Accelerated Waste Degradation and Methane Production for SEBAR System Using Active Stage Reactor

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Abstract: In our research, a representative Thai market waste was fed in three Sequential Batch Anaerobic Reactor (SEBAR) systems with differences of recirculated leachate quantities (10%, 20% and 30% of initial digester water volume) between the set of two digesters. The results showed the effective leachate recirculation help supporting digester start-up. The fresh waste digester (NEW) reactor using the highest rate of leachate recirculation (30%), was ready to be uncoupled only after 17 days compared to 23 days and 26 days for the digesters using a 20% and 10% recirculation rate. The important of increasing recirculated leachate volume is increasing buffer and microbial population in the NEW reactor. Transferring of aggressive TVA from NEW reactor can help reduce its toxicity and also induced more TVA released with appropriated proportion of TVA: ALK as well as enhance methane production in OLD reactor. The TVA levels in leachate of NEW reactor with 30% recirculated leachate volume rapidly reach to maximum value on the 4th recirculation times, that corresponded to daily methane production. That 3rd recirculation times with methane produced on 2.1 L/day, respectively. After uncoupling condition, three NEW reactors can produce methane continued for a further 45-50 days with similar methane yields of 0.22-0.26 L/g VS for the whole experiment.

Keywords: Market Waste, Methane Production, Sequential Batch Anaerobic Reactor, Anaerobic Digestion, Waste Degradation

1. INTRODUCTION

This research focus on the anaerobic digestion by using market waste as material due to this process give several benefits such as (I) improve global warming problem (II) support as alternative sources of energy instead fossil fuel and (III) solve the solid waste explodes problem [1]. Anaerobic digestion is a complex biological process, in which compounds are converted to biogas, consisting primarily of methane and carbon dioxide, through a series of reactions mediated by several groups of microorganisms [2]. The methane which produced form in-vessel of solid waste anaerobic digestion not only to reduce solid waste quality to generate electricity on site generation, but it also can be taken to prevent methane released to the atmosphere as well as reduced air pollution produced from electricity generation. To accelerate the methane production from market waste anaerobic digestion, it is necessary to achieve an optimum condition of anaerobic system for market waste. In an attempt to overcome these aim we studied a Sequential Batch Anaerobic Reactor (SEBAR) system [3-5] fed with a representative market waste (Cabbage 40%, Chinese cabbage20%, other vegetable matter 20% and fruit 20%).

A prototype SEBAR design involves a minimum of two reactors; a reactor contained fresh market waste (NEW) is started-up by coupling with a stabilized reactor as an inoculation reactor (OLD) [3-5,6]. During coupling period, leachate from the bottom of stabilized reactor is recirculated to the top of the NEW reactor after recirculated it through the OLD reactor (procedure so called sequencing). In general, it is hypothesized that during sequencing, leachate that is recirculated from the OLD reactor carries with its microorganisms, nutrients and buffering agents to the NEW reactor. Also the products of solubilization and acidogenesis (high concentration of TVA) are recirculated back from the NEW reactor into the OLD reactor where it is converted to methane and carbon dioxide. Thereby these help rapidly inoculate to NEW reactor and promote methane production. Sequencing is continue everyday until the biogas methane content of a ‘NEW’ reactor exceeded 30% and the pH in the leachate had risen to 6.5, it was ready to be uncoupled from the OLD reactor. The both reactors in SEBAR series then are directly recirculated upon the same reactor until the almost waste components are degraded. The NEW reactor will become a stabilized reactor (OLD) and can then be used to start-up another NEW reactor and the process continued.

Although coupling of the NEW reactor with such a well-stabilized OLD reactor has proved effective, the process of starting up a NEW reactor takes a long time. Therefore, several previous studied proved that using the active stage reactor instead a stabilized reactor as OLD reactor help reduce start-up time of a fresh waste reactor. Due to the coupling of a reactor, undergoing degradation in the active phase, the inoculums may provide a more balance population of hydrolysis, acetogenic and methane microorganisms than coupling with a stabilized reactor. In this study, it has been shown that it enables more rapid start-up of degradation in the fresh waste bed by increasing on the volume of leachate recirculated from the active reactor.

2. METHODOLOGY

There are three stages in laboratory studies.

2.1 Stage I: Start-up of the ‘OLD’ reactors (O1, O2, and O3)

As the first reactor of each series, the so called ‘OLD’ reactors in the three active stage reactors studies were started up by

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coupling them with a stabilized municipal solid waste reactor that had been operating for four years (the ‘Zero’ reactor). 3.7 kg (wet wt) of market waste and 2.84 L of water were placed in each of reactors O1, O2 and O3 for series1, series2 and series3, respectively, were compacted (the bulk density was 550 kg.m⁻³). During the coupling period, 500mL of leachate transfers between reactors were made every two days. In third day operation, the similar amounts of digester sludge and NaHCO₃ were added to three reactors, to increase microbial numbers and to buffer the system. After they were uncoupled from the ‘zero’ reactor on day 18, they were operated in a mode referred to here as self-recirculation (this means, for example, that the leachate produced by O1 was regularly recycled back to the top of O1). They were operated in this way until they entered into active stage (methane content of biogas > 50% for a week).

2.2 Stage II: Coupling stage (O1+N1 for series1, O2+N2 for series2, and O3+N3 for series3)

Reactor O1 was then coupled with a ‘NEW’ fresh waste reactor (N1) with leachate recirculation volume of 10% initial water in the reactor. In the same way, O2 and O3 were coupled with ‘NEW’ reactor N2 and N3 with leachate recirculation volume of 20% and 30% of initial water in the reactor, respectively. During the coupling period, leachate transfers between reactors were made every two days.

2.3 Stage III: Uncoupling stage and self-recirculation

Once the biogas methane content of a ‘NEW’ reactor exceeded 30% and the pH in the leachate had risen to 6.5, it was ready to be uncoupled from the OLD reactor [4-6]. The uncoupled reactor was then run with self-recirculation of leachate until its daily gas production dropped to less than 1 L.d⁻¹ and no further reduction in soluble COD and TVA levels occurred in the reactor leachate.

2.4 Analysis

Leachate: Total volatile acids (TVA), total alkalinity (ALK), total and soluble chemical oxygen demand (TCOD and SCOD), pH, and acid composition were analyzed every two days following Standard Methods for Examination of Water and Waste Water [7].

Gas: The volume of gas produced and gas composition were also measured every two days. The gas volume was measured by a gas meter located on top of each reactor. Gas samples were extracted using syringes and the concentrations of N₂, CH₄ and CO₂ determined by gas chromatography (GC).

Solid: The weight and composition of waste were measured by separating waste and weight individual composition of waste. Moisture content and volatile solid were analyzed by oven drying and muffle drying. The CHNS analysis was used to detect the composition of carbon, nitrogen, hydrogen and sulfur.

3. RESULTS AND DISCUSSION

3.1 Start-up of the ‘OLD’ reactors (O1, O2 and O3)

The first stage was the start up period during which the so-called OLD reactors were coupled with the stabilized ‘zero reactor’. Three OLD reactors (O1, O2 and O3) with adding buffer and sludge from anaerobic reactor took 18 days for coupling with Zero reactor and they then operated a mode self-recirculation until they entered the active stage 45 days later (Total start-up times of three OLD reactors were 64 days operation). All OLD reactors developed in a very similar way with a similar level of performance at methane content in biogas were in range 52-53% at the first day of coupling with their respective NEW reactors. Table 1 showed time period of all operation run.

<table>
<thead>
<tr>
<th>Series</th>
<th>Stage</th>
<th>Time Period</th>
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<tbody>
<tr>
<td>Series1 (Exchange leachate10%)</td>
<td>Stage I: Start up period of O1</td>
<td>Day 0-64 (64 days)</td>
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<tr>
<td></td>
<td>Stage II: Coupling period of O1 and N1</td>
<td>Day 65-90 (26 days)</td>
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<td>Stage III: Self-recirculation period</td>
<td>Day 91-186 (96 days)</td>
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<tr>
<td>Series2 (Exchange leachate20%)</td>
<td>Stage I: Start up period of O2</td>
<td>Day 6-64 (64 days)</td>
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<tr>
<td></td>
<td>Stage II: Coupling period of O2 and N2</td>
<td>Day 65-87 (23 days)</td>
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<td></td>
<td>Stage III: Self-recirculation period</td>
<td>Day 88-186 (99 days)</td>
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<tr>
<td>Series3 (Exchange leachate30%)</td>
<td>Stage I: Start up period of O3</td>
<td>Day 0-64 (64 days)</td>
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<td></td>
<td>Stage II: Coupling period of O3 and N3</td>
<td>Day 65-81 (17 days)</td>
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<td></td>
<td>Stage III: Self-recirculation period</td>
<td>Day 81-186 (105 days)</td>
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3.2 Waste degradation

Stage II (Coupling stage)

In stage II, three active stage reactors (OLD) were separated to use as an individual supporting reactor to start-up its respective fresh waste reactor, they were called O1, O2 and O3 to connected N1, N2 and N3 for series1, series2 and series3, respectively. The coupling period for all series then commenced with OLR 2.15, 4.34 and 6.49 kg.COD/m³.d for O1, O2 and O3. The results during coupling period showed in Fig 1. Due to TVA is produced from waste degradation by hydrolysis and acidogenesis microorganism activities. Therefore, we followed the progression of released TVA in the leachate as the efficiency of waste degradation.

The main benefit of SEBAR system is rapid start-up fresh waste by using leachate that is flushed out of the OLD reactor carries with it microorganism, nutrients and buffering agent to the NEW reactor, thereby rapidly inoculating it and promoting balanced growth of microbial consortia. Also the products of solubilisation and fermentation are flushed out of the NEW reactor and into the OLD reactor where it is converted into methane and carbon dioxide. The results during coupling period (Fig.1) showed that after the coupled period was commenced, alkalinity and then TVA from all NEW reactors trended increasing. The increasing recirculated leachate volume causes of more buffering transfer from OLD reactor to improve buffer in the NEW reactor. In the same time, it also exchange more aggressive TVA from NEW reactor to OLD reactor and then would be converted to methane. As essential parameter,
alkalinity can help for proper pH control, because it serves as buffer that prevent rapid change in pH. These helped N3 with highest recirculated leachate volume, abate the TVA toxicity and build fastest appropriate proportion of TVA: ALK. In addition, due to more transferred buffer from O3 with highest recirculated leachate volume to N3. The ALK values of all NEW reactors then climb to balance with their OLD reactors in the series before uncoupling day. Therefore, we found TVA level increased in all NEW reactors as well an appropriate TVA:ALK proportion for acidogenic activities was developed.

The TVA:ALK ratio in leachate of N3 was fastest reduction from 13-15 at the first day operation of three NEW reactors to lower than one on days 6th recirculation times, while N2 and N1 require 2 more recirculation times. These results corresponded with their pH, rapidly rose from its initial value of 4.18, prior to 7.46 on 3rd recirculation times for N3, 7.72 on 4th for N2 and 6.90 on 4th for N1. The suitable condition in N3 caused of more TVA released in N3 and reach to maximum value (13,350 mg/L as CH₃COOH) on the 4th recirculation times. While ALK in the leachate of N1 with lowest recirculated leachate volume gradually increase that correspond to slightly increasing of TVA with lowest maximum TVA concentration (only 10,650 mg/L as CH₃COOH) comparing with other NEW reactors. Note that all NEW reactors were found only one peak of TVA during coupling period.

**Fig. 1** Variation with time during coupling period  (a) ALK  (b) TVA  (c) TVA:ALK and  (d) Daily methane production

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Stage III: Uncoupling stage and self-recirculation

N3, N2 and N1 reached to uncoupling condition from their OLD reactors and then run with self-recirculation of leachate on day 17, 23 and 26 of operation run as showed in Fig.2.

Fig. 2 The entered days to methanogenesis phase for three NEW reactors

It is not only the second peak of TVA in N1 occurred in 7 days later uncoupling day that different patterns from other series, but its TVA also prolong production. This is because the lower recirculated leachate from O1 gradually increased the alkalinity level in N1 as well as pH had slowly risen. These conditions sustained acidification phase resulted to support suitable condition for acidogenesis microorganism activities lead to enhance waste degradation and also reduce biodegradation time. Moreover, slightly increasing of ALK can promote extent of solid degradation, and leads to improvements in term higher % percentage carbon removal and cellulose removal in series1 reactors (Fig.3) comparing with faster increasing of ALK in series2 and series3. In addition, the results also revealed the effective of slightly adding ALK by transferring leachate with high concentration of ALK form OLD reactors in SEBER system. This process can induce more solid degradation in NEW reactor when compare with adjust buffer by adding NaHCO3 only one time during start up period of three OLD reactors. That because 2 reason, (1) adding too quickly alkalinity chemical cause to prevent on the bacteria due to rapid change condition and (2) the differences optimum conditions for each group of anaerobic microorganism. The pH optimum for methanogenesis is generally accepted to be 6.8-7.4, while hydrolysis and acidogenesis bacteria favor at pH 4-6, and active growth for cellulytic bacteria can be found anywhere from pH 3 to 11. Thus, the hydrolysis step may be enhanced to degrade waste in lower pH than methanogenesis.

3.3 Methane Production

Stage II (Coupling stage)

The biogas methane content in the three OLD reactors sharply dropped after 3 days of coupling stage due to reactors achieved the high concentration of TVA via recirculated leachate from the respective NEW reactors. McCarty and WPCF report that under condition of overloading, methanogenic activity cannot remove hydrogen and TVA as fast as it is received. These leads to reduce methane production in three OLD reactor [9]. However, their methane content in biogas increased steadily again thereafter, returning to the 50% level after 4th recirculation of coupling period (Fig.4). The methane content in biogas produced by all NEW reactors gradually increased. These helped that the methanogenic microorganism in all OLD reactors can recovery themselves under overloading recirculated leachate with excess organic acid condition from NEW reactors and leaded to accelerate to onset optimum condition for methanogenesis microorganism activity.
Due to highest rate received ALK in the N3 with recirculated leachate volume 30%, it received more microorganisms and also gained more buffering. Therefore, the increasing recirculated volume helps N3 to start up rapidly and began producing methane. N3 took only 3rd recirculation times reach to maximum daily methane production in the coupling period (2.8 L/day.), while other NEW reactors cannot be detected methane in the same day. However, the NEW reactors with 20% and 10% recirculated leachate volume later gave the maximum daily methane production on the 4th and 5th recirculation times with methane produced on 2.1 and 0.7 L/day, respectively. N3 can produce methane content in biogas fastest reach to 30% on day 17 of coupling period that was the uncoupling condition and operated on its own. The results can be supported by Osman and Delia, reported that the alkalinity addition helped onset the methane production period [8]. After uncouple day, the uncoupled reactors were then again run in self-recirculation mode. Note that the system using the lowest rate of leachate recirculation (series1), the fresh waste digester gave lowest methane in the coupling period although the coupling period of this series took longest time.

**Stage III Uncoupling stage and self-recirculation**

During self-recirculation, due to the low concentrations of TVA in three OLD reactors leachate, their rate of methane production dropped sharply after 10 days later uncoupling day. In three NEW reactors, on the other hand, the comparatively high TVA levels in the recirculated leachate meant that methane production rates remained high, reaching a maximum value on day 39 for N3, day 48 for N2 and day 50 for N1 before gradually decreasing. Most of methane produced in all series gained by the respective OLD reactors, showing that methanogenesis was proceeding actively in the three OLD reactors. Due to more rapidly increasing of ALK and microorganism transferred from the supporting reactor O3 to N3. O3 was lost its capabilities of methane production after sequencing commenced. These leads to highest methane produced for N3, but slightly lowest methane produced for series3. While O1 and O2 with lower recirculated leachate volume showed more stable methane production and gave similar value of methane production in coupling period. Nevertheless, the increasing recirculated leachate volume from 10% to 20% induced to reach faster uncoupling condition and also higher methane production in N2. Thus, series2 gave slightly highest methane yield with most stable methane production comparatively other series. In series1, although N1 began more slowly to produce methane during the coupling period, it gave a similar methane production in whole series by comparative with other series. Those because the prolonged acid production in N1 supported to continue methane production in N1 and led to NEW in series1 have a good deal slightly more methane in the final part of series. Overall, all three series gave similar methane yield value of 0.19-0.22 L/g. waste dry weight with different methane production rate.
4. CONCLUSION

Increasing of recirculated leachate volume between a NEW reactor and a reactor still in an actively digesting stage results;

Series1; the gradually increasing alkalinity with low recirculated leachate volume made a suitable for solid degradation, that cause well phase transformation from solid phase to TVA in leachate. However this series requires longer time to onset methane production period. Therefore, the benefit of Series1 focuses on more elimination solid waste on site generation.

Series2; the 20% recirculated leachate volume between two reactors reveals a good result to gradually increasing both of phase transformation and chemical transformation. The 20% series gave slightly highest methane production cumulative when compare with other series. Therefore, the benefit of Series 2 focuses on stable methane production system.

Series3; excess quantities of leachate provide dilution of inhibitory product (TVA's) of waste degradation, better transport of inoculums, and a favorable condition for an increase in both the rate degradation and methane production. This provide earlier onset of methanogenesis, when compare between three series. However, the rapid decreasing of %CH$_4$ occurred in this series. Due to fastest transferred alkalinity from O3 to N3, O3 loss it methan e production capability in early day of coupling period and it took longest time to stably produce methane thereafter. This reveals that increasing over 30% of recirculated leachate volume may result in the accumulation of TVA and lead to retard rate of waste degradation. Therefore, the benefit of Series3 focuses on fast eliminated solid waste and also earlier gained methane from the system.

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6. REFERENCES


