RESEARCH PAPER

Ethanol production from municipal solid waste

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A B S T R A C T:

The organic fraction of municipal solid waste (OFMSW) has a high potential for converting to ethanol. Hydrothermal pretreatment was conducted for the solubilization of the starch fraction as well as pretreatment of the lignocellulosic fraction. The treatment liquor, which was rich in starch, was evaluated for ethanol production through simultaneous saccharification and fermentation (SSF) process using Saccharomyces cerevisiae. Solid phase was subjected to a solid-state simultaneous saccharification and fermentation (SSSF) process to obtain high titer of ethanol, leading to several advantages, e.g., lower energy and water consumption as well as lower wastewater effluent. Hydrothermal pretreatment of OFMSW at 160 °C and 20% (w/w) solid loading for 30 min resulted in a liquor containing 124 g/L soluble starch. Both liquor and solid fractions were then subjected to ethanol production and 81 g/L ethanol was obtained.

KEY WORDS: Ethanol; Municipal solid waste; Hydrothermal pretreatment; Starch; Lignocellulosic.

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1. INTRODUCTION

Municipal solid waste (MSW) production is considered as a threat to environment due to rapidly growing world population and industrialization (Ballesteros et al., 2010; Fargione et al., 2008). MSW, contained high amount of biodegradable fraction, has a high potential for bio-converting to value-added products, e.g., biofuels. Recently, ethanol production from organic fraction of MSW (OFMSW) has attracted great attention as an advanced biofuel, addressing some challenges in MSW disposal; due to its superior properties compared to landfills and other widely use processes (Mahmoodi et al., 2018; Alter, 1991).

Appreciable amount of ethanol was produced from OFMSW through the process involving consequent stages, i.e., dilute acid or hot water pretreatment, submerged liquid ethanol fermentation of the starch-rich liquor, the enzymatic hydrolysis of pretreated solids, and submerged liquid ethanol fermentation of the lignocellulosic hydrolysate, resulted in production of more than 194 g and 191 g from each kg OFMSW after dilute acid and thermal pretreatment, respectively (Mahmoodi et al., 2018; Mahmoodi et al., 2018a). Whereas, submerged liquid fermentation and separated scarification and fermentation have several advantages, e.g., mixing and control of pH, the solid-state simultaneous scarification and fermentation (SSSF) can be used as simpler, less energy consumption, high substrate concentration, and less wastewater effluent processes (Canabarro et al., 2017; Lever et al., 2010). Moreover, low ethanol titer and consequently high cost of ethanol distillation is the most important challenge deals with the...
submerged process (Galbe and Zacchi, 2007). It has been reported that ethanol distillation separation technique was feasible from the economical point of view when the ethanol concentration was more than 4% (w/w) (Galbe et al., 2007; Zhao et al., 2011). Increasing ethanol concentration from 1% to 5% was accompanied with more than 67% reduction in energy demand through distillation process with outlet concentration of 95% (w/w) (Zacchi and Axelsson, 1989; Kang et al., 2015). Generally, a high concentration of biomass (>15%) in SSF process is essential for obtaining a higher ethanol titer (Kang et al., 2015; Wingren et al., 2003). Besides, some technical challenges, e.g., difficulty in mass and heat transfer, were against solid-state fermentation, which could be solved by applying appropriate pretreatment before SSSF process and suitable microorganism to enhance ethanol production yield through high solid loading fermentation (Akhtar et al., 2017; Krishna, 2005). The enzyme accessibility of lignocellulosic fraction was improved through pretreatments and cellulose digestibility was increased. Among several pretreatment methods, hydrothermal pretreatment has several advantages over the chemical pretreatment processes, which includes not using any chemicals and lower formation of fermentation inhibitors, formed mainly through sugar degradation (Taherzadeh and Karimi, 2008). Besides, the accessibility of cellulose to enzyme was increased through the pretreatment by removing appreciable amount of hemicellulose (Mosier et al., 2005).

To our knowledge, no previous study has applied hydrothermal pretreatment and Saccharomyces cerevisiae in the SSSF of organic fraction of municipal solid waste to produce high titer ethanol. The purpose of this study was efficient bioethanol production from OFMSW pretreated by hot water through SSSF using S. cerevisiae. The effects of important factors, e.g., solid loadings of pretreatment, on glucose and ethanol yields were investigated.

2. Materials and Methods

2.1 Raw Material

In this study, municipal solid waste was collected from Isfahan MSW landfill site (Isfahan, Iran) in summer 2016. The organic fraction of municipal solid waste (OFMSW) was prepared by separating other inorganic materials (around 37%), e.g., metal, glass, plastic, newspaper, cardboard, and paper. Dried OFMSW which was dried at room temperature was milled and screened to different particle size of between 833 μm (20 mesh) and 177 μm (80 mesh).

2.2 Hydrothermal pretreatment

Hydrothermal pretreatment was performed in a 500 mL stainless steel reactor with an oil bath. Hydrothermal pretreatment was carried out with deionized water at 160 °C for 30 min (according to the optimum conditions in the previous study (Mahmoodi et al., 2018a), which the solid loading was 10, 14.3, and 20%. After pretreatment, the slurry was filtered to obtain two fraction: solid fraction and liquid fraction. Afterward, the solid fraction was deep dried using freeze-dryer (Christ, alpha 1-2 LD model, Germany) for 24 h. The composition of several components of dried solid, e.g., starch, structural carbohydrates, and lignin, were determined according to the standard methods (NREL). Sugars components in the liquid fraction were analyzed by high-performance liquid chromatography (HPLC).

2.3 Solid- state simultaneous saccharification and fermentation (SSSF)

The pretreatment solid fraction with 15% solid loading was subjected to SSF process at 37 °C for 96 h. The experiments were carried out in 0.05 M sodium citrate buffer supplemented with 1 g/L CaCl2.H2O, 5 g/L yeast extract, 7.5 g/L (NH4)2SO4, 3.5 g/L KH2PO4, and 0.75 g/L MgSO4·7H2O. Then, this solution was autoclaved at 121 °C for 20 min. After cooling the solution, 15 FPU enzyme mixture per gram of dry OFMSW, 1 g/L tween 20, and 5 g/L S. cerevisiae. The enzyme mixture was contained to Cellic® CTec2 and HTec2 (Novozyme A/S, Denmark) with a 9 to 1 ratio, respectively. The enzyme mixture activity was 113.5 FPU per mL.

The pretreatment liquid fraction in the first step was subjected to liquefaction process using the commercial enzyme of α-amylase (Liquezyme), provided by Novozymes A/S, Denmark, with 1 g/L CaCl2 (as a co-factor) at 90 °C for 2 h. Then, the liquor supplemented with nutrients, glucoamylase enzyme (Dextrozyme GA, Novozymes, Denmark), 1 g/L tween 20, and 5 g/L S. cerevisiae was incubated at 37 °C and 130 rpm.
for 96 h. All experiments were performed with two replicates.

2.4 Analytical methods

The concentration of sugars and ethanol were determined by HPLC with a refractive index (RI) detector (Jasco International Co., Tokyo, Japan). Ethanol, acetic acid, and glycerol were analyzed on an Aminex HPX-87H column (Bio-Rad, Richmond, CA, USA) at 60 °C by 0.005 mol/L sulfuric acid as a mobile phase with a 0.6 mL/min flow rate. Glucose, xylose, mannose, arabinose, and galactose were analyzed by Aminex HPX-87P column (Bio-Rad, Richmond, CA, USA) at 80 °C by 0.6 mL/min demineralized water as an eluent.

3. Results and Discussion

The aim of this study was the high titer ethanol production from OFMSW and reduction of energy consumption as well as water consumption. Therefore, after hydrothermal pretreatment at various solid loading at optimum conditions (160 °C for 30 min) reported in previous study (Mahmoodi et al., 2018a), the solid and liquid phase were separated. Next, the liquor and solid phase were subjected to SSF and SSSF process using S. cerevisiae, respectively.

3.1 Hydrothermal pretreatment of OFMSW

Hydrothermal pretreatment was conducted at different solid loading (10, 14.3, and 20% (w/w)) and 160 °C for 30 min. the pretreatment was accompanied by the solubilization of the starchy fraction as well as the pretreatment of lignocellulosic, which was improved the structure of lignocellulosic fractions.

3.2 SSSF process

The pretreated solids at different conditions were subjected to SSSF process with solid loading of 150 g/L at 37 °C for 96 h. the complex of cellulase and hemicellulases enzymes with cellulase activity of 15 FPU per g dry weight of substrate was added to the fermentation broth to hydrolyze cellulose content of pretreated solids. Monomeric sugars, were simultaneously utilized by S. cerevisiae (5 g/L) and converted to ethanol. Along with the solid phase directly fermented for ethanol production through SSSF process, the liquors remaining after hydrothermal treatments of OFMSW were subjected to liquefaction step by α-amylase, and then fermented to ethanol via SSF process by glucoamylase and S. cerevisiae (5 g/L). Fig. 1 shows the concentration of produced ethanol during 96 h fermentation process for the fermentation of both liquid and solid phase. as well as utilized glucose

Even though the fermentation was conducted for 72 h, more than 84% of ethanol production from OFMSW was obtained before 48 h fermentation. As can be seen from the figure, hydrothermal pretreatment of OFMSW with 10-20% (w/w) solid loading followed by SSSF process of pretreated solids was accompanied with 76-90% higher ethanol concentration compared to that produced from untreated OFMSW. The fermentation of pretreated solid with 10% solid loading through SSSF process resulted in the production of 31.7 g/L ethanol which was 90% higher than that obtained from SSSF fermentation of untreated OFMSW. Whereas, increasing the solid loading from 10% to 20% resulted in 7% reduction of ethanol concentration through the SSSF process of pretreated solids, the ethanol concentration was increased by more than 86% from SSF process of the liquors. This may be due to the higher concentration of starch in liquor through higher solid loading pretreatment. The highest amount of ethanol, 249 g per each Kg dry untreated OFMSW, was produced from SSF process of the liquor obtained from the hydrothermal pretreatment at 160 °C for 30 min with 10% solid loading. However, the highest ethanol concentration from the SSF process of liquors obtained after pretreatment at 20% solid loading. It means that higher ethanol concentration did not necessarily mean higher yield of ethanol production, i.e., the amount of total ethanol on the base of raw material. Fig. 2 shows the concentration of utilized glucose during 96 h fermentation process for the fermentation of both liquid and solid phase.

The overall yields of ethanol based on 1 Kg of untreated OFMSW from both solid and liquid phase after hydrothermal pretreatment at different solid loadings are shown in Table 1. When the
liquors and solids, obtained from hydrothermal pretreatment (10% solid loading) of OFMSW, were separately subjected to SSF and SSSF process, respectively, the total produced ethanol was 300 g per each Kg of dry untreated OFMSW, which was 79% of theoretical yield. The amount of ethanol achieved through these processes are significantly higher than those reported for SSF process of steel bread by S. cerevisiae, where 250 g ethanol was obtained from each Kg of dry untreated material (Kumar et al., 1998). Also, using kitchen garbage with relatively higher starch content (46%) for ethanol production accompanied with the production of 230 g ethanol per each Kg of dry untreated materials through SSF process (Wang et al., 2008).

4. CONCLUSIONS

High titer ethanol could be produced from OFMSW through a hydrothermal pretreatment, an environmental friendly method, followed by SSSF and SSF process. The liquor released from hydrothermal pretreatment, containing high concentration of soluble starch. The pretreated solid could also be used for ethanol production in SSF and SSSF process, respectively. After pretreatment at 20% (w/w) solid loading, ethanol production through both SSF and SSSF of liquor and pretreated solid with S. cerevisiae was more than 70% of theoretical yield. Moreover, the highest ethanol titer, 52 g/L, was produced during the SSF process of the liquor. Generally, a high yield of 7.4 MJ energy was obtained through interesting process from environmental and economic point of view based on each Kg of dry OFMSW.

Table 1. The amount of produced ethanol from each Kg of dry OFMSW after hydrothermal pretreatment at different solid loading and 160 °C for 30 min.

| Solid loading (% w/w) | Produced ethanol from the liquid fraction of pretreatment (g) | Produced ethanol from the solid fraction of pretreatment (g) |
|-----------------------|-------------------------------------------------------------|-------------------------------------------------------------|
| 10                    | 249.3                                                       | 50.3                                                        |
| 14.3                  | 224.4                                                       | 68.8                                                        |
| 20                    | 206.4                                                       | 69.2                                                        |

Figure 1. (a) Ethanol concentration during 96 h SSSF of pretreated OFMSW and (b) ethanol concentration during 96 h SSF of liquid of pretreatment by S. cerevisiae. The symbols indicate these conditions: (▲) 10% solid loading, (■) 14.3% solid loading, and (●) 20% solid loading in the dilute-acid pretreatment of OFMSW as well as (×) untreated OFMSW.

Figure 2. (a) Glucose concentration during 96 h SSSF of pretreated OFMSW and (b) glucose concentration during 96 h SSF of liquid of pretreatment by S. cerevisiae. The symbols indicate these conditions: (▲) 10% solid loading, (■) 14.3% solid loading, and (●) 20% solid loading in the dilute-acid pretreatment of OFMSW as well as (×) untreated OFMSW.

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