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Economic feasibility of a pilot-scale fermentative succinic acid production from bakery wastes

Koon Fung Lam[a], *Cho Chark Joe Leung*[b], *Ho Man Lei*[c], *Carol Sze Ki Lin*[b,*]

[a] *Department of Chemical Engineering, University College London, Torrington Place, WC1E 7JE London, United Kingdom*
[b] *School of Energy and Environment, City University of Hong Kong, Tat Chee Avenue, Hong Kong*
[c] *Department of Chemical and Biomolecular Engineering, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong*

ABSTRACT

In this paper, the techno-economic study for a pilot-scale production of succinic acid from food waste via fermentation was evaluated. The pilot plant was based in Hong Kong and designed for converting 1 tonne/day of bakery waste into succinic acid. The mass and energy balance of the process was simulated by computer package SuperPro Designer®. The total capital investment for the plant and the total production cost were US$ 1,118,243 and US$ 230,750/year respectively. Overall revenue generated from the process was US$ 374,041/year. The return on investment, payback period and internal rate of return of the project were 12.8%, 7.2 years and 15.3% respectively. The findings indicated that the fermentative succinic acid production from bakery waste was feasible. This is important for attracting investment and industrialization interest on the biorefinery process using domestic wastes as raw materials.

Keywords: Biorefinery; Food waste; Fermentation; Platform chemical; SuperPro Designer®

1. Introduction

Disposal and utilization of food waste, which is defined as any uneaten food or food preparation residues from residences or commercial establishments, is one of the major global challenges, particularly in Southeast Asian countries (Ngoc and Schnitzer, 2009). Adhikari et al. (2006) carried out a study which correlated the gross domestic product (GDP) of a country and the quantity of the food waste generated. The authors forecasted that the food waste problem of Asian countries in the coming decade is worse than elsewhere in the World due to the rapid economic development in the region. For instance, in Beijing, generation of municipal solid waste (MSW) increased by almost 4 times over the past three decades and the contribution of food waste was doubled between 1989 and 2006 (Li et al., 2009).

Similar to many other metropolitan cities, Hong Kong is facing an imminent and serious waste management problem. In 2009, 3,300 tonnes of food waste, as the second largest waste category, was produced and it contributed to 25% of the waste disposed to landfill (HKCAS, 2010). A worse situation is that the amount of food waste arising from the commercial and industrial sectors has been increasing steadily based on the fact that the food waste amount in 2009 was doubled as compared to the amount in 2002 (Lin et al., 2013).

Landfill, incineration and composting are common, mature technologies for waste disposal. However, they are not satisfactory for treating food waste due to the generation of toxic methane gas and bad odour, high energy consumption and slow reaction kinetics respectively. In fact, research effort has also been put on the new technology for decomposition of food waste (Yun et al., 2000). However, no valuable product is generated from the decomposition process.

Instead of disposing and decomposing the food wastes, recent research focused on utilizing it as an energy source (Iacovidou et al., 2012). Similar to the production of

* Corresponding author. Tel.: +852 3442 7497; fax: +852 3442 0688.
E-mail address: carollin@cityu.edu.hk (C.S.K. Lin).
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bio-ethanol from agricultural wastes which has been proven to be economically feasible (Bohlmann, 2006; Dutta et al., 2010). Food wastes can also be easily assimilated by microorganisms, because they are rich in sugars, vitamins and minerals. This makes food wastes suitable as raw materials for the production of secondary metabolites of industrial significance by microorganisms in controlled environments. For instance, Kapdan and Kargi (2006) reviewed the production of bio-hydrogen from various organic materials including food waste. Techno-economic evaluation of hydrogen production using potato steam peels (Ljunggren and Zacchi, 2010a) and beverage wastewater (Li et al., 2012) showed that the fermentation process was economically feasible. Ljunggren and Zacchi (2010b) further improved the economic attractiveness of the hydrogen production from starch-based food waste by digesting anaerobically the un-utilized biomass for producing methane. On the other hand, methane production from mixture of dairy manure and food waste was also reported (El-Mashad and Zhang, 2010).

In addition to the energy application, organic waste is useful for production of commercialized organic chemicals via biorefinery or white biotechnology, which defines as the production by means of fermentation or enzymatic conversion on a larger scale (Hermann and Patel, 2007). For instance, low-value by-product, glycerol, from bio-diesel production was successfully converted into value-added products via fermentation process such as succinic acid (Vlysidis et al., 2009, 2011a, 2011b) and bio-plastic (Posada et al., 2011). It is found that the co-production of the succinic acid increases the profit of a biodiesel plant by 60% (Vlysidis et al., 2009). Meanwhile, Wensel et al. (2011) reported an industrial-scale process design for production of succinic acid from agricultural wastes.

From the viewpoint of food waste management, Hang (2004) has suggested making use of the large quantities of liquid and solid wastes (food processing residues, FPR) from food industry for production of valuable bio-products. For example, fermentative production of lactic acid from a mixture of restaurant food waste, bakery by-product, barley and wheat bran was demonstrated (Yang et al., 2006). Also, a membrane integrated process for lactic acid production from sugarcane juice was economically evaluated using pilot plant scale technical data (Sikder et al., 2012). Production of biopolymer from various food industry wastes and agricultural crops is shown to be technically and economically feasible for replacing petroleum-derived plastics (Lopez Garcíaa et al., 2012). Similarly, our previous research shows that succinic acid could be produced from wheat-based and cereal-based renewable feedstocks (Du et al., 2008; Dorado et al., 2009; Lin et al., 2012).

Recently, we demonstrated that succinic acid (SA) can be produced by fermentation of bakery waste and the overall yield (1.16 g SA/total sugar) is the highest among other food waste-derived media (Leung et al., 2012; Zhang et al., 2013). In the light of the technical feasibility, the objective of this work is to evaluate the economic feasibility of the whole production process including down-stream separation and purification using computer simulation. Profitability of a pilot-scale facility to be built in Hong Kong for treating bakery waste is assessed.

2. Methodology

To evaluate the economic feasibility of succinic acid (SA) production from bakery waste, the total capital investment, total production cost and profitability of the production process were estimated. Mass and energy balance required for the estimation was simulated using the computer software SuperPro Designer 8.0. The process began with feeding 1 tonne/day of bakery waste, which was the quantity of the bakery waste collected by the Hong Kong Organic Waste Recycling Centre (HKOWRC). The plant was to be built in Hong Kong and the construction phase of the plant was 1 year. The operating lifetime of the plant was assumed to be 20 years and it operated for 312 days/year (85% of the plant utilization). The down time was for regular maintenance and engineering work. The cumulative cash flow diagrams were generated using Microsoft Excel 2010.

2.1. *Process description*

The proposed succinic acid production process in this study was reported in our previous publication (Leung et al., 2012) and the process flow is depicted in Fig. 1.

The process started by grinding of the incoming bakery wastes into pieces smaller than 1 cm^3. The bread was then blended in process water which provided a liquid medium for the subsequent enzymatic reaction at 55 °C for 24 h. Industrial-grade glucoamylase was added to the vessel (R-101 in Fig. 1) to speed up the hydrolysis of α-1,4 and α-1,6 glucosidic linkages and eventually produce β-D-glucose from starch and other polysaccharides. Meanwhile, industrial-grade protease was used to hydrolyse peptide bonds present in the bread waste to release amino acids. After the hydrolysis process, solid content of the paste was separated by centrifugation at 7000 rpm for 15 min to produce bakery hydrolysate. Small amount of oil (i.e. 3.8 wt% of the hydrolysate) was also removed. The aqueous supernatant was transferred to a fermenter (FR-101) for SA production. *Actinobacilus succinogenes* was used for the fermentative production of succinic acid. Before the fermentation, adequate quantity of *A. succinogenes* was obtained via laboratory-scale shake-flask incubation, followed by seed fermentation with supply of essential nutrients including glucose, vitamins and minerals. The required inoculum size for the fermentative SA production was 5% (v/v). Based on our previous finding, the optimal time for the fermentation at 37 °C was 44 h. Continuous supply of carbon dioxide was needed for the anaerobic reaction. Also, magnesium carbonate and sodium hydroxide were used to control the pH of fermentation broth. The experimental result showed that the overall yield of the production was 0.55 g SA per g bread. Indeed, the yield achieved using waste bread is so far the highest among the SA production using other food waste-derived media. The SA concentration of the resultant broth was 47.3 g SA/L and SA crystals with purity >99% was obtained via a novel-resin based distillation and crystallization process (Lin et al., 2010).

Solid–liquid separation by centrifugation is the first step of the down-stream process. Biomass (solid fraction of fermentation broth from both fungal and bacterial fermentations) was sold to the fish farm nearby the plant. Protein impurities and colour-like compounds that contributed to the dark brown colour of the fermentation broth was removed by adsorption using granulated activated carbon (GAC) and there was around 0.5% of SA was lost at this stage (Wensel et al., 2011). Furthermore, organic acids produced as a waste product from the microorganism were selectively removed via an ion-exchange process in which the pH of the broth was fine-tuned so it was above the pKa of the organic acids and below the pKa of SA. After the adsorption process, more than 97% of the water in the clean broth was separated by a flash drum operated