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탑형 발효기에 의한 에탄올 연속 생산

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Continuous Ethanol Production by Tower Fermentor

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ABSTRACT

A cone-type tower fermentor packed with *Sacchromyces uvarum* was employed to examine the continuous ethanol fermentation process. The maximum yeast concentration in the cone-type tower fermentor was 37.5-39.5g/ℓ, the maximum ethanol productivity at the dilution rate of 0.32hr^{-1} was 16.3g/ℓ · hr and the average ethanol yield was 0.48g EtOH/g glucose, which was 94% of the maximum theoretical yield. It was concluded that a cone-type tower fermentor might offer better perspectives for continuous ethanol fermentation.

INTRODUCTION

Considerable attention has been given to industrial ethanol production from biomass via fermentation as an alternative to its synthesis from petroleum. Tower fermentors were developed for the beverage industry in the 1960's in order to provide a continuous fermentation system that would be more productive and efficient than batch systems(1-5). Medium flows into the bottom and is fermented as it goes up through a dense bed of yeast. The fermented medium passes through a settler before the exit. A major advantage of the tower fermentor is its ability to maintain continuous operation. No centrifugation or agitation equipment is needed(1, 6).

On the other hand, high flow rates and high CO_2 production will cause the bed to break up and decrease the cell density in bed. In order to overcome the problems of CO_2 production, Shiotani and Yamane(7) proposed a horizontal packed-bed cross-flow reactor and Hamamci and Ryu(8) proposed a tapered column bioreactor, in which the cross sectional area increases with height and the increasing volume of CO_2 evolved can be accomodated without decreasing the cell density drastically.

In this study, we employed a cone-type fermentor for ethanol production and compared the performance of the cone-type tower fermentor with that of other tower fermentors.

MATERIALS AND METHODS

Strains

A flocculating mutant of *Saccharomyces uvarum* ATCC 26602 was used as the organism.

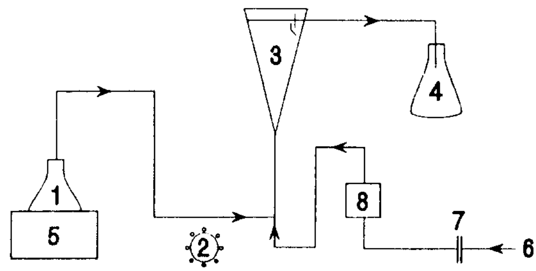
Media Composition

Media for cultivation and fermentation contained 11.0g of yeast extract, 1.7g of NH_4Cl, 0.15g of $MgSO_4 \cdot 7H_2O$, 0.08g of $CaCl_2$ and 130g of glucose per liter(pH 5.0) and was the same condition as Cysweski and Wilke(9). The medium was autoclaved for 30min, at 15 psig and 121℃.

Fermentor

A cone-type tower fermentor was constructed with 25cm height, and 6.5cm diameter at the top with a liquid volume of 300ml. At the top of the fermentor, cell recycle system with an internal baffle arrangement was installed to provide a region free of turbulence for cell settling and return to the main body of the fermentor. A heating tape wrapped around the tower was used to control the tower fermentor temperature at 30±0.5℃. The aeration rate at the base of fermentor was 37-8ml/min(0.125v/v/m) during the start-up and fermentation. An inoculum size was 300ml of inoculum and initial dilution rate was set at 0.1hr^{-1}. Thereafter the dilution rate was increased incrementally with 13.7% glucose feed until the significant concentration of glucose was reached. Fig.1 show a schematic diagram of the experimental set-up used.

Yeast Recycle %



1. Medium reservoir
2. Peristaltic pump
3. Cone-type tower fermentor
4. Product receiver
5. Shaking water bath
6. Air inlet
7. Air filter
8. Flowmeter

Fig 1. Schematic diagram of experimental apparatus.

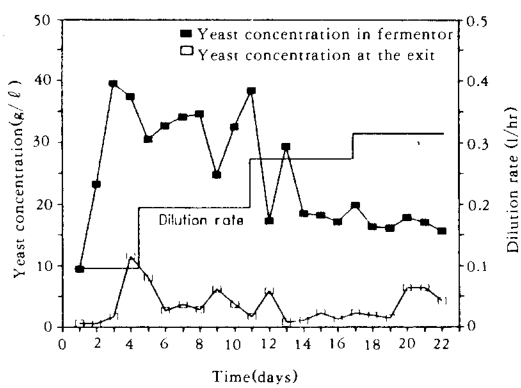


Fig 2. Effect of dilution rate on yeast concentration vs. operation days.

Yeast recycle % was calculated by using the average yeast concentration in the fermentor and in the effluent.

Yeast recycle % =

$$\left(1-\frac{\text{yeast concentration in the effluent}}{\text{yeast concentrarion in the fermentor}}\right)\times 100$$

Analysis

Ethanol concentrations were determined with gas chromatography and glucose concentrations were determined by the DNS method(10). Yeast cell density was determined by the absorbance of diluted sample, measured at 600nm.

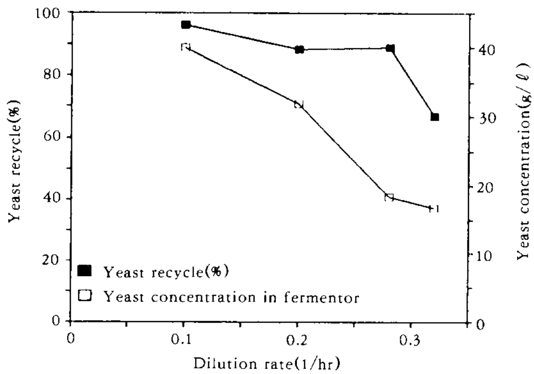


Fig 3. Effect of dilution rate on yeast recycle(%) and yeast concentration.

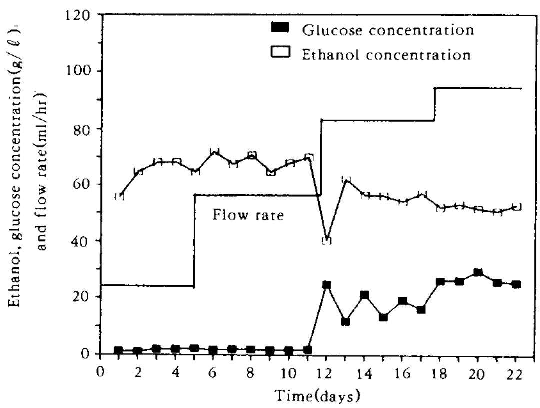


Fig 4. Effect of flow rate on glucose and ethanol concentration.

RESULTS AND DISCUSSION

Performance of Fermentor

Fig. 2 shows the cell concentrations within the fermentor and in the effluent stream, when the dilution rate increases from $0.1hr^{-1}$ to $0.32hr^{-1}$. To get a cell aggregation, an initial dilution rate of $0.1hr^{-1}$ was maintained. After 3 days operation, small flocs(about 1mm) were formed and cell concentrations in the fermentor and in the effluent were 39.5 g/ℓ and 0.5-1.6g/ℓ, respectively. At 4 days, glucose feed rate was increased to 60ml/hr. At the dilution rate of $0.2hr^{-1}$, the cell concentrations within the fermentor and in the effluent were 32.6-38.5 and 2.6-6.1g/ℓ, respectively. At 11 days, glucose feed rate was increased to 85ml/hr. At the dilution rate of $0.28hr^{-1}$, the cell concentrations within the fermentor and in the effluent were 17.1-19.9 and 1.2-2.2g/ℓ, respectively. At 17 days, glucose feed rate was increased to 95ml/hr. At the dilution rate of $0.32hr^{-1}$, the cell concentrations in the fermentor and in the effluent were 15.6-17.8 and 4.2-6.3g/ℓ. As the dilution rate was increased from 0.10 to $0.32hr^{-1}$, the cell concentrations in the fermentor was decreased from 39.5 to 15.6-17.8g/ℓ and the cell concentrations in the effluent was increased from 0.5-1.6 to 4.2-6.3g/ℓ.

The effect of dilution rate on average yeast concentration in the fermentor is shown in Fig. 3. As the dilution rate was increased from 0.1 to 0.32 hr^{-1}, the cell recycle % was decreased from 96.0 to 66.9%. During the continuous fermentation, the baffle in the fermentor recycled the yeast without clogging.

Effect of Dilution Rate

The effect of dilution rate on glucose and ethanol concentration in the effluent stream was investigated (Fig. 4). The initial glucose feed rate was 30ml/hr. At the dilution rate of $0.1hr^{-1}$, the glucose and ethanol concentration in the fermentor at the steady-state were 1.5g/ℓ and 68.0g/ℓ respectively. At 4 days, glucose feed rate was increased to 60ml/hr. At the dilution rate of $0.2hr^{-1}$, the glucose and ethanol concentration in the fermentor at the steady-state were 1.9g/ℓ and 67.7g/ℓ respectively. At 11 days, glucose feed was increased to 85ml/hr. At the dilution rate of $0.28hr^{-1}$, the glucose and ethanol concentration in the effluent at the steaty-state were 16.4 and 55.7g/ℓ. At the dilution rate of $0.32hr^{-1}$, the glucose and ethanol concentration in the effluent at the steady-state were 26.9 and 51.5g/ℓ. Although the ethanol concentration at the fermentor exit decreases with the increasing the flow rate, the ethanol productivity actually increases since it is the product of ethanol concentration and dilution rate. Fig. 5 shows that a

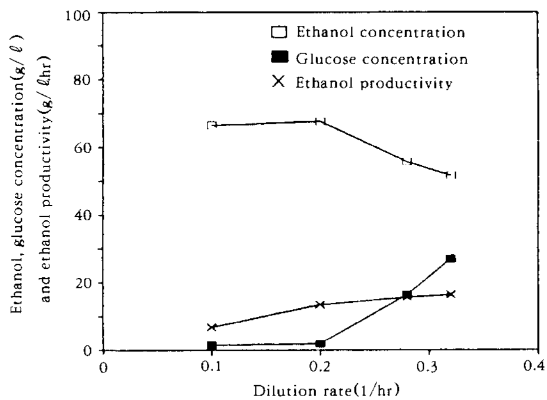


Fig 5. Effect of dilution rate on ethanol, glucose concentration and ethanol productivity.

Table 1. Comparison of ethanol productivities in tower fermentors.

System	Dilution rate (hr^{-1})	Ethanol productivity (g/ℓ·hr)	Ethanol concentration (g/ℓ) at steady state	References
Tower	0.104	8.6	82.6	1
Fermentor	0.200	11.7	59.7	
Tower	0.22	15.9	69.8	2
Fermentor	0.38	19.5	51.4	
	0.53	26.5	51.4	
Tapered	0.14	8.7	62.0	8
Bioreactor	0.27	14.0	52.0	
Tower	0.20	13.4	67.7	This study
Fermentor	0.28	15.7	55.7	This study
	0.32	17.8	51.5	This study

maximum ethanol productivity, 16.32g EtOH/L·hr, is obtained at a dilution rate of 0.32hr^{-1} and the steady-state ethanol concentration is 51.5g EtOH/L.

Ethanol Productivities

A comparison of ethanol productivity obtained in this study, based on the entire liquid volume, with the ethanol productivities reported by others who used tower fermentor with high cell densities is presented in Table 1.

Our work showed a higher productivity than Jones(1) and Ryu(8) and a little lower productivity than Prince(2). It was concluded that a cone-type tower fermentor might offer better perspectives for continuous ethanol fermentation.

Ethanol Yield and Operation Stability

The ethanol yield is calculated based on material balance at the steady-state. It is found that product yield factor is 0.46-0.49g EtOH/g glucose. An average yield of 0.48g EtOH/g glucose corresponds to 94% of maximum theoretical yield.

During 22 days operation, there was no clogging phenomena in the internal baffle and no channeling in the cone-type tower fermentor.

요 약

Cone 형태 탑형발효기에서 연속발효실험을 수행한 결과 발효조 내 최대 효모 농도는 37.5-39.5g/ℓ이었고 최대 에탄올 생산성은 희석율 0.32 hr^{-1}에서 16.3g EtOH/L·hr 이었다. 평균 에탄올 수율은 0.48 g EtOH/g glucose로서 이는 이론적 수율의 94%였다. Cone 형태 탑형발효기는 에탄올 연속생산시 효과적인 발효기로 생각되었다.

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