TECHNOLOGY AND ECONOMICS OF ETHANOL PRODUCTION FROM FODDER BEETS VIA SOLID-PHASE FERMENTATION

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SUMMARY

Operating conditions for our semi-continuous, solid-phase fermentation system were optimized for conversion of fodder beets to fuel ethanol and distiller's wet feed (DWF). This information was then used to estimate operating parameters achievable in a commercial plant, and likely baseline production costs of such a plant. Initial acidification of pulp to pH 2.9-3.2 was effective in controlling bacterial contamination. The maximum operating capacity of the fermentor was approximately 92%, with 75% used for commercial application. A fermentation time of 24 h was sufficient to completely ferment the beet pulp to 8-9% (v/v) ethanol. Based on these parameters, a fodder beet cost of $19.25/metric ton ($17.50/ton), other operating and capital costs, and a PF credit of $0.14/L ($0.53/gal), ethanol production costs were estimated to be $0.49/L ($1.87/gal).

INTRODUCTION

Previous technical/economic analyses of fuel ethanol production from corn in small scale plants have indicated considerable economic feasibility problems (Dobbs et al., 1984a). In response, researchers at SDSU conducted an extensive review of possible ethanol feedstocks, and concluded that fodder beets merited further investigation due to its high biomass and ethanol yield potential (Dobbs et al., 1984b). Our preliminary research (Gibbons et al., 1984) indicated that this feedstock was potentially competitive with corn for ethanol production in small-scale plants. Wonder and Simpson (1982) included fodder beets in their assessment of several alternative ethanol feedstocks in Australia, however they simply assumed that the cost per unit of ethanol from fodder beets was similar to that from sugar beets. More recently, fodder beets were included in a Romanian assessment of potential crops for fuel alcohol (Hurdic, 1986), but no cost analysis was included.

In many of these economic projections, it had been assumed that processes similar or identical to those used to process grain into ethanol would work satisfactorily with alternate feedstocks, such as fodder beets. We recognized, however, (Gibbons et al., 1984), as have others (Rolz et al., 1979; Kirby and Mardon, 1980), that conventional, submerged fermentation processes would not work with these high moisture/high fiber feedstocks. Beers resulting from such fermentations contain only 3-4% (v/v) ethanol, and this concentration is not distillably worthwhile (Gibbons et al., 1984).
In response to the difficulty of processing alternate crops into ethanol via conventional means, various research groups have attempted to develop novel fermentation processes. One approach is the EX-FERM process developed by Rolz, et al. (1979). The primary disadvantage of this process is the material handling problem incurred by repeatedly having to add and remove feedstock pieces from the fermentation broth (Er-el, et al., 1981). de Cabrera, et al. (1982) partially solved the problem by utilizing packed-bed fermentors. We have designed and tested a continuous diffusion fermentor which completely eliminates material flow problems and allows production of distillably worthwhile amounts of ethanol in beer (Gibbons and Westby, 1983, 1988).

The other fermentation approach, pioneered by Kirby and Mardon (1980), is termed solid-phase fermentation. Kirby and Mardon envisioned using conventional stirred-tank reactors to ferment the solid mass of pulp and yeast. We, however, found it extremely difficult to process fodder beet pulp in conventional tank fermentors because of pumping and stirring problems (Gibbons, et al., 1984). The problem was not solved even when the pulp was diluted 1:1 with water (which diluted the final ethanol content). As a result of these obstacles, we designed, and constructed a semi-continuous, solid-phase fermentor which allowed production of pulps containing 8-10% (v/v) ethanol (Gibbons et al., 1984). In tests run in the fermentor we found that unpasteurized or pasteurized fodder beet pulp became contaminated with bacteria during fermentation, while pasteurized and acidified pulp did not. In small-scale simulation tests we obtained maximum ethanol yields and concentrations when the pulp pH was 3.0 to 3.5 (Gibbons and Westby, 1986a), the beets had been ground with hammermill screens of 1.27 to 1.91 cm (Gibbons and Westby, 1986b) and the yeast inoculum was 5% (wt/wt) (Gibbons and Westby, 1986c).

The objectives of the present study were to apply these and other findings to operation of the semi-continuous, solid-phase fermentor to determine overall optimum operating parameters. From this we estimated operating parameters that would generally be achievable in a continuously operated commercial plant in order to assess the economic feasibility of such a facility.

MATERIALS AND METHODS

A diagram of the semi-continuous, solid-phase fermentor is given elsewhere (Gibbons et al., 1984, 1986). It consists of a 15.24 cm diameter by 470 cm long horizontal auger tube and flighting. At one end of the auger is the beet pulp inlet port; fermented pulp exits at the other end. Pulp is transported through the fermentor by manually turning the auger flighting (it can also be turned with a slow speed motor). In this study, the fermentor was slightly modified by enclosing the auger tube with a plastic heating/cooling jacket, which was connected to a 30°C waterbath. Water was circulated from the bath through the fermentor jacket and back to the bath (4 L/min).

Fodder beets obtained for this study were stored frozen until use. To operate the semi-continuous solid-phase fermentor, the fodder beets were thawed, washed, manually sliced into 8-10 cm cubes, and passed through a 1.5 KW hammermill with a 1.27 cm screen size (Gibbons and Westby, 1986b). Beet pulp was then manually mixed with concentrated sulfuric acid to reduce pulp pH to 2.9 - 3.2 (Gibbons and Westby 1986a). Following pH adjustment, acidified pulp was inoculated by manually mixing in a yeast broth culture. The procedure used to prepare the yeast inoculum broth and the amount used with fodder beet pulp has