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Kurt A. Rosentrater, *United States Department of Agriculture*

Heath R. Hall, *Utah State University*

Conly L. Hansen, *Utah State University*

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Anaerobic Digestion Potential for Ethanol Processing Residues

Kurt A. Rosentrater, Ph.D., Agricultural and Bioprocess Engineer

USDA, ARS, North Central Agricultural Research Laboratory
2923 Medary Avenue, Brookings, SD, 57006, krosentr@ngirl.ars.usda.gov

Heath R. Hall, Graduate Student

Center For Profitable Uses of Agricultural Byproducts, Utah State University
NSF, 750 N 1200 E, Logan, UT, 84322-8700, hrh@cc.usu.edu

Conly L. Hansen, Ph.D., Professor

Center for Profitable Uses of Agricultural Byproducts, Utah State University
NSF, 750 N 1200 E, Logan, UT, 84322-8700, chansen@cc.usu.edu

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Abstract. *The production of corn-based ethanol in the U.S. is dramatically increasing, and consequently so is the quantity of byproduct materials generated from this processing sector. These coproduct streams are currently solely utilized as livestock feed, which is a route that provides ethanol processors with a substantial revenue source and significantly increases the profitability of the production process. With the construction and operation of many new plants in recent years, these residuals do, however, have much potential for value-added processing and utilization in other sectors as well. This option holds the promise of economic benefit for corn processors, especially if the livestock feed market eventually becomes saturated with byproduct feeds. Anaerobic digestion, which has been successfully utilized to produce methane from a variety of food and organic processing residues, has not yet been used in the ethanol industry. The objective of this study, therefore, was to assess the potential for using ethanol processing residue streams as feedstocks for anaerobic digestion. Toward that end, laboratory testing of anaerobic digestibility has been conducted and biochemical methane yields have been measured during a 45 day trial. Results indicate that whole stillage and thin stillage produced acceptable levels of methane, but CDS was the most promising coproduct. It yielded a BMP of 45% that of theoretical, which is remarkably high, and thus should be examined further in follow-up studies.*

Keywords. *Anaerobic Digestion, Biochemical Methane Potential (BMP), Condensed Distillers Solubles (CDS), Distillers Dried Grains with Solubles (DDGS), Distillers Wet Grains (DWG), Ethanol, Methane, Thin Stillage, Whole Stillage.*

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Introduction

Currently corn grain is the primary biological material that can be economically converted into ethanol on an industrial scale. The corn-based fuel ethanol industry is poised to produce substantial quantities of biofuel during the coming century as this industry continues its rapid expansion. The number of corn ethanol plants, and their processing capacities, has been markedly increasing in recent years. At the end of 2005, 97 manufacturing plants in the U.S. had an aggregate production capacity of nearly 16.3 billion L/y (4.3 billion gal/y). These numbers are expected to continue to increase in coming years due, in part, to the RFS. More information on the industry's growth can be found in Lyons (2003), BBI (2006), and RFA (2006).

Fuel ethanol manufacturing from corn grain results in three main products: ethanol, the primary end product, residual nonfermentable corn kernel components (e.g., protein, oil, fiber, and minerals), and carbon dioxide. Anecdotally, the rule of thumb commonly used in the industry states that for each 1 kg of corn processed, approximately 1/3 kg of each of these constituent product streams will be produced. The production process consists of several steps, including grinding, cooking, liquefying, saccharifying, fermenting, and distilling the corn grain. In-depth information on this process can be found in Dien et al. (2003), Jaques et al. (2003), Tibelius (1996), and Weigel et al. (1997), but is beyond the scope of this paper.

Following fermentation, the nonfermentable residual materials are removed from the process stream during the distillation stage in the form of whole stillage. Excess water is removed via centrifugation; this thin stillage is then processed through evaporators to produce condensed distillers solubles (CDS). The solids removed from the centrifuge, known as distillers wet grains (DWG), are then combined with the CDS, dried, and then sold as distillers dried grains with solubles (DDGS) for livestock feed. If the CDS is not added during the drying of DWG, the resulting product is known as distillers dried grains (DDG), which does not have added solubles. The sale and utilization of these coproduct streams contributes substantially to the economic viability of ethanol manufacturing, and is thus a vital component to each plant's operations. As energy costs continue to rise, however, many processors are beginning to examine other alternatives for coproduct utilization, especially avenues that could provide higher rates of return, such as energy generation.

Anaerobic digestion is one such avenue that should be explored. It is a process where biological materials are converted by microorganisms into methane and other gases, and thus can be used to produce biorenewable energy supplies. There are a variety of systems, processes, and technologies that can be used to accomplish this conversion. Gunaseelan (1997) and Mata-Alvarez et al. (2000) provide comprehensive overviews. To date, however, no studies have yet examined anaerobic digestion as a means to utilize ethanol process residues. Toward this end, the objective of this study was to assess the potential of ethanol manufacturing coproduct streams for use as a feedstock for anaerobic digestion.

Materials and Methods

Biochemical methane potential (BMP) is a measure of the total methane (CH_4) that can be produced under anaerobic conditions for a given substrate. As a wide variety of materials can be anaerobically digested to produce methane gas, this is a useful test to measure to what extent a particular substrate can be converted. BMPs have been investigated for a variety of waste streams over the years (Chynoweth et al., 1993; Deren et

al., 1991; Owen et al., 1979; Owens and Chynoweth, 1993; Smith et al., 1988; Tong et al., 1990; Turick et al., 1991).

To quantify BMPs for ethanol residues in this study, a method similar to that described by Owen et al. (1979) was used. Ethanol coproducts examined in this study included WS, TS, CDS, DDG, and DDGS. Samples of each were collected from a traditional dry grind ethanol processing plant in South Dakota, and were frozen until needed for the study. To serve as an inoculant for the trials, sludge was collected from an Induced Blanket Reactor (IBR) anaerobic digester on a dairy farm near Ogden, UT, which is maintained at an operating temperature of 35°C (Cheong and Hansen, 2006). Prior to experimentation, the sludge was passed through a 425µm sieve in order to remove large particles and to ensure uniformity.

At the outset, each of the substrates was analyzed for total solids(TS) and volatile solids (VS) (APHA, 1992), in order to provide a common basis to compare relative amounts of subsequent biogas production. Chemical oxygen demand (COD) of each of the substrates was also determined.

Experiments were performed in 160 mL serum bottles, each of which contained 13 g of inoculum, 1 g of substrate, and 1.4 g of sodium bicarbonate as a buffer. The buffer was used to ensure that acidification of the substrate, which occurs during the digestion process, would not cause pH to drop to an inhibitory level. Often a defined nutrient medium is added to samples during digestion to ensure that lack of nutrients does not limit the ability of the microorganisms to digest the waste. In this case, however, additional media was not added, because the inoculum was animal manure, and preliminary analysis has shown abundant quantities of all necessary nutrients. Each bottle was then filled with approximately 130 mL of distilled, deionized water, which left approximately 15 mL of headspace. A control, which contained inoculum, buffer, and water, was used for comparison. The biogas produced by this control was assumed to be the result of endogenis respiration, or further breakdown of other organic materials found in the inoculum. Another control, which contained 1% sucrose as a substrate, was also utilized for comparison purposes. After filling, the bottles were purged of oxygen by flushing with nitrogen gas, after which the bottles were immediately capped with a rubber stopper using an aluminum seal. Bottles were then placed in an incubator which was maintained at a temperature of 38°C.

Throughout the duration of the study, biogas production volume was measured by inserting a needle on a graduated syringe through each rubber stopper, and allowing pressures to equilibrate to ambient air pressure, in order to maintain the integrity of the stoppers. Each collected sample was then analyzed using chromatography for CH₄, O₂, H₂, and N₂, the balance of which was assumed to be CO₂. Collection ended after 45 days, when gas production had stopped in each bottle.

For each substrate studied, three replicate samples were utilized. Statistical analyses on all collected data were performed via Microsoft Excel v. 2003 (Microsoft Corporation, Redmond, WA) software.

Results and Discussion

DDG and DDGS did not lend themselves to the production of methane; the other coproduct streams did, however. Initial levels of TS, VS, and COD for these coproduct materials are provided in Table 1. Over the course of the study, cumulative biogas (total), cumulative methane, and methane as a fraction of the biogas produced, was determined (Figure 1). CDS produced twice the amount of methane as whole stillage, and contained

more than double the amount of VS. Thin stillage, on the other hand, produced the least biogas of all the substrates, but also contained the lowest concentration of VS. Overall, the methane content of the biogas for these three substrates was approximately 74%. Thus it appears that these coproduct materials have much potential for use as anaerobic digestion substrates and can produce relatively high quality biogas streams.

Upon further examination (Figure 2) it can be clearly seen that, out of all of the coproducts studied, the CDS appeared to be a substrate with high viability. Comparing each of these to the 1% sucrose solution (Figure 3), CDS produced approximately 45.7% of this potential methane, which is remarkably high. The whole stillage and thin stillage only produced 14.3% and 10.5%, respectively.

Overall, the ethanol coproducts in this study produced biogas between 15 and 26 ft³/lb VS. This is quite notable compared to animal manures, which typically produced biogas on the order of 11 to 13 ft³/lb VS. Overall, the ethanol coproducts in this study produced biogas between 15 and 26 ft³/lb VS (Table 2). This is quite notable compared to animal manures, which generally produce biogas on the order of 11 to 13 ft³/lb VS (data not shown).. Total biogas production, methane production, and methane as a proportion of the total have been tabulated in terms of TS, VS, COD, waste weight, and waste volume for comparison purposes.

Conclusions

Laboratory testing of anaerobic digestibility was conducted on various ethanol processing coproducts, including DDG, DDGS, whole stillage, thin stillage, and CDS. Biochemical methane yields were measured for each. Results indicate that DDG and DDGS did not have much potential for methane production, but whole stillage and thin stillage produced acceptable levels. Of all the materials studied, though, CDS was the most promising; it yielded a BMP of 45% of theoretical, based on a 1% sucrose solution, which is remarkably high. Because it is a very suitable substrate for anaerobic digestion, follow-up studies should pursue the inclusion and scale-up of CDS in anaerobic digestion systems. As the fuel ethanol industry continues to grow, greater quantities of coproducts will inevitably be generated. Anaerobic digestion may be one route to utilize these coproducts, as well as offset growing energy demands for the production processes themselves.

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Table 1. Characteristics of inoculum and corn ethanol coproducts use as substrates for anaerobic digestion.

Property	Substrate				
	Sucrose	Inoculum	Thin Stillage	Whole Stillage	CDS
Total Solids (g/L)	1000	23.0	61.9	116.6	315.3
Volatile Solids (g/L)	1000	14.0	53.2	107.8	270.1
VS/TS (%)	1.00	60.87	85.95	92.45	85.66
COD	--	--	650.0	910.0	887.5

Table 2. Biogas and methane production for corn ethanol coproducts (in various units).

Property	Substrate		
	Thin Stillage	Whole Stillage	CDS
Biogas			
(ft ³ / lb TS)	23.03	16.90	12.85
(ft ³ / lb VS)	26.80	18.28	15.00
(ft ³ / lb COD)	2.19	2.17	4.56
(ft ³ / lb substrate)	1.43	1.97	4.05
(ft ³ / gal substrate)	11.93	16.43	33.78
Methane			
(ft ³ / lb TS)	17.08	12.36	9.50
(ft ³ / lb VS)	19.87	13.37	11.09
(ft ³ / lb COD)	1.63	1.58	3.37
(ft ³ / lb substrate)	1.06	1.44	3.00
(ft ³ / gal substrate)	8.84	12.01	25.02
Methane as Proportion of Biogas (%)	74.1	73.1	73.9

Figure 1. Cumulative biogas and methane produced by substrates in the BMP assay.

Figure 2. Average methane production (+/- 1 s.d.) from corn ethanol coproducts.

Figure 3. Potential methane production from corn ethanol coproducts (% of theoretical).