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Estimation of methane and electricity potential from canteen food waste

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Abstract. Biomass is currently seen as one of the renewable feedstock sources. Indonesia has abundant biomass material include food waste, which was directly disposed to landfill or surrounding environment without any proper treatment. The aims of this study were to characterize canteen food waste and to estimate its energy potential, in terms of methane potential and electricity. A laboratory scale of Biochemical Methane Potential (BMP) test was carried out under controlled and batch condition. The calculation of theoretical methane potential was carried out using Buswell Equation. Electricity energy potential was also calculated. The characterization analysis found that canteen food waste has higher organic material content, mainly carbohydrate, protein and lipid. This indicating its potential to be used as feedstock for biogas/methane production. The measured methane potential was found at value of 0.191 m$^3$/kg VS, which was lower than theoretical methane potential of 0.300 m$^3$/kg VS. The estimation of electricity potential found that 473.8 kWh of electricity can be generated per ton fresh canteen food waste.

1. Introduction
Biomass is one of the alternative resources for renewable energy production, include food waste (FW) and tofu solid waste/dreg waste (TW). FW is rich in organic matters (i.e. carbohydrate, protein, and lipid) [1]. According to Anggraeni et al. [2], TW contains crude protein of 34.94%TS, fats of 20.47%TS, crude fiber of 39.46%TS, and ash of 1.71%TS. Thus, these biomass can be a potential feedstock for biogas production using anaerobic digestion (AD) technology [3]. AD process is able to provide bioenergy sources (i.e. biogas, electricity and heat) and organic residues (known as digestate), rich in macro nutrients (i.e. N, P dan K), thus suitable for substituting synthetic fertiliser [4].

The Biochemical Methane Potential (BMP) test is used to determine the biodegradability of a substrate under anaerobic conditions by monitoring the cumulative methane production during the test period [5]. Jensen et al. [5], then added that, BMP measurement can provide important information including the anaerobic digestibility and potential biogas (methane) production from substrates which is useful for evaluating, designing, and optimising the AD process. Several studies on BMP of FW have reported that FW has a high biodegradability rate under anaerobic condition [6, 7]. For example, the BMP of mixed FW was in the range of 0.440–0.480 m$^3$/kg VSadded, therefore, correspond to an excellent alternative for commercial methane production [7].
Biogas from AD process can be converted into electricity or heat using combined heat and power unit [8]. The estimation of electricity generated from biogas is beneficial to predict the investment and operational cost of AD plant as well as the biogas production cost [9]. Therefore, this study was aimed to identify FW characteristics and its effect on biogas, as well as to estimate its electricity potential.

2. Materials and Methods

2.1. Feedstocks and inoculums
FW was freshly collected from the Universitas Brawijaya canteen, and TW was from tofu agroindustry in Kendalsari, Malang. FW was then grinded and stored in plastic containers and kept cold storage. While, for TW there was no particle size reduction treatment, it was directly stored in plastic containers and kept at room temperature upon arrival at Bioindustry Laboratory. The parameters analysis include elemental analysis and proximate analysis (i.e. moisture content/MC, ash, total solids/T, and volatile solids/VS)

Inoculum for the BMP test was prepared from digestate taken from a full-scale mesophilic digester treating cattle slurry at Balai Besar Pelatihan Peternakan in Batu City. Digestate was collected in a 5-litre container. The digestate is then sieved through a 1 mm screen to remove larger particles. The inoculum was analysed for pH, temperature (°C), MC, ash, TS, and VS.

2.2. BMP test set-up
BMP test was performed in a manual BMP system using water bath for 30 days. The test will be carried out at 37 °C in triplicates with an inoculum to substrate ratio (I/S ratio) in the range of 6. BMP test was carried out using 250-ml serum bottle with working volume of 40 ml. Three sets of blank samples are included in the test to measure the indigenous methane production from the inoculums. The positive controls (α-cellulose) are used to test the activity of the inoculum. Samples FW alone (100% FW) and co-digestion of FW and TW (ratio of 50:50 on a wet weight basis) were tested in this study. The serum bottles were placed in a water bath at 37 °C without shaking. Pressure was measured using a Digitron 2026P absolute pressure meter (Electron Technology, UK) on a daily basis.

2.3. Analysis
TS and VS determination was based on Standard Method 2540 G [10]. pH was measured using a digital pH meter, calibrated in buffers at pH 7 and 9.2. Biogas production was calculated by converting pressure readings to gas volume in the headspace at standard temperature and pressure (STP) of 273.15 K and 101.325 kPa. Elemental analysis was performed using elemental analyser (628 Series Elemental Determinator, LECO). The methane concentration used to calculate specific methane potential (SMP) was the value obtained from calculation using Buswell equation [11], with the assumption that 85% organic biomass breakdown:

\[
\text{CcHhOoNnSs} + \frac{1}{4}(4c - h - 2o + 3n + 2s) \text{H}_2\text{O} = \frac{1}{8}(4c + h - 2o - 3n - 2s)\text{CH}_4 + \frac{1}{8}(4c - h + 2o + 3n + 2s)\text{CO}_2 + n\text{NH}_3 + s\text{H}_2\text{S}
\]

(1)

Where: C, H, O, N are the fraction on a TS basis, the molecular formula subscriptions (c, h, o, n and s) is the molar proportion of mass fraction of C, H, O, N and S elements

The methane potential is the amount of methane produced on a daily basis. It was calculated using the following equation [12]:

\[
\text{SMP} = \frac{\text{CH}_4 \times \text{MC}}{\text{I} / \text{S}}
\]
Where: BMP is the normalised methane volume (ml CH\textsubscript{4}/g VS), V\textsubscript{S} is the mean value of accumulated methane volume from reactor with inoculum and substrate, V\textsubscript{B} is the mean value of methane volume from reactor with inoculum only (blank), m\textsubscript{IS} represents the mass of VS of inoculum added in the sample, m\textsubscript{IB} represents the mass of VS of inoculum added in the blank sample, and m\textsubscript{VS,sS} represent the mass of added substrate in the reactor.

The theoretical SMP was then calculated using Buswell equation and the values were compared with the measured SMP. Electrical potential estimation was calculated with the assumption of 1 m\textsuperscript{3} biogas has a calorific value of 22 MJ, and 1 m\textsuperscript{3} methane is equal with 36 MJ. With assumption of electrical conversion efficiency of 35%, therefore 1 m\textsuperscript{3} biogas will yield 2.14 kWh (electricity) and 1 m\textsuperscript{3} methane will yield 10 kWh.

3. Results and Discussion

3.1. Substrates characteristics

The study showed that FW and TW contain high organic contents as shown by VS value of more than 95\% on a TS basis (Table 1). The elemental analysis also indicated that samples have carbon content of approximately 43\% TS. In terms of the mixture of FW and TW at ratio of 50:50 on a wet weight basis also has high organic contents of 97\% TS. These findings confirmed their suitability to be used as feedstock in AD process.

| Parameter          | FW     | TW     | FW:TW (50:50) |
|--------------------|--------|--------|--------------|
| TS (%WW)           | 25.69  | 9.63   | 19.11        |
| VS (%WW)           | 24.83  | 9.52   | 18.55        |
| VS/TS (%TS)        | 96.65  | 98.84  | 97.07        |
| MC (%)             | 74.31  | 90.37  | 80.89        |
| Ash (%)            | 0.86   | 0.11   | 0.56         |
| Elemental composition (%TS) |        |        |              |
| C                  | 42.23  | 42.70  | n.m.         |
| H                  | 7.46   | 6.59   | n.m.         |
| O                  | 47.60  | 48.06  | n.m.         |
| N                  | 2.71   | 2.65   | n.m.         |

3.2. BMP test results

The BMP test results showed that FW (100\%) and FW:TW (50:50) had a rapid biogas production after a short lag time (2 days) and reached a plateau after 10 days: the average SMP were 0.191 and 0.166 m\textsuperscript{3}/kg VS, respectively. These values were lower than the theoretical SMP values of 0.356 and 0.347 m\textsuperscript{3}/kg VS (Figure 1). The difference was possibly influence by the I/S ratio used, as reported in a previous study [13]. This study confirmed that FW has a high methane potential and suitable to be valorised via AD process, either in a single- or in a co-digestion AD.

After end of BMP test, the digestate characterisation results have confirmed its high organic matters content. As shown in Table 2, digestate from FW and FW:TW (50:50) contains VS at value of ~97\%TS. This indicates that the digestate has a potential for further application and valorisation, such as for composting, biofertiliser, soil conditioner, growth media, nutrients, or other high value-added
products. As stated by Monlau et al. [9], alternative pathways of digestate valorisation include use of digestate’s liquid fraction for substituting nutrients in algae cultivation, use of digestate’s solid fraction for bioenergy production through biological (i.e. AD) or thermal process (i.e. pyrolysis) and for high value products (i.e. biochar, activated carbon) through pyrolysis route.

![Figure 1. Comparison of theoretical and measured SMP from the BMP test: FW (100% FW) and FW:TW (50:50) Data are expressed as means of triplicate samples.](image)

Table 2. Digestate characteristics after BMP test.

| Parameter     | FW 100% | FW:TW (50:50) |
|---------------|---------|---------------|
| MC (%)        | 74.31   | 80.89         |
| Ash (%)       | 0.86    | 0.56          |
| TS (%WW)      | 25.69   | 19.11         |
| VS (%WW)      | 24.83   | 18.55         |
| VS/TS (%TS)   | 96.65   | 97.07         |

3.3. Electricity Potential Estimation

Table 3 shows that the estimation of electricity potential from 100% FW and FW: TW (50:50) samples were 473.8 kWh/ton and 307.2 kWh/ton, respectively. The amount of energy generated is depended on the biogas volume produced and the methane concentration. Based on the Buswell calculation results, the theoretical methane concentration for FW was 53.3%, which is well within the standard of good quality biogas of 50-70% [9]. A high methane concentration may contribute to the increase in the energy potential from biogas such as electricity yield. The findings in this study, are therefore, indicate that FW has a great potential to be valorised as electricity sources, both under single- or co-digestion AD process.

Table 3. Electricity potential estimation single- and co-digestion AD of FW

| Substrate     | Energy/ day (MJ/day) | Methane volume (m³CH₄) | Electricity Potential (kWh) |
|---------------|----------------------|------------------------|-----------------------------|
| FW           | 0.034                | 47.38                  | 473.8                       |
| FW:TW (50:50) | 0.029                | 30.72                  | 307.2                       |

This is in agreement with other studies which reported that FW is a potential feedstock for bioenergy due to its high biogas potential and yield. For example, a study by Banks et al. [14] reported that addition of FW to anaerobic digester increase biogas and energy yields, which providing additional income to the farm by approximately 50%. Another study also reported that after considering a comprehensive energy and mass balance assessment, the electricity potential from FW
was 405 kWh/ton, with a stable biogas production of 642 m³/ton VS and methane concentration of ~62% [15].

With the FW production of more than 30.90 million in Indonesia, there are a great potential application for biogas production. Currently, FW is remained disposed directly to landfill due to lack of recycling practices enforced by the local or national government. Problems of facilities, technology, fundings for research and development of FW valorisation, regulations of FW management, as well as adequate awareness among individual or communities have impeded the application of AD system in Indonesia for valorising FW into biogas or other high-added value products [1]. Therefore, the challenges of the success FW valorisation application emphasised on the effort of the government, with or without collaboration of relevant stakeholders (i.e. universities, NGO, communities), to develop sustainable technology with the concept of integrated biorefineries [4]. Thus, this can trigger the production of more advanced products from FW which will be beneficial for economic growth and development in Indonesia in a sustainable and environmentally friendly ways.

Yet, further in-depth and comprehensive assessment is required include energy balance, mass balance to obtain net energy production from AD of FW, as well as its techno-economic analysis and environmental assessment, particularly in the case of FW for biogas practice in Indonesia.

4. Conclusion
FW is potential as feedstock for AD, either as single- or co-digestion process. BMP test indicated higher biogas production was resulted from FW only. Digestate still contains VFA, particularly acetic acid but in a low amount. This study confirmed that FW have potential to be valorised as electricity via AD pathway route. Yet, further improvement in AD process of FW is critical. Particularly, study under semicontinuous system to examine the stability of AD process treating FW in practice.

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