Anaerobic co-digestion of chicken manure with energy crop residues for biogas production

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Abstract. Biogas or bio-methane is an alternative energy source produced by anaerobic digestion (AD) technology whereby the organic matter is degraded by naturally present microorganisms and converted into a combustible gas. This paper focus on the utilization of anaerobic co-digestion (AcoD) method since biogas yield so far remains minimum based on mono-digestion alone due to low energy content. In this work, empty fruit bunch (EFB), oil palm frond (OPF) and sugarcane bagasse (SB) are being used as co-digestion additive since energy crop residues are known for its high carbon and energy content to enhance the process. A series of five 1.5L reactors were set up for a mesophilic condition at temperature 40°C, with initial pH range of 7-8, for 60 days of retention time. The mono-digestion reactor of chicken manure is labelled as DC1, and the co-digestion reactors with sugarcane bagasse, OPF and EFB are labelled as DSB, DOPF and DEFB, respectively. The recorded C/N ratio of co-digestion reactors were improved to be in a favourable range of 15 to 35 with DSB being the highest at 17.74 compared to that of control reactor at 11.35. As a result, total biogas production for DSB increases up to 36% due to its significantly high carbon content from sugarcane bagasse that provide stability for the bacterial growth and its activities. Sugarcane bagasse act as a good carbon source for the AD system, thus enhance the methane production. On the other hand, DOPF and DEFB give 13% and 41% lesser total biogas volume, however, produces much higher methane concentration compared to the control reactor. This shows that DOPF and DEFB give a higher methane yield which defines the more stability and efficiency of digestion process.

1. Introduction

Biogas is a renewable form of energy that is estimated as the fourth biggest energy producer covering up to 15% of global energy demand [1]. Biogas produced from wastes, residues and energy crops can burn as well as liquefied natural gas, but does not emit as much greenhouse gases (GHGs) to the
environment [1]. Therefore, biogas is a versatile renewable energy source that is useful for fossil fuel replacement in power and heat production, as well as natural gas for producing chemicals and materials [2]. Anaerobic digestion (AD) is one of the most common technologies that has been evaluated as energy-efficient and environmentally beneficial technology for bioenergy production and considered to be an optimal treatment for efficient waste management techniques [1]–[3]. There are 3 main processes in AD system, which is hydrolysis, acid forming phase and methane forming phase that involve environmentally sensitive microorganisms in the absence of oxygen [4][5]. The waste such as animal manure will be converted into methane-based energy that can be used for cooking, heating and electricity, as well as high quality organic fertilizer from the effluent residue as it is believed to double crop yields [3][4]. Therefore, biogas production from AD not only contribute to the reduction of biodegradable waste, but helps in increasing the source of income for the agricultural sectors [3].

Anaerobic co-digestion (AcoD) process is an advanced method of AD in which several substrates are mixed in order to increase the efficiency of the digestion process. In comparison to anaerobic monodigestion, this integration is believed to have a better biogas yield through balancing micronutrients that is effective to overcome nutrient limitations and allows higher output of biogas [6][7]. Studies have found that poultry waste such as chicken manure are nitrogen-rich biomass but relatively low in carbon source which is inefficient for AD process, while crop residues have been used as feedstock for bioenergy in the past decades for its significant carbon content [8]. Therefore, this paper highlight the utilization of anaerobic co-digestion of chicken manure with local energy crop residues to optimize biogas production qualitatively and quantitatively.

2. Methodology
2.1. Feedstock, Inoculum and Energy Crop Residues
The main resource of chicken manure were collected from Dindings Poultry Development Center Sdn Bhd (DPDC), Segari located at Manjung, while cow dung that is used as inoculum was collected at Sikh settlement at Kampar, Perak. On the other hand, 6 types of energy crop such as paddy, maize, sugarcane bagasse and pineapple plant were collected from Titi Gantung Agricultural Center, Perak, while empty fruit bunch (EFB) and oil palm frond (OPF) were collected from FELCRA Nasaruddin Palm Oil Mill located in Bota, Perak. All feedstock and raw materials were stored in the cold room at 4°C to ensure their freshness for experimental purposes.

2.2. Characterization of Feedstock
Chicken manure and energy crop residues were tested for characterization analysis in order to identify their composition and properties which include calorific value, moisture content and CHN content. Total of six different local energy crop residues have been used which are paddy, OPF, corn cob, pineapple plant, EFB and sugarcane bagasse. All samples were dried at 105°C overnight before grind and sieve for a smaller size. The biogas product were analysed using Gas Chromatography (GC) to identify the concentration of methane and other gases present in the biogas. The best three energy crop residues from the characterization result were selected for further AcoD process. C/N ratio were calculated using the formula as follow.

$$R = \frac{Q_1(C_1 \times (100-M_1)) + Q_2(C_2 \times (100-M_2)) + Q_3(C_3 \times (100-M_3))}{Q_1(N_1 \times (100-M_1)) + Q_2(N_2 \times (100-M_2)) + Q_3(N_3 \times (100-M_3))}$$

where R is C/N ratio, Q is the mass of material, C is carbon percent, N is nitrogen percent and M is the moisture percent.
2.3. Experimental Apparatus
The anaerobic set-up is illustrated as Figure 1. An air-tight 1.5L bottle is used as the main digester body to allow the anaerobic condition for the AD process to take place. Tubing with valves were installed to control the direction of biogas produced for collection. Biogas volume is measured using water displacement method, with NaCl solution as solvent to prevent the absorption of biogas into the water [9]. The biogas collected in graduated cylinder is then pumped out into gas bag for gas sampling every 10 days for further GC analysis to determine the concentration of methane and carbon dioxide for each digester set-up.

![Figure 1. Experimental set-up for anaerobic digestion process.](image)

A series of 5 digester bottles were used for the AD process. The solid content consist of chicken manure, energy crop and cow dung that is mixed with ratio 7:3:10 respectively, with total solid to water ratio of 1:3. The digester is set to temperature of 40°C using water bath (WNE45, MEMMERT) for retention time of 60 days.

3. Result and Discussion
3.1. Characterization of Feedstock
Table 1 shows the elemental analysis for chicken manure and energy crop residues.

| Feedstocks               | Experimental |            |            |            |            |
|--------------------------|--------------|------------|------------|------------|------------|
|                          | Total C (%)  | Total N (%)| C/N ratio  | Moisture (%)| Energy content (kJ/kg) |
| Chicken Manure           | 42.88        | 3.7795     | 11.348     | 27.463      | 6905       |
| EFB                      | 40.52        | 0.94       | 43.10      | 51.64       | 21060      |
| OPF                      | 36.55        | 1.50       | 24.36      | 46.96       | 17846      |
| Corn cob                 | 36.02        | 0.83       | 43.66      | 56.61       | 16804      |
| Sugarcane bagasse        | 33.64        | 0.32       | 106.79     | 62.48       | 16676      |
| Pineapple plant          | 34.71        | 0.63       | 55.10      | 88.60       | 16588      |
| Paddy plant              | 31.6         | 1.24       | 25.67      | 33.08       | 15176      |
From Table 1, C/N ratio for chicken manure is expectedly low which is below 15, while the optimum C/N ratio for maximum biogas yield is in between 20-30 [10]. Besides, low energy content is also detected for chicken manure which is 6905 kJ/kg. On the other hand, the energy crop residues result in high content of carbon content with EFB being the highest which is 40.52% followed by OPF with 36.55%. This carbon percent is relatable to the energy content by EFB and oil palm frond that give higher energy content among all samples which is 21 060 J/g and 17846 J/g respectively. On the other hand, sugarcane bagasse poses significantly high C/N ratio that is beneficial for biogas production. Therefore, EFB, OPF and sugarcane bagasse were selected as co-substrate for AcoD with chicken manure.

### 3.2. Biogas Production and Composition

Table 2 displays the calculated C/N ratio for each digester. DC1 is the control digester of chicken manure only, while DC2 is the control digester to investigate the effect of inoculum addition in AD process. The AcoD of chicken manure with sugarcane bagasse, OPF and EFB are labelled as DSB, DOPF and DEFB, respectively.

**Table 2. Calculated C/N ratio for each digester**

| Digester       | DC1 | DC2 | DSB | DOPF | DEFB |
|----------------|-----|-----|-----|------|------|
| Chicken manure (g) | 200 | 100 | 70  | 70   | 70   |
| Cow dung (g)    | -   | 100 | 100 | 100  | 100  |
| SB (g)          | -   | -   | 30  | -    | -    |
| OPF (g)         | -   | -   | -   | 30   | -    |
| EFB (g)         | -   | -   | -   | -    | 30   |
| C/N ratio       | 11.35 | 12.77 | 17.74 | 15.41 | 17.13 |
| pH              | 8.61 | 8.57 | 7.35 | 7.61 | 8.16 |

**Figure 2.** Comparison of accumulated biogas in each digester.

From Figure 2, the anaerobic process in every digester result in high amount of biogas production which is almost 1000 ml daily. This shows that the AD process works effectively at 40°C which is the optimum temperature for methanogenic bacterial growth. In addition, the initial pH for every digester
are measured to be above 5 and 6.2 which are favourable for acid-forming and methane-forming bacteria.

Based on the graph plotted in Figure 2, DC2 gives a better result compare to DC1. The addition of inoculum in the system provide the stability of biomethanogenesis during process start-up, thus enhance the performance of anaerobic digestion [6]. On the other hand, total biogas production for DSB increases up to 36% due to its significantly high carbon content from sugarcane bagasse that provide stability for the bacterial growth and its activities. Sugarcane bagasse act as a good carbon source for the AD system, thus enhance the biogas production.

3.3. Biogas Composition

![Gas composition of DEFB](image)

**Figure 3. Gas Composition for DEFB.**

Figure 3 shows the gas composition in DEFB for every 10 days. In the earlier days, minimum amount of methane has been produced which is less than 15% but increases up to almost 50% methane concentration at day 40. The lignin structure acts as a protective layer to internal cellulose as it gives high resistance towards microbial attacks, thus causing DEFB for hinder hydrolysis process. Therefore, the AcoD process is partially incomplete and organic matter mostly be converted into byproducts carbon dioxide and nitrogen gas.

From Figure 2, DEFB shows the lowest trend of biogas volume which is 41% lesser compared to the control digester, however it produces much higher methane concentration (Figure 3). According to Hamzah et al [11], the lignocellulosic structure of EFB that is high cellulose content but low in lignin content favoured higher methane yield in biogas composition. Low level of lignin can enable easier penetration and less resistance for the microbial attacks, while high cellulose content in EFB will yield to high glucose level through hydrolysis which will be further converted to methane during the AcoD process [11][12]. This composition in EFB makes it favourable to be used as highly potential additive to enhance a more stable and efficient AcoD process.

4. Conclusion

In conclusion, the co-digestion digestors appears to improve biogas production and methane yield. The addition of energy crop residues significantly improves the characteristic and organic content of an anaerobic system which results in a better bacterial performance and biogas production compared to that of mono-digestion. High carbon content in energy crop residues alter and improve the overall co-
digestion C/N ratio of chicken manure and energy crop residues, thus provide more food for bacterial growth. In addition, cellulose and hemicellulose content bounded in lignin structure in energy crop residues are the main components that will be converted into glucose and methane in biogas. Lignocellulosic structure of EFB has a high cellulose content but low in lignin, where this condition favours high methane yield during AcoD.

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