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Short Communication

# Comparison of methane production potential, biodegradability, and kinetics of different organic substrates

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## HIGHLIGHTS

- Methane production potential, BD, and kinetics of various substrates were compared.
- Both of elemental and organic analysis could be used to calculate the TMY and BD.
- 15% VS of lignin was a critical point in AD of lignocellulosic and manure wastes.

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## ABSTRACT

The methane production potential, biodegradability, and kinetics of a wide range of organic substrates were determined using a unified and simple method. Results showed that feedstocks that contained high energy density and easily degradable substrates exhibited high methane production potential and biodegradability. Lignocellulosic biomass with high content of fibrous compositions had low methane yield and biodegradability. Feedstocks with high lignin content (⩾15%, on a TS basis) had low first-order rate constant (0.05–0.06 1/d) compared to others. A negative linear correlation between lignin content and experimental methane yield (or biodegradability) was found for lignocellulosic and manure wastes. This could be used as a fast method to predict the methane production potential and biodegradability of fiber-rich substrates. The findings of this study provided a database for the conversion efficiency of different organic substrates and might be useful for applications of biomethane potential assay and anaerobic digestion in the future.



## 1. Introduction

Anaerobic digestion (AD) of organic materials has been developed for more than 100 years. Today, AD is commercially applied to treat a wide range of organic substrates to reduce the organic pollutants and produce renewable energy source in the form of biogas (a mixture mainly of methane and carbon dioxide). Before utilization in large scale AD systems, organic substrates should be characterized to determine their biogas production potential that would help in determining the economics of these systems. Biomethane potential (BMP) assay has been proved to be a simple and reliable method to assess the biogas yield of organic substrates (Angelidaki et al., 2009; Labatut et al., 2011). Besides, according to the analysis of elemental or organic composition, a theoretical methane yield of material could be calculated and then the biodegradability of substrate could be estimated. Thus, the process of methane production evaluation is valuable for designing and assessing the performance of an anaerobic digester.

Up to now, the definition of a standard protocol in evaluation of the methane production potential still remains a challenge (Elbeshbishy et al., 2012; Li et al., 2013a). Due to the differences in equipment, operation conditions, experimental protocols, and calculating methods, BMP assays of substrates conducted by different researchers are usually not comparable (Angelidaki et al., 2009). Moreover, there are many expressions and definitions to calculate the theoretical methane yield (TMY) of feedstocks, which make it hard to compare the biodegradability data from literatures (Kaparaju et al., 2009; Triolo et al., 2011). There is, therefore, an urgent need to standardize the method used in assessment of methane production potential, so that it would be possible to compare the differences among various organic substrates by using one simple and unified method.

On the other hand, despite of the simplicity of BMP assay, it will usually last for 1–2 months, which is time-consuming and costly.

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**Nomenclature**

| | | | |
|---|---|---|---|
| AD | anaerobic digestion | TS | total solid |
| BMP | biomethane potential | VFA | volatile fatty acid |
| BD | biodegradability | VS | volatile solid |
| $BD_{ele}$ | biodegradability calculated from $TMY_{ele}$ | *Molecular formula* | |
| $BD_{org}$ | biodegradability calculated from $TMY_{org}$ | Carbohydrates (as $C_6H_{10}O_5$) | |
| EMY | experimental methane yield obtained in BMP assay | Lignin (as $C_{10}H_{13}O_3$) | |
| TMY | theoretical methane yield | Lipids (as $C_{57}H_{104}O_6$) | |
| $TMY_{ele}$ | theoretical methane yield calculated based on elemental composition | Protein (as $C_5H_7NO_2$) | |
| $TMY_{org}$ | theoretical methane yield calculated based on organic composition | VFA (as $C_2H_4O_2$) | |

Innovative techniques for predicting methane production potential or biodegradability are, therefore, of a great importance. Previous studies have focused on lignin content of a substrate as a predominant variable to predict methane yield and biodegradability of that substrate. Labatut (2012) observed a good linear correlation between methane production and lignin content of several lignocellulosic materials. Triolo et al. (2011) found that lignin content was a significant parameter affecting the methane production potential. For now, more work that using different organic substrates should be done to validate and renovate the prediction model.

The objectives of this study were to: (1) compare methane production potential, biodegradability, and kinetics of different typical substrates using one simple and unified protocol; and (2) examine the influence of lignin content on methane production potential of lignocellulosic substrates and animal manures, and then renovate the prediction model.

## 2. Methods

### 2.1. Substrates and inoculum

BMP tests were carried out for animal manures, crop straws, food and green wastes, processing organic wastes, energy grass, and other lignocellulosic biomass. The selection of these substrates covered a wide range of chemical compositions and substrates diversity. The lignocellulosic substrates were ground with a mill (KINGSLH, China) to pass a 1-mm mesh (TPATE, China). Inoculum used in this study was digested sludge from Xiaohongmen municipal wastewater treatment plant in Beijing, China. Before utilization, inoculum was acclimated and degassed at 37 °C for about three weeks (Li et al., 2013a). Cellulose, hemicelluloses, and lignin contents were determined after analyzing the studied substrates for neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) using an AMKOM 2000 Fiber analyzer (AMKOM, USA). Other analyses and measurements were conducted according to the reported methods (El-Mashad and Zhang, 2010; Kaparaju et al., 2009; Li et al., 2013b) with minor modifications. Details can be found in Supplementary material.

### 2.2. Biomethane potential assay

A simple BMP assay was carried out based on the slightly modified protocol described by Li et al. (2013b). Briefly, different organic wastes were tested in triplicate using 1 L glass bottles with a working volume of 0.5 L. The initial volatile solid (VS) concentration was 3 g VS/L and the corresponding substrate to inoculum (S/I) ratio was adjusted to 0.5. After adding and mixing the needed amounts of substrates and inoculum, tap water was added to fill up the working volumes. All digesters were tightly closed with rubber stoppers and screw caps. The headspace of each digester was purged with nitrogen gas for 2 min. Digesters were then kept in an incubator maintained at 37 °C. No additional nutrient solution was added to BMP assay. Three blank digesters that contained the same amount of inocula and water were also incubated as corrections for biogas production. All digesters were manually shaken twice a day for about 1 min. Measurements of biogas yield and composition were included in details in Supplementary material.

### 2.3. Theoretical methane yield and biodegradability

In this study, two typical methods for calculating theoretical methane yield (TMY) were applied to determine the difference on their abilities to estimate the methane production potential and biodegradability of organic substrates. Theoretical methane yield could be obtained based on elemental compositions of organic substrates (expressed as $TMY_{ele}$) using Buswell formula (Buswell and Mueller, 1952; Li et al., 2013a) as shown in Eqs. (1) and (2):

$$C_nH_aO_bN_c + \left(n - \frac{a}{4} - \frac{b}{2} + \frac{3c}{4}\right)H_2O \rightarrow \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4} - \frac{3c}{8}\right)CH_4 + \left(\frac{n}{2} - \frac{a}{8} + \frac{b}{4} + \frac{3c}{8}\right)CO_2 + cNH_3 \quad (1)$$

$$TMY_{ele}\left(\frac{\text{mL CH}_4}{\text{g VS}}\right) = \frac{22.4 \times 1000 \times \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4} - \frac{3c}{8}\right)}{12n + a + 16b + 14c} \quad (2)$$

In addition, based on the organic composition, TMY (expressed as $TMY_{org}$) could also be calculated by Eq. (3) (Kaparaju et al., 2009; Triolo et al., 2011):

$$TMY_{org}\left(\frac{\text{mL CH}_4}{\text{g VS}}\right) = (373\text{VFA} + 496\text{Protein} + 1014\text{Lipids} + 415\text{Carbohydrates} + 727\text{Lignin})/100 \quad (3)$$

with VFA (as $C_2H_4O_2$), lipids (as $C_{57}H_{104}O_6$), protein (as $C_5H_7NO_2$), carbohydrates (as $C_6H_{10}O_5$), and Lignin (as $C_{10}H_{13}O_3$) as % of VS (Angelidaki and Sanders, 2004). Anaerobic biodegradability (BD) of the substrate could be calculated based on the experimental methane yield (EMY) and theoretical methane yield (TMY) as follows (Elbeshbishy et al., 2012): $BD_{ele} = EMY/TMY_{ele}$; $BD_{org} = EMY/TMY_{org}$

## 3. Results and discussion

### 3.1. Characteristics of substrates

The characteristics of the studied substrates are shown in Table 1. Chicken, dairy, and swine manures showed lower VS/TS ratios (72.4–75.3%) compared to other lignocellulosic feedstocks