Progressive Two-Stage Efficient Codigestion of Food Waste and Petrochemical Wastewater for Higher Methane and Hydrogen Production

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The valorization of agro-modern waste through anaerobic codigestion signifies a remarkable prospect for waste treatment and sustainable energy source generation. This study intended to improve the codigestion of food waste and petrochemical wastewater by an advanced two-phase process. In view of concentric acidogenic and methanogenic stages, intended for upgrading execution and diminishing pollution. The ideal food waste to petrochemical wastewater proportion was assessed under batch operations. From that point, codigestion was carried out by continuous feeding operations weighting single-and two-phase digestions. The outcomes exhibited that the supplementation of petrochemical wastewater in codigestion with food waste incredibly improved the anaerobic system. The maximum methane generation was acquired codigesting the two wastes at equivalent proportion by utilizing the creative two-phase system. The proposed framework achieved the highest methane production of 259 mL/g volatile solid, which is more than double than the single-phase system and 11% greater than that of conventional two-phase system.

Keywords: Methane, Anaerobic codigestion, Petrochemical wastewater, Food waste.

INTRODUCTION

The best possible management and valorization of agro-industrial effluents through anaerobic systems offers a substantial prospect to pollution control and sustainable energy source generation [1]. Food waste is the fundamental output of food business [2]. It is categorized by an extremely high organic matters and low buffering capacity; subsequently, anaerobic codigestion of food waste can prompt fast fermentation that produces lower biogas profitability [3].

During petrochemical wastewater anaerobic digestion, huge amount of volatile fatty acid is produced which is inhibitory to methane production [4]. A few investigations have exhibited that cofermentation of food waste with petrochemical waste-water may keep up ideal pH and increase biogas generation [5], yet the ideal substrate proportion and the hypothetical gas generation varies in every particular case.

Anaerobic digestion is chosen in light of the fact that food waste typically shows high fermentation potential and needs longer HRT, and due to the little scale and disintegration of food processing industries. In course of the most recent decade, different bioreactor arrangements had been assessed and suggested for biogas enhancement from wastes [6]. Easy design frameworks experience less operational difficulties, and produces economic advantages in planning, development and executions. However, codigestion and two-phase digesters provides high treatment ability and system balance than the individual fermentation and the utilization of single-phase systems [7].

This investigation intended to build up an advanced two-phase process dedicated to the cofermentation of food waste and petrochemical wastewater that may combine the benefits of the traditional procedures with the high productivity of multi-phase digesters. Therefore, a continuous two-phase process was established so that first acidogenic phase was introduced into the methanogenic digester with a concentric structure (Fig. 1). From our perspective, this is the latest study to increase the codigestion of food waste and petrochemical wastewater by assessing distinctive designs.
methane potential (BMP) method [8]. The tests were led in
ogenic performance of wastes was estimated by biochemical
codigestion to be used in the continuous digesters. The methan-
examination to distinguish the ideal working conditions for
substances and inoculum are listed in Table-1.

by Siddique and Wahid [8]. The fundamental properties of
anaerobic digester (ID) treating municipal wastewater as reported
gathered from a palm oil mill situated in Kuantan (Malaysia),
methanogenic microbs from a palm oil mill (POM) effluent
sludge for the anaerobic degradation tests. They comprised of
Sdn. Bhd., Terengganu, Malaysia.

wastewater was collected from Petronas Penapisan (Terengganu)
water (IPWW), food wastes were acquired from a restaurant
experiments were food wastes (IFW) and petrochemical waste-
utilized as (W) influent wastewater for the anaerobic degradation
test, the digesters were seeded by anaerobic sludge ID and
operated under equal substrate proportion of 50:50 (WPWW:
la) test with trivial changes [9]. In contrast to BMP tests,
carrying out for the momentary biochemical hydrogen potential
(BHP) test with trivial changes [9]. In contrast to BMP tests,
ting of batch experiments planned to assess the ideal acidogenic
states to begin the two-phase system. The examinations
were carried out for about 14 days and stopped when methane was seen in the biogas. The digesters
were run with 50:50-WFW:WPWW volumetric proportion. The
acidogenesis was measured at room temperature (22 °C) and
mesophilic (37 °C) states. The batch experiments were observed weekly.

Continuous codigestion: The experiments were done utilizing three laboratory-scale digesters, where one-and two-
phase systems were set. The one-phase system was performed in a totally blended digester (D1, Fig. 1). The two-phase system
was performed utilizing two distinct plans: in the primary design (D2), a second tiny totally blended reactor was included prior to the methanogenic container (Fig. 1). The second two-
phase digester (D3) comprised of a solitary vessel that involved both the acidogenic and the methanogenic phases. The previous
was concentrically incorporated into the subsequent with the
goal that the fermented effluent was fed by gravity at methano-
genic phase (Fig. 1).

The methanogenic digester had a capacity of 600 mL for D1 and D2, and 800 mL for D3; the acidogenic stage had a
capacity of 130 and 200 mL in D2 and D3, individually. Each
digester were fed by feeding pumps. A 21 days HRT was main-
tained for methanogenic stage and 6 days of HRT was main-
tained for acidogenic stage. Organic loading rate of 1.9 and
1.8 kg COD m3/d for the one-and two-phase digester was main-
tained, individually. Based on the outcomes acquired by batch
tests, the digesters were seeded by anaerobic sludge ID and
operated under equal substrate proportion of 50:50 (WPWW: WFW).

three individual inoculum were experimented as seed-
ludge for the anaerobic degradation tests. They comprised of
methanogenic microbes from a palm oil mill (POM) effluent
gathered from a palm oil mill situated in Kuantan (Malaysia),
petrochemical wastewater sludge (IPWW) and sludge from a
anaerobic digester (ID) treating municipal wastewater as reported by Siddique and Wahid [8]. The fundamental properties of
substances and inoculum are listed in Table-1.

Batch experiments: Batch tests were done as fundamental
examination to distinguish the ideal working conditions for
codigestion to be used in the continuous digesters. The methan-
genomic performance of wastes was estimated by biochemical
methane potential (BMP) method [8]. The tests were led in
tricipate in 100 mL containers by including 5 mL of inocula
and 50 mL of wastewater comprising of codigestion waste
blends. The containers were kept under 37 °C. The observations
were done until full methane generation reduction (up to hundred
days).

Three arrangement of batch test were carried out. The initial
experiment was led to assess the effect of the three inoculum
(IFW, IPWW and ID) on the two substrates (WFW and WPWW) used in
codigestion (in equivalent volume proportions). Subsequent biochemical methane potential (BMP) experiment was done
to distinguish the ideal blend proportion of two substrates
utilizing ID as inoculum; hence, two substrates were processed at various IFW: IPWW proportions varying from 0 to 100 % v/v
with a regular interval of 10 % increment. The third arrange-
ment of batch experiments planned to assess the ideal acidogenic
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operated under equal substrate proportion of 50:50 (WPWW: WFW).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Inoculum IPOME</th>
<th>IFW</th>
<th>I0</th>
<th>Wastewater WPWW</th>
<th>WPWW</th>
<th>Influent Feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/mL)</td>
<td>1.01 ± 0.02</td>
<td>1.07 ± 0.03</td>
<td>1.03 ± 0.02</td>
<td>1 ± 0.1</td>
<td>1 ± 0.1</td>
<td>–</td>
</tr>
<tr>
<td>pH</td>
<td>5 ± 0.1</td>
<td>4 ± 0.1</td>
<td>5 ± 0.1</td>
<td>4.98 ± 0.1</td>
<td>6.81 ± 0.1</td>
<td>6.8 ± 0.1</td>
</tr>
<tr>
<td>COD (g/L)</td>
<td>22 ± 2</td>
<td>13 ± 2</td>
<td>23 ± 3</td>
<td>59 ± 2</td>
<td>9.6 ± 0.2</td>
<td>36 ± 7</td>
</tr>
<tr>
<td>Carbohydrates (g/L)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>43 ± 3</td>
<td>1.5 ± 0.4</td>
<td>12 ± 5</td>
</tr>
<tr>
<td>Proteins (g/L)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1.5 ± 0.5</td>
<td>0.5 ± 0.2</td>
<td>0.9 ± 0.2</td>
</tr>
<tr>
<td>Total solids (g/L)</td>
<td>12 ± 0.1</td>
<td>24.1 ± 5</td>
<td>32 ± 4</td>
<td>58 ± 9</td>
<td>26 ± 0.2</td>
<td>36.4 ± 3</td>
</tr>
<tr>
<td>Volatile solids (g/L)</td>
<td>5 ± 0.2</td>
<td>13 ± 3</td>
<td>15 ± 2</td>
<td>53 ± 8</td>
<td>18 ± 0.2</td>
<td>30.5 ± 4</td>
</tr>
<tr>
<td>Density (g/mL)</td>
<td>1.01 ± 0.02</td>
<td>1.07 ± 0.03</td>
<td>1.03 ± 0.02</td>
<td>1 ± 0.1</td>
<td>1 ± 0.1</td>
<td>–</td>
</tr>
</tbody>
</table>
The laboratory scale digesters were operated under mesophilic state at 37 °C. Prior to beginning the analyses, the digesters were run for roughly one month so as to adapt the biomass to the substrate. The digesters were run for over two months and their execution was assessed under steady states.

**Analysis:** All the water quality parameters were analyzed by standard methods [10]. The biogas generated by the three digesters was estimated by OMEGA® engineering gas-meters. Biogas composition and VFAs were measured according to Siddique and Wahid [8].

### RESULTS AND DISCUSSION

WFW and WPWW were different in characteristics because of their organic matters and pH (Table-1). In addition, WFW had higher portions of starches and proteins than WPWW. WPWW had a pH that was fundamentally higher than that of WFW. Consequently, the option of petrochemical wastewater (PWW) to food waste (FW) in codigestion can produce more efficient anaerobic digestion [11].

**Batch experiment:** The initial batch experiments were performed to assess three unique inoculum. The BMP experiment brought about methane yields of 27 ± 5, 258 ± 6 and 321 ± 8 L/kg for IPOME, IPWW and I0, respectively. The methane content in the biogas produced by I0 was higher (69 ± 8%) than that of IPOME (65 ± 5%) and IPWW (59 ± 6%). Therefore, I0 was chosen for the codigestion of WFW and WPWW since it produced higher methane generation.

The second arrangement of BMP experiments were led so as to assess the effect of various WFW:WPWW proportions on anaerobic digestion interceded by I0. The methane generation from WFW and WPWW were 13 ± 4 and 131 ± 8 mL/g, respectively. The BMP experiment of WFW (WFW:WPWW::100:0) produced lower methane. The mix of WFW and WPWW provided greater methane generation (Fig. 2). The methane yield of the codigestion in the equal proportion of WFW and WPWW improved to 321 ± 5 mL/g which was 2.51 times more than that of obtained from petrochemical wastewater (PWW) and 3 times more than that of food wasted (FW) when digested individually.

In spite of the fact that methane yield enhanced with WFW (WFW:WPWW proportions of 0:100 to 50:50), CH4 generation decreased when the WFW proportion was higher than 60 % (Fig. 2). Consequently, the outcomes show that codigestion appears to be significantly stronger with the enhancement of the WFW portion and there is a limit beneath which the system turns to acidification. When WFW portion was higher than 60 %, the pH drops beneath [6]. The enhancement of the WFW portion up to 60 % incredibly enhanced the methane generation because of the higher substance of biodegradable organics of WFW [12].

Most extreme methane generation and reduction of methane generation were estimated after roughly 20 and 50 trial days, individually. Thus, the laboratory scale methanogenic phases were calculated for HRT 21 days. The third batch experiments were completed to decide the ideal states of acidogenic period of two-phase codigestion. The pH of anaerobic effluent reduced only the day after the start of preliminaries by achieving pH of 4.5-5.0 toward the end of the analyses. The fermentation, because of formation of VFAs, caused the hindrance of methanogenic movement combined with hydrogen growth in biogas [13]. Absolute aggregation of VFAs upto 3701 mg/L was observed in the acidogenic digesters.

Biogas generation was a higher under mesophilic conditions (84 mLH2/g) than the lower heat (42 mLH2/g). These outcomes were similar with those observed by fermentative batch experiments on organic waste [9] and by persistent mode on food waste [14]. Most extreme level of VFAs and H2 content (69 ± 5 %) was seen inside the initial 5 days; in this manner, the HRT of 6 days was connected for the acidogenic phase at mesophilic states of two-phase anaerobic digesters (Table-2).

**Continuous experiments:** The feed was regularly operated by combining WFW and WPWW at a volumetric proportion of half and kept at 4 °C. The subsequent feed properties are listed in Table-1. The pH trend in the fermentation media of acidogenic and methanogenic phases of D2 and D3 were alike (Table-2); in addition, D3 appeared to reach marginally higher (21 %) was observed inside the initial 5 days; in this manner, the HRT of 6 days was connected for the acidogenic phase at mesophilic states of two-phase anaerobic digesters (Table-2).

Both two-phase systems appeared to demonstrate better SCOD elimination contrasted than the single-phase digester (Table-2); in addition, D3 appeared to reach marginally higher SCOD elimination than D2. The SCOD elimination under the acidogenic phases for both two-phase digesters were observed to be roughly 31 %. The carbohydrates in the effluents was lower than 0.5 g/L, equivalent to eliminations that were constantly higher than 94 % (Table-2). The VFA gathered in acidogenic phase were 6.8 g/L and 5.9 g/L for D2 and D3; they were then reduced by acetotrophic methanogens in the methanogenic phase. Conversely, VFAs in D1 stayed stable in the range of 1.6 and 1.99 g/L.

The level of VFA in the present examination was lower than those studied by different investigations treating food waste (FW) and petrochemical wastewater (PWW) uniquely, showing that the codigestion of the two substrates enormously improved the removal of VFAs. Ghaly [15], utilized a two-phase digester at HRT of 21 days, observed VFA level more than 1.99 g/L and lower than 0.1 g/L for cheesy waste and cattle.
manure individually. The methane generation rate under steady condition was commonly stable in each of the three digesters. D2 and D3 produced methane generation around 39 % higher than D1 (Table-2). Also, in spite of the fact that the biogas properties of three digesters fit with in the range of anaerobic digestion of agro-industrial waste [16], the two-phase digesters performed better than the single-phase system through methane content (Table-2). It should be noted that substantial hydrogen productions were gathered from the acidogenic phase of D2 (Table 2) because of the total physical division of two phases, while the methane content was consistently underneath 4 %.

The methane production and methane content in the biogas were higher in two-phase digesters than in single-phase digester (Table-2). It should be noted that the methane level of 62 % identified in D2 was linked with the methanogenic phase, while methane content (59 %) of D3 was estimated over the two phases. The outcomes of the continuous operation (Table-2) indicated lower methane production than those acquired in batch conditions (Fig. 2).

The greatest methane generation of 321 mL/g volatile solid obtained in batch tests is identified with "extreme" biogas generation that is acquired with a longer digestion period (51 days) than the HRT of continuous operation. The methane production acquired in this investigation are complying [11,17].

The outcomes, subsequently, show a lot higher efficiency of two-phase than the single-phase one treating food waste and petrochemical wastewater in cofermentation.

Conclusion

The outcomes exhibited that the anaerobic digestion of food waste and petrochemical wastewater at half volumetric proportion gives higher methane productions than when the two substrates digested independently. In addition, the examination shows a lot higher effectiveness of two-phase process instead of single-phase process treating food waste and petrochemical wastewater in cofermentation. The two-phase concentric digester acquired a marginally higher methane generation that could be clarified by better utilization of hydrogen delivered in the acidogenic stage that could produce an enhancement of anaerobic digestion for agro-industrial substrates.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

REFERENCES