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Intrinsic kinetics of continuous growth and ethanol production of a flocculating fusant yeast strain SPSC01

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Abstract

The intrinsic kinetics of continuous yeast cell growth and ethanol production for a self-flocculating fusant yeast strain SPSC01 was investigated by means of mechanically dispersing the flocs and correspondingly established floc size distribution on-line monitoring technique using the focused beam reflectance measurement system, through which the floc intra-particle mass transfer limitation was effectively eliminated, but its ethanol formation metabolism was not affected. Modified kinetic models were developed, which can be used to predict the continuous kinetic behaviors of SPSC01, especially when low dilution rates are applied and limiting substrate concentrations are undetectable and almost all kinetic models developed previously are failed in predicting corresponding kinetic behaviors. Both substrate and product inhibitions reported for freely suspended yeast cell ethanol production were also observed for SPSC01 when high gravity media were fed and relatively high levels of residual sugar and ethanol presented. Model parameters were evaluated through numerical calculation method and validated by experimental data

$$\mu = \frac{0.584C_S}{0.155 + C_S + C_S^2/160.7}\left(1 - \frac{P}{125}\right)^{3.68} + 0.004 \quad \text{for growth,}$$

$$\nu = \frac{1.998C_S}{0.427 + C_S + C_S^2/366.7}\left(1 - \frac{P}{125}\right)^{1.72} + 0.060 \quad \text{for ethanol production}$$

These intrinsic kinetic models can be further used to develop the observed kinetic models that quantitatively correlate the impact of the self-flocculating yeast cell size distributions on their apparent rates for yeast cell growth, substrate uptake and ethanol production and optimize the ethanol production process.

Keywords: Yeast; Self-flocculating; On-line monitoring; Continuous growth and ethanol production; Intrinsic kinetics

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Nomenclature

C_S	residual sugar concentration ($g\,l^{-1}$)
C_{S_0}	initial sugar concentration ($g\,l^{-1}$)
D	dilution rate (h^{-1})
K_I	substrate inhibition constant for growth ($g\,l^{-1}$)
K_S	Monod constant for growth ($g\,l^{-1}$)
K_I^*	substrate inhibition constant for ethanol formation ($g\,l^{-1}$)
K_S^*	Monod constant for ethanol formation ($g\,l^{-1}$)
M	mode of the chord length distribution (μm)
P	ethanol concentration ($g\,l^{-1}$)
P_{max}	maximum ethanol concentration ($g\,l^{-1}$)
R^2	square of the correlation coefficient
T	cultivation time (h)
X	biomass concentration (dry cell weight per volume) ($g\,l^{-1}$)

Greek letters

α	ethanol inhibition constant for growth
θ	ethanol inhibition constant for ethanol formation
μ	specific growth rate (h^{-1})
μ_i	maximum specific growth rate ignoring the effect of ethanol inhibition (h^{-1})
μ_{max}	maximum specific growth rate (h^{-1})
μ_0	specific cell growth rate at zero concentration of limiting substrate (h^{-1})
ν	specific ethanol production rate (h^{-1})
ν_i	maximum specific ethanol production rate without ethanol inhibition (h^{-1})
ν_{max}	maximum specific ethanol production rate (h^{-1})
ν_0	specific ethanol production rate at zero concentration of limiting substrate (h^{-1})

1. Introduction

The gradual depletion of crude oil and the biological environmental deterioration resulted from the over consumption of petroleum-derived transportation fuels have garnered great attentions again, which makes it urgent to develop alternatives that are both renewable and environmentally friendly. Bioethanol, produced from renewable biomass such as sugar and starch materials at present and maybe lignocellulosic materials in the near future, is believed to be one of these alternatives.

Currently, freely suspended yeast cells are widely used in ethanol production industry all around the world and yeast cells leave bioreactors with fermented broth during continuous operations. Therefore, high yeast cell densities cannot be achieved inside bioreactors and the process productivity is inevitably lower unless yeast cells are separated by centrifuges and partly recycled into bioreactors. However, high capital investment of centrifuges and energy consumption of centrifuge running greatly hinder the application of centrifuges in ethanol production plants, especially in developing countries where energy cost is relatively high and the centrifuges need to be imported.

Flocculating of yeast cells, usually spontaneously happened, has been widely investigated and used for separating yeast cells from beer in brewery industry (Verstrepen et al., 2003). Ethanol production using self-flocculating yeast strains has also been reported and different bioreactor configurations been developed, correspondingly, such as air-lift bioreactor (Bu'lock et al., 1984), single packed column bioreactor (Gong and Chen, 1984; Jones et al., 1984; Admussu and Korus, 1985) and two-stage packed column bioreactors in series coupled with a settler (Kuriyama et al., 1993) and without a settler (Kida et al., 1990), CO_2 suspended-bed bioreactor coupled with a buffer and a separation tank (Limtong et al., 1984) or only with a separation tank for CO_2 to be separated and recycled (Kida et al., 1989).

The biggest advantage of ethanol production using self-flocculating yeast strains is that much higher yeast cell density can be achieved without any additional energy consumption and equipment capital investment compared with freely suspended yeast cell ethanol production systems. Although the isolations of self-flocculating yeast strains with desirable ethanol production performances are very time-consuming, they are still under their ways (Sree et al., 2000; Nahvi et al., 2002). As the mechanisms controlling yeast cell self-flocculating were revealed at the levels of molecular biology (Dengis et al., 1995; Jin and Speers, 1998) and the genes that control yeast cell self-flocculating were identified and cloned (Watari et al., 1989, 1990,