Performance and Operational Characteristics of Modified Anaerobic Hybrid Baffled (MAHB) Reactor Treating Low Strength Recycled Paper Mill Effluent (RPME) Wastewater

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ABSTRACT

The performance and operational characteristics of a laboratory scale modified anaerobic hybrid baffled (MAHB) reactor were studied using recycled paper mill effluent (RPME) wastewater. MAHB reactor was continuously operated at 35°C for 90 days with organic loading rate (OLR) increased from 0.14 to 0.57 g/L/dy. This present study demonstrated that the system was proficient in treating low strength RPME wastewater. Highest carbon oxygen demand (COD) removal were recorded up to 97% for an organic loading of 0.57 g /L/dy while effluent alkalinity assured that the system pH in the MAHB compartments were of great advantages to acidogens and methanogens respectively. Methane and biogas production rate shows increment as the load increases, which evidently indicated that the most significant approach to enhance gas production rates involves the increment of incoming substrate moderately. Variations of biogas and volatile fatty acid (VFA) in different compartments of MAHB reactor indicated the chronological degradation of substrate. The compartmental structure of MAHB reactor provided its strong ability to resist shock loads. From this present study, it shows the potential usage of MAHB reactor broadens the usage of multi-phase anaerobic technology for industrial wastewater treatment.

***Keywords**: MAHB rector, recycled paper mill effluent (RPME), performance, operational characteristics, COD removal, VFA, methane, biogas*

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INTRODUCTION

Generally, treatments of low strength wastewater were done using aerobic processes. However, these processes have several drawbacks which are high operational and maintenance costs, high energy consumption, high sludge production and considerable investment. Highlighted disadvantages limit the application of aerobic processes in the developing country. Due to this, an alternative process which is anaerobic treatment seems to be an ideal and reasonable solution for environmental protection [1, 2] due to not only consume lower quantity of energy, but also produce less sludge which indicates less treatment cost required.

Bachmann and McCarty firstly develop an anaerobic baffled reactor (ABR) which was described as a series of Upflow Anaerobic Sludge Blanket (UASBs) [3]. It consists of a series of vertical baffles which forces the wastewater to flow upwards through the series of compartments that contains mixed anaerobes as the wastewater passed from the inlet to the outlet of the reactor. This system enables high degree of sludge retention under high hydraulic load, simple construction, low operation and maintenance cost [4, 5].

Although ABRs were broadly used to treat low strength wastewater, a thorough literature survey [6,7] revealed that there is no application of novel modified anaerobic hybrid baffled (MAHB) reactor for the treatment of low strength wastewater discharged from recycled paper mill industry. This novel MAHB reactor is a combination of regular suspended and fixed biofilm systems in a single reactor to take advantages of both biomass types together with the modification of baffled-reactor configurations seems to be a good candidate to be used in this study to treat recycled paper mill effluent (RPME). The most significant benefits of this design was its capability to nearly perfectly realize the staged multi-phase anaerobic theory, allowing different bacterial groups to develop under more favourable conditions, low costs and without the associated control problems [8].

The purpose of this present study is to examine the performance and characteristics of MAHB reactor treating low strength RPME wastewater in terms of chemical oxygen demand (COD) removal, volatile fatty acid (VFA) concentration, pH value, methane content and biogas production.

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Materials and Methods

Experimental set-up

MAHB reactor (Figure 1) was set up with a working volume of 58 litres and consists of 5 separate compartments of equal volume. The MAHB reactor was maintained at a constant temperature of about 35°C using water bath. The MAHB reactor was seeded with anaerobic granular sludge from the anaerobic pond taken from Malpom Sdn Bhd and were mixed with 750 mg /L COD of RPME as substrate. Every day, 1 L of RPME was added until the reactor became full. During the stabilization period, the RPME were continuously added at hydraulic retention time (HRT) of 4 days and organic loading rate (OLR) of 0.14 g/L/dy. The pH of the digesters was kept without any adjustment during this period. The acclimatization of sludge with wastewater during the start-up period was monitored by the daily measurement of biogas production and effluent COD until steady state is achieved.

Once steady state was achieved, the HRT was increased to 7 days for different OLR of 0.29, 0.43 and 0.57 g/L/dy. For each HRT, the reactor was operated until it reached steady state condition where various parameters (pH, COD concentration, VFA concentration, biogas volume and methane content) were monitored.

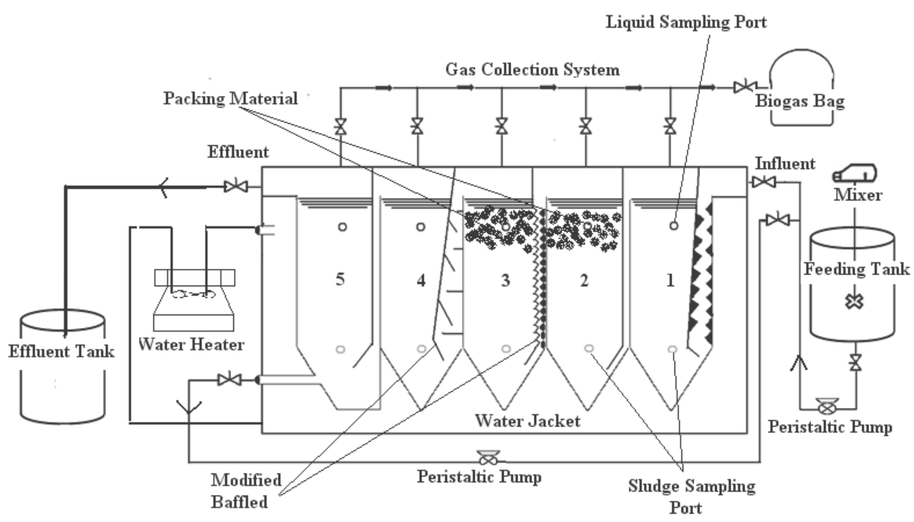

Figure 1: Lab Scale MAHB reactor

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Analytical Method

Samples of influent, effluent and each compartments of MAHB reactor were collected every two days for analysis of COD, pH and biogas for each different parameter. Methane content and biogas were also determined at each steady state condition. For VFA, it was measured weekly. Composition of biogas was determined using Shimadzu Gas Chromatography with a Flame Ionization Detector (GC-FID) with a propack N column. Carrier gas was helium set at a flow rate of 50 mL/min, column temperature of 28°C, detector temperature of 38◦C and injector temperature of 128◦C. VFAs were measured using esterification methods. Triplicate samples were collected for each parameter reading to increase the precision of the results, and only the average value was reported throughout this study. Conventional parameters such as pH were measured according to the Standard Methods [9] while COD was measured using Spectrophotometer DR-2800 according to the reactor digestion method [10].

Results and Discussion

Chemical Oxygen Demand (COD) Removal

MAHB reactors were subjected to four different changes in the feed concentration which corresponds on the changes of feeding COD concentration. COD variations within the MAHB reactor were shown in Fig 2. For each increment in OLR, COD removal efficiency showed increment gradually with the passage of time.

Throughout the first 28 days of start-up, the highest COD removal rate was 86%. From then on, COD removal efficiencies kept above 94% at each steady state condition. Result shows that a change in feeding COD concentrations did not have any noticeable effect on the stability and performance of MAHB reactor. This indicates that MAHB reactor had high ability to resist shocking loading rate. Results showed that 96% COD removal were achieved within 31 days at OLR of 0.29 g/L/dy (Stage 1). The removal of COD from RPME wastewater was generally good at 0.43 and 0.57 g/L/dy (Stage 2 and 3) with the highest removal efficiency achieved was 97.49% at day 63. Not just provides high COD removal efficiency, the effluent COD concentration were less than 150 mg/L.

During start up stage, under a constant and long retention time coupled with a steady increase in substrate concentration, a positive effect on development of appropriate microbial

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culture contributes to the better performance of MAHB reactor [11]. Ever since the loading rates were only increased when steady state conditions were achieved for the present loading condition, the microorganisms in individual compartments have acclimatized to increasingly OLR, hence great reactor stability and superior performance was provided.

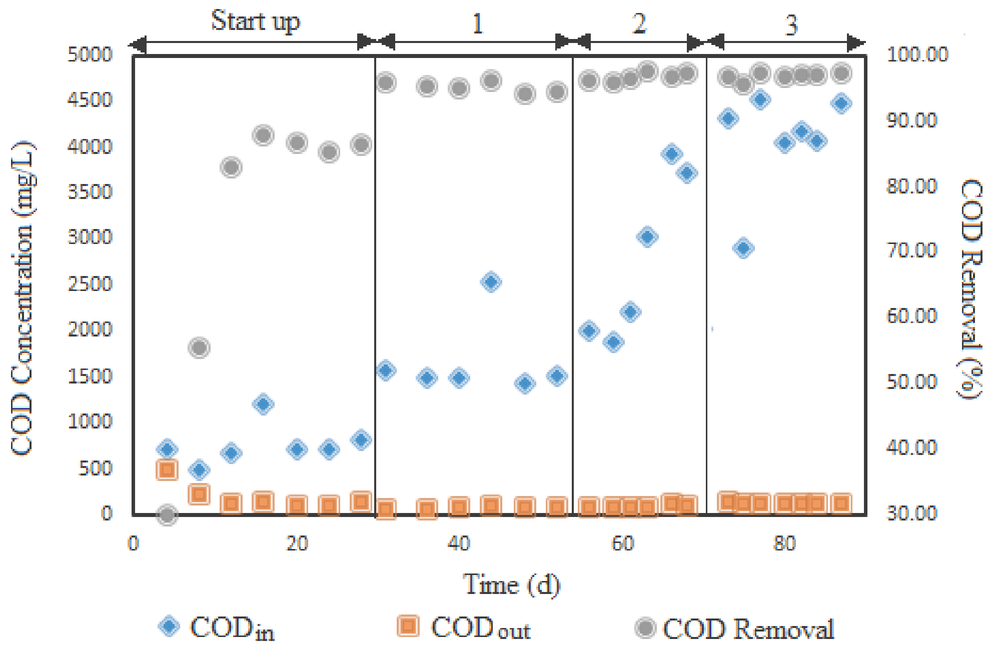

Figure 2: COD variation and COD removal efficiency of MAHB reactor against various loading rates

pH profile

Values of pH for each different compartment for all different OLRs conditions tested were illustrated in Figure 3. Levels of pH of each individual compartment show a narrow change regardless of the OLRs. At OLR of 0.14 g/L/dy, the pH of all different compartment shows declining behaviour. When the OLR was further increased to 0.57 g/L/dy, a downward tendency of pH was observed. This is mainly due to increment of VFA concentration as the influent COD concentration increased. The change characteristics of pH along the MAHB reactor can indicate whether the anaerobic system is working normally after each change of OLR, also as a control parameter of hydrolysis acidogenesis phases in MAHB reactor.

pH profile shows an increment along the reactor from Compartment 1 to 5. This shows that Compartment 5 could maintain the acidity in terms of pH and VFA concentration

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at pH level in a range of 6.3 to 7.3 which provide for effective anaerobic digestion to occur. The pH values in this compartment were maintained at nearly neutral and constant level due to VFA consumption.

The considerably increased in pH level in the rear end compartment of the reactor provides a better condition to generate a methane rich biogas as the methanogens attained maximum activity in terms of acetate conversion under pH level of 6.8 and 7.0 [12]. Similar pattern was also recorded by Dama *et al* [13].

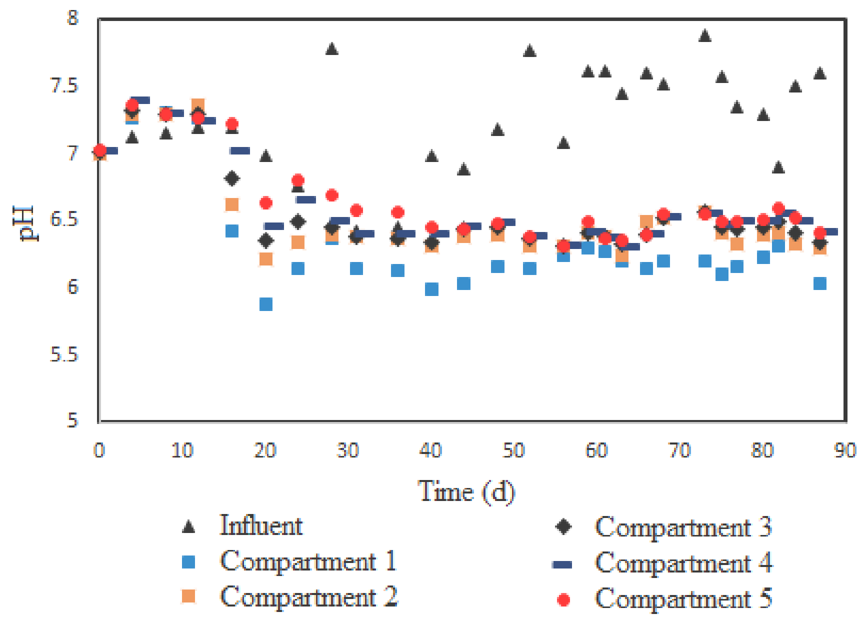

Figure 3: pH variation against various loading rates

Volatile Fatty Acid (VFA)

Figure 4 shows the variation of VFAs in each compartments of MAHB reactor. VFA concentration in compartment 1 were 66 mg/L 65.7 mg/L, 67.8 mg/L and 131 mg/L at OLRs of 0.14, 0.29, 0.43 and 0.59 g/L/dy respectively. It shows that VFA concentration in Compartment 1 increased as the influent COD improved. Similar pattern was recorded for subsequent compartments. VFA concentration was highest in Compartment 1 and decreased stepwise along the compartment which is consistent with the COD concentration profile. This is due to the accumulation of VFA contributes to the gradual increase of dissolved COD throughout the whole experiment.

VFA peak shifted down to Compartment 2 due to increasing feed strength. This is as a result of substrate could not be hydrolysed to catabolic intermediates completely by

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acidogens in Compartment 1. It is concluded that relative differences between Compartment 1 and 2 were gradually smaller under each OLR which are 74%, 84%, 70% and 67%, respectively. High VFA concentration in front of MAHB reactor showed that leading compartments were conquered by acidogenesis microbes, resulting in VFA accumulation, whereas low level of VFA were dominated in last end compartment which indicates that methanogenesis appears in the last two compartments. Result obtained shows a consistent pattern with the sequential degradation of fatty acids where higher VFA were first produced in front compartment (Compartments 1 and 2) and then were further converted to acetate (Compartment 2 and 3), then followed by conversion to methane in Compartment 5.

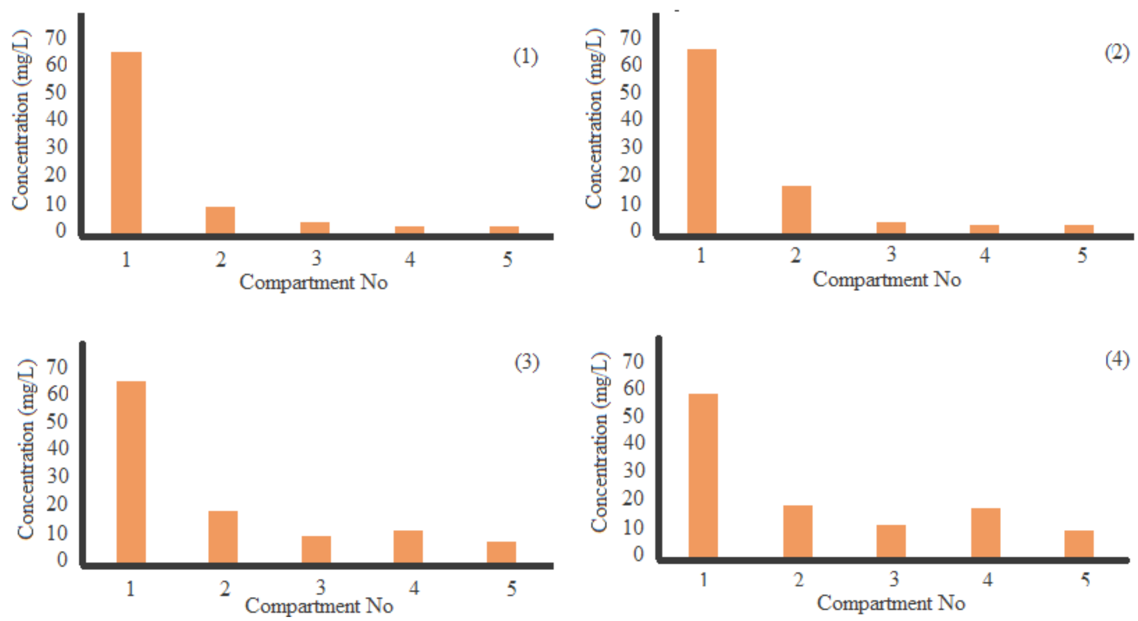

Figure 4: The VFAs variation of each compartment against various loading rates; (1) 0.14 g COD/L/dy, (2) 0.29 g COD/L/dy, (3) 0.43 g COD/L/dy and (4) 0.59 g COD/L/dy.

Biogas production and composition

Biogas production rate shows increment with the increasing load, increased from 5.31 to 7.21 L/dy for loading rate of 0.14 to 0.57 g/L/dy (see Fig. 5). This indicates that moderate substrate feeding is the most effective approach to improve gas production rates. As the OLR rising, the anaerobic bacteria in the MAHB reactor will rapidly reproduce which resulted in apparent increased in biogas yield [14].

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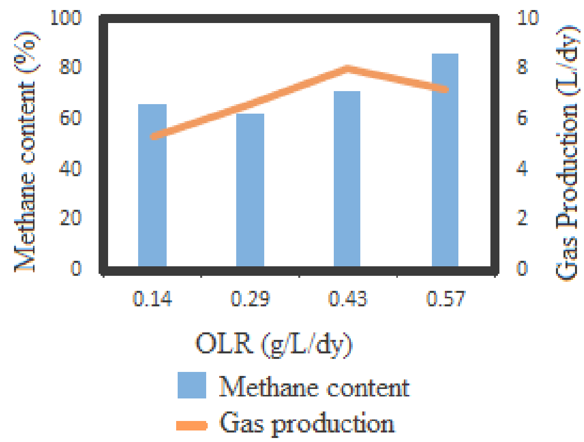

Figure 5: Variation of biogas against various loading rates

Once the OLR increased, the substrate was excessive compared to the biomass in the first compartment, so more substrate flowed into the subsequent compartments. Consequently, all compartment yields more biogas that contributes to the increasing of total biogas produced.

Methane content in biogas shows gradual increment as the OLR increased. This indicates the growth characteristics of the microbial populations inside the MAHB reactor. High OLR gaves more biomass for the microbes to convert them as a substrate to methane. Acidogenic bacteria hydrolyze complex polymer substrate to organic acids, alcohol, hydrogen, and carbon dioxide, followed by the conversion of the above intermediates to acetate by hydrolysis and acidogenesis. In final stage, the methanogens converts simple compounds (i.e. acetate, methanol, and combining carbon dioxide with hydrogen) into methane. Actually, this pattern follows the accepted understanding of multi-staged anaerobic digestion, i.e. hydrolysis, acidogenesis, acetogenesis and methanogenesis [15].

Conclusion

Based on the result obtained, it is concluded that MAHB reactor is suitable for anaerobic process treating low strength recycled paper wastewater with a performance;

- The COD removal efficiency achieved more than 90% after a successful and short start up.

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- As the organic loading rate increased to 0.57 g/L/dy, excellent stability performance were achieved as high as 97% COD removal, methane content of 85.95% and biogas produce of 7.21 L/dy.
- Rapid acidification of recycled paper mill effluent (RPME) in the front compartment contributes to the decrease of pH values.

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