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Importance of chemical pretreatment for bioconversion of lignocellulosic biomass

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ABSTRACT

Lignocelluloses are often a major or sometimes the sole components in different waste streams from various sources such as industries, forestry, agriculture and municipalities. It represents an as-of-yet untapped source of fermentable sugars for significant industrial use. Many physico-chemical, structural and compositional factors hinder the hydrolysis of components present in the biomass to sugars and other organic compounds that can later be converted into fuels. During the past few years, a large number of chemical pretreatment methods including lime, acid, steam explosion, sulfur dioxide explosion, ammonia fiber explosion, ionic liquid and others have been developed for efficient pretreatment of biomass. Many pretreatment methods have shown high sugar yields i.e. more than 90% of the theoretical yield from lignocelluloses. In this review, we discuss various chemical pretreatment processes, feasibility of the processes at industrial scale in terms of the mechanisms involved, advantages, disadvantages and economic assessment. It is not possible to define the best pretreatment method as it depends on many factors such as type of lignocellulosic biomass, process parameters, environmental impact, economical feasibility, etc. However, some of these chemical pretreatments have disadvantages such as formation of inhibitory compounds especially furfural and 5-hydroxyl methyl furfural (HMF).

Contents

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1. Introduction

The depletion of fossil fuel reserves, the unstable panorama of the fuel prices and, more recently, increasing environmental and political pressures have increased the industrial focus towards alternative fuel resources, and encouraged the search of plant biomass derived fuels [1,2]. Biomass is inexpensive, renewable, widely available and environment friendly. Extensive research has been carried out on ethanol production from lignocellulosics in the past two decades [3–5]. The advances in microbiology, biotechnology and genetic engineering are leading to a new concept for converting renewable biomass to valuable products. The integration of these biomass-based processes into the commercialization will provide the possibility for the development of sustainable model for the production of commodity products [6]. In this respect, lignocellulosic biomass has contributed towards an alternative to the petroleum-based transportation fuel [7].

Lignocellulosic wastes (LCW) are composed of cellulose, hemicellulose and lignin [8]. Some other materials such as ash, proteins, pectin, etc. are also found in the lignocellulosic residues in different proportion based on the sources [9]. These may be categorized based on their sources such as industrial waste (sawdust, paper mill discards, food industry residues, etc.), forestry waste (grasses, hard and soft wood, etc.), agricultural residues (straws, stovers, peelings, cobs, stalks, nutshells, non-food seeds, etc.), domestic wastes (kitchen wastes, sewage, waste papers, etc.), and municipal solid wastes [10,11]. Due to the close association of cellulose and hemicellulose with lignin in the plant cell wall, pretreatment is necessary to make these carbohydrates available for enzymatic hydrolysis and fermentation [12].

Pretreatment can partially remove lignin and hemicellulose, reduce cellulose crystallinity, and increase the porosity (accessible surface area) of the biomass [13,14]. Various physical, chemical and biological pretreatment methods have been investigated by various researchers in the last three decades. Among all the investigated pretreatment methods, chemical pretreatment has been proven to be a promising one when these were followed after anaerobic digestion [15]. During the process of chemical pretreatment, degradability remains mainly in the solid phase, and the subsequent solid separation is easy. However, a large amount of chemicals and water are required in most of the chemical pretreatments, which need recycling of chemicals, disposal of waste solution, and sometimes high temperature and thus, could result in high facility investment, high treatment cost and potential environmental pollution [16,17]. Although, a large portion of glucose and xylose are degraded to hydroxymethyl furfural (HMF) and furfural, respectively, which are found to be inhibitory to microbial processes [4,18]. This review is based on various chemical pretreatment processes, their industrial applications in terms of the mechanisms involved, advantages, disadvantages and economic feasibility.

2. Necessity of pretreatment

The pretreatment process is required to break down the lignin structure and disrupt the crystalline structure of cellulose, so that the acids or enzymes can easily access the cellulose to hydrolyze into monomers [16,17]. Pretreatment allows to change the structure of the lignocelluloses such as increasing the surface area and porosity of biomass; modifying and removing the lignin, partially polymerizes and removes the hemicelluloses, and reduces the crystallinity of cellulose [19]. The pretreatment processes solely or in combination can enhance the bio-digestibility of the wastes for biofuel production, and increase accessibility to the enzymes [20,21]. It results in increase in digestibility of the difficult biodegradable materials, and improves the yield of ethanol or biogas from the wastes (Fig. 1).

Although the pretreatment is a most expensive process in biomass-to-fuels conversion, it has a great potential for improvement in the efficiency of the process and lowering of the cost through further investigations [22,23]. Recent investigations have clearly proven that there is a direct correlation between the removal of lignin and hemicelluloses and the digestibility of cellulose [24,13]. Theoretically, fractionation of any biomass species allows to solubilize the majority of the hemicelluloses into the solution, and leaves the cellulose fraction intact [25,26].

3. Pretreatment processes

Pretreatment methods can be divided into different categories: physical (milling and grinding), physic-chemical (steam explosion, hydrothermolysis, wet oxidation, etc.), chemical (alkali, dilute acid, oxidizing agents and organic solvents), biological, electrical, or a combination of these [13,22,23,27]. The schematic configuration of pretreatment is shown in Fig. 2. The following pretreatment

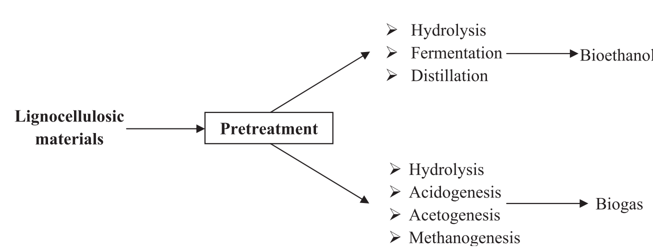

Fig. 1. Pretreatment of lignocellulosic materials prior to bioethanol and biogas production.