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Double-stage Batch Fermentation of Beer

I. Theoretical Background

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二段回分式 麥酒醱酵 Ⅰ. 理論

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ABSTRACT

Fermentation models of beer having higher efficiencies with a minimum change in conventional batch fermentation condition have been designed. By diluting the fermenting mass with one half or one third volume of fresh wort after three days of the conventional batch fermentation and completing the rest of the fermentation in five or four days, about 20 to 30 percent increase in the fermentation efficiency over the regular 9-day batch beer fermentation is theoretically feasible.

INTRODUCTION

The previous survey on the condition of the conventional batch beer fermentation (1) indicated that all elemental factors examined i. e., fermentation period, heterothermal condition, spontaneous agitation, stratification, and foam covering during the fermentation were responsible on the formation of flavor compounds in the traditional beer. In order to avoid undue change in the flavor characteristics the above factors were kept unchanged and some new ways of fermentation having higher efficiencies compared to the conventional batch process have been proposed.

As it was described in the previous report (1) the yeast population in the commercial batch fermentor reaches to the peak in about three days after pitching. The wort temperature which was initially 10°C also reaches to the maximum of 14°C at this stage. Because of the high yeast population together with the high temperature, the fermentation speed at this point is the highest over the entire fermentation period. Since the wort is well circulated by the rising movement of carbon dioxide bubbles at the third day of the fermentation, we may transfer the wort easily without distroying the stratification pattern of the normal batch fermentation. In the present designs this efficient stage of fermentation was emphasized and tried to extend substantially by replacing certain portions of the fermenting mass with fresh wort after three days of regular batch fermentation.

Fermentation models and their efficiencies

Single-stage batch fermentations : The conventional batch method with a fermentation period

of nine days has been designated as a standard fermentation of beer in this study. The total work for the standard fermentation using a single fermentor is expressed as 9 tank-days. Should a fermentation ended up by eight days, a day would be saved with the total work of 8 tank-days and thus the efficiency gained by 11%. Similarly the efficiency gains for shorter fermentations were also calculated and shown in Table 1.

Table 1. Single-stage Batch Fermentation Models* and their Efficiencies.

Fermentation	Period (day)	Work (tank-day)	Work Saved (tank-day)	Efficiency Gained (%)
9-day Single (standard)	9	9	0	0
8-day Single	8	8	1	11
7-day Single	7	7	2	22
6-day Single	6	6	3	33

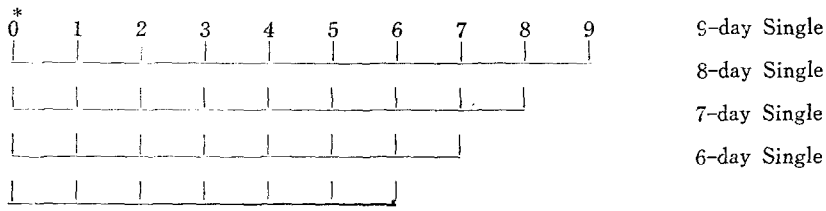
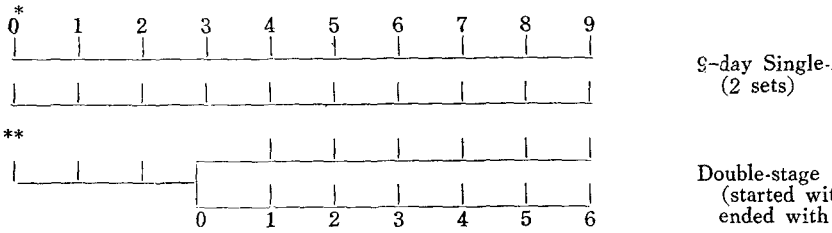


Table 2. Double-stage Batch Fermentation Models and their Efficiencies. One half volume of fermenting mass is replaced with the same volume of fresh wort after three days of the initial stage fermentation.

Fermentation	Period (day)	Work (tank-day)	Work Saved (tank-day)	Efficiency Gained (%)
9-day Single (standard, 2 sets)*	9	18(9×2)	0	0
Double-stage				
1st stage 2*nd stage*				
3 days (1 set) + 6 days (2 sets)	9	15(3×1+6×2)	3	17
〃 5 days (2 sets)	8	13(3×1+5×2)	5	28
〃 4 days (2 sets)	7	11(3×1+4×2)	7	39
〃 3 days (2 sets)	6	9(3×1+3×2)	9	50



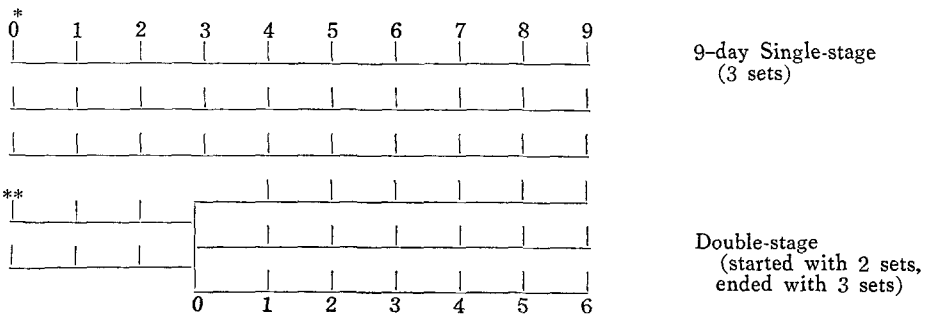
Double-stage batch fermentation replacing 1/2 *volume with fresh wort*: Table 2 shows some models of increasing efficiency with minimal changes in fermentation conditions. Fermentation starts in a batch as usual. After three days the fermenting mass is diluted with the same amount of fresh wort making two batches and fermentation continues. A 17% gain in efficiency is theoretically possible by this method without changing the total fermentation period of nine days. If one day could save in the second stage having the total period of 8 days the efficiency gain will be 28%. Further cuts in the second stage having 39% and 50% efficiency gains, however, seem to be of little practical value.

Double-stage batch fermentation replacing 1/3 *volume with fresh wort*: The principle for the models in Table 3 is also the same as above, except that the dilution ratio of fermenting wort to fresh one is 2 to 1. Because of the less portion for the fresh wort, it may be possible to shorten a couple of days from the second stage expecting 33% of efficiency gain.

The theoretical efficiency gains in the foregoing models are summarized and compared in Figure 1. By simply adopting the doublestage fermentation concept without reducing the 9-day period, one may expect 11% (—△—) or 17% (—●—) gain in fermentation efficiency which are equivalent to the 8-day or 7. 5-day single-stage fermenta tion (—○—) respectively. One day reduction from the second stage period may be possible with efficiency gains of 22% (—△—) and 28% (—●—) which are equivalent to that of the 7-day or 6. 5-day single-stage fermentation (—○—). In the case of the double-stage fermentation with a less portion of fresh wort (—△—) even two days reduction from the secondstage expecting a 33% efficiency gain may be worth-while to try.

Table 3. Double-stage Batch Fermentation Models and their Efficiencies. One third volume of fermenting mass is replaced with the same volume of fresh wort after three days of the initial stage fermentation.

Fermentation	Period (day)	Work (tank-day)	Work Saved (tank-day)	Efficiency Gained (%)
9-day Single (standard, 3 sets)*	9	27(9×3)	0	0
Double-stage				
1st stage 2*nd stage*				
3 days (2 sets) + 6 days (3 sets)	9	24(3×2+6×3)	3	11
〃 5 days (3 sets)	8	21(3×2+5×3)	6	22
〃 4 days (3 sets)	7	18(3×2+4×3)	9	33
〃 3 days (3 sets)	6	15(3×2+3×3)	12	45



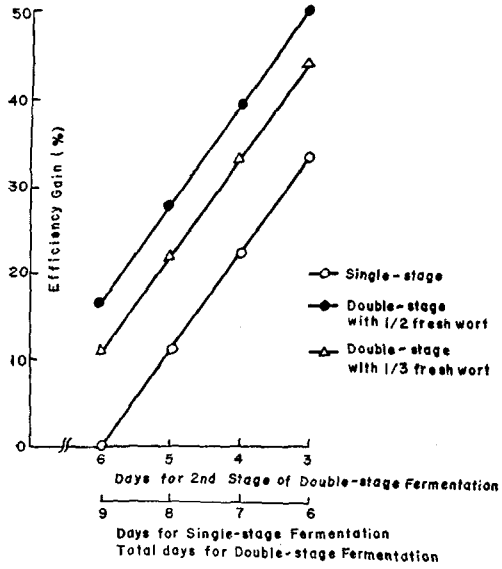


Fig. 1. Comparison of Efficiencies between Fermentation Models of Single-stage and Double-stage Batch Fermentations.

DISCUSSION

For the bottom fermentation of beer, a wide range of fermentation periods are adopted in different countries. It has been reported that in Denmark (2) it is usual to ferment for 8 days at 9—10°C. In Western Germany (3) the time of fermentation may range from 5 to 14 days and the temperature 5—9°C. American practice is to ferment for 6 to 9 days at temperatures rising from 10—13°C but beeing reduced to as low as 5°C before the completion(4).

The standard fermentation period of 9 days in the present study is based on the regular operation time of a commercial brewery which belongs to the category of the above American style as was described in the previous report (1). It may not be very difficult to shorten a day from the 9-day fermentation period, but to reduce two or three days without changing the product quality would be almost impossible for this particular beer. However, if we apply the present double-stage batch fermentation principle we may expect to obtain efficiency gains equivalent to the 7-day or 6-day single-stage batch fermentation with minimum change in beer quality, because the total fermentation period for the double-sgtae fermentation is longer than that for the single-stage batch fermentation to get the same fermentation efficiency. A confirmation study for the possibility will be followed.

要　約

從來의 麥酒醱酵에 따른 제반條件을 可能한 限 그대로 維持하면서 效率이 높은 醱酵法을 몇가지 設計해 보았다. 醱酵開始後 3日만에 醱酵液의 $\frac{1}{2}$ 또는 $\frac{1}{3}$量을 새로운 麥汁으로 代置한 다음 5日또는 4日로써 醱酵를 完成시키므로써 再來의 9日間回分醱酵에 比하여 約 20 내지 30%의 效率上昇이 理論的으로 可能하다.

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