Temperature effect towards methane gas production and performances of anaerobic fixed bed reactors

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Abstract. This study was conducted to observe the effect of temperature towards methane gas production and performances of Anaerobic Fixed Bed Reactors (AFBR) in degrading artificial wastewater. During seeding and acclimatization as well as operation at normal loading rates the reactor was controlled at 35 ± 1 °C. The reactor temperature was then switched to room temperature to compare its performance with performance of the temperature controlled reactor. Seeding was performed by wastewater feeding at concentration of 5,300 mgCOD/L. Seeding was continued to acclimatization after COD efficiency reached about 30% and mixed liquor volatile suspended solids (MLVSS) in the reactor were in the range of 28 to 29 g/L. Acclimatization was conducted by step increased feeding while obtaining organic loading rates (OLR) of 530 mgCOD/L/day and 40 days HRT, and it was stopped when COD efficiencies almost constant at about 80% were achieved. Normal loads at OLR of 530 mgCOD/L/day and HRT of 40 days resulted in COD efficiencies in the range of 80 to 92%, produced methane gas ranged from 80 to 170 ml/day, at pH around 7 during controlled temperature. At room temperature, COD efficiencies decreased to the fluctuated range of 78 to 84%, methane gas dropped to the highest of 144 ml/day but pH range was still at around 7. At OLR 1.5 times normal OLR (795 mgCOD/L/day) and HRT of 40 days, the controlled temperature reactor shows superiority by producing efficiencies in the range of 84 to 94% and 260 mL/day of CH\textsubscript{4} as the highest gas produced during observation. Efficiencies of COD obtained during uncontrolled temperature dropped to the range of 60 to 80%. The uncontrolled temperature reactor only produced the highest CH\textsubscript{4} production of 48 mL/day. pH from both reactors still ranged in the normal pH range about 7. It shows that AFBR has to be controlled at around 35 °C to produce higher COD efficiencies and methane gas production.

1. Introduction
Anaerobic digestion is a common technology used to anaerobically treat high organic contents of wastewater. Wastewater produced from sugar, poultry, pulp and paper, and pharmaceutical industries are examples of industrial wastewater to be degraded anaerobically. This type of wastewater is generally difficult to be degraded by using aerobic digestion system since this wastewater type contains high organic compounds. The application of anaerobic digestion to degrade high organic contents of such wastewater has widely been cited in literature [1].

There are three stages occurring during anaerobic digestion, i.e. hydrolysis, acetogenesis, and methanogenesis. During hydrolysis, organic compounds such as lipids, polysaccharides, proteins, and nitrates will be degraded into simpler organic compounds such as fatty acids, monosaccharides, and amino acids by cellulose, amylase, protease, and lipase enzymes. The simpler organic compounds will be converted into formic acid, hydrogen, and carbon dioxide during acetogenesis. During this stage, volatile fatty acids (VFAs) will also be produced. At the stage of methanogenesis, these VFAs will be
degraded to methane by methane producing bacteria. Acetic acid, hydrogen, and carbon dioxide will be decomposed by methanogenic bacteria during methanogenesis stage to become methane and carbon dioxide. Methanogenic bacteria consume acid produced by acetogenic bacteria and acid producing bacteria provide ideal atmospheric conditions for methane producing bacteria [2, 3, 4]. However, if the content of VFA in the system is too high, the growth of methane producing bacteria will be disturbed so that the degradation will be affected. Therefore, to provide ideal conditions for consortium microorganisms to grow and properly function, all stages have to occur proportionally [5, 6].

Methane produced from the aforementioned three anaerobic stages of degradation is the main benefit of anaerobic degradation system since methane gas can be applied as an alternative energy in related industries. The other benefits include lower energy consumption as aeration is not required, production of low quantity of well stabilized sludge, and odor-free treatment as anaerobic digestion has to be carried out in sealed vessels.

Jerger and Tsao [7] obtained that Alcaligenes sp, Aerobikacter sp, Clostridium, Escherichia sp, Methanobacteriaceae, and Propionibacterium are among anaerobic microorganisms which have to be maintained in the reactors to produce methane gas. Attention has to be paid to provide ideal conditions for these anaerobic microorganisms, i.e. several factors effecting the growth of consortium microorganisms anaerobically. These include temperatures, pH, nutrients, toxic materials, etc. This study was conducted to observe the effect of temperature towards the growth of anaerobic microorganisms in terms of methane gas produced and performances of the reactor. The reactor type of Anaerobic Fixed Bed Reactors (AFBR) is used since this reactor type provides the bed in which microorganisms could attach on the surface of the carriers. Attachment of microorganisms on the carriers is to enhance biomass retention within the reactor so that de-linking of solid retention time (SRT) from hydraulic retention time (HRT) occurs. By de-linking SRT from HRT, the reactor could perform much better since more attached microorganisms separated from suspension microorganisms withdrawn in the effluent stream [8].

2. Materials and Methods

2.1. Synthetic wastewater, inoculums, and reactor

The synthetic wastewater consists of chemicals containing nutrients needed by growth of microorganisms and its composition follows wastewater composition applied Budiastuti et al. [9]. The wastewater represents high organic contents of wastewater to be degraded anaerobically. The inoculums were in the form of abattoir seed sludge, which was obtained from an abattoir house in Padalarang, West Java, Indonesia. The synthetic wastewater composition fulfills the requirement of COD:N:P for anaerobic conditions [10]. The reactor used was the Anaerobic Fixed Bed Reactors (AFBR) produced by Armfield [11]. The reactor contains bioball carriers where attachment of microorganisms is expected to occur on the surface of these carriers [9]. This reactor is completed with gas collection tanks in which measurements of resulting biogas take place. The biogas is measured by using a water displacement system. Water displaced by the gas overflows from the tank base.

About 2 L seed sludge was poured into the reactor (AFBR) maintained at 35 ± 1 °C and feeding with increases of influent flow rates at the feed concentration of 5,300 mg COD/L was then performed. Effluent from the reactor was not withdrawn during this feeding period until the active volume of reactor of about 4 L was obtained. Seeding was stopped and continued by acclimatization while obtaining organic loading rate (OLR) of 530 mg COD/L/day and at hydraulic retention time (HRT) of 40 days.

2.2. Operations, HRT, and analysis parameters

During normal operations, the OLR was maintained at 530 mg COD/L/d and HRT of 40 days. This OLR was defined as the normal load. Normal loads were initially conducted at 35 ± 1 °C by applying automatic control equipment equipped in the AFBR and then the reactor was switched to room temperature, with no control temperature equipment. The switched temperature step was repeated
during loading rates of 1.5 times normal loading rates or at OLR of 795 mg COD/L/d and HRT of 40 days.

Parameters taken during room temperature and controlled temperature operations were chemical oxygen demand (COD), total gas, and reactor pH. Parameters taken during seeding and acclimatization were COD and mixed liquor volatile suspended solids (MLVSS). Analysis of total gas, conducted to observe the composition of methane gas and other gases produced, was done in the Chemical Engineering Department of ITB in Bandung, Indonesia by using gas chromatography Varian Star 3400. Measurements of influent COD and effluent COD were then converted to reactor efficiencies by substraction of both COD measurements devided by influent COD times 100%. From CH₄ produced and efficiencies obtained, the reactor performances were determined.

3. Results and Discussions

3.1. Operations during seeding and acclimatization

Performance of the AFBR during seeding is shown in Figure 1 whereas its performance during acclimatization is not shown but the acclimatization was performed by step increased feeding until COD efficiencies of about 80% were obtained. Figure 1 shows that the concentrations of microorganisms represented by MLVSS measurements were in the range of 28 to 29 g/L. This shows sufficient numbers of microorganisms to ensure that acclimatization performed by these mixed culture microorganisms would be successfully guaranteed [5, 9, 12]. The acclimatization, performed straight away after seeding, would probably be also successful by achieving constant increases of efficiency after day 1 during seeding (Figure 1).

![Figure 1](image-url)  
*Figure 1. Reactor efficiency (♦) and MLSS (▓) during Seeding*

3.2. Operations during normal loads of 530 mg COD/L/day

Operations during OLR of 530 mg COD/L/day were decided to be classified as normal loads to which higher organic loads were compared. Operations performed during this study were conducted at normal organic loads and at 1.5 times normal loads. Both operations were conducted at HRT of 40 days.
Figure 2 shows benefit of controlling temperature of the reactor. At room temperature, the highest COD efficiency is only 84% whereas at controlled temperature at 35°C, the highest COD efficiency is 92%. The trend of efficiency fluctuation is also better during temperature control than during room temperature. For the last two days reactor efficiencies are stable at 92% at controlled temperature of 35°C. It is also shown in Figure 2 that pH during controlled temperature at 35°C is more stable compared to pH during uncontrolled temperature. Even though the range of pH in both reactors is still in the normal pH range [4], however, pH actually shows the latest indication of unsuccessful degradation [8, 13]. The reactor pH could be still stable in the normal pH range when reactor buffer is capable to stabilize the reactor pH.

\[ \text{CH}_4 \] produced during controlled temperature at 35°C is also better compared to \[ \text{CH}_4 \] produced during room temperature (Figure 3). The highest \[ \text{CH}_4 \] production is 170 mL/day compared to 144 mL/day. Both curves show increased trends, however, the controlled temperature reactor produced increased trend steeper than the increased trend of uncontrolled temperature reactor.

Figure 3. \[ \text{CH}_4 \] production at OLR 530 mg COD/L/day (+, room temperature), (x, 35°C), and at OLR 795 mg COD/L/day (▲, room temperature), (●, 35°C)

3.3. Operations during organic loads of 795 mg COD/L/day

Such obtained during normal loads, the temperature controlled AFBR shows results much better than the results obtained during room temperature, especially in terms of reactor efficiencies (Figure 4) and \[ \text{CH}_4 \] production (Figure 3). As shown in Figure 4, at room temperature, the highest COD efficiency is
only 80% whereas at controlled temperature of 35°C, the highest COD efficiency is 94%. Moreover, for the last two days, reactor efficiencies are stable at 94% at controlled temperature of 35°C. During uncontrolled temperature, efficiencies of AFBR were almost the same at about 60% except at day 3 (Figure 4). This may result from the effect of temperature as well as the organic overload condition. Uncontrolled temperature reactor could not stand to be overloaded 1.5 times loads without maintaining reactor temperature at the optimum temperature [8, 13].

pH ranges measured during observation from both reactors were no distinctive differences (Figure 4). However, such have been mentioned above, pH ranges from both reactors which are in the normal pH range, might be resulted from the situation where pHs were not affected by variations of temperature. Effect towards pH is most influenced by buffer condition in the reactors. Buffer contained in the chemical compositions of synthetic wastewater may probably be capable to maintain the reactor pH at the normal pH range.

![Figure 4](image_url)

**Figure 4.** Reactor efficiency (♦ room temperature), (■ 35°C), and pH (⧫ room temperature), (□ 35°C) at OLR 795 mg COD/L/day and HRT of 40 days

Figure 3 shows increases of methane gas produced during temperature control at 35°C at OLR 795 mg COD/L/day. Methane gas production increased from 120 to 260 mL/day. This is proportional with the increases of reactor efficiencies from 84 to 94%. On the other hand, methane gas produced during uncontrolled temperature only slightly increased from 40 mL/day to 48 mL/day during observation (Figure 3). The low increase of CH₄ production may have been resulted from the effect of uncontrolled temperature as well as the organic overload condition [1, 8, 14]. Uncontrolled temperature reactor could not stand to be overloaded 1.5 times loads without maintaining reactor temperature at the optimum temperature.

4. Conclusions
Temperature affects the performance of AFBR either during normal loads of 530 mg COD/L/day or OLR of 795 mg COD/L/day at the same HRT of 40 days. The effect is worse during 1.5 times normal OLR, which might be caused by the effect of temperature as well as the effect of organic loads. COD efficiencies and methane gas produced became lower but pH was not affected since reactor buffer could probably maintain the reactor pH at the normal pH range.

Acknowledgment
Financial support of this work by the Directorate Research and Community Services, Ministry of Research, Technology, and Higher Education, through the Program of Fundamental Research No. 0126.4/PL1. R7/LT/2016 is gratefully acknowledged.
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