Available online at www.sciencedirect.com

SciVerse ScienceDirect

http://www.elsevier.com/locate/biombioe

BIOMASS & BIOENERGY

Techno-economic analysis of succinic acid production using adsorption from fermentation medium

Çağrı Efe [1], *Luuk A.M. van der Wielen, Adrie J.J. Straathof* *

Department of Biotechnology, Delft University of Technology, Julianalaan 67, Delft, The Netherlands

ARTICLE INFO

Article history:
Received 16 August 2011
Received in revised form
3 June 2013
Accepted 7 June 2013
Available online 2 July 2013

Keywords:
Succinic acid
Process analysis
Production cost
Fermentation
Adsorption
Zeolite

ABSTRACT

Fermentation of renewable resources is becoming increasingly attractive for production of C_4 bulk chemicals. One interesting C_4 building block is succinic acid. This study presents a conceptual design of a process for succinic acid production. The process begins with aerobic fermentation using a hypothetical *Saccharomyces cerevisiae* strain at pH 4. After centrifugation the broth is sent to adsorption. A ZSM-5 zeolite is used to preferentially adsorb succinic acid. Desorption is performed using hot water. This water is then flashed off, and succinic acid is crystallized and dried. The plant capacity is set to 30 kt a^{-1} according to the projected demand. Cane sugar is the selected feedstock. The calculated selling price of succinic acid is 2.26 \$ kg^{-1} with the potential to decrease to values as low as 1 \$ kg^{-1}. Major recommendations include experimental investigation of the feasibility of the metabolic engineering of the *S. cerevisiae* strain, of the fermentation parameters, of the crystallization, and of the process integration.

1. Introduction

Fermentative production of succinic acid is one of the most attractive options to replace the fossil oil-based production of bulk chemicals by bio-based production [1–4]. Traditionally, succinic acid fermentation has been performed at neutral pH, and high titers and yields have been achieved [3,4]. However, maintaining neutral pH leads to the necessity to remove counterions of succinate from the fermentation medium, resulting in tedious and costly purification processes, which increase the costs of succinic acid. To overcome this, researchers have started utilizing metabolic engineering techniques to reduce the fermentation pH [5] so that succinic acid will be present in its nondissociated form, which is preferred. Anticipating such efforts, previous studies [6–8] proposed the use of hydrophobic zeolites to recover succinic acid from fermentation medium and separate it from its salts. This adsorption method proved to be efficient in a technical sense. However, for the process to be applicable the production costs should be sufficiently low. In this study, we present the conceptual design of a low pH fermentative succinic acid production followed by an adsorption step on high-silica ZSM-5 zeolite as the main recovery step. Desorption using water at 150 °C instead of base prevents that succinic acid is converted

* *Corresponding author*. Tel.: +31 15 2782330; fax: +31 15 2782355.
E-mail addresses: L.A.M.vanderWielen@tudelft.nl (L.A.M. van der Wielen), A.J.J.Straathof@tudelft.nl (A.J.J. Straathof).
[1] Present address: Unilever, Saray Mah. Dr. Adnan Buyukdeniz Cad. No. 13, Umraniye, 34768 Istanbul, Turkey.
0961-9534/\$ – see front matter
http://dx.doi.org/10.1016/j.biombioe.2013.06.002

into succinate, whereas desorption using organic solvent would leave some organic solvent on the zeolite and not avoid a high temperature desorption step [6].

The assumed low pH fermentation unit is followed by a cell removal step. The effluent is fed to a batch adsorption unit that works in tandem to facilitate continuous overall operation. Non-adsorbing succinate salts are eluted from the column and sent back to the fermentation unit. This recycle controls the fermentor pH at the desired low level and minimizes the requirement to control it by adding inorganic bases instead. Therefore, the recycled salts can be directly utilized in preparation of the fermentation feed. During succinic acid formation the fermentation pH will drop from 5.5 to values as low as 3.5–4, which are still tolerated by the microorganisms [5].

This study reports the conceptual design of a process according to the aforementioned concept, to produce 30 kt a^{-1} succinic acid with a purity assumed sufficient (>99.5%) for follow-up chemical conversions. Design of the unit operations and economic analysis of the plant are covered. The mass and energy balances are taken into account but due to space restrictions they are not mentioned in this text. The primary aim is not to investigate the feasibility of the individual unit operations but to estimate the succinic acid production cost using the proposed process, so that future research targets for this process can be identified. Alternative process types will not be evaluated.

The plant is assumed to be constructed in Brazil. Brazil is the major sugar exporting country with almost 570 Mt sugarcane harvest in 2009 [9]. This harvest was used for production of 31 Mt of sugar and 27.5 Mt of ethanol. In addition to this large raw material availability, the investment and operational costs are also lower in Brazil than in Europe or the USA. In the design, it is assumed that one year has 330 days of working time.

2. Process description

The proposed succinic acid production plant (Fig. 1) is composed of upstream succinic acid fermentation and downstream concentration and purification sections. The upstream section starts with feed sterilization (E-101 – E-103). In this unit, a mixture of fresh nutrients and recycled Na_2Succinate-rich adsorption raffinate is heated to 134 °C and cooled to 30 °C (fermentation temperature). The sterilized feed is sent to batch fermentation vessels (V-101 – V-103). Produced fermentation broth is centrifuged to remove cell mass in centrifuges (F-101), the cells are recycled to the fermentors and the cell free broth is fed to batch adsorption columns (C-101) that work in tandem. When one is loaded by fermentation supernatant (C-101/1) the second (C-101/2) is being regenerated to desorb succinic acid. Desorption is carried out by hot water at 150 °C (above atmospheric pressure), which is supplied by a water heater (E-105). After every three cycles, the column is exposed to hot air that is produced in a direct fire heater (E-104) to remove fouling components. Desorption effluent is transferred to a flash drum (V-104) to remove the excess heat by evaporating a portion of the water. The liquid from the flash drum is transferred to storage tanks (V-105) to facilitate continuous operation further downstream. This liquid is further concentrated in an evaporator (E-106) and the concentrated liquid is fed to a continuous crystallizer (V-106). The crystals are removed by rotary vacuum filtration (F-102) and the mother liquor is recycled to the adsorption column (C-101). The wet succinic acid crystals are dried in a rotary dryer (E-107). The overhead vapor of the flash drum (V 104) and evaporator (E-106) is recycled to the water heater (E-105). Details of the design can be found in Section 4.

3. Design methods

3.1. *Raw materials*

C_6 sugars are the major raw material for fermentative production, but recent concerns on competition with raw materials for human nutrition leads to a focus on second generation raw materials (i.e. lignocellulosic) for fermentations. Another non-food raw material option would be molasses from sugar production. Molasses are rich in sugar which does not crystallize due to the high concentration of

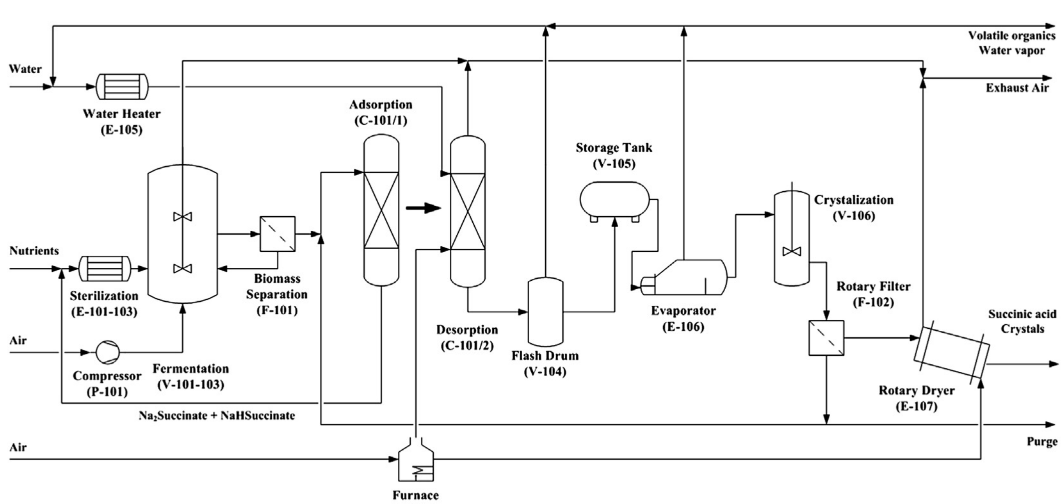

Fig. 1 – Process flow diagram.