Conference Paper

Anaerobic Biodegradability of Agricultural Renewable Fibers

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Natural fiber-based paper and paperboard products are likely disposed of in municipal wastewater, composting, or landfill after an intended usage. However, there are few studies reporting anaerobic sludge digestion and biodegradability of agricultural fibers although the soiled sanitary products, containing agricultural fibers, are increasingly disposed of in municipal wastewater or conventional landfill treatment systems, in which one or more unit operations are anaerobic digestion. We conducted a series of biodegradation studies using corn stalk and wheat straw pulp fibers to elucidate biodegradability and biodegradation kinetics under anaerobic sludge digestion conditions. The degradation results indicate that corn stalk achieved 78.4% biodegradation and wheat straw 72.4% biodegradation, all within 56 days of the study. In comparison, corn stalk generated more biogas than wheat straw. Unlike any raw agricultural crop residues, anaerobic biodegradation of agricultural fibers is largely unaffected by the presence of lignin, physical sizes of crop stalks, and plant cell wall constituents.

1. Introduction

Commodity fibrous materials have been mostly pulped from softwood or hardwood trees, which are a main source of virgin raw material for pulp and paper. In recent years, society has become more conscious of environmental concerns and responsible resource utilization. Nonwood alternative natural materials such as agricultural residues (corn stover, rice or wheat straw, bagasse and cotton stalk, etc.) are increasingly being explored to temper the supply and cost fluctuations of conventional wood-based pulp fibers despite the challenges of nonwood material collection, transportation, storage, and pulping as discussed by Chandra [1]. It is commercially attractive to integrate agricultural fiber manufacturing together with bioenergy and biofuel production. An example of such a processing integration is based on a novel hot water treatment and subsequent mechanical refining explored by Raymond and Closset [2], Kelley [3], and Leponiemi et al. [4]. The fiber fraction derived from such a low cost processing option can be utilized for printing, writing or specialty grades paper outlined by Won and

Armed [5], bathroom tissue, and containerboard applications exemplified by Hurter [6]. Sustainable packaging industries (<http://www.s-packaging.com/>) use natural fibers such as wheat straw for protective packaging applications, which is a great eco-friendly alternative to traditional Styrofoam (EPS) and plastic packaging. Many developing countries such as China and India, where the forest resources are limited, have turned to nonwood plants and agrobased materials for papermaking reported by Chandra [1] and Atchison [7]. Currently, the use of agricultural residues for pulp and papermaking in the United States is negligible. However, Ahmed and Zhu [8] pointed out there are abundant agricultural remnants which are available annually for fiber-based product manufacturing.

The aforementioned products, after being soiled or used, would be likely disposed of either in a municipal wastewater treatment system, composting, or conventional landfill. Today's containerboard recycling activity may delay final disposal fate but it cannot be avoided since the recycled fibers have a limited useful lifespan. This paper addresses anaerobic sludge digestion of corn stalk and wheat straw pulp fibers to assess their anaerobic biodegradability.

2. Experimental

2.1. Materials. Corn stalk pulp was provided by USDA Forest Products Laboratory (Madison, WI, USA). The FQA data indicate the fiber length is 0.699 mm (fiber length weighted), fiber width or diameter is $22.1\mu\text{m}$, and its carbon content is 42.6%. Wheat straw pulp was obtained from Shandong Pulp and Paper Co. Ltd. (Jinan, China). The fiber length is 1.769 mm (fiber length weighted), fiber width or diameter is $28.7\mu\text{m}$, and its carbon content is 40.0%. The reference material is cellulose powder, which was purchased from Sigma-Aldrich (St. Louis, MO, USA).

Anaerobically digested sludge was collected from the Neenah-Menasha Sewerage Commission (Neenah, WI, USA) for the proposed investigation, which operates single-stage digestion with sludge residence time estimated to be about 14 days. Sludge solids content in the digested sludge was 2.5% and the pH for the digested sludge was within a range from 7.4 to 7.8. The sludge colour is black because of the presence of organic matter.

2.2. Methods. American Society for Testing and Materials—ASTM D5210-92 [9]—was used to carry out experiments to assess agricultural fiber biodegradation under anaerobic conditions. The sample volume for anaerobic sludge digestion is 100 mL with 25 mL as headspace in each serum bottle, which contained 10% sludge inoculum by volume and about 0.2 grams of the pulp material. The gas samples were taken using a burette apparatus by water displacement in the 100 mL burette and time intervals varied during the course of sample anaerobic digestion. In the first couple of weeks, sampling intervals were three days or shorter and one week apart towards the end of the sample anaerobic digestion. The temperature during sample sludge digestion was fixed at 35°C throughout the experiment. A specific bacteria genus name is not available because this is a consortium of anaerobic bacteria that are responsible for pulp sample biodegradation. Cellulose powder was used as a reference material to check the activity of the inoculum rather than using bacteria count. If less than 70% biodegradation is observed with the reference (on the basis of CO_2 and CH_4 production), the test must be regarded as invalid and should be repeated with fresh inoculum.

2.3. Biodegradability Estimate. The fiber sample weight was about 0.2 grams for each anaerobic sludge digestion experiment reported in this paper. The potential total gas production from a fibre sample, $V_{\text{Theoretical}}$, can be estimated using a carbon content in actual fiber composition analysed and one mole of gaseous carbon occupying 22.4 L under standard conditions. For experiments other than standard conditions, a correction factor has been considered in calculations for a percentage of algal biodegradation, as shown in ASTM 5210-92 [9].

The accumulated net CO_2 and CH_4 gas generation, $\sum V_{\text{Sample}}$, was obtained from an average of three samples after the accumulated CO_2 and CH_4 gases, generated from three blanks that are just anaerobically digested sludge inoculum

FIGURE 1: Corn stalk and wheat straw fiber anaerobic sludge digestion results.

without the presence of the agricultural fiber sample, $\sum V_{\text{Blank}}$, are subtracted. Equation (1) is then used to estimate agricultural fiber sample biodegradability, which is outlined by Shi and Palfery [10]:

$$\text{Biodegradability} = \frac{\sum V_{\text{Sample}} - \sum V_{\text{Blank}}}{V_{\text{Theoretical}}} \times 100\%. \quad (1)$$

Cellulose is normally used as the reference material so that biodegradation of carbohydrate samples can be compared. The evolved gas ($\text{CO}_2 + \text{CH}_4$) volume is dependent on only the carbon amount regardless of the CO_2 and CH_4 ratio stated by Itävaara and Vikman [11].

3. Results

ASTM D5210-92 [9] as described above was followed to assess agricultural fiber anaerobic biodegradability. Each sample weight was about 0.2 grams with three replicates. The average results from anaerobic sludge digestion of corn stalk and wheat straw fibers are shown in Figure 1, which indicates that corn stalk fiber produced more biogases (157.5 mL) than wheat straw fiber (139.5 mL). Biodegradability of corn stalk fiber is estimated to be 78.4% according to (1). For wheat straw fiber, it achieved 72.4% biodegradation. The testing duration for all samples was 56 days and cellulose powder, used as a reference material, achieved 73.2% biodegradation. Unlike any raw agricultural crop residues, anaerobic biodegradation of agricultural fibers is largely unaffected by the presence of lignin studied by Singh et al. [12], chemical pretreatments by Song et al. [13], and plant cell wall constituents, which complicates biodegradability calculations by Richard [14].

This study shows that corn stalk fiber biodegraded faster than wheat straw fiber, especially within the first 30 days of sludge digestion. The rate of anaerobic biodegradation can be modeled according to the first-rate kinetic model outlined by Shi et al. [15], which is to be covered separately. The difference in fiber biodegradability and biodegradation kinetics is due

to accessibility of anaerobic bacteria to internal structures of a cellulosic component in each type of the fiber studied.

4. Conclusions

The data presented above provide a new understanding of the fate of agricultural fibers in the environment, which is important to facilitate product design for the environment, particularly for those of wastewater treatment facilities and bioreactor/conventional landfills.

Agricultural residues remaining from the harvest of food-based crops such as wheat straw, rice, and corn stalk are important sources of papermaking fiber. Judicious choices will be inherently driven by relative abundance and delivered cost, compatibility with existing manufacturing infrastructure, contribution to product characteristics and manufacturing efficiency, environmental sustainability objectives, economic viability, and success of products in the marketplace. Kimberly-Clark announced ambitious sustainable development goals to reduce its forest fiber footprint at Rio+20 United Nations Conference on Sustainable Development in 2012, which included a goal of 50% reduction of wood fiber sourced from natural forests by 2025. Agricultural crop remnants fit well with corporate sustainability strategy and more product research and development activities using nonwood natural fibers are expected in the future.

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