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Pie waste – A component of food waste and a renewable substrate for producing ethanol

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ABSTRACT

Sugar-rich food waste is a sustainable feedstock that can be converted into ethanol without an expensive thermochemical pretreatment that is commonly used in first and second generation processes. In this manuscript we have outlined the pie waste conversion to ethanol through a two-step process, namely, enzyme hydrolysis using commercial enzyme products mixtures and microbial fermentation using yeast. Optimized enzyme cocktail was found to be 45% alpha amylase, 45% gamma amylase, and 10% pectinase at 2.5 mg enzyme protein/g glucan produced a hydrolysate with high glucose concentration. All three solid loadings (20%, 30%, and 40%) produced sugar-rich hydrolysates and ethanol with little to no enzyme or yeast inhibition. Enzymatic hydrolysis and fermentation process mass balance was carried out using pie waste on a 1000 g dry weight basis that produced 329 g ethanol at 20% solids loading. This process clearly demonstrate how food waste could be efficiently converted to ethanol that could be used for making biodiesel by reacting with waste cooking oil.

1. Introduction

As the population increases the demand for energy increases and many non-renewable fossil energy resources, such as crude oil and natural gas, are shrinking. Renewable energy can help the growing energy demand and is considered carbon neutral, which will benefit the environment. Currently first generation biofuels produced in the United States is ethanol using starch from corn grains (Naik et al., 2010). Ethanol can be produced from multiple sources including grains (e.g. barley, sorghum, and wheat) and other plant sources (e.g. sugar cane juice and sugar beet). Producing ethanol using edible food materials has sparked a food vs. fuel controversy, since many people in the world are starving (Tenenbaum, 2008). However, second generation biofuels which produce ethanol using agricultural residues (e.g. corn stover, sugar cane bagasse, wheat straw, sorghum stubble), perennial grasses (e.g. switch grass, miscanthus), municipal solid waste, and forest woody residues have the potential to end this controversy (Naik et al., 2010; Balan, 2014).

Other industrial waste (e.g. pie waste, apple pomace, grain shells, fruit peels, damaged produce, etc.) could also be used to make biofuels that will not affect the food supply chain (Magyar et al., 2016a,b). Most food waste is usually landfilled, burned, used as fertilizer after composting, converted to biogas using anaerobic digestion or used as animal feed (Baiano, 2014; Kiran et al., 2014; Yan et al., 2011). Sending food waste to landfills or combusting them to generate electricity can be an expensive proposition (costing the city council and municipality as much as $100 per ton), and can cause several environmental issues, such as water contamination or dioxin formation (Kiran et al., 2014; Yan et al., 2011; Zhang et al., 2014). When cattle, swine, and poultry are fed with food waste from different sources, there is a good chance that they will develop health problems such as improper nutrition, hygiene issues, and virus outbreak (Yan et al., 2011). Turning food waste into ethanol and other valuable products can help increase the fuel supply chain and prevent several environmental issues. Fig. 1 summarized the process of making biodiesel from pie waste by first producing ethanol, followed by reacting with used cooking oil in the presence of alkali.

According to the Food and Agriculture Organization of the United Nations (www.FAO.org) about a third of food produced worldwide ends up as waste due to logistic issues associated with transportation, distribution and storage. Annual, about 1.3 billion tons of food is wasted worldwide (Gustavsson et al., 2011). The United States is no exception. According to the United States Department of Agriculture (USDA) in 2010, 430 billion pounds of food was produced in the United States and a third ended up as

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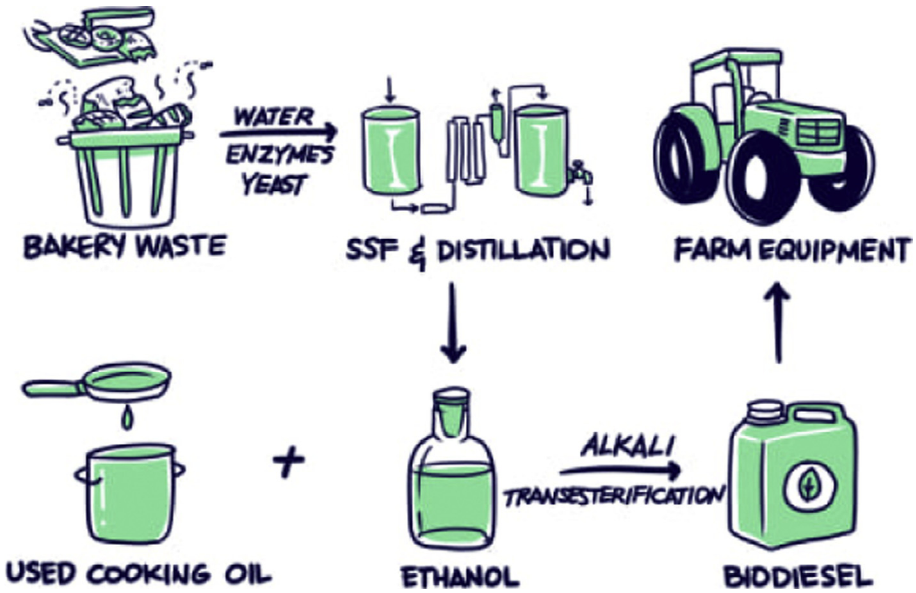

Fig. 1. Concept picture showing how pie waste could be converted into biodiesel. Ethanol produced from pie waste could be processed with used cooking oil from restaurants in the presence of alkali using trans-esterification process to produce bio-diesel that could be used in farm equipment's.

food waste (Buzby et al., 2014). Most households generate food waste by buying excess perishable groceries or throwing away excess uneaten food. Industrial food waste is generated due to low quality, spoilage, or excess production (Parfitt et al., 2010). Reducing food waste before it reaches consumers can help reduce food prices. Farms food waste causes less sellable food produced per production costs and food waste in stores causes selling prices to go up allowing the store to make a profit. Reducing food waste can also increase food security, since more edible food means fewer people going hungry. Even though it is impossible to eliminate food waste, it can be reduced when the food waste generated in industry can be used as feed stock for energy production. Depending on the type of food waste received at an ethanol production facility, the processing conditions, sugar conversion enzyme requirements, and biofuel production efficiency will vary.

One challenge faced while converting food waste to energy is because food spoils easily when the moisture content (MC) is high. Drying is often necessary for long term food waste storage (Sotiropoulos et al., 2016). However, removing moisture from food waste requires additional resources that consume heat energy. Able to use food waste without storing or drying would be ideal. Building biofuel production factories close to food waste sources can help resolve this problem and reduce transportation cost. Several companies have used food waste to produce energy. They include Tyson - the world's largest meat producer formerly used chicken, beef, and pork fat to produce biodiesel, Disney World used uneaten food to generate electricity for the theme park, and Arizona Biodiesel converts used vegetable cooking oil to biodiesel via transesterification process (Tyson Foods, 2014; Waste Management World, 2014). Many small-scale biodiesel processing plants are being erected in rural areas to fuel farm equipment and run generator sets.

Food waste from the baking industry is considered inedible, but is sugar rich and can be converted into fuel such as ethanol. The pie waste used for this study did not pass Sara Lee's strict quality control imposed on their products supplied to customers and excess dough. The collected food waste was dried to increase the shelf life and further processed to ethanol using simultaneous saccharification and fermentation (SSF). Details about enzyme product combinations, enzyme dosage, different solid loadings, fermentation conditions, and pie waste processing logistic issues are provided in this manuscript. To our knowledge this is the first study that provides detailed mass balance on enzyme hydrolysis and microbial fermentation to produce ethanol from pie waste which is one source of food waste.

2. Material and methods

2.1. Pie waste solids and processing condition

About 10 kg of pie waste solids were obtained from Sara Lee Pie Company in Traverse city, Michigan, USA. The pie waste was sun-dried for couple of days after shredding them into small pieces by hand at Northwestern Biodiesel, Traverse City MI before being shipped to Michigan State University, East Lansing MI. The samples were received at 12% MC, then pulverized to powder in a blender to make it homogeneous, further dried to 6.6% MC in a forced air oven operated at 50 °C for 24 h, and stored in vinyl bags at −20 °C for further use. For the experiments in this project pie waste was used as is and solids were not subjected to any washing or solvent extraction.

2.2. Sugar and Lignin composition analysis

Sugar and Lignin content of the pie waste was analyzed using the National Renewable Energy Laboratory (NREL) protocol Hames et al., 2008; Sluiter et al., 2005, 2008; Sluiter and Sluite, 2010. Fructose content was estimated by incubating 5 g (DWB) of sample in 45 mL water (10% solids (w/v)), incubated at 30 °C, 150 rpm for 24 h, in a 125 mL conical flask. A liquid sample was collected after centrifugation at 10,000 rpm for 5 min and analyzed by HPLC for estimating fructose. The following equation was used to determine the percentage of water soluble fructose in pie waste sample.

$$(C * V)/(M * (1 - \%MC)) * 100\% = \%\text{water soluble fructose}$$

where C = gram/liter fructose in sample; V = reaction volume in liters; M = mass of wet solids in grams; MC = moisture content of the solids.