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Comparison of Chemical Pretreatment Methods for Cellulosic Biomass

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Abstract

The variety in physiochemical characteristics of cellulosic biomass reveals the need for pretreatment technologies to help in the rapid and efficient conversion of carbohydrate polymers into fermentable sugars. Suitable pretreatment methods enhance the enzymatic hydrolysis of biomass because of the crystalline structure of cellulose and the complex structure of lignin and hemicellulose. The choice of pretreatment method affects on the sugar yield, avoids the degradation of sugars derived from hemicellulose and minimize the formation of inhibitors for subsequent fermentation steps. A suitable process should minimize heat and power requirements to be cost effective in operation. The present review focuses on various chemical pretreatment methods for lignocellulosic biomass based on recent reports in literature. An analysis of the methods shows that the composition of biomass is the main factor in the selection of pretreatment method.

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Keywords: cellulosic biomass, cellulose, pretreatment, lignocellulosic, lignin, hemicellulose, enzymatic hydrolysis

1. Introduction

Lignocellulose biomass is a complex that mainly consists of cellulose, hemicellulose, and lignin [1]. The composition of these compounds directly depends on their source, whether hardwood, softwood, or grass. Cellulose with a particular crystalline structure that is insoluble in water is resistant to depolymerization.

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Hemicellulose, which provides structural backbone to plant cell wall, is a branched polymer of glucose or xylose. According to literature [2], cellulose and hemicellulose are probable sources of fermentable sugars. These sugars are first produced after a pretreatment process of cellulose polymer, followed by enzymatic hydrolysis. Lignin provides further strength to plant cell walls, but hinders the enzymatic hydrolysis of carbohydrates. Several chemical pretreatment approaches have been developed to remove hemicellulose and lignin and decrease the crystallinity of cellulose to enhance the biodegradability of cellulose and sugar yield in enzymatic hydrolysis to maximize the volumetric productivity of the cellulosic feedstock. Highly digestible solids that enhance sugar yields while avoiding the degradation of sugars and minimizing the formation of inhibitors for the subsequent fermentation steps are produced during the treatment process. These technologies are cost effective, with minimum heat and power requirements; they are also environment friendly [3]. This study aims to review promising chemical pretreatment methods with emphasis on suitable feedstock these methods are used for and the merits and disadvantages of each method. This paper shows the importance of the pretreatment process for the subsequent enzymatic hydrolysis and conversion of cellulosic feedstock to valuable products in fermentation. Fig. 1 represents the pretreatment steps that finally lead to the generation of sugars as substrates for biofuel production.

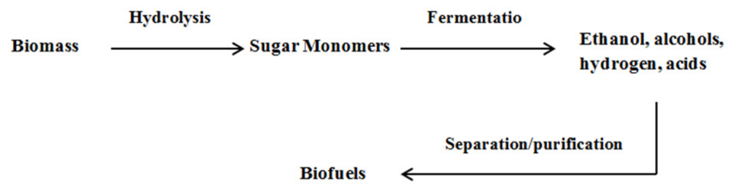

Fig 1. Schematic of the conversion of lignocellulosic biomass to fuel (4)

2. Acidic Pretreatment

Acid pretreatment usually involves the addition of concentrated or diluted acids of 0.2 w/w% to 2.5 w/w% to the biomass, and continually mixing at 130 °C to 210 °C. Dilute acid hydrolysis is performed in two different conditions, namely, high temperature (T > 160 °C) in continuous mode for low solid loading and lower temperature (T ≤ 160 °C) in batch mode for high solid loading [5]. In strong acid hydrolysis, concentrated strong acids such as H_2SO_4 and HCl are used without subsequent enzymatic hydrolysis. This reaction is carried out in mild temperature conditions with different types of feedstock and high sugar yield [6]. In dilute acid hydrolysis, the firm structure of the lignocellulosic materials is cracked, followed by the removal of hemicelluloses, which increases the porosity and enzymatic digestibility of biomass [7]. Organic salts can also be used in dilute acid treatment [8]. The key advantage of this method is the high solubility of hemicellulose and lignin in acid, with high yield of glucose without need for subsequent enzymatic hydrolysis [9]. However, the recovery of acids used in this process is expensive and corrosion-resistant equipment is costly [10]. In addition, inhibitors of fermentation such as hydroxyl methyl furfural are produced in high concentration, thereby reducing the effectiveness of this method [11]. The method is suitable for biomass with low lignin content because lignin is not removed from the biomass. Moreover, the optimal condition of the acid pretreatment is extremely important.

3. Alkaline Pretreatment

In this method, biomass is soaked in alkaline solutions, such as calcium, potassium, sodium and ammonium hydroxide and then mixed at a suitable temperature for a certain amount of time. This process