USE OF IONIC LIQUIDS FOR IMPROVEMENT OF CELLULOSIC ETHANOL PRODUCTION

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Cellulosic ethanol production has drawn much attention in recent years. However, there remain significant technical challenges before such production can be considered as economically feasible at an industrial scale. Among them, the efficient conversion of carbohydrates in lignocellulosic biomass into fermentable sugars is one of the most challenging technical difficulties in cellulosic ethanol production. Use of ionic liquids has opened new avenues to solve this problem by two different pathways. One is pretreatment of lignocellulosic biomass using ionic liquids to increase its enzymatic hydrolysis efficiency. The other is to transform the hydrolysis process of lignocellulosic biomass from a heterogeneous reaction system to a homogeneous one by dissolving it into ionic liquids, thus improving its hydrolysis efficiency.

Keywords: Lignocellulosic biomass; Ionic liquids; Ethanol production

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Technical Bottleneck for Economical Production of Cellulosic Ethanol

Cellulosic ethanol is the bio-ethanol that is produced from lignocellulosic materials including forest wastes, agricultural wastes, industrial wastes, and energy crops. It is a versatile solvent and an important chemical raw material, and it also can be used as a transportation fuel, thus reducing gasoline consumption. Unlike conventional grain-based ethanol, which is derived from crops such as corn, wheat, or soybeans, the cellulosic ethanol has a wide feedstock source and it does not cause food supply problems. At the same time, its production emits less greenhouse gases and has much higher net energy yield in comparison to conventional grain-based bio-ethanol production. Therefore, cellulosic ethanol production has drawn much attention in recent years. Although the cellulosic ethanol production was first industrialized in Germany in 1898 and much technical improvement has been made to lower its production cost, it is currently still facing significant technical challenges to make it economically feasible at an industrial scale, where it needs to compete with the conventional grain-based ethanol. Cellulosic ethanol production includes two sub-processes: saccharification and fermentation. Saccharification converts the carbohydrate in lignocellulosic biomass into fermentable sugars, and fermentation converts fermentable sugars into ethanol. The technical challenges for economical production of cellulosic ethanol involve two aspects: the efficient conversion of carbohydrate in lignocellulosic biomass into the fermentable sugars, and seeking suitable micro-organisms for ethanol fermentation. Relatively speaking, the former is more important in terms of reducing the overall process cost; not only is it relatively expensive, but it also affects the later fermentation process. Because of the strongly crystalline structure of cellulose and the presence of the complex structures of lignin and hemicellulose enmeshed with cellulose in lignocellulosic biomass, although extensive research work has been carried out to improve the saccharification process, the efficient conversion of carbohydrate in lignocellulosic biomass into the fermentable sugars is still a headache, and it becomes a technical bottleneck for economical production of cellulosic ethanol.

Use of Ionic Liquids for the Efficient Conversion of Carbohydrate in Lignocellulosic Biomass into Fermentable Sugars

Ionic liquids are a group of new organic salts that exist as liquids at a relatively low temperature (<100 ^{o}C). Interest in ionic liquids has grown steadily in recent years because their non-detectable vapor pressure and unique solvent properties provide the possibility for clean manufacturing in chemical-related industries, including the efficient utilization of lignocellulosic materials. A series of studies have shown that lignocellulosic materials or some of their components can be dissolved in such hydrophilic imidazolium-based ionic liquids as 1-butyl-3-methylimidazolium chloride, 1-allyl-3-methylimidazolium chloride, 1-benzyl-3-methylimidazolium chloride, and 1-ethyl-3-methylimidazolium acetate. The carbohydrate content of an ionic liquid solution can be easily recovered by addition of an anti-solvent, such as water and ethanol. After recovery of the carbohydrate, the ionic liquid can be reused or recycled. By controlling suitable carbohydrate recovery conditions, it can effectively reduce the crystallinity of cellulose in the recovered carbohydrate and remove the lignin. These studies have demonstrated that ionic liquids can be an effective technical tool for utilization of lignocellulosic materials.

As for cellulosic ethanol production, the use of ionic liquids has provided a new platform to improve the saccharification process for the efficient conversion of carbohydrates in lignocellulosic biomass into the fermentable sugars by two different pathways. One involves pretreatment of lignocellulosic biomass using ionic liquid, which can effectively remove the lignin and reduce the crystallinity of the cellulose; thus it has potential to significantly accelerate the rate of enzymatic hydrolysis of carbohydrate in lignocellulosic biomass and increase the yield of the fermentable sugars. The other pathway involves carrying out the hydrolysis of carbohydrate in lignocellulosic biomass in a homogeneous solution by dissolving it into ionic liquids. This is in marked contrast to the conventional approach, which involves a heterogeneous reaction, involving acid catalysis of enzymatic action at the interface between a liquid phase and the biomass. Whether chemical or enzymatic hydrolysis is adopted, the homogeneous hydrolysis process is carried out under relatively mild conditions; thus it can effectively increase the yield of the fermentable sugars and decrease the formation of byproducts that will have a negative effect on the later ethanol fermentation. However, the use of ionic liquids to improve the saccharification process is a relatively new technique, and it is still facing some technical challenges to become it as a commercially viable process. One of them is how to deal with the negative effects of ionic liquids on the hydrolysis enzyme stability and ethanol fermentation. In any case, the use of ionic liquids has provided a potential alternative to break the technical bottleneck for economical cellulosic ethanol production.