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# Study on Performance of a Modified Anaerobic Baffled Reactor to Treat High Strength Wastewater

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**Abstract:** The main problem associated with the treatment of high strength materials in an Anaerobic Baffled Reactor (ABR) is difficult breakdown of fat, protein and hydrocarbon molecules at early stage of anaerobic decomposition due to uncertain selection of Hydraulic Retention Time (HRT) and therefore organic loading rate (OLR). Thus, in this study a modified four-compartment ABR with a working volume of 50 L was designed to determine the treatment efficiency and methane production rate of high strength wastewater. The first compartment in the ABR was doubled in size to provide longer solid retention time. Based on C/N ratio of 30, a mixture of 62% kitchen waste and 38% sewage sludge was used as substrate and fed to the reactor continuously. Initially the characteristics of kitchen waste were measured and the amounts of fat, protein cellulose, hemicellulose and lignin were found in proper level for anaerobic decomposition. Next the effects of different HRT and OLR were evaluated in the reactor. COD reduction and biogas production were investigated at different HRT (5, 4, 3 and 2 days) and OLR (2, 3, 4, 5 and 6 kg/m$^3$day). Results show that the highest COD removals (74.5 and 75.4%) were observed at 3 days HRT and OLR of 2 kg/m$^{-3}$ day, respectively. While the best production of biogas (7.40 and 9.10 L day$^{-1}$) was observed at 5 days HRT and OLR of 6 kg/m$^3$ day, respectively.

**Key words:** High strength wastewater treatment, hydraulic retention time, organic loading rate

## INTRODUCTION

The successful application of anaerobic technology to the treatment of high strength wastewater is critically dependent on the development of high rate anaerobic bioreactors. These reactors achieve a high reaction rate per unit reactor volume (in terms of kg COD/m$^3$ day) by retaining the biomass in the reactor. High rate anaerobic biological reactors may be classified into three broad groups according to the mechanism used to achieve biomass detention which are, fixed film, suspended growth and hybrid system (Barber and Stuckey, 1999).

The anaerobic baffled reactor (ABR) was initially developed by McCarty and coworkers at Stanford University (McCarty, 1981). Then the process of ABR was used and described by Bachmann *et al*. (1983, 1985) with strong synthetic wastewater. The ABR can be described as a series of Upflow Anaerobic Sludge Blanket (UASB) reactors, which does not require granulation for its operation (Barber and Stuckey, 1999). In an ABR series of vertical baffles force the wastewater to flow under and over them as it passes from inlet to outlet. Bacteria within the reactor gently rise and settle due to flow characteristics and gas production in each compartment. Each chamber has a vertical baffle to force wastewater to flow under and over it.

The most significant advantage of the ABR is its ability to separate acidogenesis and methanogenesis longitudinally down the reactor, allowing the different bacterial groups to develop under most favorable conditions (Grobicki and Stuckey, 1992). This study mainly focused on the operational characteristics of an ABR in COD removal, biogas production and methane content from high strength wastewater.

An anaerobic baffled reactor operates with a combination of several anaerobic process principles, the three basic steps involved are: (a) hydrolysis, (b) fermentation and (c) methanogenesis. Equal inflow distribution and the wide spread contact between new and old substrate are important process features. It is known that a three-chamber reactor, together with physical modifications, provided a longer solid retention time and superior performance than the reactor with only two compartments (Barber and Stuckey, 1999).

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Further analysis shows that despite losing more solids, the three-compartment reactor is more efficient at converting the trapped solids to methane. Therefore, it is recommended in many literature sources that the anaerobic baffled reactor should be equipped with at least 3 chambers (Grobicki and Stuckey, 1992; Nachaiyasit and Stuckey, 1995; Yang and Moengangongo, 1987). However, the main problems associated with the treatment of high strength materials in a baffled reactor is incomplete breakdown of fat, protein and hydrocarbon molecules at early stage of anaerobic decomposition due to insufficient HRT and OLR. Therefore, in this study a modified ABR with four compartments which the first one was double in size, to provide adequate HRT and therefore OLR, were examined to evaluate the COD reduction and biogas production efficiency.

## MATERIALS AND METHODS

**Substrate:** The kitchen wastes were collected from kitchen refuse of a canteen located at Universiti Kebangsaan Malaysia. Part and quarterly methods were used as standard procedures in preparing samples (Tchobanoglous *et al*., 1993). The samples were then mixed thoroughly in the laboratory, shredded and grounded into a size of approximately 1×1×0.5 cm prior to analysis for chemical composition.

**Seed materials:** Sewage sludge was used as seed material and brought from a municipal wastewater treatment plant (Indah Water Konsertium (IWK) Sdn. Bhd.) in Serdang, Selangor branch. The sewage sludge was collected from the sewage sludge return pipeline and immediately brought to the laboratory. The C/N ratio of applied sewage sludge was 6.3/1 with 75% moisture content. Proper mixture of kitchen waste and sludge was calculated based on Tchobanoglous *et al*. (1993) as follow:

$$\frac{C}{N} = \frac{\text{C in unit mass of kitchen waste} + x(\text{C in unit mass of sludge})}{\text{N in unit mass of kitchen waste} + x(\text{N in unit mass of sludge})}$$

**Reactor configuration:** A laboratory scale Anaerobic Baffled Reactor (ABR) system used in the study was fabricated using plexiglass. The ABR consisted of four chambers and a vertical baffle (Fig. 1) separated each chamber. The working volume of the reactor was 50 L (length, 75 cm; breadth, 27 cm; height, 25 cm). The baffled reactor was modified to reduce up-flow liquid velocities and to accept the whole substrate.

Two tanks as influent tank and effluent tank were designed for feeding and removing the materials to and from the reactor. A gas collector was also provided for collection, calculation and analysis s on the amount of biogas. The down-flow chambers were 3 cm above the reactor's bottom to route the flow to the center of the up-flow chamber to achieve better contact and greater mixing the feedstock and solids. The first compartment was bigger in size, which was 34 L, while the following compartments were 17 L. This physical modification provided longer solids retention time and superior performance as compared to the reactor with similar size compartments. The edges on baffles slanted on 45° to route the flow towards the center of the compartment and, hence, encourage mixing.

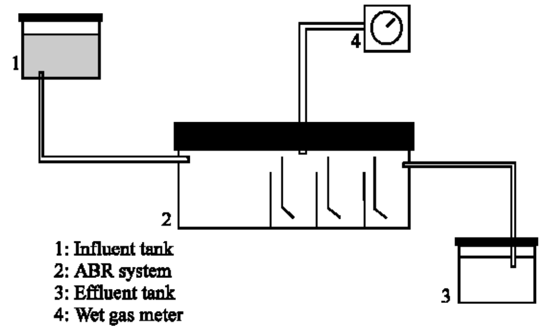


Fig. 1: Anaerobic baffled reactor configuration

**Analytical methods:** The characteristics of kitchen waste were initially determined by analyzing the samples using analytical methods given by USEPA (2004). Samples were analyzed for moisture content, total solids, total volatile solids, ash content, total organic carbon, Kjeldahl nitrogen, fat, protein, cellulose, hemicellulose and lignin. A total of 40 samples were analyzed and mean value for each parameter was calculated. Gas samples were collected by gas sampling injectors and a sample of 100 ML was used for each run. The biogas composition ($CH_4$+$CO_2$) was determined by using a Gas Chromatograph (NUCON 5700) equipped with a thermal conductivity detector and stainless steel column of length 6 ft, OD 1/4 inch, ID 2 mm, containing Porapak Q 100 having mesh range 80-100. The carrier gas used was $H_2$ and the analysis was carried out at a carrier gas flow rate of 30 mL min$^{-1}$ with the injector, column and detector temperatures maintained at 120, 90 and 120°C, respectively. Gas volume was measured using water displacement method. According to the APHA-AWWA (1992) Dichromate reflux method was selected for determining Chemical Oxygen Demand (COD).

## RESULTS AND DISCUSSION

**Characteristics of kitchen waste:** Table 1 shows the characteristics of periodically collected kitchen waste. The amounts for organic polymer such as fat, protein, cellulose, hemicellulose and lignin was found in desirable level as these organic polymers have very important role in the first stage of anaerobic digestion of organic compounds and their present is vital, because these organic polymers are broken down by extra-cellular enzymes produced by hydrolytic bacteria and dissolves in the water. C/N ratio for kitchen waste was found 38.2/1, which was higher than appropriate amount. Bacteria normally use up carbon 25-30 times faster than they use nitrogen (Polprasert, 1996). Therefore, at this ratio of C/N (25-30/1) the digester is expected to operate at its best performance.

Therefore, as C/N ratio of shredded kitchen waste is not sufficient for full decomposition, other sources of N such as human nightsoil, animal manures or sewage sludge are needed to be added to the kitchen waste (Vesilind *et al.*, 2002). Thus, sewage sludge as a source of nitrogen was added to kitchen waste based on mentioned calculation. The result shows that the composition of 62 and 38% of kitchen waste and sludge has the C/N ratio of 30 and is suitable to undergo anaerobic digestion.

**Start-up of ABR at different hydraulic retention times:** The continuous operation of the ABR was started using an initial COD concentration of 25 g $L^{-1}$ at HRT of 5 days. The ABR was run continuously and observations were made at particular HRT. When there were no more variations in different parameters such as COD removal, biogas production and methane content then the HRT was decreased. The results in Table 2 show that there was little variation in the percent COD removal with decrease in retention time, but there was an increase in methane content and biogas production. This suggested that at higher retention times there was limited availability of substrate for methanogenesis as most of the COD was utilized for new cell synthesis. However, the decrease in retention time resulted in more availability of substrate, which could be converted to biogas. The increase in methane content may be attributed to the increase in the growth of anaerobes particularly methanogens in the newly synthesized biomass.

**Effects of organic loading rate in the ABR system:** The effect of different OLR was studied in a continuous system by varying the COD of the influent substrate and the result are illustrated in Table 3.

Table 1: Chemical composition of kitchen waste

| Parameters | Weight fraction (%) or ratio |
|---|---|
| Total solids | 14.8 |
| Total volatile solids | 89.5 |
| Ash | 10.5 |
| Total organic carbon | 49.7 |
| Kjeldahl nitrogen | 1.3 |
| C/N ratio | 38.2 |
| Fat | 8.7 |
| Protein | 6.7 |
| Cellulose | 14.9 |
| Hemi-cellulose | 9.9 |
| Lignin | 8.5 |

Table 2: Performance of anaerobic baffled reactor at different hydraulic retention time

| HRT (day) | $COD_{in}$ | $COD_{ou}$ (g $L^{-1}$) | COD (g $L^{-1}$) | Biogas (L $day^{-1}$) removal (%) | Methane content (%) |
|---|---|---|---|---|---|
| 5 | 25.0±0.3 | 8.1±0.4 | 67.6 | 2.72±0.01 | 61.3±0.6 |
| 4 | 24.7±0.8 | 7.5±0.3 | 69.6 | 3.45±0.01 | 63.4±0.5 |
| 3 | 25.1±0.3 | 6.4±0.2 | 74.5 | 4.90±0.02 | 67.7±0.5 |
| 2 | 24.8±0.4 | 7.3±0.6 | 70.5 | 7.41±0.02 | 71.2±0.3 |

Table 3: Performance of anaerobic baffled reactor at different organic loading rate

| OLR ($kg/m^3d$) | $COD_{in}$ | $COD_{out}$ (g $L^{-1}$) | COD (g $L^{-1}$) | Biogas (L $day^{-1}$) removal (%) | Methane content (%) |
|---|---|---|---|---|---|
| 2 | 10.2±0.3 | 2.5±0.2 | 75.4 | 3.37±0.02 | 63.4±0.5 |
| 3 | 15.3±0.1 | 4.2±0.3 | 72.3 | 5.17±0.03 | 69.5±0.3 |
| 4 | 20.5±0.2 | 7.3±0.5 | 64.3 | 6.12±0.01 | 68.6±0.4 |
| 5 | 25.1±0.4 | 9.2±0.1 | 63.3 | 8.34±0.06 | 65.4±0.2 |
| 6 | 30.0±0.4 | 12.8±0.4 | 57.3 | 9.10±0.05 | 62.2±0.5 |

The best COD removal efficiency of 75.4% was observed when the OLR was 2 $kg/m^3d$. Low organic loading rates have a better efficiency in COD removal (Grover *et al.*, 1999). When the OLR was higher the COD removal efficiency was decreased. The result shows COD removal efficiency of 72.3, 64.3, 63.3 and 57.3% at OLR of 3, 4, 5 and 6 $kg/m^3d$, respectively. This observation is consistent with results from other researches where they found that the better efficiency of COD removal occurs at an organic loading rate below 3 kg $m^{-3}$ day (Bae *et al.*, 1997; Boopathy and Tilche, 1991; Nachaiyasit and Stuckey, 1995). On the other hand, an increase in biogas production was observed with an increase in organic loading rate despite the decrease in percent COD removal. According to the kinetic considerations, high substrate concentrations will encourage both fast bacteria and organisms' growth (Barber and Stuckey, 1999). This may be attributed to the fact that although there was a decrease in COD removal at higher loading rates; even then the biogas production was more at higher OLR than at lower OLR. The increase in OLR resulted in a decrease in methane content and this resulted in an increasing rate of acidogenesis and non proportional growth of methanogens, which consumes $CO_2$ as substrate to produce methane (Grover *et al.*, 1999).

## CONCLUSION

Treatment efficiency of the modified ABR shows that the larger compartment in the modified ABR acted as a natural filter and provided superior solids retention for the small particles. The modified reactor can collect twice the amount of solid material than a reactor with three equal chambers. Observation in different HRTs showed that there was little variation in the percent of COD removal with decrease in retention time, but there was an increase in methane content and biogas production due to more availability of substrate which could be converted to biogas. When the OLR was higher than 2 kg $m^{-3}$day COD removal efficiency was decreased, but an increase in biogas production was observed with an increase in OLR.

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