Dear Friends,

The diagrams are from a thesis by Erica Carlsson that worked on the LCA of producing SA from food waste. The succinic acid paper refers to this paper in terms of inventory and diagrams. Erica herself also refers to the paper by Lam et al. which is about producing SA from bread waste. I mean that we can use Carlsson and Lam’s papers as previous references. There is a little difference in their inventories.

Diagram

Description automatically generated

*Figure 4: Simplified flowcharts of Option 2: FW to SA*

*(Erica Carlsson)*

Diagram

Description automatically generated

*Figure A.3: Simplified flowchart of Option 2: FW to SA. The dashed lines indicate the system boundary while the solid lines indicate the foreground respectively background system. (Modified after Lam et al (2014)) (Erica Carlsson)*

Graphical user interface

Description automatically generated with medium confidence

*Figure B.2: Detailed flowchart of the foreground system of Option 2: FW to SA. (Modified after* *Lam et al (2014)) (Erica Carlsson)*

***Process Description***

The process started by grinding of the incoming bakery wastes into pieces smaller than 1 cm3. The bread was then blended in process water which provided a liquid medium for the subsequent enzymatic reaction at 55 ◦C for 24h. Industrial grade glucoamylase was added to the vessel to speed up the hydrolysis of α 1,4 and α1,6 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 15min 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 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 44h. 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 at 105 ◦C and 1.2 atm, resulting in the raw SA product which consisted of 44 wt% of water. After cooling the raw product liquid stream to 4 ◦C, the supersaturated SA was crystallized to form the SA crystals. The residue solution was recycled and fed to the flash drum whereas the wet SA crystals were finally dried by a tray dryer to obtain anhydrous SA crystals as the final product. Since the operating conditions of most equipment were mild, heat integration was not considered for simplification in this study (*Lam et al (2014) Economic feasibility of a pilot-scale fermentative succinic acid production from bakery wastes).*

Table 1

Life cycle inventory (LCI) data for the production of 1 kg SA (data compiled based on information from [Lam et al. (2014)](#_bookmark13) and [Carlsson (2016)](#_bookmark17)).

Table

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(This table belongs to the article written by: Gadkari et al. 2021. Life cycle analysis of fermentative production of succinic acid from bread waste)

*Table 1: The main LCI results, inputs and outputs for processing 1 tonne of food waste, d.m. respectively production of 1 tonne SA crystals. (Erica Carlsson 2016)*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **LCI Results** | **Option 1:**  **FW to biogas** | **Option 2:**  **FW to SA** | **Option 2:**  **FW to SA** | **Unit** |
| 1 tonne processed FW, d.m. | 1 tonne processed FW, d.m. | 1 tonne produced SA crystals |
| **Inputs** | | | | |
| Mixed food waste | 3.3 | 3.3 | 7.4 | tonne |
| Landfill gas | 364 | n/a | n/a | kWh |
| Fuel oil | 1.7 | n/a | n/a | kWh |
| Electricity | 258 | 274 | 611 | kWh |
| Water | 2.6 | 32 | 71 | tonne |
| Enzymes | n/a | 1.8 | 4.1 | kg |
| DDGS | n/a | 1.1 | 2.4 | tonnes |
| Steam | n/a | 11.0 | 24.5 | tonnes |
| Propagated E.Coli | n/a | 0.07 | 0.17 | kg |
| MgCO3 | n/a | 74.2 | 166 | kg |
| NaOH | n/a | 53.4 | 119 | kg |
| CO2 | n/a | 139 | 311 | kg |
| HCl | n/a | 21.4 | 47.7 | kg |
| NaCl brine | n/a | 4.1 | 9.1 | tonnes |
| NREU | 2.1 | 4066 | 9075 | MJ-eq |
| REU | 0.95 | 308 | 687 | MJ-eq |
| **Outputs** | | | | |
| Biogas (sold share) | 1195 | n/a | n/a | kWh |
| Liquid biofertiliser | 3.24 | n/a | n/a | tonnes |
| Solid biofertiliser | 0.01 | n/a | n/a | tonnes |
| Solid residue | 0.13 | n/a | n/a | tonnes |
| SA crystals | n/a | 0.4 | 1.0 | tonnes |
| Biomass | n/a | 2.9 | 6.4 | tonnes |
| **Emissions to air** | | | | |
| Nitrogen oxides | 0.057 | 597 | 1333 | g |
| Ammonia | 0.005 | 75 | 166 | g |
| Sulfur dioxide | 0.060 | 608 | 1357 | g |
| Carbon dioxide, fossil | 0.019 | 194 | 434 | kg |
| Carbon dioxide,  biogenic | 0.024 | 9.7 | 21.6 | kg |
| Methane, fossil | 0.041 | 998 | 2228 | g |
| Methane, biogenic | 0.011 | 11 | 25 | g |
| Chromium VI | 0.003 | 20 | 46 | mg |
| Arsenic | 0.019 | 128 | 285 | mg |
| PAH | 0.007 | 113 | 253 | mg |

**References**

Lam, K.F., Leung, C.C.J., Lei, H.M., Lin, C.S.K., 2014. Economic feasibility of a pilot scale fermentative succinic acid production from bakery wastes. Food Bioprod. Process. 92 (3), 282–290

Carlsson, E., 2016. LCA of existing and emerging routes to bio-based chemicals master’s thesis. Chalmers University of Technology, Gothenburg, Sweden.