic Wastewater, Coal Mine Drainage, Stormwater in the Mid-Atlantic Region, 1-3, 1999 843F00002, 843F00001, 843F00003.