Bio-Ethanol Production from Sweet Sorghum Straw by Dry Milling Process

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Abstract— Due to rapid growth in population and industrialization, worldwide ethanol demand is increasing continuously. Conventional crops such as corn and sugarcane are unable to meet the global demand of bioethanol production due to their primary value of food and feed. Therefore, lignocellulosic substances such as agricultural wastes of crops like sweet sorghum straw are attractive feed stocks for bioethanol production. Requirements of electricity may be supplied by solar- and wind-farms. The energy consumption rate includes each person’s share of electricity and fuel used in making foods and goods and their transport. Approximately 1281 MW biogas is potentially produced from agro wastes in India.

Ethanol is at present the most widely used liquid biofuel for motor vehicles. The importance of ethanol is increasing due to a number of reasons such as global warming and climate change. Bioethanol has been receiving widespread interest at the international, national and regional levels. Ethanol has potential as a valuable replacement of gasoline in the transport fuel market. However, the cost of bioethanol production is more compared to fossil fuels. The world bioethanol production in 2006 is 39 billion liters and has reach 100 billion liters in 2015 and is expected to reach 200 billion liters in 2020. Brazil and the USA are the two major ethanol producers accounting for 62% of the world production. Large scale production of fuel ethanol is mainly based on sucrose from sugarcane in Brazil or starch, mainly from corn, in the USA. Current ethanol production based on corn, starch and sugar substances may not be desirable due to their food and feed value. So sweet sorghum can be an alternative for ethanol production and India can be a major contributor in this sector as producing more than 50 percent of sweet sorghum of world production. It has been estimated that 442 billion liters of bioethanol can be produced from lignocellulosic biomass and that total crop residues and wasted crops can produce 491 billion liters of bioethanol per year, about 16 times higher than the actual world bioethanol production.

Lignocellulosic materials are renewable, low cost and are abundantly available. Bioethanol production could be the route to the effective utilization of agricultural wastes. Rice straw, wheat straw, corn straw, sorghum straw and sugarcane bagasse are the major agricultural wastes in terms of quantity of biomass available. Sweet sorghum (Sorghum bicolor (L.) Moench) is an important biomass energy crop that is used for the production of bioethanol (Sun et al., 2012; Davila-Gomez et al., 2011; Han et al., 2012; Rao et al., 2012; Yu et al., 2012) because both the juice and stalk of sorghum are used as a feedstock for bioethanol (Dogaris et al., 2012). Sorghum is the fifth major cultivated crop in the world (Umakanth et al., 2012). This crop offers several advantages over other energy crops, such as short growing cycle (3-5 months), higher abiotic resistance (Almodares & Hadi, 2009), higher rate of carbon sequestration (50 g/m2.day), higher concentration of sugars in its stalks, less requirements of fertilizers (Sher et al., 2012) and pesticides (Serna-Saldivar et al., 2012), and cultivation under different climates (Reddy et al., 2005; The global production of bioethanol from sorghum ranges between 3-9 m3/ha (Holou & Stevens, 2012). Recent studies show that bioethanol produced from sweet sorghum is more economical than the bioethanol produced from sugarcane in the USA (Tamang, 2010 ;) Researchers are continuously.
striving for the development of new and improved sorghum varieties which may provide higher sugar contents and biomass (Liu et al., 2012). All of these varieties yield lignocellulosic biomass that can be used as a feedstock in bioethanol production. This review aims to present a brief overview of the available and accessible technologies for bioethanol production using sweet sorghum agro wastes.

A new technology in ethanol production has shifted to dry mills, partly because dry mills cost less to build. In 2004, 75 percent of ethanol production came from dry mills and only 25 percent from wet mills (Renewable Fuels Association). As a result, most new technologies are being developed for dry-mill production.

II. RAW MATERIALS

The major agro wastes mentioned in the preceding section are the most favorable feed stocks for bioethanol production due to their availability throughout the year. Worldwide production of these agro wastes. Asia is the major producer of rice straw and wheat straw, whereas corn straw and bagasse are mostly produced in America. India is the major contributor in the production of sweet sorghum in the world. These agro waste also vary in chemical composition, cellulose being the major component. These agro-residues are also utilized as animal fodder, as domestic fuel, and as fuel to run boilers. The utilization fraction of wheat straw, rice straw and corn straw is too low and varies with geographic region. Each year a large portion of agricultural residues is disposed of as waste.

Sorghum is one of the most important cereal crops in the world and is one of the four major food grains of our country. It is a staple food for millions of poor rural people in India.

As studied, in about 100 gms of sweet sorghum it contains about 70.7 gms of carbohydrates which is major contributor for bioethanol production. Starch is the major storage form of carbohydrate in sorghum. And India stood at third rank in production sweet sorghum during year 2014. The mature stems of sweet sorghum contain about 73% moisture and the solids are divided in structural and non-structural carbohydrates. Approximately 13% are non-structural carbohydrates composed of sucrose, glucose and fructose and like any many other agrowaste sorghum also contains large amount of lignocellulose composition.

III. ETHANOL PRODUCTION PROCESS

Though new technology may eventually blur the distinction between them, ethanol is produced by one of two processes: wet milling and dry milling. Wet milling initially accounted for most of the ethanol fuel production in the United States, but new construction has shifted to dry mills, partly because dry mills cost less to build. In 2012, 75 percent of ethanol production came from dry mills and only 25 percent from wet mills (Renewable Fuels Association). As a result, most new technologies are being developed for dry-mill production. Dry-milling plants have higher yields of ethanol; a new plant can produce 2.8 gallons per bushel, compared with about 2.7 gallons for wet mills.

In this process, the sorghum agro waste is cleaned before it enters the mill. The milling step consists of grinding the sorghum agro waste and adding water and acid to form the mash. And mash is cooked and an enzyme added, and this process called saccharification. The mash must be cooled to at least 95o F before the yeast is added. The yeast converts the glucose into ethanol and carbon dioxide (CO2).

A. Pretreatment

The most important processing challenge in the production of biofuel is pretreatment of the biomass. Lignocellulosic biomass is composed of three main constituents namely hemicellulose, lignin and cellulose. Pretreatment methods refer to the solubilization and separation of one or more of these components of biomass. It makes the remaining solid biomass more accessible to further chemical or biological treatment. The lignocellulosic complex is made up of a matrix of cellulose and lignin bound by hemicellulose chains. The pretreatment is done to break the matrix in order to reduce the degree of crystallinity of the cellulose and increase the fraction of amorphous cellulose, the most suitable form for enzymatic attack. Pretreatment is undertaken to bring about a change in the macroscopic and microscopic size and structure of biomass as well as submicroscopic structure and chemical composition. It makes the lignocellulosic biomass susceptible to quick hydrolysis with increased yields of monomeric sugars.

Goals of an effective pretreatment process are

1) Formation of sugars directly or subsequently by hydrolysis
2) To avoid loss and degradation of sugars formed
3) To limit formation of inhibitory products
4) To reduce energy demands and
5) To minimize costs

Physical, chemical, physicochemical and biological treatments are the four fundamental types of pretreatment techniques employed. In general a combination of these processes is used in the pretreatment step. There is a variety of methods that have been proved to be efficient for the lignocellulose hydrolysis. The most commonly used are briefly described below.

1) Physical Pretreatment

The first step for ethanol production from agricultural solid wastes is comminution through milling, grinding or chipping. This reduces cellulose crystallinity and improves
the efficiency of downstream processing. The agro waste materials were oven-dried at 50°C for more than 24 h, grounded into particles of about 2-10 mesh in diameter using a stainless-steel grinder, and stored in pill vials at room temperature.

2) Chemical pretreatment (Acid hydrolysis)
Acid hydrolysis pretreatment is considered as one of the most important techniques and aims for high yields of sugars from lignocellulosics. It is usually carried out by concentrated or diluted acids (usually between 0.2% and 2.5% w/w) at temperatures between 130°C and 210°C. Sulfuric acid is widely used for acid pretreatment among various types of acid such as hydrochloric acid, nitric acid and phosphoric acid. Acid pretreatment can utilize either diluted or concentrated acids to improve cellulose hydrolysis. The acid medium attacks the polysaccharides, especially hemicelluloses which are easier to hydrolyze than cellulose. However, acid pretreatment results in the production of various inhibitors like acetic acid, furfural and 5-hydroxymethylfurfural. These products are growth inhibitors of microorganisms. Hydrolysis’s to be used for fermentation therefore need to be detoxified. Moiser reported higher hydrolysis yield from lignocelluloses pretreated with diluted H2SO4 compared to other acids. A saccharification yield of 74% was obtained from wheat straw when subjected to 0.75% v/v of H2SO4 at 121°C for 1 hrs.

3) Enzymatic Hydrolysis
Enzymatic hydrolysis has attracted increasing attention as an alternative to concentrated acid hydrolysis because the process is highly specific, can be performed under milder reaction conditions (pH around 5 and temperature less than 50°C) with lower energy consumption and lower environmental impact. In addition, it does not present corrosion problems, and gives high yield of pure glucose with low formation of by-products that is favorable for the subsequent hydrolysate use in fermentation processes. Cellulose and hemicelluloses enzymes cleave the bonds of cellulose and hemicellulose respectively. Cellulose contains glucan and hemicellulose contains different sugar units such as mannann, xylan, glucon, galactan and arabinan.

Enzymatic hydrolysis of cellulose is a reaction carried out by cellulase enzymes, which correspond to a mixture of several enzymes, among which at least three major groups are involved in the hydrolysis of cellulose:
1) β-1,4-endoglucanase (EC 3.2.1.4.), which attacks regions of low crystallinity in the cellulose fiber creating free chain ends;
2) β-1,4-exoglucanase or cellubiohydrolase (EC 3.2.1.91.), which degrades the molecule further by removing cellobiose units from the free chain ends;
3) β-glucosidase (EC 3.2.1.21), which hydrolyzes cellobiose to produce glucose.

A wide variety of cellulolytic fungi and bacteria have been reported. Usually, lignocellulosic materials must be pretreated prior to the enzymatic hydrolysis in order to make the cellulose more accessible to enzymes.

Various factors influence yields of monomer sugars from lignocellulose. Temperature, pH and mixing rate are the main factors of enzymatic hydrolysis of lignocellulosic material. Other factors that affect yield are substrate concentration, cellulose enzyme loading, and surfactant addition. High substrate concentration may lead to substrate inhibition. Cellulose contributes to the major cost of the lignocellulosic ethanol technology. Therefore, an efficient pretreatment is to be selected to decrease cellulose crystallinity and to remove lignin to the maximum extent, so that hydrolysis time as well as cellulose loading will be minimized. Surfactants modify the cellulose surface by adsorbing lignin onto surfactant and thus the surfactant prevents the enzyme from unproductive binding with lignin and lowers enzyme loading.

B. Fermentation
Bioconversion of various biomass sources into ethanol by different microorganisms is called as fermentation. Ethanol production from SSS derived from starch and sucrose has been commercially dominated by the yeast Kluyveromyces marxianus CECT10875.

The saccharified biomass is used for fermentation by several microorganisms. But the industrial utilization of lignocelluloses for bioethanol production is hindered by the lack of ideal microorganisms which can efficiently ferment both pentose and hexose sugars. For a commercially viable ethanol production method, an ideal microorganism should have broad substrate utilization, high ethanol yield and productivity, should have the ability to withstand high concentrations of ethanol and high temperature, should be tolerant to inhibitors present in hydrolysate and have cellulolytic activity. The processes usually employed in the fermentation of lignocellulosic hydrolysate are simultaneous saccharification and fermentation (SSF) and separate hydrolysis and fermentation (SHF). Conventionally or traditionally the SHF process has been employed but SSF is superior for ethanol production since it can improve ethanol yields by removing end product inhibition and eliminate the need for separate reactors. It is also cost effective but difference in optimum temperature conditions of enzyme for hydrolysis and fermentation poses some limitations. Studies have shown that SSF is a better alternative to SHF. The slow xylose consumption during fermentation in SHF may be due to the presence of toxic compounds which inhibit the growth and fermentation activity of the microorganism. In the fermentation using the hydrolysate, the glucose concentration decreased rapidly from 40.0 to 9.1 g/l after 2 d. However, 12.1 g/l xylose and 0.6 g/l cellobiose were detected after 2 d, an indication that they were not utilized by yeast cells during fermentation. Results indicated that ‘Kluyveromyces marxianus’ CECT10875 could readily ferment glucose in hydrolysate to ethanol but hardly metabolize xylose. The ethanol production rate in the early phase of the culture was relatively slow but rapidly increased after 1d. Fermentation was completed after 2 d, where ethanol reached a maximal concentration of 24.6 g/l with approximately complete depletion of glucose. This indicates that the consumption of glucose by yeast cells was virtually in sync with the ethanol production.

In addition, the ethanol yield was 0.67 g ethanol/g glucose, which is substantially higher than the ethanol yield (0.45 g ethanol/g glucose).

IV. Conclusion
One of the most promising research priorities in agricultural production is the genetic improvement of crops with high
economic relevance. In the case of sorghum for fuels there are important advances in the development of biomass, sweet and high yielding grain varieties and hybrids, but is yet one of the most important and critical research topics. The new cultivars should be adapted to marginal lands and also they must be resistant to pests, other phytopathogens and stable facing water stress.

Sorghum straw has good potential as a raw material for ethanol production. The process for alcohol production using sorghum straw, although a little expensive, is still preferable as it is environment-friendly compared to molasses. Use of sorghum for ethanol fermentation will use up to 50% dried of the sorghum straws, which will help farmers realize a good price for their produce. Ethanol producing companies, research institutions, and the Government can coordinate with farmers to strategically develop value-added utilization of sorghum.

Sorghum which contains high value of Lignocellulosic materials including agricultural and agro-industrial wastes contain several high value substances such as sugars, minerals and protein. Disposal of these wastes to the soil or landfill causes serious environmental problems, so its economical and environmental friendly to use it for bioethanol production is more economical.

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