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Membrane-assisted extractive butanol fermentation by *Clostridium saccharoperbutylacetonicum* N1-4 with 1-dodecanol as the extractant

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ABSTRACT

A polytetrafluoroethylene (PTFE) membrane was used in membrane-assisted extractive (MAE) fermentation of acetone–butanol–ethanol (ABE) by *Clostridium saccharoperbutylacetonicum* N1-4. The growth inhibition effects of 1-dodecanol, which has a high partition coefficient for butanol, can be prevented by employing 1-dodecanol as an extractant when using a PTFE membrane. Compared to conventional fermentation, MAE–ABE fermentation with 1-dodecanol decreased butanol inhibition and increased glucose consumption from 59.4 to 86.0 g/L, and total butanol production increased from 16.0 to 20.1 g/L. The maximum butanol production rate increased from 0.817 to 0.979 g/L/h. The butanol productivity per membrane area was remarkably high with this system, i.e., 78.6 g/L/h/m^2. Therefore, it is expected that this MAE fermentation system can achieve footprint downsizing.

1. Introduction

A major problem during fermentation processes is severe end-product inhibition, which decreases cell growth and product concentration in the fermentation broth. *In situ* recovery of end products during fermentation is a key point in the overall process, which aims to solve this problem. Liquid–liquid extraction can be applied to recover a product using extractants, such as organic solvents, which results in improved cell growth and productivity by decreasing end-product inhibition (Ishii et al., 1985; Taya et al., 1985; Roffler et al., 1987; Ishizaki et al., 1999). The extraction efficiency depends on the partition coefficient of the extractant used and the targeted product. However, a major limitation is that an extractant with a high partition coefficient often leads to microbial toxicity because of direct contact between the fermentation broth and the extractant (Evans and Wang, 1987).

Membrane-assisted extractive (MAE) technique is an approach that can overcome this major limitation. In MAE fermentation, the two phases of extractant and fermentation broth are separated by a porous membrane. The membrane can be either hydrophilic or hydrophobic and the interface is immobilized by the impregnation of its pores with one of the two phases depending on the membrane affinity (Kiani et al., 1984; Eksangsri et al., 2005). This has advantages of no dispersion or emulsion formation between the two phases (Yeh and Huang, 1995; Juang et al., 2000; Sciubba et al., 2009). Furthermore, it prevents the cells from making direct contact with the extractant, and thus can reduce the microbial toxicity of the extractant. MAE technique allows the selection of a wide range extractants, including microbial toxic extractants, with high partition coefficient for *in situ* recovery of end products during fermentation.

Acetone–butanol–ethanol (ABE) fermentation by *Clostridium* species shows end-product inhibition, particularly butanol, which severely inhibits cell growth and substrate consumption, and butanol production at a concentration of 12–16 g/L (Jones and Woods, 1986). The low butanol production is the bottleneck to progress ABE fermentation as an industry although biobutanol (bio-based butanol) continues to receive attention as a source of fuel because of its superior properties compared to bioethanol in terms of higher energy density and lower volatility (Lee et al., 2008). Several MAE–ABE fermentation systems have already been investigated (Jeon and Lee, 1987; Grobben et al., 1993). Their studies used combinations of relatively hydrophobic polymeric membranes and non-toxic extractants, such as a silicone membrane and oleyl alcohol (Jeon and Lee, 1987), or a polypropylene membrane and a

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