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AN OVERVIEW ON FUEL ETHANOL PRODUCTION FROM LIGNOCELLULOSIC BIOMASS

Dr. M.P. Singh*

*Department of Agricultutal Sciences,
Teerthanker Mahaveer University, Moradabad, Uttar Pradesh, INDIA
Email id: studentswelfare@tmu.ac.in
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ABSTRACT

The current progressive depletion of world's energetic resources based on non-renewable fuel and energy use is increasing day by day. Moreover, it is generally known that fossil fuel consumption is the main driver of global warming. The method to address these issues relies on the potential adoption technologies for alternate sources of energy. The review deals with fuel ethanol generation using plant-based lignocellulosic biomass as raw materials. In this article, the technologies for generating fuel ethanol with the major research possibilities for enhancing them are described. The complexity in the biomass processing is detected by the study of different steps involved in the conversion of lignocellulosic biomass into fermentable sugars. Further, the fermentation processes with its essential characteristics are described based on biomass conversion. Comparative index for various kinds of biomass for fuel ethanol generation is given. Finally, some closing comments on current research addressing the pre-treatment together with biological conversion of biomass into ethanol are given.

KEYWORDS: *Biofuel, Ethanol, Fermentation, Hydrolysis, Lignocellulosic biomass, Pre-treatment.*

INTRODUCTION

There is one renewable option that solar energy may be utilized in the form of biomass. A significant area of global potential of bio-energy resources is represented in the form of energy crops and lignocellulosic complexes. Further, conversion of lignocellulosic biomass into biofuels is one of the key options for the development and utilization of alternative energy sources. In addition, plant-based biofuel manufacturing for gasoline replacement will improve the economic growth. Thus, the development of biofuels, particularly bio-ethanol, has acquired strategic significance.

Biofuels are described as transportation fuels generated from biological resources, or via biological processes. Biofuels may be liquid (e.g., ethanol, butanol, long chain alcohols, fatty acid esters, biodiesel, algal diesel, alkanes, methanol), gas (e.g., hydrogen, methane), solid (e.g., wood chips, sawdust, grass clippings, agricultural waste, manure), or electri cal. Thesecan be generated from various primary energy sources, such as plant biomass, algae, and solar energy as well as CO_2 plus secondary energies, such as hydrogen and electricity. These may be generated

via biological methods mediated by bacteria or cascade enzymes, chemical catalysis (e.g., gasification, pyrolysis, and aqueous phase reforming), or a mix of these two[1]–**[5]**.

Ethanol is an appealing alternative fuel because it may be mixed with gasoline and utilized as clean alcohol in engines with higher octane number and heat of vaporization. Bio-ethanol production has grown quickly since several nations aimed toward decreasing oil imports, increasing rural economy along with enhancing the quality of air.

Lignocellulosic Biomass and its Advantages in Bio-Ethanol Production:

Lignocellulosic complex is considered as the most common biopolymer in the world and as one of the possible raw materials for ethanol synthesis. About 50 percent of the global biomass is regarded as the lignocellulosic biomass and its total yearly output is estimated to be about 10–50 billion ton. Generally, lignocellulosic biomass for bio-ethanol (as fuel) production can be differentiated into the following six groups: crop residues (sugarcane bagasse, sweet sorghum bagasse, pulp, wheat straw, rice straw, rice hulls, and barley straw), softwood (pine and spruce), hardwood (aspen and poplar), cellulose wastes material such as newsprint and waste office paper, herbaceous biomass material (thimothy grass, alfalfa hay, switch grass, coastal Bermuda grass), and municipal solid wastes (MSW) (MSW). A significant number of research for establishing large-scale ethanol production from lignocellulosic biomass have been carried out globally. However, greater degree of complexity in processing the feedstock is the primary limiting factor for ethanol production, and this is directly linked to the composition of lignocellulosic material. Cellulose and hemicellulose are the two major polymers of the biomass that break down into fermentable sugars, which are subsequently turned into ethanol, however the breakdown of lignocellulosic biomass is a complex and energy-consuming process.

Biofuel production is more demanding in contrast to fossil fuels, thus the sources of energy will to a greater degree be local and offer security of supply. The global output of biofuels reached 105 billion liters in 2010, which is an increase of 17 percent from 2009, out of which biofuels contributed approximately 2.7 percent to the world's road traffic.

Conversion Process of Ethanol Production:

Production of ethanol from lignocellulosic waste offers a lot of benefits, but lack of production facilities is the major barrier. Currently, ethanol is generated from starch-based material in which a liquefaction phase is required to make starch soluble, thus making accessible for conversion to fermentable sugar, and the hydrolysis process for glucose synthesis from starch, which is ultimately fermented to ethanol. Figure 1 provides an overview of bio-ethanol manufacturing process. There are a lot of parallels between the lignocellulosic- and the starch-based processes for ethanol production, but lignocellulosic-based con version is experiencing greater difficulties due of techno-economic constrains. Many feasible alternatives to lignocellulose-to-ethanol process are there, however the following worrying characteristics must be addressed in contrast to the existing ethanol production method based on sugar or starch material **[6]–[9].**

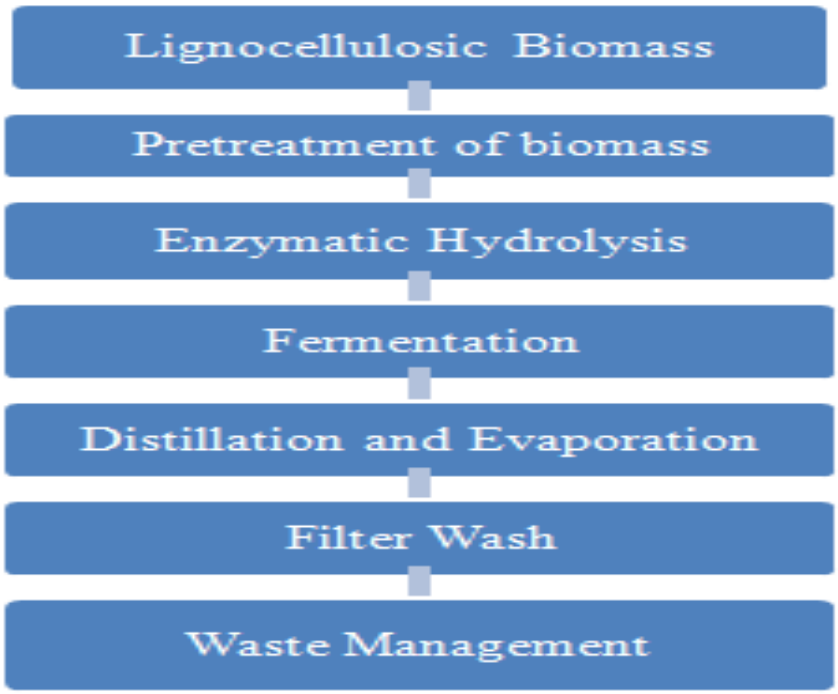

Figure 1: Illustrates the overview of bio-ethanol production process

Pre-Treatment of Lignocellulosic Biomass:

Pre-treatment of lignocellulosic biomass is the primary difficulty in ethanol production, and is considered as the most costly phase. The lignocellulosic biomass has a complicated structure and is made 165 up of cellulose, hemicelluloses, and lignin. In the pre-treatment process, the complex structure of cellulose is broken down for the availability of free cellulose for enzyme reaction to obtain free sugars for fermentation. In cellulose hydrolysis, accessible surface area is one of the most worrying aspects. Theoretically, less than 20 percent cellulose hydrolysis is done in the absence of pre-treatment (directly with enzymes), whereas it is approximately 90 percent when pre-treatment is done. Therefore, the primary goals of the pre-treatment procedure are lignin and hemicelluloses removal, reduction to crystalline cellulose complex, and increasing the porosity of raw substrate.

Physical Methods:

In order to decrease cellulose crystallinity, waste materials may be used by a combination of processes such as screening, chipping, grinding, and milling. This reduction procedure provides an easier access of cellulases to the biomass surface followed by boosting the conversion of cellulose. The overall energy requirement for the mechanical pre-treatment of lignocellulosic biomass relies on the final particle size and properties of lignocellulosic biomass. The mechanical pre-treatment techniques enhance cellulose reactivity in enzymatic hydrolysis but are less appealing because of high energy consumption and capital expenditure. Pyrolysis has also been attempted as one of the physical methods for biomass pre-treatment since cellulose fastly degrades at high temperatures.

Physico-Chemical Method of Pre-Treatment:

Physico-chemical pre-treatment techniques for lignocellulosic biomass are regarded as one of the oldest and the most researched approaches in contrast to physical pre-treatment procedure. In this category, steam explosion is one of the most researched techniques for the pre-treatment of lignocellulosic biomass, during which hemicellulose and lignin are transformed into soluble oligomers by autohydrolysis reaction by saturated steam at high pressure. Temperature, chip size, and moisture availability are the major variables influencing the steam explosion pre-treatment. Temperature and time are believed to operate in a combined way during the steam explosion pre-treatment, and that is why this is termed severity index, and may be described as a correction term when the process is operating under acidic circumstances.

Chemical Methods:

The history of chemical pretreatment technique for lignocellulosic biomass conversion began a century ago. Chemical pre treatment techniques are the most researched ways among all pre-treatment procedures and include use of various chemical agents such as ozone, acids, alkalis, peroxide, and organic solvents. In general, inorganic acids such as H_2SO_4 and HCl have been mainly utilized for biomass pre-treatment. Use of diluted H_2SO_4 in hydrolysis reaction has been developed owing to fast reaction rates, and resulted in high value-added products such as furfurals, phenolic, aldehyde and aliphatic chemicals. Although this technique is a strong contender for cellulose conversion, significant expenses make this process less affordable.

In one of the experiments, Schell et al. clearly showed that prior treatment of maize stover with dilute acid at pilot plant size utilizing high solid loading at 190℃ produced a xylose yield of 77 percent. Dilute acid pre-treatment technique for lignocellulosic biomass has been established effectively and continues in two stages: de-polymerization stage of hemicellulose at 140℃ for 15 min so that the compound production, such as furan and carboxylic acids, may be prevented. In the second step, treatment with dilute acid at 190℃ for 10 min increases cellulose accessibility greater for enzymatic hydrolysis.

Biological Techniques:

Most technologies needed costly equipment and significant energy usage due to the necessary process requirements. Biological pre-treatment with various rot fungus is an environmentally acceptable approach. The major benefits of biological pre-treatments over high-cost, high-energy-consumption lignin degradation are low energy needs and moderate ambient conditions. This technique is restricted for industrial applications because to the sluggish procedures. Many white rot fungi have been found to breakdown lignin, and they've been utilized to make lacasses for the decomposition of lignocellulosic biomass. White rot and soft rot fungus target both cellulose and lignin, whereas brown rot fungi mostly attack cellulose. Brown rot fungus use the enzymes peroxidases and laccasse to attack lignin.

Lignocellulosic Hydrolyzates Detoxification:

Along with fermentable sugars, a variety of chemicals that may impede fermentation are produced during the pre-treatment and hydrolysis of lignocellulosic biomass. Hydrolysis of organic molecules, estrification of sugar acids, and solubilization of phenolic compounds and their derivatives all produce inhibitory chemicals.

Lignocellulosic Biomass Fermentation:

HydrolyzatesThe fermentation of biomass hydrolyzates entails many steps that are carried out in distinct units (hydrolysis and fermentation). Separate hydrolysis and fermentation is the name for this system (SHF). SSF, on the other hand, is a process that takes place in a single unit.

Hydrolysis and Fermentation Separated (SHF):

After the cellulose is pre-treated and hydrolyzed, a fraction is produced that includes the cellulose in an accessible state. Fermentation converts the resulting cellulose hydrolyzate into ethanol once the hydrolysis process is completed. One of the most appealing aspects of SHF is that each stage may be carried out under optimum circumstances, increasing the likelihood of product recovery. The availability of cellulose (for glucose conversion), reaction duration, temperature, pH, optimum enzyme unit, and substrate loading are the most essential factors to be considered for the saccharification phase. Distillation is the most common and well-known method of ethanol purification in industry. It makes use of the variations in the volatilities of the constituents in a combination. The fundamental concept is that heating a mixture concentrates low boiling point components in the vapor phase.

Simultaneous Saccharification and Fermentation (SSF):

Because of its higher ethanol production and lower energy usage, the SSF process is more appealing than the SHF. In this method, cellulases (for hydrolysis) and microbes (for fermentation) are combined in the same process unit, enabling glucose to be produced and immediately consumed by microbial cells, culminating in the generation of ethanol. As a result, carbohydrates' inhibitory impact on cellulases is neutralized. The use of more diluted medium, on the other hand, results in a low-concentration end product. Furthermore, this process operates at non-optimal hydrolysis settings, necessitating larger enzyme doses, which increases substrate conversion rate as well as process cost. As we mentioned in the outset of this study, enzymes play a critical part in improving the overall economics of ethanol production, so finding ways for reducing cellulase dosages and characteristics such as thermostability, which aids in hydrolysis at higher temperatures, is critical. Many scholars have suggested the use of surfactants to achieve this goal.

Fermentation of Pentose Sugar:

One of the major challenges in producing bio-ethanol from lignocellulosic biomass is that S. cerevisiae can only ferment mono and disaccharides, but not pentose sugar (mainly xylose). Recombinant DNA technology (genetic engineering) may be a way to get around this problem. Separate fermentation of pentose and hexose carbohydrates using pentose fermenting yeasts and bacteria-like microorganisms may be a possible solution to this issue.

Yeats like Pichia stipitis, Candida shehatae, and Pachysolentannophilus can use pentose sugar, but their ethanol production rate from glucose is much lower than that of S. cerevisiae.

DISCUSSION

Transportation fuels made from biological materials or via biological processes are known as biofuels. The most popular technique for generating fuel ethanol is fermentation. The starch and sugars in maize, sugar cane, and sugar beets are fermented by yeast in the most prevalent ethanol manufacturing methods today. In other areas of the globe, sugar cane and sugar beets are the

most frequent feedstocks used to produce gasoline ethanol. Almost majority of the ethanol produced today comes from starch and sugar-based feedstocks. These feedstocks include sugars that are simple to extract and ferment, making large-scale ethanol production feasible. Corn is the most important crop in the United States, and it is used as the feedstock for most domestic ethanol production.

CONCLUSION

Increased global production of gasoline ethanol necessitates the development of cost-effective and ecologically friendly ethanol manufacturing methods. The cost of producing ethanol, in particular, should be minimal. The major issue of the cost structure for current commercially available technologies is the expense of feeds (over 60%) combined with processing costs. It is necessary to identify several cost-effective pre-treatment techniques depending on the kinds of lignocellulosic biomass and productivity.

The use of a low-cost cellulase enzyme cocktail and improvements in characteristics like thermostability and alkaliophilic nature of enzymes would assist to reduce the total cost of ethanol production. Lignocellulosic biomass is a potential option for ethanol production because to its output, input energy ratio, and widespread availability in tropical and temperate climates. One of the advantages of using lignocellulosic biomass as a feedstock for ethanol production is that it is unrelated to food production. This suggests that large amounts of bio-ethanol may be produced without requiring huge swaths of fertile cultivable land to be devoted to bio-energy production. Furthermore, lignocellulosic biomass may be processed in a variety of ways to produce a variety of high-value products, including methanol, hydrogen, and energy. Furthermore, using genetic engineering for pentose fermentation, genomic sequencing, environmental genomics, and/or metagenomic technologies to improve pre-treatment methods and identify metabolic pathways may help to make bio-ethanol production more cost-effective, practical, and commercially viable.

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