**Enhanced butanol production from Isopropanol-Butanol-Ethanol (IBE) fermentation by an integrated gas stripping-pervaporation process.**

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**Highlights**

* Isopropanol-butanol-ethanol fermentation joined to gas stripping-pervaporation system
* *C. beijerinckii* DSM6423 fermented successfully industrial sugarcane-sweet sorghum juices
* 559 g/L of butanol were obtained in an IBE fermentation with gas striping-pervaporation

**1. Introduction**

*n*-Butanol is a four-carbon alcohol used as an advanced biofuel as well as a commodity chemical. It can be produced through the acetone-butanol-ethanol (ABE) or isopropanol-butanol-ethanol (IBE) fermentation by various *Clostridium* spp. in which a solvent mixture is produced. The production of isopropanol instead of acetone, which is corrosive, makes the produced mixture of solvents (IBE) to be used as fuel [1]. The raw material used for biobutanol production and the energy consumption are the major costs in an ABE [2] or IBE fermentation. Both sugarcane and sweet sorghum are crops which have high amount of soluble fermentable sugars. The low product concentrations reached in the fermentation broth, which is probably a consequence of cell toxicity by butanol, cause an intensive energy consumption. In order to overcome this problem gas stripping and pervaporation are the main recovery techniques studied for *in situ* butanol recovery process. Pervaporation coupled directly to the fermentation can present fouling in the membrane. The aim of this work was to evaluate a hybrid *in situ* gas stripping-pervaporation process to recover butanol of a batch fermentation of sugarcane and sweet sorghum juices using *C. beijerinckii* DSM 6423. Gas stripping was used to continuously remove butanol from fermentation broth, followed with pervaporation to further condense butanol.

**2. Methods**

Batch fermentation from the industrial medium of sugarcane and sweet sorghum juices was performed in a 2.5-L bioreactor using *Clostridium beijerinckii* DSM 6423. Fermentation conditions were: 35 ºC, initial pH 6.0 and 150 rpm. Gas stripping started at 23 h at a gas flowrate of 0.7 vvm and condenser temperature 0 ºC. Sugars were determined by HPLC using a Shodex SUGAR KS-801 column at 55 ºC and 0.7 mL/min. Organic acids and solvents were determined by GC equipped with a flame ionization detector and a fused silica column. Pervaporation assays were done with a polydimethylsiloxane (PDMS) membrane. Pervaporation conditions were: flow rate 50 mL/min, vacuum 20 mbar, feed and condensation temperature 70 and -6 °C, respectively. An IBE aqueous solution with the same condensate composition as that obtained from the fermentation coupled with *in situ* gas stripping (I-B-E: 46-36-6 g/L) was used as the feed solution. Isopropanol, butanol and ethanol were determined by HPLC using an Aminex 87-H column at 30°C and 0.6 mL/min. To evaluate the pervaporation performance, partial permeation flux and selectivity were calculated.

**3. Results and discussion**

Sugar and solvent profiles are shown in Fig. 1. A sugar conversion of 98% was obtained in 158 h which demonstrated that the gas stripping system successfully mitigated butanol inhibition. As expected, sugar conversion was reflected in higher solvent concentration. Butanol and isopropanol concentrations reached were 7.8 and 10.9 g/L, respectively (total solvent as IBE 19.6 g/L). The average solvent concentration in the condensate was 47.5 g/L isopropanol, 33.1 g/L butanol, 4.9 g/L ethanol. Neither acetic nor butyric acids were detected in the condensate.



**Figure 1.** Fermentation batch profiles with *in situ* gas stripping from sugarcane-sweet sorghum juices. Dashed lines indicate the total production including products collected in the gas stripping condensate and those remained in the fermentation broth. The arrow indicates when the gas stripping started.

The condensate was then submitted to pervaporation for further butanol dehydration. At the beginning of the pervaporation butanol and IBE fluxes were 100 and 134 g/hm2 respectively, which declined to 39 and 52 g/hm2 after 38 h because of the decrease in their retentate concentrations. Isopropanol and ethanol fluxes were lower (9-32 and 1-2 g/hm2, respectively). Butanol selectivity varied between 50-78, while for isopropanol and ethanol were stable at less than 6. The hydrophobic characteristic of the PDMS contributed to the high selectivity for butanol and low selectivity for isopropanol and ethanol. The separation efficiencies and concentration in the condensate during 38 h were: 16, 83 and 8 % and 140, 559 and 10 g/L for isopropanol, butanol and ethanol, respectively. Results showed that the membrane was effective to recover butanol from feed with high butanol concentration.

**4. Conclusions**

The strategy used allows alleviating butanol inhibition and to recuperate a condensate containing high butanol concentration (559 g/L), which could reduce energy consumption in the final product recovery.

**References**

1. S. Bankar, G. Jurgens, S. Survase, H. Ojamo, T. Granstrom, Fuel. 136 (2014) 226-232.
2. D. Cai, Y. Wang, C. Chen, P. Qin, Q. Miao, C. Zhang, P. Li, T. Tan, Bioresour. Technol. 211 (2016) 704-710.