

Enhancement of performance and biodegradability kinetics of aerobic-anaerobic sludge digestion

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Abstract. The excess sludge problem from a wastewater treatment plant is a great concern due to the high cost of sludge management accounting for about 20% to 50% of the total operating cost. Therefore, sludge reduction is critical. Currently, aerobic and/or anaerobic sludge digestions are widely used in the industries for treating the excess sludge. The objective of this research was to study the effects of aeration rate and temperature on the excess sludge reduction by using the aerobic-anaerobic digestion system in the laboratory. The aeration rates of 1.0, 0.5, and 0.1 volume air per volume slurry per minute (vvm) at the room temperature and the thermophilic temperature ($55 \pm 2^\circ\text{C}$) were investigated. The results showed that the highest removal efficiency of aerobic sludge digestion was obtained at the thermophilic temperature and aeration rate of 1.0 vvm. The removal efficiency of organic matter in terms of COD, total solids (TS) and volatile solids (VS) were 34.76%, 33.01% and 43.45%, respectively. Consequently, the highest specific growth rate of microorganisms was 0.39 per hour and the substrate removal rate was 0.55 milligram COD_{removed} per milligram VSS per hour. Furthermore, slowly biodegradable organic matter was hydrolyzed to readily biodegradable organic matter and inert soluble organic matter. When the sludge effluent from aerobic sludge digestion was feed to the anaerobic sludge digestion, the removal efficiency of organic matter in terms of COD, TS and VS were increased by 25%, 17% and 28%, respectively. Moreover, the obtained methane production rate in the anaerobic sludge digestion was approximately 0.234 m³/kg COD removed.

1 Introduction

The activated sludge process is the most widely used biological process for domestic wastewater treatment. During aerobic biological treatment, organic pollutants are mineralized into carbon dioxide and water with the generation of an excess bacterial biomass commonly known as a waste activated sludge. The treatment, handling and disposal of this excess sludge account for up to 60% of the total wastewater treatment plant operating costs [1]. The large amount of waste sludge, constituting of refractory and non-biodegradable cellulose compounds, leads to difficulty of sludge disposal [2]. Sludge stabilization is employed to deduct germs and prevent sludge decomposition. The process can be conducted by chemical processes such as lime stabilization, physical processes such as heat stabilization and ultrasound, and bio-organic processes such as composting, anaerobic digestion, and aerobic digestion. The aerobic digestion process is similar to the method of the activated sludge (AS), which aims at eliminating organic dust or volatile solid. Not only does the aerobic digestion stabilize sludge, but it also reduces the quantity of excess sludge from the process [3-5]. As a result, the dewatering process can be achieved more easily and the sludge decomposition is prevented [6].

Anaerobic digestion on the other hand, employs microorganisms in the decomposition of organic substance in an anaerobic digestion environment by transforming organic substance into methane (CH₄), carbon dioxide (CO₂), and water [3, 5]. However, numerous kinds of bacteria are needed. Each type of bacteria has its own function in the digestion process. Previous studies suggested that the anaerobic digestion at thermophilic temperature, 50-55°C, reduces the solidification by 40-50% and lessens the dissolvable chemical oxygen demand (COD) by 20-30% during 10-15 days of the hydraulic retention time (HRT). When the digestion process was set at mesophilic temperature, 37 °C, the COD was proved to be reduced by 35% and 60% during 30 days and 20 days of the HRT, respectively [7-10]. On the other hand, the aerobic digestion sets at thermophilic temperature, 55°C, reduces 33% of the solidification and eliminates 65% of the dissolvable COD within 15 hours. It also creates less volatile acid at this temperature. Apart from this, results of the studies suggested that higher level of aeration can effectively increase the level of decomposition [11-12]. With the intention to enhance the excess sludge reduction and increase the biodegradable, in this study, the processes of the aerobic-anaerobic digestions with a variation of the aeration rate and temperature were investigated.

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2 Materials and method

2.1 Sludge samples

In order to evaluate the continuous performance of the aerobic-anaerobic digestion system, the excess sludge collected from the wastewater treatment plant of an industry was preserved at the temperature 4 °C for an inhibition of the microorganism growth. The characteristics of the excess sludge are presented in Table 1.

Table 1. Characteristic of excess sludge from activated sludge process.

Parameter	Value
Total Solids, TS (mg/L)	10,372±507
Total Volatile Solids, TVS (mg/L)	9,317±550
Suspended Solids, SS (mg/L)	9,699±622
Volatile Suspended Solids, VSS (mg/L)	8,693±647
Total COD (mg/L)	10,880±657
Soluble COD (mg/L)	530±56
Total BOD (mg/L)	2,174±626
Soluble BOD (mg/L)	544±92
TBOD/TCOD	0.27
VS/TS	0.90

2.2 Experimental set-up

The schematic diagram of the experimental set-up consisting of a sludge storage and aerobic-anaerobic digestion unit and the operating conditions are shown in Figure 1 and Table 2, respectively.

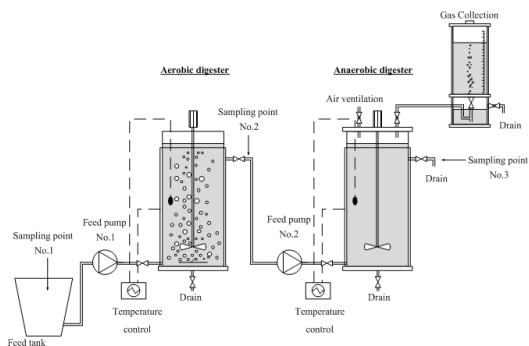


Fig. 1. Schematic diagram of the experimental set-up.

The effluent stream from the aerobic digestion reactor was transferred to the anaerobic digestion reactor. The working volume of both reactors was 10 L. In the aerobic digestion reactor, the sludge was mixed by the diffused aeration system placed at the bottom of the reactor to maintain an aeration rate of 0.1, 0.5 and 1.0 vvm. (volume air per volume slurry per minute). The temperature was maintained at the ambient temperature for mesophilic condition and 55±2 °C for thermophilic condition.

Table 2. The operating conditions of the aerobic-anaerobic digestion processes.

Operating conditions	Aerobic digestion (AeD)	Anaerobic digestion (AnD)
pH	6.8-7.2	-
Organic loading rate	1.0-1.125 kgVSS/m ³ -d	Effluent from AeD
Temperature (°C)	Ambient and 55±2	Ambient and 55±2
Aeration rate (vvm)	0.1-1.0	-
HRT (days)	8	8

2.3 Kinetic evaluations

The oxygen uptake rate (OUR) experiments were conducted to determine the biodegradability kinetic coefficients of the aerobic heterotrophs following the procedure conducted by [13]. The batch tests shown in Figure 2 were maintained at the temperature 30±0.5 °C, pH 7±0.2, and added the suppressing nitrification of 10 mg N-ammonia/L. The initial ratio of substrate to microorganism (S_0/X_0) was about 1.0-2.0. Suspended solids (MLVSS) concentration (X_0) in the sludge samples was about 300 mg/L for the batch tests and the various substrate concentrations (S_0) that govern the quality of the batch respirometric tests. The OUR results were used for calculating the maximum specific growth rates (μ_{max}), substrate utilization rate (r_x), half-velocity constant (K_s), and sludge yield coefficient (Y) based on Monod kinetics by regression analysis.

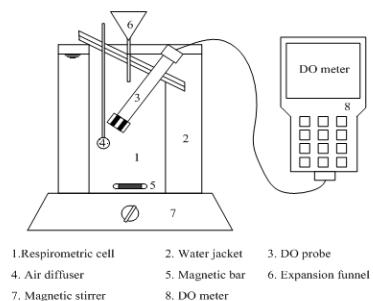


Fig. 2. Respirometer: 1) Respiration cell, 2) Water jacket, 3) Air diffuser, 4) DO probe, 5) Magnetic bar, 6) Magnetic stirrer, 7) Expansion funnel, 8) DO meter, and 9) Water bath.

2.4 Analytical methods

The influent and effluent samples were analyzed for total solids (TS), total volatile solids (TVS), suspended solids (SS), volatile suspended solids (VSS), total chemical oxygen demand (total COD) and soluble chemical oxygen demand (soluble COD) following the Standard Methods for the examination of water and wastewater, and [14]. The carbonaceous material characterizations were measured in terms of the COD parameter subdivided into a number of fractions following [15].

3 Results and discussion

3.1 Effects of aeration rate and temperature in aerobic digestion

A primary sludge treatment process is required to increase the proportion of easily degradable organic material in the process. A further address in this research was the observation of the influence of temperature and aerating rate on the common processes of the aerobic and anaerobic degradation. It can be drawn from the study that, in the aerated degradation process, the solid reduction and COD removal in the forms of TS, VS, and COD were found to be 28.20%, 35.76%, and 30.46%, respectively, for the aerating rate of 1.0 vvm at the mesophilic temperature (AeM1). For the aerating rate of 0.5 vvm (AeM2), it was found to be 24.83%, 35.76%, and 27.05% for TS, VS, and COD, respectively. The reduction efficiency was obtained around 19.53%, 25.01%, and 20.50% for TS, VS, and COD, respectively, when the aerating rate of 0.1 vvm (AeM3) was applied, as shown in Figure 3. Nevertheless, when using the statistical t-test with the 95% confidence, it turned out that the aerobic degradation processes at the mesophilic temperature with the studied variation of aerating rates did not have a statistical significant difference in terms of the solid reduction efficiency.

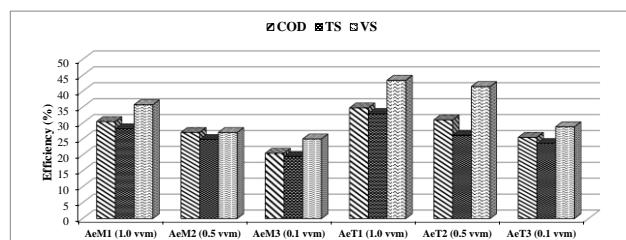


Fig. 3. Variations of efficiency remove organic matter on aerobic digestion.

For the aerobic digestion process at the thermophilic temperature, the reduction efficiencies of TS, VS, and COD were 33.01%, 43.45%, and 34.76%, respectively, with the aerating rate of 1.0 (AeT1). It has proved to perform better compared to those with the aerating rates of 0.5 vvm (AeT2) and 0.1 vvm (AeT3) [11]. However, the solid reduction efficiencies were not significantly different for the introduced aerating rates at the thermophilic temperature when testing with the statistical t-test at the 95% confidence. Noticeably, the average solid removal efficiency at the thermophilic temperature was slightly higher than that at the mesophilic one.

Higher removal efficiency of organic matter in terms of TS, VS, and COD was obtained at higher aeration rates (1.0 and 0.5 vvm) because they provide sufficient dissolved oxygen for the aerobic bacteria to use for converting the hydrolysable substrate to readily biodegradable substrate, for the uptake growth of the biomass, and for maintenance purposes.

3.2 Efficiency in the aerobic-anaerobic digestion processes

The average organic matter reduction efficiency at the thermophilic temperature is higher than that at mesophilic for the organic matter removal of the excess sludge using the common aerobic and anaerobic degradation process. Under the studied conditions, approximate 35-50% solid reduction at 16 days HRT-8 days aerobic exposure and 8 days anaerobic exposure. The aerating rate of 1.0 vvm at the mesophilic temperature in aerobic digestion (AeM1) and anaerobic digestion (AnM1) yielded the removal efficiency of 41.45%, 50.81% and 45.08% for TS, VS and COD, respectively. The aerating rate of 0.5 vvm condition in aerobic digestion (AeM2) and anaerobic digestion (AnM2) resulted in the reduction efficiency of 34.42%, 48.81% and 37.02% for TS, VS and COD, respectively. The thermophilic aerobic digestion (AeT1) and anaerobic digestion (AnT1) with the aerating rate of 1.0 vvm produced the removal efficiency of 50.40%, 71.28% and 59.49% for TS, VS and COD, respectively, while the thermophilic aerobic digestion (AeT2) and anaerobic digestion (AnT2) with the aerating rate of 0.5 vvm removed 28.35%, 61.82% and 49.23% for TS, VS and COD, respectively.

With the incorporation of the anaerobic process, the solid reduction efficiency at the thermophilic temperature was found to be in the range of 13-15 % while falling between 10-13% at the mesophilic temperature, as shown in Figure 4. It was further found that the efficiency of reducing easily vaporized sludge varied with the change of temperature and aerating rate [7-8, 10, 16]. When applying the statistical t-test at the 95% confidence, the anaerobic degradation processes at the thermophilic temperature showed the significant difference in terms of solid reduction efficiency.

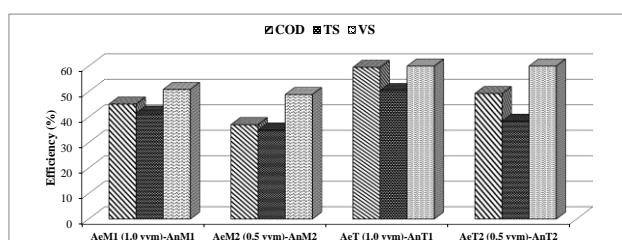


Fig. 4. Average efficiency in aerobic-anaerobic digestion process at mesophilic and thermophilic temperature.

Gas production shown in Table 3 was 0.062, 0.058, 0.211 and 0.156 L/d for AnM1, AnM2, AnT1 and AnT2, respectively at a gas production rate 0.009-0.046 m³/kg VS_{fed}. The thermophilic temperature condition increased the gas production because it is suitable to hydrolyze much organic matter into the soluble forms that could immediately be. These conditions could make the organic matter release from the inner fractions to the outer fractions, thus increasing the hydrolysis rate of granular organics and improving the digestion efficiency [11-12]. For the effect of temperature on the anaerobic digestion, it was found that the thermophilic anaerobic digestion was much faster than the mesophilic anaerobic digestion. In thermophilic anaerobic digestion, the waste activated

sludge had the thermal lysis of microbial cell as the dominant mechanism, resulting in the high degradation rate. References [17] showed that the performance of the reactor could be improved with the increase in temperature and HRT 20 days. The COD removal increased from 35% in the mesophilic condition to 45% in thermophilic, the gas production were 0.33 and 0.45 m³/kg VS_{fed} at the mesophilic and thermophilic conditions, respectively.

Table 3. Variations of gas production on anaerobic condition

Condition	AnM1	AnM2	AnT1	AnT2
Gas production (L/day)	0.062±0.011	0.058±0.011	0.211±0.059	0.156±0.047
Gas production rate				
- m ³ /kg VS remove	0.174±0.049	0.163±0.038	0.254±0.073	0.243±0.066
- m ³ /kg COD remove	0.060±0.006	0.058±0.006	0.234±0.074	0.221±0.094
- m ³ /kg VS _{fed}	0.009±0.002	0.008±0.002	0.063±0.015	0.046±0.014
- m ³ /kg COD _{fed}	0.006±0.001	0.006±0.001	0.044±0.013	0.043±0.012

3.3 COD fractionation and biodegradability kinetics

COD fractionations were evaluated for the potential biodegradability and the results are illustrated in Fig 5. The result showed that the slowly biodegradable organic matter was hydrolyzed to the readily biodegradable organic matter and inert soluble organic matter. Readily biodegradable organic substrate (S_S) decreased at different aerating rates and temperatures. Slowly biodegradable organic substrate (X_S) and inert soluble organic matter (S_I) had the maximum value at the aerating rate of 1.0 vvm. The inert particle organic matter (X_I) had the minimum value at the aerating rate of 1.0 vvm. This showed that the hydrolysis from X_S into S_S and S_I occurred more at the higher aerating rate, and the removal of organic matter was also more efficient at the higher aerating rate. With the observation of TS, VS, and COD removal efficiency at the aerating rate of 1.0 vvm, at the thermophilic temperature condition, X_I reduced by the ratio of the rate of the hydrolysis and biodegradable was higher than that at the mesophilic temperature.

The biodegradability kinetics of the microbial aerobic digestion at the thermophilic and mesophilic condition with the aerating rate 1.0 0.5 and 0.1 vvm is shown in Table 4. As the result, the highest specific growth rate of microorganisms was 0.39 per hour and the substrate removal rate was 0.55 milligram COD removed per milligram VSS per hour. It showed that the μ_{max} and R_X was higher when increasing the aeration rate. However, the aeration rate of 1.0 and 0.5 vvm provided no significant difference in the rates of the microbial growth and substrate removal. As a result, the ratio of increases substrate due to the growth of microorganisms increases, to uptake substrate that removed easily biodegradable. This is consistent with the removal efficiency of organic matter in terms of COD, TS and VS. When the μ_{max} and R_X on the thermophilic and mesophilic conditions were compared, the thermophilic μ_{max} and R_X were found to be greater than the mesophilic ones. This

showed that the temperature importantly effects the specific growth rate. At the same aerating rate, higher temperature results in a well growth of microbes. According to k_d, it showed that the death rates increased when the aerating rate decreased.

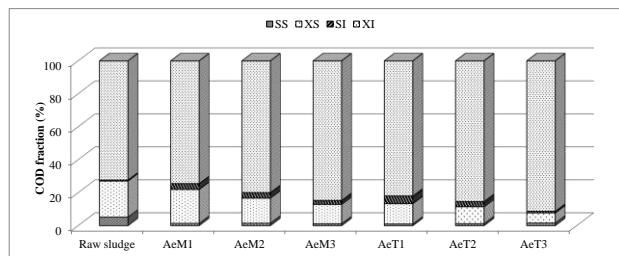


Fig. 5. COD fraction on aerobic digestion

Table 4. Biodegradability Kinetic on aerobic digestion

Parameter	Mesophilic			Thermophilic		
	1.0 vvm	0.5 vvm	0.1 vvm	1.0 vvm	0.5 vvm	0.1 vvm
μ_{max} (h ⁻¹)	0.34	0.33	0.31	0.39	0.37	0.33
R _X (mg COD removed/mg VSS-h)	0.52	0.51	0.41	0.55	0.52	0.40
Y (mg VSS/ mg COD removed)	0.66	0.65	0.75	0.70	0.72	0.80
k _d (d ⁻¹)	0.0996	0.0999	0.1048	0.0923	0.0929	0.1001
K _s (mg/L)	200	255	230	160	205	210
$\mu_{max}/Y * K_s (*10-3 L/mg-h)$	2.57	1.99	1.79	3.48	2.51	1.96

4 Conclusions

Temperature and aeration rate are the factors affecting the removal of organic matter in the aerobic digestion process because, at high temperature, the dissolve oxygen was limited and thus, the amount used in the decomposition of organic matter not enough. The results showed that the highest removal efficiency of the aerobic sludge digestion was obtained at the thermophilic temperature and aeration rate of 1.0 vvm. The removal efficiency of organic matter in terms of COD, total solids (TS) and volatile solids (VS) were 35%, 33% and 43%, respectively. As the result, the highest specific growth rate of microorganisms was 0.39 per hour and the substrate removal rate was 0.55 milligram COD removed per milligram VSS per hour. The maximum specific growth rate (μ_{max}) of microorganisms in the aeration rate of 1.0 and 0.5 vvm was higher than that of the aeration rate of 0.1 vvm, and the rate of removal substrate was in the same pattern. In addition, the thermophilic temperature condition provided the faster rate decomposition of organic matter than the mesophilic one. The amount of the thermophilic organic matter was less than the mesophilic condition. Furthermore, the slowly biodegradable organic matter was hydrolyzed to the readily biodegradable organic matter and inert soluble organic matter. Finally, the sludge effluent from the aerobic sludge digestion fed to the anaerobic sludge digestion resulted in the improvement of the removal efficiency of organic matter in terms of COD, TS and VS

by having increased 25%, 17% and 28%, respectively. Moreover, the methane production rate in the anaerobic sludge digestion was obtained approximate $0.234 \text{ m}^3/\text{kg COD removed}$.

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