Fuel Alcohol Production from Whey and Grain Mixtures

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In the United States, because of recent increases in cheese production to nearly 4 billion pounds yearly, more than 38 billion pounds of fluid whey are generated each year. Although considerable advances have been made recently in developing novel approaches for the utilization of surplus whey, more than half of the whey produced is thrown away or dumped into the sewer. For example, in Nebraska only 140 million of the 700 million pounds of whey produced annually are used, while 560 million pounds are wasted.

Liquid whey contains approximately 5% lactose, 1% protein and 1% fat and salts. As such, dumping huge quantities of whey down the drain constitutes a significant loss of a potential energy source as well as imposing a large biochemical oxygen demand on our waste water treatment facilities. Fermentation of the lactose to ethanol for use in gasohol (10% alcohol/90% gasoline fuel blend) is an attractive alternative in light of today's current petroleum shortages and ever increasing costs.

Preliminary studies revealed that lactose in sweet as well as acid whey can be fermented into alcohol. Whey obtained from the manufacture of Cheddar, Mozzarella, Swiss and other hard cheeses is sweet whey, whereas the Cottage cheese whey is called acid whey because of its high acid content. To optimize the economics of the process, the highly nutritious and relatively expensive whey proteins were recovered by ultrafiltration and the resulting permeate used for alcohol production. One hundred milliliter aliquots of permeate were inoculated with a trained lactose fermenting Kluyveromyces yeast or a combination of K. fragilis and the classical alcohol producer Saccharomyces cerevisiae. As shown in Table 1, there were no differences in the utilization of lactose or the production of ethanol when either the K. fragilis or the mixed culture was used.

Table 1. Fermentation efficiency of selected organisms in sweet whey permeate[a]

Culture	% Residual lactose		% Ethanol
	12h	24h	24h
K. fragilis	0.21	0.10	2.0
K. fragilis + S. cerevisiae	0.25	0.12	2.0

[a]The whey permeate contained 5.1% lactose initially.

Theoretically, 180 grams of lactose would be expected to yield 92 grams of ethanol and 88 grams of carbon dioxide. The 5.1% lactose in whey would yield approximately 2.5% ethanol assuming 100% efficiency. A more realistic estimate of 70-75% efficiency would result in the production of 70 million gallons of ethanol from the 23 billion pound annual whey surplus in the U.S. According to our estimates (Table 2)

the cost would be $1.02 to $1.07 per gallon of ethanol. These figures, however, are based on dry whey powder and do not take into account the unfeasibility of distilling a dilute ferment of 2% alcohol. Low energy concentration would be required in order to make fermentation of liquid whey economically feasible.

Table 2. Costs for producing ethanol from dried whey powder

Whey costs[a]	$110
By-product credit	- 85
	$ 25
Direct costs	
Conversion	$ 40
Loan interest	13
Indirect costs[b]	
Depreciation	13
Taxes	8
20% return	8
	$ 1.07

[a]Based on 20 lbs of dried whey @ $5.50/cwt.

[b]Figures adapted from Scheller (1).

Additionally, another process involving fermentation of whey:grain mixtures has also been developed in our laboratory. As shown in Fig. 1, the whey permeate replaces the water required in the preparation of the grain mash. The amount of corn which is otherwise required is reduced proportionately to the amount of whey sugar in the process and the residual whey solids are part of the distiller's dried grain. This process requires no equipment modification other than the addition of a whey handling facility at the alcohol plant.

Figure 3 shows the course of fermentation by K. fragilis when mash was prepared with sweet whey permeate and 20% less corn than normal. There appeared to be adequate sugar for fermentation by the K. fragilis as indicated by the production of approximately 12% alcohol in 60 hours. Substitution of whole sweet whey or whole acid whey for the water also appeared to have no adverse effect on the fermentation. As shown in Table 3, the production was slightly higher in the early stages when whole whey rather than permeate was used. By 60 hours, however, the sweet whey permeate, sweet whey and acid whey all produced 12% ethanol.

At the present time studies are underway to compare the fermentation efficiency of the K. fragilis and a mixed culture of K. fragilis and S. cerevisiae on whey:grain mixtures with reduced grain and, for comparison, on standard water mashes. Preliminary results indicate that up to 24% of the grain requirement can be replaced with the whey with no apparent loss in fermentation efficiency.

A feasibility study is currently underway to utilize the whey:grain fermentation process for a 21,000,000 gallon alcohol plant in Wisconsin. Such a plant would require about 7.5 million bushels of corn and 96 million gallons of whey based on a 15% reduction in the

Table 3. Ethanol production by K. fragilis with various types of whey in a 20% reduced grain system

Substrate	% Ethanol				
	12h	24h	36h	48h	60h
Sweet whey permeate[a]	4.4	6.7	10.9	11.8	12.2
Sweet whey[b]	7.4	10.7	11.5	11.7	12.1
Acid whey[b]	7.6	10.3	11.8	12.2	12.0

[a]Data are an average of four separate trials with duplicate samples taken at each time interval.

[b]Data are an average of three separate trials with duplicate samples taken at each time interval.

corn requirement. The substitution of whey would amount to a savings of more than a million bushels of corn per year amounting to a total of nearly 3 million dollars or 14 cents per gallon of alcohol.

References:

1. Scheller, W. A. 1977. The Use of Ethanol-Gasoline Mixtures for Automotive Fuel. Proc. Symp. Clean Fuels from Biomass and Wastes. Institute of Gas Technology, Orlando, Fla.

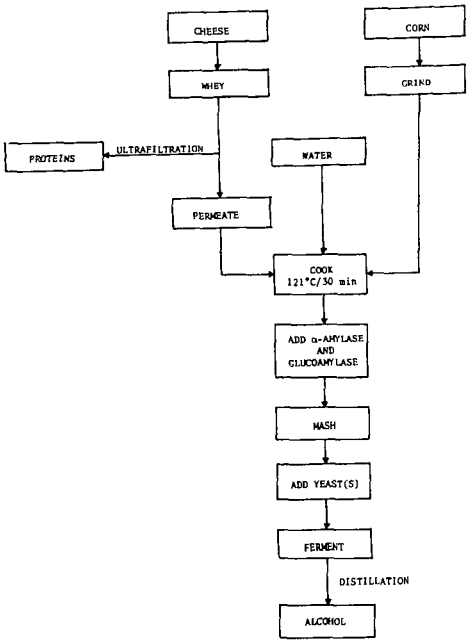

Fig. 1. Schematic of combining whey and grain to product industrial alcohol.

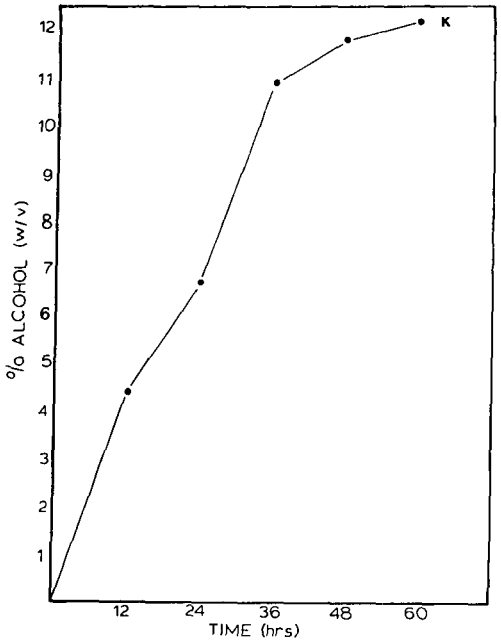

Fig. 2. Alcohol production in a medium in which the water is replaced by undiluted sweet whey permeate and the concentration of grain is 20% less than normally used.