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The effect of Mesophilic and Thermophilic Temperature on the Performance of an Up-Flow Anaerobic Sludge Bed (UASB) Reactor.

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ABSTRACT

The performance of an anaerobic reactor depends on various factors such as wastewater composition, organic loading rate (OLR), hydraulic retention time (HRT), seed sludge, temperature, and reactor configuration. In the present study, an up-flow anaerobic sludge bed (UASB) reactor was used for the treatment of synthetic wastewater. Specifically, this study was carried out in order to investigate the effect of temperature on the reactor performance when OLR was gradually increased. The reactor was operated at two different temperatures; mesophilic (37^{o}C) and thermophilic (57^{o}C). The maximum COD removal efficiency of the mesophilic operation was low compared to the thermophilic (75.3 and 81.2% respectively). The volatile acid concentration was 80 mg/L throughout the thermophilic and mesophilic experimental study. The MLVSS/MLSS ratio confirms that the utilization of biomass during the thermophilic operation was high. From the study, it was concluded that temperature plays a major role in anaerobic reactor operation, and thermophilic condition provided better reactor performance.
Keywords: UASB, anaerobic treatment, mesophilic, thermophilic, MLVSS/MLSS ratio

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INTRODUCTION

Anaerobic digestion is widely used as a cost-effective method to treat a wide range of the pollutant that is hazardous to the environment [1]. The process performance is entwined complexly between the factors such as temperature, pH, feed type, OLR, HRT, biomass population, and the presence of recalcitrant compounds in wastewater. The temperature in anaerobic digestion can be considered as an extremely important factor as it's capable of changing the biomass population [2]. The difference in the temperature displays dominance of different species of microbes which digest the wastewater via varying biomechanism [3].

Mesophilic temperature (37oC) is an optimum temperature for anaerobic microbes and majority of anaerobic microorganism thrives well in this temperature [4]. Thermophilic temperature (57oC) is not a niche for many anaerobic microorganisms, as only extremophiles can thrive in this temperature. In terms of reaction kinetics, thermophilic digestion seems to have an advantage over mesophilic digestion. This is because a high-temperature reactor operation provides additional energy that increases the rate of feed substrate conversion by anaerobic microorganisms [5]. Despite having the advantage in terms of energy level, thermophilic reactor operation has its drawbacks too. Major drawbacks of thermophilic operations were high energy consumption and high discharge of suspended solids. However, at mesophilic temperature, feed substrates have low energy level yet have its advantages as well [5]. Specifically, the advantages were lower energy consumption and stable reactor performance [6]. COD removal directly reflects the substrate utilization by anaerobic microorganism in the reactor. Volatile Fatty Acid (VFA) variation in the reactor also indicates the activity of anaerobic bacteria. MLVSS/MLSS ratio was used to authenticate the COD removal performance and VFA variation in the reactor [7].

The aim of this study was to assess the performance of the up-flow anaerobic sludge bed (UASB) reactor at two temperatures, namely thermophilic and mesophilic. A synthetic wastewater containing glucose was used as a substrate for the anaerobic microorganisms. The reactor performance was evaluated in terms of COD removal, VFA, and MLVSS/MLSS ratio.

MATERIALS AND METHODS

Up-Flow Anaerobic Sludge Bed (UASB)

The up-flow anaerobic sludge bed (UASB) reactor can work in a wide range of temperatures, from mesophilic to thermophilic. For this study, a mesophilic temperature of 37°C and thermophilic temperature of 57°C were selected for the reactor operation. For the purpose of comparison, two identical UASB reactors were used in the current experiment. The reactors were capable to work in a wide range of HRT from hours to days with the aid of a peristaltic pump. The reactors consist of 18 cm internal diameter by 110 cm height, with an active volume of 20 L. The reactors had a 3-phase separator baffle, (2 circle disks with pore size diameter of 2 mm) and placed 2 cm below the effluent ports, to prevent floating granules from being washed out with the effluent. Sampling ports are placed at 8 cm intervals (lowest being 21 cm from the base) that allowed biological solids and liquid samples to be withdrawn from the sludge bed. The influent wastewater entered through a 2.7 cm internal diameter down comer tube in the head plate that extended to within 105 cm of the reactor base and allowed feed to flow upward through the sludge bed. Temperature controller and heater were installed to maintain the reactor temperature at 37^{o}C and 57^{o}C.

Synthetic Wastewater

The synthetic wastewater was made from consumer grade glucose obtained from a local grocery, mixed with clean filtered water and had the following characteristics: pH=8.0 (NaOH buffer added), COD=1500mgL^{-1}.

Reactor Operations

The reactors were seeded with anaerobically digested sewage sludge from Bunus Sewage Treatment Plant, Kuala Lumpur. A total of 7 L of sieved sludge was added to each reactor and filled with tap water up to 20 L mark. Then the reactors were flushed with excess nitrogen gas to remove remaining air within the reactor space. The reactors were allowed to stabilize at a temperature of 37^{O}C and 57 ^{o}C for 24 hours. The start-up of the reactor was carried out using synthetic wastewater with very low COD concentration. Once the reactors attained a steady state condition (>80% COD removal), the feed concentration was increased gradually by reducing the amount of water. OLR was increased stepwise from 0.125 to 0.375 kg $CODm^{-3}d^{-1}$ at an HRT of 4 d. The optimum macronutrient to COD ratio was maintained at (COD: N: P, 250: 7: 1) by adding N100 macronutrient supplement and trace elements were also added due to lack of trace elements in the synthetic wastewater.

Sampling and Analysis

Sample analysis such as COD, pH, suspended solids (SS), and volatile suspended solids (VSS), and VFA were conducted according to Standard Methods [8].

RESULT AND DISCUSSION

Figure 1 illustrates thermophilic digestion and showed high COD removal efficiency, up to 60.5% in the initial phase of the experiment. Later, the COD removal efficiency increased to approximately 80% at the end of the reactor operation. The COD removal efficiency of the thermophilic reactor observed to be stable from throughout the experimental period. The only exception was observed at day 24 of the reactor operation, where a sudden drop in the COD removal efficiency was observed. From that point onwards the COD removal appeared to have gain momentum and gradually increased up to 80%. The sudden drop in the COD removal efficiency was correlated to the gradual decrease in the pH (data not included), from day 1 to 30, confirming the domination by acidogenic bacteria [9]. From day 32 onwards the COD removal efficiency improved, suggesting that the methanogenic bacteria dominated the reactor [10].

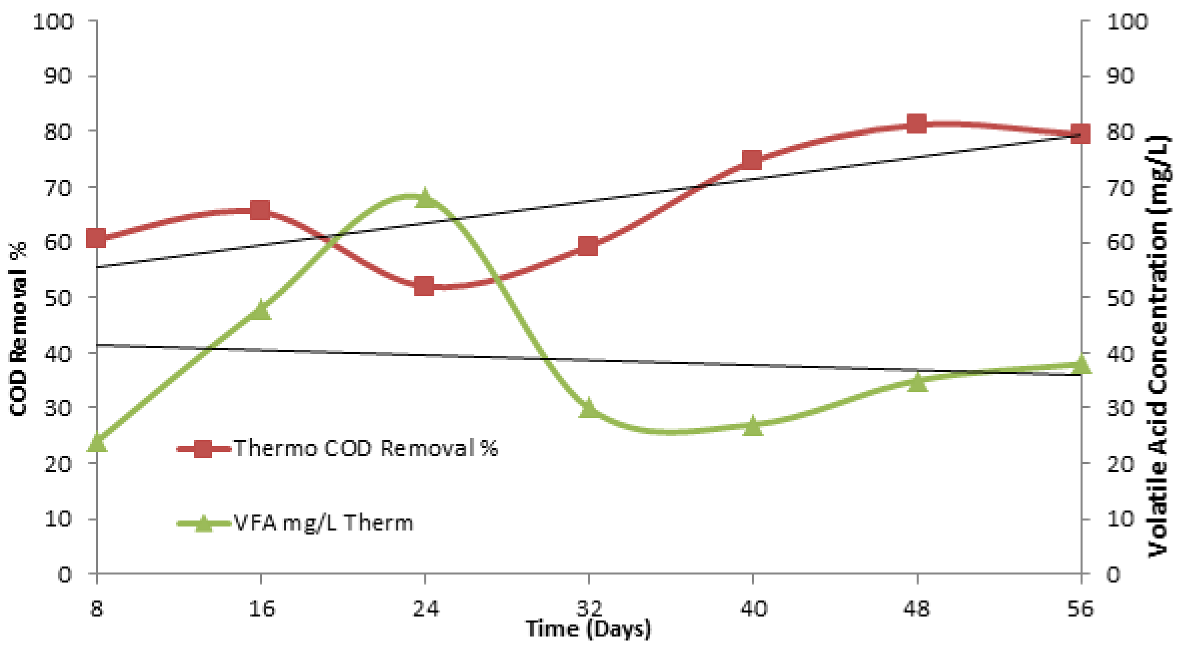

Figure 1: Variation of total volatile acids and COD removal profile during thermophilic digestion

Figure 2 illustrates the mesophilic digestion, and it can be seen that steady increase in the COD removal efficiency up to 75.3% until day 48. At the end of the reactor operation, the COD removal efficiency dropped substantially to 46.5%. It can be suggested that at mesophilic temperature, acidogenic bacteria dominated the reactor at initial phase and methanogens at the latter stage. The drop in pH (data not included) showed that acidogenic population thrived better than the methanogenic bacteria at the final stage [11]. However, the profile of COD removal efficiency was different in both conditions. A low COD removal efficiency was observed at the initial stage of the mesophilic digestion compared to thermophilic. A stable pH suggested that the thermophilic reactor was dominated by the methanogenic bacteria and fluctuating pH in the mesophilic indicated that there was fluctuating imbalance occurs between methanogenic and acidogenic bacteria [11].

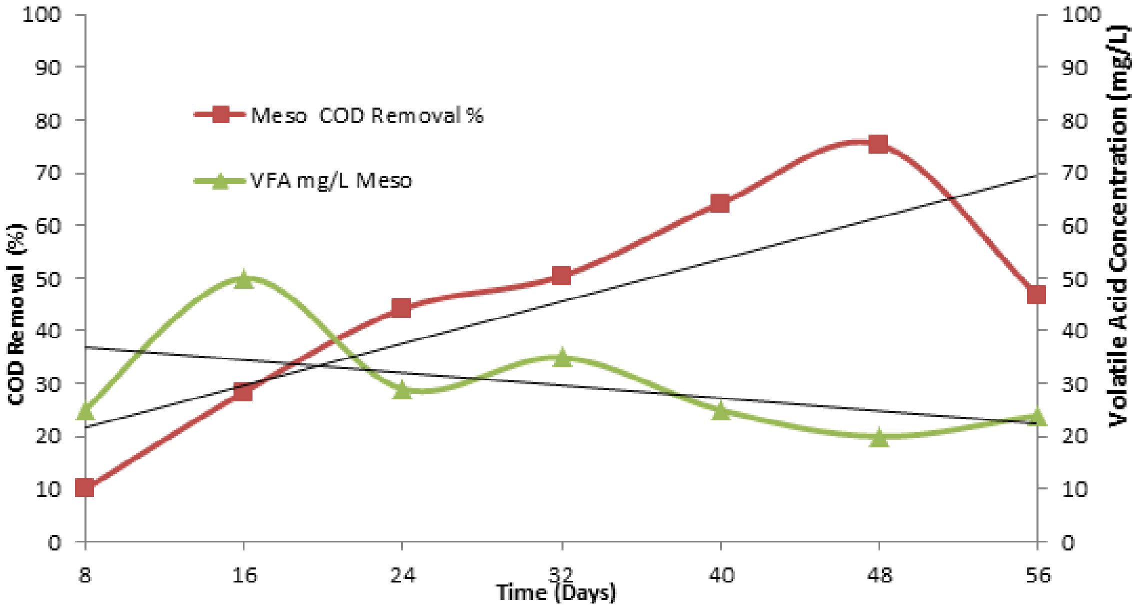

Figure 2: Variation in total volatile acids and COD removal profile during the mesophilic digestion

Figure 3 illustrates the variation of MLVSS/MLSS ratio in the mesophilic and thermophilic reactor. MLVSS/MLSS ratio is a good indicator of a healthier biomass in the reactor [12]. Overall the condition of biomass in thermophilic digestion was better compared mesophilic digestion because thermophilic digestion have achieved higher MLVSS/MLSS ratio. This was due to the additional energy available in thermophilic digestion that has boosted the feed utilization rate by microbes [12]. Moreover, the high temperature also creates a unique niche for thermophilic bacteria by eliminating other possible competitors [13]. This allows the thermophilic bacteria to dominate the feed utilization. Whereas in mesophilic digestion the temperature is lower, and the feed could be shared by various biota including the mesophilic and thermophilic bacteria [14]. A high MLVSS/MLSS ratio also possibly denotes high solid washout that could be one of the disadvantages of the thermophilic digestion.

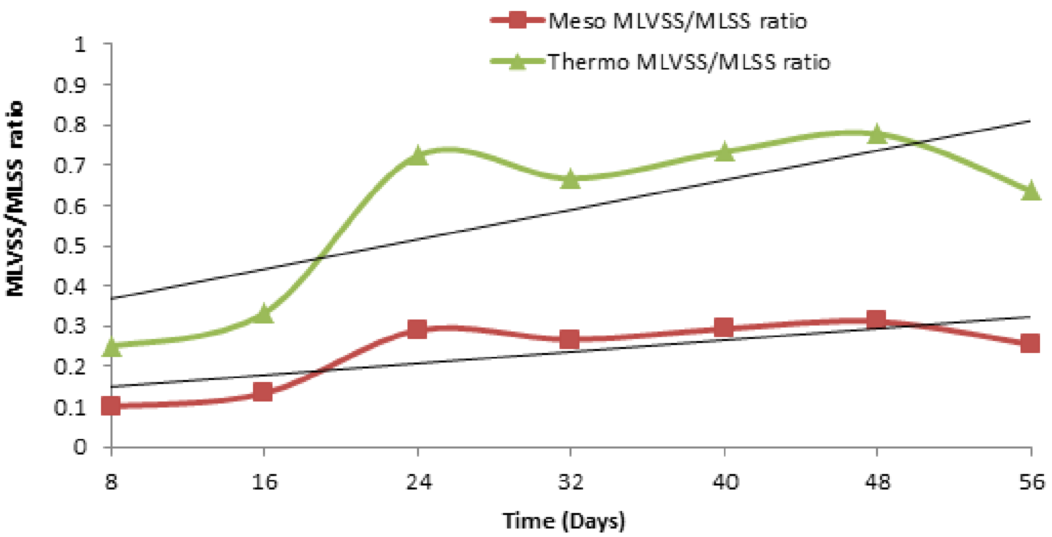

Figure 3: Comparison in variation of MLVSS/MLSS ratio in thermophilic and mesophilic digestion

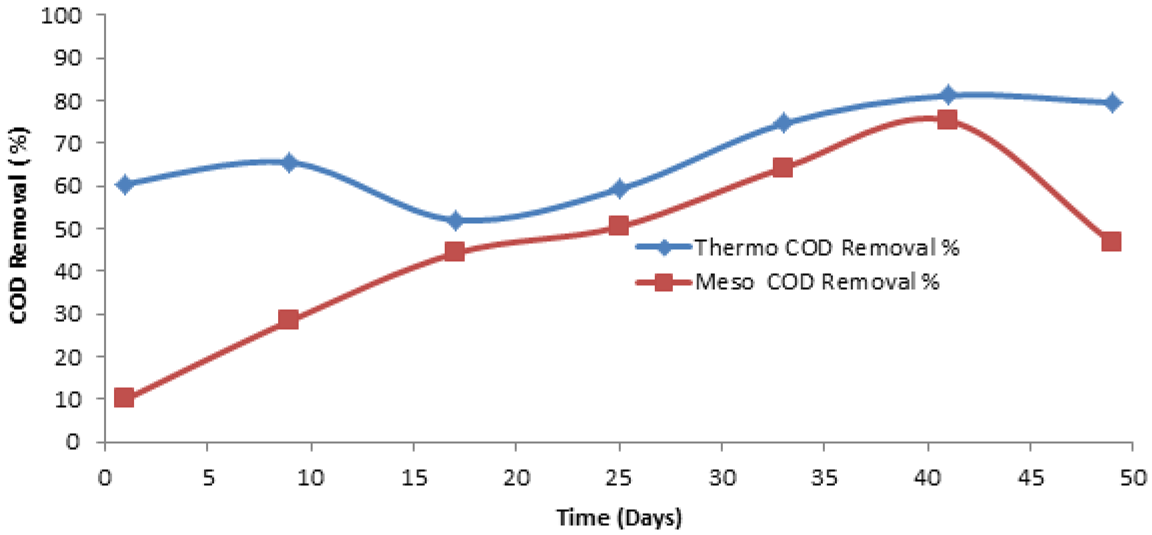

Figure 4: COD removal profile at mesopholic and thermophilic digestion

When comparing the COD removal efficiency of mesophilic and thermophilic digestion, it was evident that both processes showed high COD removal (up to 80%). Further analysis of the data reveals a minor fluctuation in the pH that could affect the COD removal efficiency of the mesophilic biota. On the other hand, thermophilic digestion proved to be a much more stable and reliable compared to mesophilic digestion. The pH plays an important role in both digestion modes [15]. In mesophilic digestion, fluctuations in pH was observed due to the fact that the biota was highly diverse, whereas in thermophilic digestion the pH was stable, and fluctuations in pH were not observed because biota was dominated only few species that could prevail in that temperature [16].

CONCLUSIONS

From this study, it was found that the thermophilic digestion process is most suitable for the anaerobic digestion of synthetic wastewater. However, the process has its disadvantages such as high solid washout and high energy consumption that makes it least appealing choice in the aspect of cost effectiveness. The mesophilic process that is proven to be inferior to thermophilic has its disadvantages such as instability in pH, and high diversity of microbes serves to be the reason behind its poor performance. Nevertheless, the mesophilic digestion also has its advantages such as minimum power consumption. From this study, it can be concluded that mesophilic digestion is highly feasible (by controlling pH) and if possible nurture isolated cultures of methanogens and acidogens in the sludge to aid their domination.

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