Analysis of Chemical Oxygen Demand (COD) removal rate using Upflow Bioreactor with Central Substrate Dispenser (UBCSD)

Kevin N. Nwaigwe¹ and Christopher C. Enweremadu²

Abstract—The Chemical Oxygen Demand (COD) end value of effluent leaving a typical biogas digester into the environment is of immense importance as it determines the eco-friendly state of the effluent. In order to evaluate this value, a work on the analysis of Chemical Oxygen Demand removal rate from organic municipal waste (OMW) is presented. Experimentation was carried out using an upflow bioreactor with central substrate dispenser (UBCSD) for 10-days retention time on the effluent from the digester. A reactor of 64.8 litres in volume with a feeder tank volume of 250 litres was used so that the amount of substrate contained in the feeder tank can be sufficient enough to feed the bioreactor unit. The OMW was prepared into slurry and fed into the digester for analysis. The results showed an average COD removal rate of up to 95% indicating a very high efficiency for the digester. This outcome indicates that effluent from the UBCSD digested substrate is suitable and safe for use as organic fertilizer in agricultural practices.

Keywords—COD removal, bioreactor, organic municipal waste, UBCSD

I. INTRODUCTION

Developments in bioreactor technology have moved from the conventional bioreactors to more recent configurations. The trend has been towards improving the mixing and fouling challenges within the digestion chamber. After digestion, the content of the wastewater from the digester is of importance as it can be a strong pollutant. The end values of the COD and BOD discharged to the environment is of primary importance. Using the Upflow Bioreactor with Central Substrate Dispenser (UBCSD) [1] which is a recent research development, analysis is undertaken to evaluate the rate of COD removal from municipal organic waste substrate. Basically, the UBCSD uses inherent features to solve some of the problems associated with the existing bioreactors. As a result of its central substrate dispenser (CSD) feature, it can assist immensely in minimizing the recorded mixing and fouling problems associated with some of the conventional bioreactors. This is expected to assist in enhancing effluent stabilization, biogas production, and consequently pave way for reduction in maintenance requirement problems. The substrate flow processes by which UBCSD is characterized is different from the flow situation observed in standard Upflow reactors and other reactors such as Continuous Stirred Tank Reactors (CSTR), Fluidized Bed Reactors, Sludge Tank Reactor systems, etc. Its configuration also differs from the others. There are two kinds of flow situations observed in this type of bioreactor viz, a downward flow of substrate by gravity, and a cross-flow of substrate achieved by the central dispensing unit (CSD). Fig. 1 is a typical UBCSD.

Fig. 1 Schematic of a typical upflow bioreactor with central substrate dispenser (UBCSD)

Several works have been done towards parametric assessment of bioreactors for improved efficiency and safer environment. In a work to investigate the effect of clinoptilolite on the performance of membrane bioreactor (MBR), the results of short term filtration showed that the trend of transmembrane pressure (TMP) increase in terms of flux will be slower in hybrid membrane bioreactor with clinoptilolite (HMBR) leading to improvement of biological wastewater treatment quality and ease of membrane operation [2]. In a work towards experimental evidence for osmotic pressure-induced fouling in a membrane bioreactor, a lab-scale membrane bioreactor (MBR) was continuously operated to investigate the membrane fouling [3]. The chemical potential of water varied along with cake depth. The formed cake layer was found to be much hydrated and elastic. These findings provided the direct evidence for the existence of osmotic pressure mechanism. In a work aimed to investigate the efficiency of nutrient removal in a modified membrane bioreactor (MBR) used for treatment of wastewater containing high level of ammonium, nutrient removal from synthetic wastewater in the control membrane bioreactor without

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clinoptilolite (CMBR) and zeolite membrane bioreactor with clinoptilolite (ZMBR) were compared [4]. In ZMBR, about 24% more N-NH$_4^+$ removal was achieved owing to combination of nitrification and cation exchange. It was also found that ZMBR application resulted in 10% increase in TN removal in comparison with CMBR. In contrast, no significant difference was observed in chemical oxygen demand (COD) removal. Only low amounts of nitrate and phosphate were removed during the first days of experiments. The results demonstrated that clinoptilolite is highly effective in reducing ammonium content of wastewaters.

Chemical Oxygen Demand (COD) is a measurement commonly used to determine substrate quality. Organic material content enjoys the greatest percentage in the overall composition of municipal solid wastes. The organic fraction is 45 to 50% [5]. As these substances oxidize or stabilize, they combine with some of the oxygen dissolved in the water. The amount of oxygen used is therefore a good indicator of the amount of waste present. The COD values indicate the amount of oxygen (in milligrams per litre of product) needed to oxidize or stabilize these wastes. Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are two different ways to measure how much oxygen the wastewater from a digester will consume when it enters the environment. Industries normally focus more on COD and municipalities more on BOD removal. Efforts must be made to reduce these values to protect the environment. Ability to reduce COD and BOD values is a key factor in selecting biodigester types for digestion of substrates. COD removal efficiency of most substrates varies between 51-79% [5]. Similarly, the combination of a bioreactor and microfiltration system allowed for a high COD reduction of 95% [6]. In a study of electrochemical treatment of biodigester effluent followed by anaerobic digestion, a COD removal from an initial value of 1536 mg/L to 240 mg/L was achieved [7]. In another study, average COD removal rate of 48.5 using cow dung as substrate was achieved [8]. This present work is studying COD removal rate using UBCSD. The aim is to evaluate the ability of UBCSD to remove COD from municipal organic wastes during digestion to acceptable limits achieved using conventional bioreactors.

II. MATERIALS AND METHOD

This experiment was conducted using an upflow bioreactor with central substrate dispenser (UBCSD). The reactor has 64.8 litres in volume with a feeder tank volume of 250 litres so that the amount of substrate contained in the feeder tank can be sufficient enough to feed the bioreactor unit. The system was allowed to run for a period of 24 hours with the intent to influence practically the dissolution of almost all the resident oily and chemical substances present in the vessels. However, following the expiration of 24 hours, the liquid content of the reactor was discharged via the effluent disposal system. Subsequently, the process was repeated, but this time, the feeder tank and the bioreactor vessels were filled with only distilled water with a view to ensuring that the remaining soapy substances were totally flushed out of the system. To further ensure that the fermentation phase of the actual experiment is not inhibited in the least, the system was finally filled with the actual working substrate and was allowed to run in the system for a period of 4 days to establish an enabling environment for virtually uninterrupted biochemical activities. Following the end of 4 days period, the bioreactor content was as well flushed out just to pave way for the actual envisaged experiment. The Organic Municipal Waste (OMW) was milled into powdered form to produce a 500 μm mesh size. A 25kg quantity of this ground OMW was used to prepare the slurry with 250 litres of distilled water. The substrate was prepared by the insertion of a mixer into the tank containing the mixture of OMW and distilled water. The mixer was operated for about 30 minutes to achieve homogeneity. Basically, to help enhance the microbial activities during the operation of the bioreactor, a measured quantity (2 kg) of some substances from the rumen of the digestive system of a freshly slaughtered cow was mixed with 5 litres of distilled water and after undergoing filtration through 100 μm sieve, was introduced into the prepared substrate. The rumen is the largest among the four compartments that make up the stomach of a cow. It is practically where fermentation and initial process of digestion occur in the digestive system of a cow. The rumen houses some microorganisms, and its addition into the working substrate was aimed at improving the biodegradation process of the organic content of the slurry by the action of bacteria. The resulting mixture of the slurry and the substance from cattle rumen was then pumped into the feeder tank from the reservoir tank by the aid of the feed pump. However, the filling of the feeder tank was not expected to last more than three (3) minutes so as not to interfere with or affect negatively the actual experimental results, since the biological actions of the microorganisms were expected to have commenced soon after the mixing phase was concluded. To achieve an anaerobic condition for the fermentation process, the bioreactor vessels were completely filled with the substrate to ensure that the void spaces were covered to eliminate all particles of air in the vessel. This de-airing process was achieved with the help of de-airing valves incorporated into the system. Following the de-airing process, it was imperative to create a headspace within the vessels towards their uppermost parts where the gaseous products (biogas) of the fermentation process could be accommodated. This was accomplished by removing one (1) litre volume of the substrate from bioreactor vessels leaving a vacuum above the substrate level in reactors. The reactor was allowed to run without interruption for a period of 10 days at 37°C and a recording of the biogas production was made every six (6) hours. The biogas generated was at each set period liberated into the biogas collector tank made of stainless steel pipe of 15 cm diameter and 150 cm height. The gas tank was

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initially filled with water which was saturated with acidified brine solution, coloured with a blue dye to enhance visibility of the liquid levels. The volume of the biogas was demonstrated by the displacement of water in the gas collector tank. The digestate and effluent were expelled and collected for further analysis.

III. RESULTS AND DISCUSSION

The results of experiments carried out show the performance of the reactor in terms of COD reduction. The percentage COD removed (%tage COD) is given by the relationship:

\[ \text{%tage COD} = \frac{\text{COD}(0) - \text{COD}(t)}{\text{COD}(0)} \]  

(1)

Where COD\(_{(0)}\) is the initial COD or the COD at \( t = 0 \), its numerical value is \( 120320 \) mg/l; while COD\(_{(t)}\) = the COD at any time \( t \).

<table>
<thead>
<tr>
<th>Time (days)</th>
<th>COD Reduction (Mg/l)</th>
<th>COD Removed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>120,320</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>114,641</td>
<td>4.70</td>
</tr>
<tr>
<td>2</td>
<td>107,158</td>
<td>10.9</td>
</tr>
<tr>
<td>3</td>
<td>89,321.7</td>
<td>25.8</td>
</tr>
<tr>
<td>4</td>
<td>69,563.8</td>
<td>42.2</td>
</tr>
<tr>
<td>5</td>
<td>54,178</td>
<td>55.0</td>
</tr>
<tr>
<td>6</td>
<td>42,192.6</td>
<td>64.9</td>
</tr>
<tr>
<td>7</td>
<td>32,859.6</td>
<td>72.7</td>
</tr>
<tr>
<td>8</td>
<td>18,033.7</td>
<td>85</td>
</tr>
<tr>
<td>9</td>
<td>14,044.7</td>
<td>88</td>
</tr>
<tr>
<td>10</td>
<td>5,775.4</td>
<td>95.2</td>
</tr>
</tbody>
</table>

**TABLE II**

<table>
<thead>
<tr>
<th>Reactor</th>
<th>Biogas Potential ( B_{max} ) (ml)</th>
<th>Biogas Prod Rate, ( R_b ) (ml/d)</th>
<th>Biogas Prod Lag Phase ( t ) (days)</th>
<th>((R^2)) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>UBCSD</td>
<td>53440</td>
<td>9148.93</td>
<td>0.18</td>
<td>0.9926</td>
</tr>
</tbody>
</table>

**TABLE III**

<table>
<thead>
<tr>
<th>Reactor</th>
<th>((R^2)) Value</th>
<th>([\ln \text{COD}(0)])</th>
<th>(k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UBCSD</td>
<td>0.9178</td>
<td>12.100</td>
<td>0.2857</td>
</tr>
</tbody>
</table>

The experimental results obtained for the reactor was analyzed using statistical tools at various HRTs. The process performance of the reactor in terms of COD removal at various HRTs is represented in Fig. 2.

![Fig. 2 Plot of COD reduction versus HRT (days) for UBCSD](image1.png)

**Fig. 2 Plot of COD reduction versus HRT (days) for UBCSD**

The COD reduced from its initial value 120,320 mg/l to 5775.4 mg/l for UBCSD at the HRT of 10 days. However, from Fig. 3, it can be seen how the percentage COD (%COD) reduction increased with HRT (days) until the tenth (10th) day when it assumed its maximum of 95.2%. The graph was plotted with R-square value of 0.9952. Interestingly, the % COD reduction achieved in the UBCSD is in close proximity to the reported values [9] in the combination of a bioreactor and microfiltration which allowed a high COD reduction of 95%.

![Fig. 3: Plot of %COD reduction versus HRT (days) for UBCSD](image2.png)

The COD reduced from its initial value 120,320 mg/l to 5775.4 mg/l for UBCSD at the HRT of 10 days. However, from Fig. 3, it can be seen how the percentage COD (%COD) reduction increased with HRT (days) until the tenth (10th) day when it assumed its maximum of 95.2%. The graph was plotted with R-square value of 0.9952. Interestingly, the % COD reduction achieved in the UBCSD is in close proximity to the reported values [9] in the combination of a bioreactor and microfiltration which allowed a high COD reduction of 95%.
However, carrying out a MATLAB plot of InCOD versus HRT (days) using a linear regression approach (Fig. 4), an equation were generated. The equation generated closely conforms to a model developed [10] based on Fenton’s reaction in first order kinetics as:

$$\text{InCOD}(t) = -kt + \text{InCOD}(0)$$  \hspace{1cm} (2)

The experimental initial COD value is given as:

$$\text{COD}(0)_{\text{Exp}} = 120320 \text{ mg/l}$$  \hspace{1cm} (3)

Applying the natural logarithm of the experimental COD \([\text{COD}(0)_{\text{Exp}}]\\), we have:

$$\text{InCOD}(0)_{\text{Exp}} = \text{In}120320 = 11.698$$  \hspace{1cm} (4)

The value for the first order kinetic constant \((k)\) of COD for UBCSD is 0.2857. \(k\) is an important parameter which is used as a measure of the rate at which the substrate COD is reduced. A careful consideration, however, of the \(k\)- value obtained in relation to the COD reduction achieved the reactor shows that substrate stabilization improves as \(k\) increases. Besides, since the effluent in the UBCSD was found to be significantly stabilized, its sludge has the tendency of posing very little environmental threat. Therefore, it exhibits the capacity to generate effluent that can serve as good fertilizer for agricultural activities.

IV. CONCLUSION

The process performance of a UBCSD reactor in terms of COD removal was discussed. The flow features and configurations of the reactor were also carefully considered. It is noteworthy that the reactor was examined and subjected to anaerobic conditions for the sole purpose of evaluating the COD removal rate.

Several steps were undertaken in order to prepare the bioreactor system for the actual experimental phase. The reactors were allowed to run without interruption for a hydraulic retention time (HRT) of 10-days and a mesophilic temperature of 37°C. A recording of the biogas production was made in every six (6) hours and the biogas generated was at each set period liberated into the biogas collector tanks provided for this purpose. The COD level of the substrate was measured on a daily basis and the overall results achieved were tabulated and analyzed. The specific conclusions drawn from this study include that:

- The success accomplished in the UBCSD, is believed to be as a result of the central substrate dispenser (CSD) unit incorporated into the UBCSD which helped to generate an up-flow, cross-flow and down-flow pattern of the substrate for efficient mixing and maintenance of process stability.
- Percentage COD (% COD) reduction achieved in the UBCSD is in close proximity to reported values in literature.

REFERENCES


