

Feasibility and Availability Study for the Conversion of Raw Corn Starch to Ethanol in the Continuous Reactor Separation

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ABSTRACT

A system, comprised of a continuous reactor separator (CRS) column continuously producing ethanol and an absorbing column continuously removing and concentrating ethanol produced in the reactor, was developed. The CRS was a four stage reactor and total volume was about 4 liters. Four level of total solids, 10%, 15%, 20% and 30%, was used in this study. 92% of the total solids was raw corn starch and 8% was ground malt. The yeast strain used was *Kluyveromyces fragili* 2415 and the enzyme was Fermentzyme L-200 in this study. Operation temperature 38°C was selected. The experiment ran continuously for 37 days. The experiment results indicated that 79% raw corn starch was converted to ethanol in CRS. Effect of PH, yeast density and malt content on conversion of raw corn starch to glucose and glucose to ethanol was also investigated. The studies proofed that PH, Yeast density and malt ratio influenced significantly conversion of raw corn starch to ethanol.

Key wards: Ethanol processing Starch fermentation Yeast

INTRODUCTION

Ethanol can be used for motor fuel, or as a fuel additive to replace lead in gasoline, or as a chemical feedstock. Ethanol production by fermentation processing constitutes a large section of biological and agricultural engineering. More attention has been paid to fuel ethanol production from biomass since 1970. It was stimulated not only by the limitation of non-renewable petroleum source, but also by agriculture and the environment.

Corn starch is widely used as raw materials in ethanol production. Theoretical calculations indicate that processing one ton of corn could obtain 400 liters ethanol (Rhonda Hosein & Winston A. Mellows 1988). However current batch fermentation technology for ethanol production involves liquefaction, saccharification and fermentation. These processes require large scale operation, large capital investment, and large energy consumption. About half of this energy is associated with drying and evaporating the stillage, and half with fermentation and distillation (M. Clark Dale, 1993). The Continuous Reactor Separator (CRS) is a novel system. In this system, continuous saccharification and fermentation of polysaccharides, such as starch, cellulose and other biomass,

can be quickly completed. Raw corn starch does not need to cook. Anhydrous ethanol may be obtained from feed concentration as low as 3 to 4% sugar with low energy consumption for ethanol recovery and dehydration when the CRS is coupled with solvent absorption recovery of the ethanol. This system will allow lower capital costs, lower energy usage, and lower labor costs.

Many factors are involved in the CRS. Any one of the factors will influence the conversion of raw starch to ethanol. This study focuses on the feasibility and availability for conversion of raw corn starch to ethanol in a laboratory scale CRS. Goals of the research were to determine the factor of influence on the process and to analyze the effect of the factors on conversion.

MATERIALS AND METHODS

CRS fermentation equipment. A CRS experimental apparatus was designed and built in the laboratory. This apparatus consisted of a CRS column and an absorbing column (Fig. 1). The CRS column had four stages. The volume of each stage was about one liter. The first stage volume was a little bit bigger than the others. Feed solution, enzyme, yeast, and nutrient medium were continuously fed to the top of the column. Ethanol produced in each stages was stripped with air and the stripping stream was absorbed by an absorb column. Stripping air was supplied by a compressor and absorbing water was supplied by a special pump and tank.

Feed solution. Feed mash was made of raw corn starch and ground malt. Total solids levels used in this study were 10 %, 15%, 20% and 30% by weight. The starch was 92% and malt was 8% by weight in the total solids. The starch used in this study was partly from Iowa (General Mills) and partly from market (ARGO, CPC International). The raw starch samples were dried in an oven to determine moisture content. Drying temperature was 103 °C and was for 72 hours. Average moisture content of the starch was 12.6% (wet basis). The malt came from Sigma Chemical CO. Before mixing, The ground malt was passed through a sieve NO.30 to remove bigger particles (USA Standard Testing Sieve). In order to prevent bacterial contamination, 250 ppm Sodium Bisulfite (SO₂) (J. T. Baker Inc.) was added in the solution. After mixing, PH was adjusted to desired value with ammonia and phosphoric acid (H₃PH₄) (Mallinckrodt).

Enzyme. Enzyme used in this study was Fermentzyme L-200 (Solvay Enzymes Inc.). The enzyme was a liquid glucoamylase derived from selected strains of Aspergillus niger var and capable of hydrolyzing both alpha -D-1, 6 glucosidic branchiopods and the predominating alpha -D-1,4-glucosidic linkages of starch. The enzyme was necessary to break down the starch into fermentable sugars and increase alcohol yield.

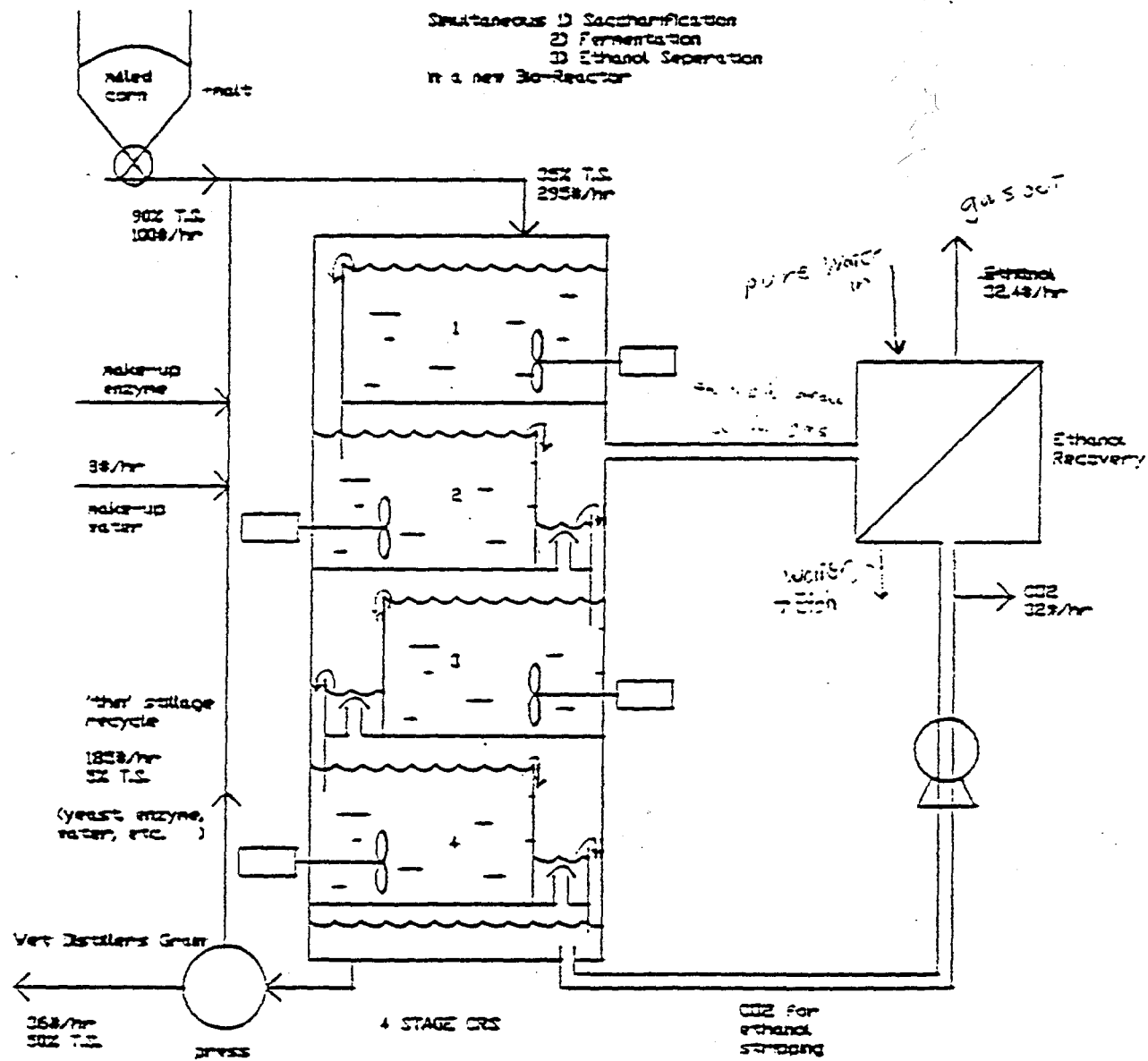


Figure 1. The CRS concept with simultaneous starch hydrolysis in a 'no-cook' process.

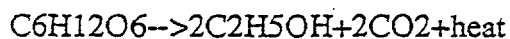
Microorganism. The microorganism used in this study was Kluyveromyces fragilis 2415. The strain had a high temperature tolerance and high fermentation rate. Both high temperature tolerance and high fermentation rate were desirable in fermentation and separation of ethanol production. The yeast was cultured for 24 hours before using.

Nutrient media. Two nutrient media were used in this study. The composition of the first medium was yeast extract 3 grams per liter, malt extract 3 grams per liter, and peptone 3 grams per liter. The second medium was composed of yeast extract 6 grams per liter, malt extract 6 grams per liter, and peptone 6 grams per liter. Before using, the media was autoclaved for 2 hours at temperature 120 °C.

Fermentation procedure. Continuous fermentation separation runs were performed. The feed solution, enzyme, and yeast were fed by a combined pump (Masterflex, Cole-parmert Instrument Co.). The pump was controlled by a timer. Supplying schedule of the feed was 1 minuter on and 9 minute off. The air and water was supplied continuously. Running each 24 hours, two ml sample from each stage and from the absorbing column outlet was taken. Concentrations of ethanol and glucose of the fermentation and separation were determined by high-pressure liquid chromatography (HPLC). The results were compared with a known standard ethanol and glucose concentration samples. Yeast density and remaining starch particles were checked by microscope. PH of slurry was checked by PH meter. Operating temperature was kept at 38°C. The fermentation separation experiment ran continuously for 37 days.

RESULTS AND DISCUSSION

Theoretical conversion of raw starch to sugar and sugar to ethanol. Starch is a condensed polymer of glucose. In CRS, starch was continuously converted to glucose by the enzyme and glucose was converted to ethanol by the yeast. A summery of the chemical reaction involved in this conversion is as follows:



Preliminary calculations indicate that one unit of starch could convert to 0.51 units of ethanol theoretically. However not all of starch can convert to ethanol. In the fermenting process with yeast, about 5% of the sugar is used by the yeast to produce biomass and by-products. Therefore the best result of conversion of one unit starch to ethanol was about 0.46 unit. The maximum conversion to ethanol that could be obtained in the CRS was equal to

$$\text{Ethanol (g/hr)} = 0.46(\text{g}) * \text{Feed solution (ml/hr)} * \text{Total solids (\%)} * \text{Dry matter (\%)}$$

Suppose the total solids of the feed was 20% (w/v). Starch of the total solids was 92% and the ground malt was 8% by weight. Assume malt used in this study contains 70% starch and the moisture content was as same as corn starch. Ethanol should be produced at a rate of 7.9 g per hour. The one of the results was shown in Fig. 2 and the figure was presented in Table 1. HPLC analysis was shown in Fig 3. Conversion of total solids, ethanol and glucose was indicated in Fig. 4.

Fig. 2 Conversion of Starch to Ethanol

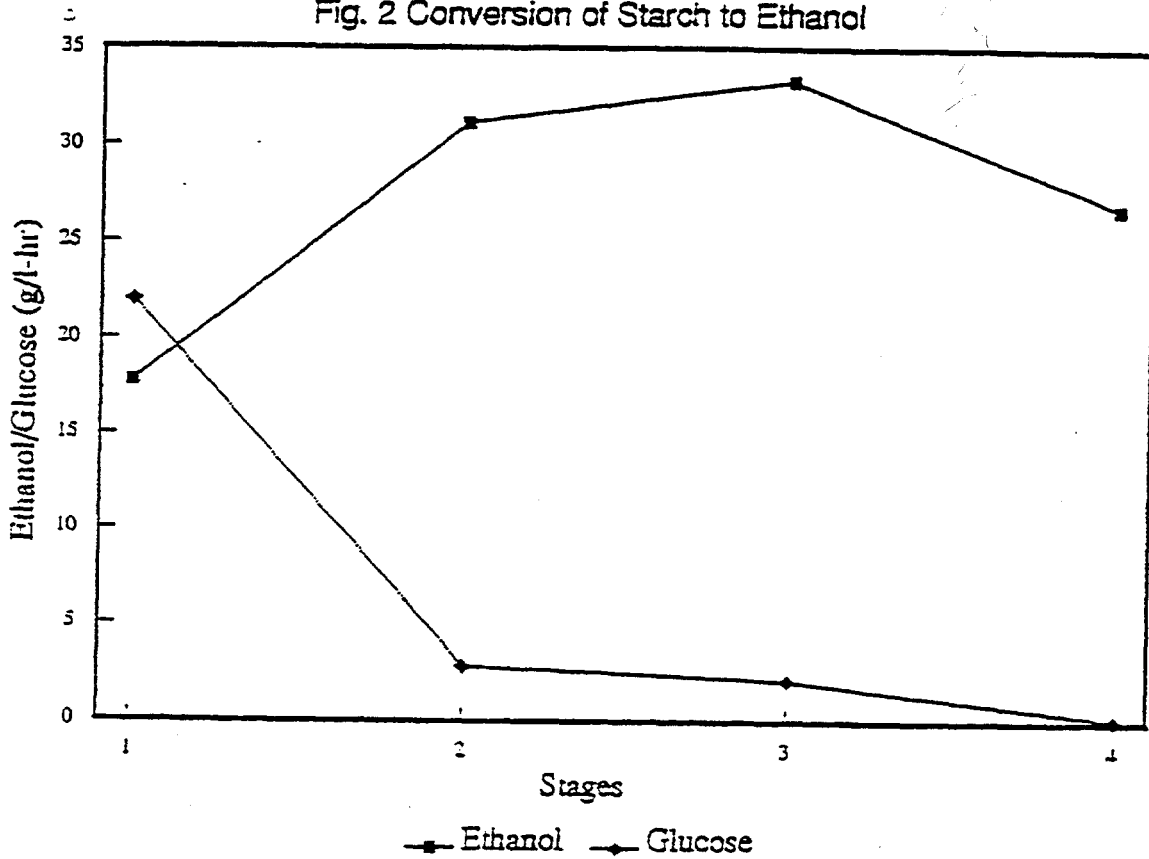


Fig. 3 HPLC Analysis Results

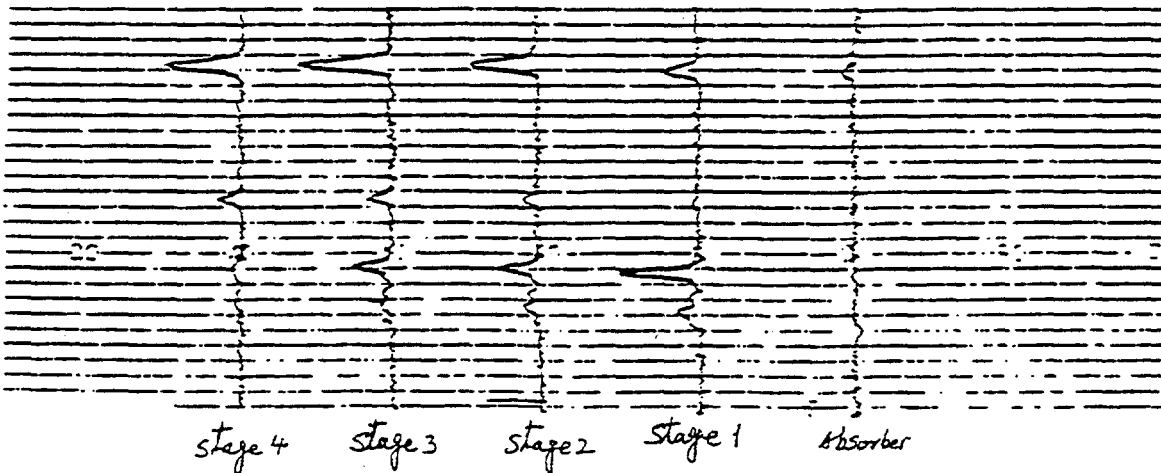


Table 1 Conversion of starch to ethanol

Stage	Ethanol(g/l-hr)	Glucose(g/l-hr)
1	17.8	22
2	31.1	2.8
3	33.3	2.1
4	26.7	0.1
absorber	8.9	

The results indicate that 79% of the raw starch had been converted to ethanol. The ethanol stripped and absorbed was 57% and that remain in the last stage was 43%. The glucose was nearly exhausted by yeast. Experimental conditions were PH = 3.5 - 4.0, YMP 3,3,3. The enzyme level was 200 and yeast density was over 15 million per cubic millimeter.

Effect of malt on conversion of starch to glucose

The effect of malt on conversion of raw starch to glucose was investigated. experimental results was shown in Fig. 5 and the data was presented in Table 2.

Table 2 Effect of malt on conversion of starch to glucose

Stage	malt in total solids	
	8%	0
1	80.62	17.42
2	70.6	18.2
3	63.6	21.2
4	65.0	22.0

It is obvious that malt can help the conversion of starch to glucose. The glucose concentration using ground malt in the different stages increased to as high as about 1.9 - 3.6 times when compared to experiment using no malt. Furthermore, the saccharification time was shortened. It was helpful to accelerate conversion of glucose to ethanol.

Effect of PH on conversion of starch to ethanol

The fermentation environment was important. One of the important factor was PH. The effect of PH on conversion of starch to ethanol were studied. Test results was shown in Fig. 6A and Fig. 6B and the Data was indicated in Table 3.

Table 3 Effect of Ph on conversion of starch to ethanol

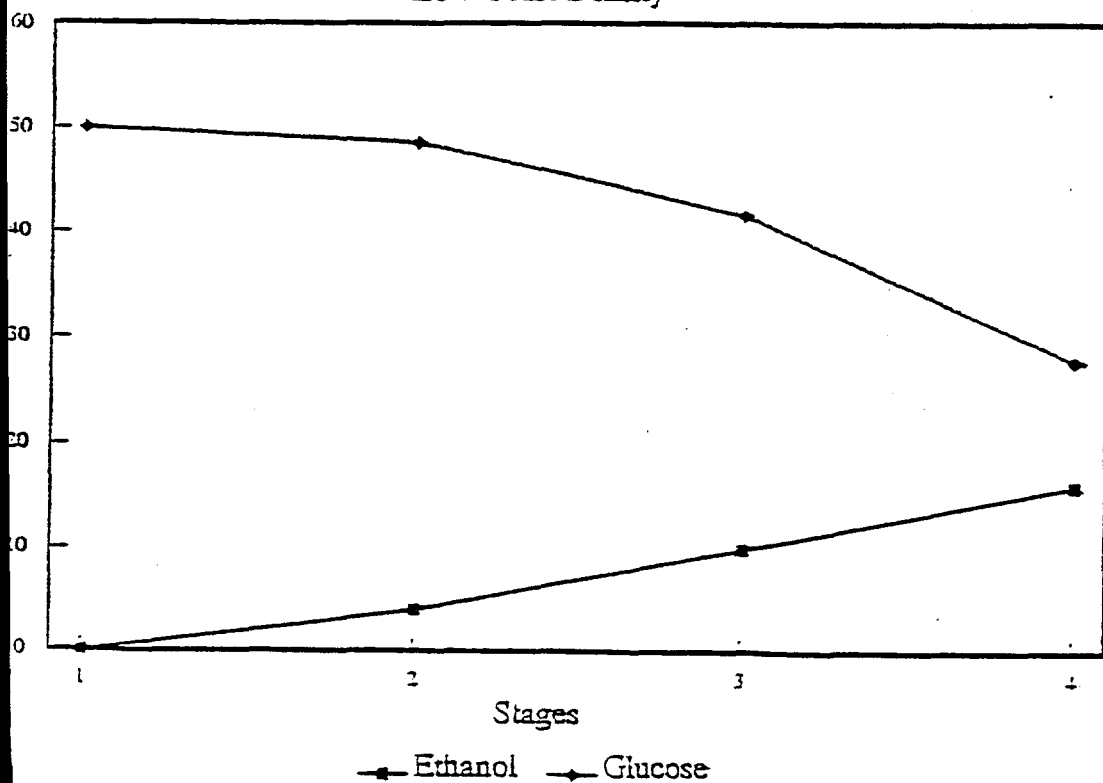
Stage	Low PH			High PH		
	Ph	ethanol	glucose	Ph	ethanol	glucose
1	2.9	0	50	3.9	12	11.4
2	2.83	4	48.6	4.04	24	1.6
3	2.88	10	41.7	4.09	25	1.4
4	2.9	16	27.8	3.98	23	1
absorber					6	

The experiments indicated clearly that yeast did not work well when PH was lowed to 3. It was much better to control the PH at about 4.

The effect of yeast density on conversion of starch to ethanol

Test results using different yeast densities are shown in Fig. 7A and Fig. 7B and the data was represented in Table 4.

Fig. 7A Effect of Yeast Density on conversion of Starch to Ethanol
Low Yeast Density



CONCLUSIONS

The CRS is a economical process in the conversion of raw starch to ethanol. It was found that 79% of raw starch was converted to ethanol on a laboratory scale.

PH and microorganism density have a significant upon the conversion of raw starch to ethanol. PH should be controlled at about 4 and yeast density should be over 15 million per cubic cent meter. Malt concentration also has an effect upon the conversion of raw starch to glucose.

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