Process Biochemistry 27 (1992) 239–245

Bioconversion of Waste Paper to Ethanol

Morris Wayman, Shu Chen & Kim Doan

Department of Chemical Engineering and Applied Chemistry, University of Toronto, Toronto, Canada M5S 1A4

(Received 14 November 1991; accepted 12 December 1991)

A preferred process is described for efficient bioconversion of waste paper to ethanol. The paper was given a short saccharification by cellulase enzymes at 45 °C followed by fermentation in the continued presence of the enzymes at 37 °C. Ethanol yields were 350–400 litres/t of waste paper, at 8% ethanol by volume. In some of these runs, commercial cellulase was used, in others our laboratory preparation of cellulase was used; in both cases a small amount of cellobiase was also needed. There was no pretreatment before saccharification as is common with lignocellulosics. A new fermenter design well suited for waste paper processing or for cellulase production is described. The amount of paper in municipal solid waste in North America is about 100 million t yearly, enough, upon bioconversion, to replace 16% of all North American gasoline by ethanol.

INTRODUCTION

Uncertainty about the supply of crude oil from the Middle East, the associated high cost of maintaining that supply, and concerns about atmospheric pollution attributed to the use of petroleum-based motor fuels has re-awakened technical interest in cellulosics as a source of ethanol as motor fuel. Recent research has been reviewed by Wayman & Parekh.[1] The vast quantity of household trash (municipal solid waste, MSW) generated annually in the advanced industrial countries is a further stimulus for such work. The amount of waste paper generated annually in North America and finding its way to landfill sites as MSW is about 100 million t, enough, upon bioconversion, to replace about 16% of all North American gasoline by ethanol.

The prospect of conversion of so much MSW paper to fuel ethanol has resulted in considerable pilot plant and experimental activity. In 1976, a facility to convert the cellulose content of MSW to ethanol was installed at the Gulf Chemicals Pittsburgh, Kansas, petrochemical complex. It had a nominal capacity of 1 t of feedstock per day, enough to produce 80000 litres of ethanol yearly. The process employed cellulase enzymes produced on site by the fungus *Trichoderma reesei*, saccharification being followed by fermentation by common bakers' yeast *Saccharomyces cerevisiae*. In 1980 the feedstock was changed to steam-exploded aspen wood, based on the prospect of dedicated planta-

Corresponding author: Dr M. Wayman. Telephone: (416) 9784905; Fax: (416) 9788605

Process Biochemistry 0032-9592/92/$5.00

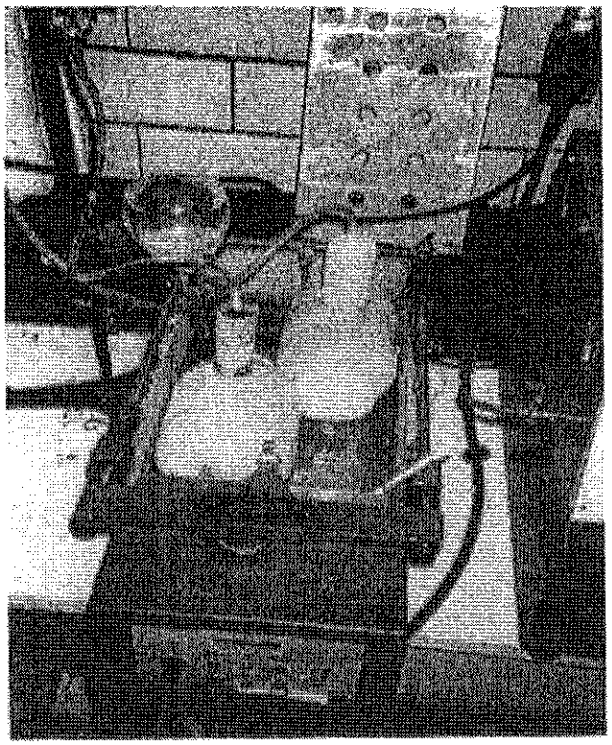

Fig. 1. 2·5 litre reciprocal shaking bioreactors.

tions. The operation, which was discontinued for lack of funding in 1982, has been described by Emert & Katzen.[2]

In 1985, Procter and Gamble Paper Products sulphite pulp-paper mill in Mehoopany, Pennsylvania, faced a problem with excessive fibres in their effluents, and established a pilot plant for bioconversion of the cellulosic fibres to ethanol, at the same time considering MSW as a possible feedstock (Bob Barkley, Procter and Gamble, private communication). The pilot plant took in 3–5 t of fibres each day. There was no pretreatment before saccharification, since the cellulose had already had extensive 'pretreatment' in the pulping. Simultaneous enzymatic saccharification and fermentation was practised, using purchased cellulase enzymes.[3] After about 1 year of operation, the project was abandoned; contributing factors to the pilot plant closure being the high cost of purchased enzymes, and the expected high capital cost for a complete cellulosic ethanol plant.

A pilot plant for the bioconversion of lignocellulosics to ethanol was built by Institut Français du Petrole at Soustons, France, using Stake steam pretreatment,[1] followed by saccharification by cellulase enzymes made on site, followed by fermentation.[4] This pilot plant can process 3 t/h of cellulosics, including, presumably, MSW.

The Tennessee Valley Authority (TVA) has long been associated with bioconversion of wood to ethanol,[1] and has recently studied bioconversion of MSW, using dilute acid pretreatment and acid hydrolysis followed by fermentation.[5]

The diversity of pilot plant designs illustrates that no single process for bioconversion of cellulosics or MSW paper has yet emerged as best. There are several technical questions which remain to be answered: is pretreatment of paper before saccharification necessary? Is enzymatic saccharification to be preferred to acid hydrolysis? Can enzymes be made cheaply on site? Should saccharification be complete before fermentation, or should the two process steps be simultaneous? How can the difference between optimal temperature of saccharification (45–50 °C) and fermentation (30–32 °C) be reconciled? Should the waste paper be added all at once at the beginning, or is fed batch more productive? This paper will attempt to answer these questions. To assist assessment of various options, performance targets were established: 350–400 litres ethanol per tonne of waste paper; ethanol concentration of 6+% by volume; and 54 h maximum total time for saccharification and fermentation.

MATERIALS AND METHODS

Materials and microorganism

A variety of waste paper samples were collected locally. The commercial cellulase used in this work was Multifect S-850 (Finnish Sugar Company, Finland, 344 IU/g,[6] 37·9% protein). Also, cellulase produced in our laboratory[7] was used. The cellobiase was Novozym 188 (Novo, Denmark, 91·5 IU/ml). Fermentation was by *S. cerevisiae*, Fleischmann's yeast purchased in a local grocery store.

Analytical procedures

Paper samples were analysed by dissolving the cellulose in 72% sulphuric acid at room temperature, diluting with cooling to 4% sulphuric acid, heating in an autoclave at 121 °C for 1 h, filtration of the lignin, neutralization with lime and, after vacuum evaporation, analysis of the resulting sugar solution by HPLC (Sugar Analyser 1, Waters,