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Recovery of lactic acid and other organic acids from food waste ethanol fermentation stillage: Feasibility and effects of substrates

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ABSTRACT

Recycling ethanol fermentation stillage from food waste could help to resolve the pollution problems, but it would lead to the accumulation of lactic acid (LA), which had a negative effect on ethanol fermentation. In this study, bipolar membrane electrodialysis was used to recover LA as well as other fatty acids in the stillage, and the corresponding parameters that affected this process were investigated. Pretreatment via centrifugation and ultrafiltration reduced the turbidity successfully. Experiments on simulated and real stillage showed that organic acids such as formic acid and acetic acid had a slight effect on the separation of LA, but the existence of chloride ions could form strong anion competition with lactate ions. Simulation experiments with sodium chloride reduced the recovery of LA from 98% to 92%. The recovery rate of LA from real stillage could reach 71.2%. After electrodialysis, the stillage can be reused in ethanol fermentation, the fermentation time was shortened to 24 h, and the ethanol yield increased.

1. Introduction

For the sustainable development of society, the recycling of waste has become more and more important. Food waste (FW) accounts for a large proportion of municipal solid waste (15%–63%) [1]. It has high organic, volatile solid (85%–95%), and moisture content (75%–85%) and is easily degraded and deteriorated. There are many ways of reusing the waste, such as composting and production of pig feed, biomethane, biodiesel, ethanol, and lactic acid (LA) [2].

The use of FW to produce ethanol can take full advantage of the rich nutrients in FW and obtain fuel. However, a large quantity of stillage will be produced; one way for dealing it is stillage recycle fermentation [3]. This method can reduce pollution and utilize proteins, amino acids, and various metal ions in stillage [4]. In our previous study, LA was determined to be the major accumulated by-product along with stillage recyling. A significant inhibition phenomenon was observed after 5 times recycling. Although the addition of calcium carbonate could alleviate the influence of LA on ethanol fermentation, if we can separate the accumulated LA in the stillage, it will provide better economic benefits.

LA is an important natural organic acid. It has received increasing attention as one of the most important building blocks for the production of polylactic acid [5,6]. At present, the main methods of LA production are microbial fermentation and chemical synthesis. Biological fermentation is inexpensive, utilizes a wide range of raw materials, and produces optically pure L- or D-lactic acid, which make it superior to chemical synthesis. More attention has also been paid to the utilization of renewable carbohydrates as a carbon source for LA fermentation [7,8]. However, the major cost of LA production is due to its downstream separation and purification steps [9]. As LA exists in the form of lactate salt in the fermentation broth, acidification and removal of impurities are required for future separation [10].

The extraction methods of LA include precipitation, solution extraction, adsorption, distillation, and nanofiltration [11]. Electrodialysis has the advantages of diversity, sophisticated functions, and technological compatibility [12,13]. Danner et al. used monopolar electrodialysis to extract LA from grass silages and obtained press extraction yields of 31–96 g of lactate per kilogram of silage dry matter (g LA/kg DM) [14]. Chen used conventional electrodialysis (CED) to remove 80% lactate from acid whey [15]. Lopez-Garzon used bipolar membrane electrodialysis (BMED) to recycle LA and other carboxylic acids in the fermentation broth [16]. BMED is known as an energy-saving process because it can directly convert electrolyte salts into corresponding acids and bases without the addition of any other chemical agents [17]. The main factors affecting electrodialysis are pH, current, velocity, and concentration ratio. In the stillage, a lot of

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organic acids such as lactic acid, formic acid, acetic acid, and propionic acid are found. BMED can conduct simultaneous recovery of various acids, but there are few studies on the effects of various acids under electrodialysis on the extraction of LA. Furthermore, the effects of other components in the stillage from FW ethanol fermentation would also be investigated.

In this study, the ethanol fermentation stillage from FW was used as the raw material to extract LA. It contained a large amount of suspended solids, oils, and fats, and a small amount of residual sugar, protein impurity, and amino acids [18,19]. The ion exchange membranes (IEMs) of electrodialysis have poor pollution resistance; in addition, the presence of various impurities will increase the viscosity of the crude liquor and affect the turbulence level of the solution [20], leading to a decrease in membrane performance and an increase in running costs [21]. Therefore, stillage pretreatment is necessary before electrodialysis. Zhang used a flocculation–filtration system to treat FW fermentation broth and reduce SS and oil content [22]. Kim centrifuged the fermentation liquid to remove the suspended matter, followed by nanofiltration [10]. Many studies have used ultrafiltration (UF) for liquid purification, for example, coagulation–UF process for wastewater reclamation to remove viruses [23], UF membranes for raw apple juice purification [24], and UF for removing the residual lignin in ionic liquid solution, followed by electrodialysis to recover the ionic liquid 1-butyl-3-methylimidazolium bromide [25].

In the present study, the feasibility of using electrodialysis to separate LA from FW stillage was studied. The influence of different substances in the stillage on electrodialysis and recovery of lactic acid was studied by simulation experiments. Simultaneous recoveries of formic acid, acetic acid, and propionic acid in stillage were also compared, and the factors affecting the recovery rate of organic acids were investigated.

2. Materials and methods

2.1. Raw materials

In this experiment, the raw material for LA extraction is the fifth batch of stillage after distillation from FW ethanol fermentation. The specific stillage recycling fermentation procedure is shown in Fig. 1, and the fermentation procedure was described in our previous article [2]. Fig. 1 shows the process and the fifth batch of stillage used for pretreatment and electrodialysis (on the right in Fig. 1).

Table 1
The characteristics of the fifth batch stillage.

Item	Unit	Value
TCOD	kg COD/m^3	161 ± 11
SCOD	kg COD/m^3	146 ± 9
Total Solids (TS)	kg TS/m^3	17 ± 4
Volatile Solids (VS)	kg VS/m^3	14 ± 4
Total Nitrogen (TN)	kg N/m^3	10.6 ± 0.3
Organic acids	kg COD/m^3	112 ± 7
pH	–	4.1 ± 0.4

The properties of the stillage used in the experiment are summarized in Table 1. TS was approximately 17 kg TS/m^3, the organic acid content was approximately 112 kg COD/m^3, and the main component was LA, with a concentration of 92 ± 10 g/L.

2.2. Pretreatment of stillage

High-speed centrifugation was used to remove suspended solids with a rotation rate of 4000 rpm for 15 min. The supernatant was collected for UF. A hollow fiber UF device (Tianjin MOTIMO Membrane Technology Co., Ltd.) was used in the study. The device consisted of one module equipped with a tubular PVDF membrane with pore size and membrane surface area of 0.2 µm and 0.5 m^2, respectively. The stillage was injected into the UF membrane via a peristaltic pump with a flow rate of 100 rpm. When the system pressure reached 20–40 kPa and remained stable, the solution was collected and turbidity was measured. At the end of the experiment, the UF membrane was alternately washed with acid and alkali solution. Finally, 1% sodium bisulfite-filled membrane modules were used to prevent bacterial growth.

2.3. Electrodialysis by bipolar membrane equipment

A laboratory-scale BMED instrument was used (Shandong Tianwei Membrane Technology Co., Ltd.), with a membrane surface area of 10 cm × 20 cm and an effective area of 80%, it was assembled with 10 cell pairs. In the membrane stack, bipolar membranes (FUMATECH, Germany) and cation exchange membranes (Shandong Tianwei Membrane Technology Co., Ltd.) were arranged alternately. To adjust the conductivity at the beginning of the experiment, 10 g/L of LA was

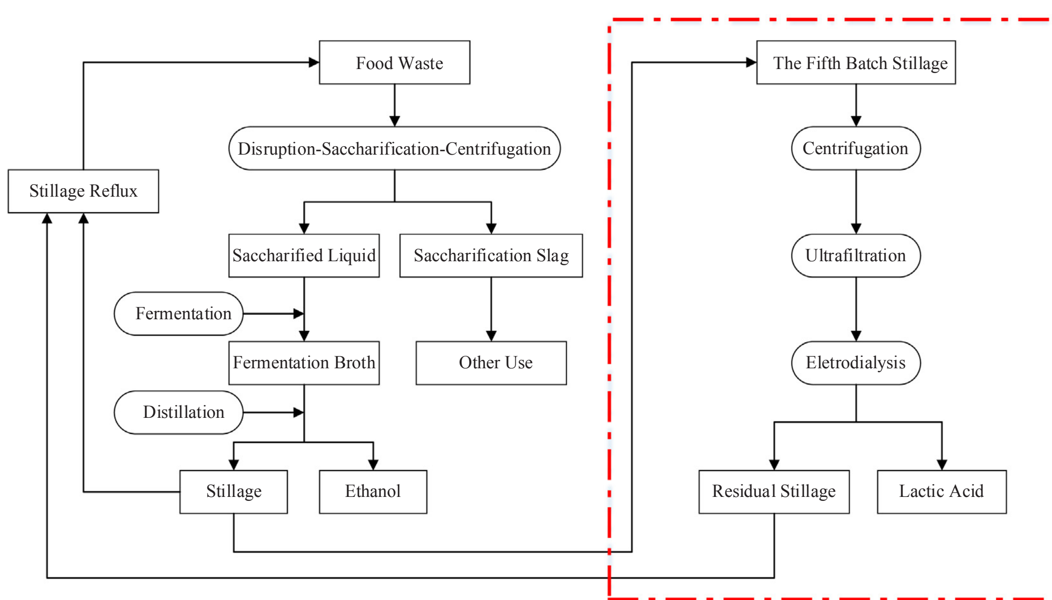

Fig. 1. Technology roadmap in this study.