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Comparison of two laboratory methods for the determination of biomethane potential of organic feedstocks

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ABSTRACT

The increased interest in anaerobic digestion systems has led to the increased need for laboratories to conduct biomethane potential (BMP) to determine the possible usefulness of various feedstocks. There is currently no standard method, but two well established methods have emerged as standardized methods for BMP testing. These two methods are the Automated Methane Potential Testing System, or AMPTS and the German DIN standard method using eudiometers. While these are widely-used, there have been no comparison of how these systems relate to each other in terms of BMP results for identical feedstocks. This study compared the BMP results for ten feedstocks using both the AMPTS and DIN methods to see if the results can be directly related. Results suggest that the methods provide different BMP results for 8 of the ten tested feedstock ($p < 0.05$). Each method has advantages in terms of using it for BMPs, but overall results suggest that users of these methods should be aware of method differences when comparing results between methods or labs. For those interested in determining BMPs for larger-scale projects they should choose a testing facility that has experience with both methods and understands the differences in results between methods. While both methods can provide valuable information, it is important to be cautious in interpreting the results of these methods when compared to each other and likely the many in-house methods that various labs have developed.

1. Introduction

With increasing regulations at the local and state level limiting organic waste disposal in landfills, other usages for these wastes has become increasingly important. One of these possible uses is in anaerobic digestion (AD) facilities that produce methane and then usually electricity and/or thermal energy (Daelman et al., 2012; German Bio Energy Techonology, 2015). Anaerobic digestion is a basic process of for bacterial decomposition or organic wastes in which archaea synthesize methane from more complex organic substrates (Manyi Loh et al., 2013).

Substrates used vary from manure from different livestock such as sheep, cows and pigs, to food waste, yard waste, and any other type of organic substrate from which methane can potentially be generated. The use of AD systems not only is able to prevent health impacts from wastes, divert waste from landfills, prevent air and water pollution, and generate renewable energy (St. Pierre and Wright, 2013). Additionally, the process of biodigestion is a good method for bacterial and pathogen control, by destroying pathogenic microbes in substrates.

There are different types of AD including wet, high-solids, and dry AD technologies (Monson et al., 2007). Each type is suited to treat a different type of organic substrate. For example, wet systems (<10% solids) are typically used for manure-based systems at dairy farms while a dry AD system may be used to treat food waste products. AD systems usually operate at either a mesophilic range of approximately 38 °C or a thermophilic temperature of approximately 55 °C (Korres et al., 2013). There are many AD currently being used at medium and big sized farms around the world, with the purpose of controlling animal and crop waste, and by taking advantage of anaerobic digestion to produce biogas, which serves as a way to generate electricity, and as fuel for vehicles and cooking (Goodrich, 2005; Pham et al., 2014). Additionally, the UW Oshkosh owns and operates three biogas systems that treat organic wastes from three different type of organic waste streams. The UWO operates a wet system at a 9000 head dairy farm, a high-solids system at a small farm (120 head of cattle), and a dry system treating food wastes.

One of the challenges with using AD technology is the difficulty in assessing how much biogas can be produced from a particular substrate (the biomethane potential or BMP) (Khanal, 2009). This is important information to have in the design phase of each AD system so that the system can be sized properly for the feedstock being treated. The amount of methane is critical to understanding the business side of the operations as well (UW Oshkosh Biogas Systems unpublished data). Additionally, as systems operate for some time the feedstocks may change, new feedstocks may become available, or mixtures may be needed for operational reasons. It is critical to the operations to understand how these feedstocks will impact methane (and subsequent biogas) produced by

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the AD facility. Again the BMP results from lab tests are critical to understanding both the operational, biological, and financial operations of both operating AD systems and ones being considered for construction.

The BMP analysis needs to be conducted in a relatively short period of time, for the lowest possible cost in a standardized manner. There are few methods that are universally accepted for the determination of BMPs for organic wastes (Amaya et al., 2013). The German Institute of Standardization or Deutsches Institut für Normung (DIN) has developed a standard laboratory DIN 38414-17 method for the analysis of biogas production (Deutsches Institut für Normung, 2015a,b,c). This method uses a specialized glass device called an eudiometer that measures changes in gas volume, allowing the assessment of biogas production over a six week period. This is the standard method used in many parts of the world. The method requires specialized glassware, is labor intensive, but allows for the measurement of both biogas quantity and quality. The Automated Methane Potential Testing System II (AMPTS) is a newly developed BMP testing system and method developed in Sweden. This method uses a more automated system that automatically measures biogas production in bioreactors holding both inoculum and substrate at the start of the experiment. As biogas is produced, a carbon dioxide fixing unit in the AMPTS system binds carbon dioxide, which is a major product in anaerobic digestion and the methane content of the biogas is calculated by subtracting this amount from the total amount of biogas recorded in a flow-through cell. This laboratory method requires a specialized piece of equipment, provides biogas quantity (but not quality), and is conducted in a shorter amount of time than the DIN method.

While both the AMPTS and DIN standard methods have been used by a number of laboratories for BMP determinations, there is no clear relationship between the results from each method. Additionally, many research and academic laboratories have custom systems to determine BMPs. With various methods being reported and no clear comparisons of methods it makes it a challenge, if not impossible, to compare results from one study to another. Confounding these results is the fact that each commercial system has different operational conditions that are not easily mimicked by other lab test systems. Thus, there is great need to understand the relationship between BMP values from different methods and move toward a common testing method. The results of these BMP tests can influence the construction and/or operation of multi-million dollar biogas facilities.

The overall objective of this study is to compare BMP results obtained from the AMPTS and DIN standard methods to determine if there is a consistent relationship between the methods. Specifically, ten unique feedstocks, or substrates, will be evaluated for BMP using both the DIN standard and the AMPTS method. Additionally, the overall biogas produced as well as the quality of the biogas produced will be compared.

2. Methods

2.1. Feedstock analysis

Samples used in this study were supplied by the Environmental Research and Innovation Center (ERIC) at UW Oshkosh and were ones that were being utilized in the UWO biodigester on campus. Samples were collected in Ziploc® freezer bags from larger samples and stored at 4 °C for up to 24 h before feedstock analysis was done. The following analysis was conducted on each sampled tested: pH (APHA, 1998, 9045D), total solids (DIN 12880) and volatile solids (DIN 12879). The same parameters also were tested for the percolate from the UWO biodigester used as the inoculum and used as a negative control and the cellulose microcrystalline used as positive control. Substrate analysis was performed as a basis for DIN and AMPTS methods loading amount calculations. Analysis was done after allowing the “fresh” samples to reach room temperature before testing.

2.2. Automated methane potential testing system II

The AMPTS II system was set-up and operated in accordance with the bioprocess Control Operation and Maintenance Manual (Bioprocess Control, 2015). The amount of inoculum and substrate needed in each reactor, was determined by using the Bioprocess Control software per the operations manual. Substrates were weighed using plastic weight boats. Reactor bottles were loaded with the appropriate amount of inoculum and substrate, as shown in the guidelines of the experiment section in the Bioprocess Control Operation and Maintenance Manual (Table 1). The tubing was purged with nitrogen to ensure that water was completely removed from the tubes.

The reactors were placed in the water bath, in the same order used for the CO_2 fixing unit placement. The water bath was filled with milliQ water, allowed to reach operating temperature before placing reactors in the bath, and maintained at 38 °C (±1 °C). The plastic glass with 15 circular openings was placed on top of the water bath, which served as a barrier to prevent evaporation of the milliQ water. A leakage test was performed for the bioreactors at the beginning of the test and showed that none of the 14 bioreactors had gas leaks prior to starting the experiment (Table 2).

The tubing and gas measurement cell was flushed with nitrogen gas in order to create anaerobic conditions. This was done by unplugging the Tygon® tubing from one of the bioreactors metal openings. The unplugged Tygon® tube was the connected to a tank containing nitrogen. The nitrogen tank valve was opened with a low gas flow for 30 s. The Tygon® tubing was then closed with a tube clamp, to prevent oxygen from entering the bioreactor. The flush gas was closed and disconnected. The procedure was repeated for each of the 14 bioreactors in the water bath. Each of the flow cells in the gas volume measuring device was opened manually, in order to release the remaining gas in the unit.

The AMPTS® software provided by Bioprocess Control™ was started and the control panel was opened and the motors for each of the bioreactors were activated. The bioreactor motors were set to stir the contents every 30 min for the duration of the study.

The devices used in the experiment were monitored daily. The water bath and the gas measuring device's water levels were kept to manufacturer standards, throughout the 21 day experiments. MilliQ water was used to fill these devices. The CO_2 fixing units were monitored daily for changes in color from blue to colorless. A change in color indicated saturation of the CO_2 medium. Clamps were used to prevent flow of gas in and out of the system. CO_2 fixing units were washed and filled to the 80 mL mark with the NaOH indicator medium as needed. The CO_2 fixing unit was re-connected to the Tygon® tubing and flushed.

The experiment was conducted over 28 days. Data was recorded throughout the operation by the Bioprocess Control™ software. Raw data of biogas production per day for each feedstock was recorded in duplicate. A report was generated by the Bioprocess Control™ software, in the report tab for further analysis. Average biogas production in mL was calculated from the duplicate tested feedstocks. Raw data for the AMPTS systems was analyzed for both 21 days and 28 days. This was

Table 1
Weight (g) of inoculum and substrate added to the AMPTS bioreactors.

Feedstock	Substrate	Grams added
Paper sludge	76.04	323.96
Waste jelly	26.28	373.72
Lactose pellets	22.25	377.75
Used cattle bedding	20.51	379.49
Manure scrap	27.68	372.32
Potato sludge	71.13	328.87
Parlor water	24.71	375.29
Fresh straw	19.25	380.75
Cyanobacterial biomass	33.36	366.64
Hot dog casings	40.63	359.37
Positive control	15.94	384.06
Negative control	400.00	0.00