BRIEFING NOTE

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DEMONSTRATION OF THE CONVERSION OF PAPER SLUDGE WASTE TO ETHANOL

Zinhle Ngubane, Daneal C.S. Rorke, Johann F. Görgens, Eugene van Rensburg
Stellenbosch University, South Africa

KEY FINDINGS

Target ethanol concentrations and yields were achieved using two types of paper sludge (PS) feedstocks. A maximum ethanol concentration of 34 g/L was achieved using recycled fiber PS, corresponding to a yield of 74% of the maximum theoretical ethanol concentration, at an enzyme dosage of 7 filter paper units per gram dry solids (FPU/g DS) and a solid loading of 28.5% (w/w). Fermentation of virgin fiber PS produced a maximum ethanol concentration of 36 g/L, corresponding to a yield of 69% of the maximum theoretical ethanol concentration at an enzyme dosage of 8 FPU/g DS and a solid loading of 20% (w/w). Up to 70% of the initial moisture was removed, and the fermented solids were successfully pressed to below 20% (w/w) moisture. The fermentation process demonstrated the bioconversion of hemicellulose and cellulose fractions of PS enhancing dewaterability; however, the variation in the physical properties of the two PS streams was observed to influence fermenter operational requirements during simultaneous saccharification fermentation (SSF).

INTRODUCTION

The project aimed to demonstrate the technical feasibility of converting paper sludge (PS), a waste material generated by paper mills into ethanol, valorizing the material which would have otherwise been destined for landfills.

The Bioresource Engineering group at Stellenbosch University (SU) has conducted more than 10 years of research on paper sludge fermentations. The key purpose of this research was to offer the pulp and paper industry an alternative technology to valorize this high-moisture waste stream. As such, SU designed and built a containerised mobile demonstration plant which houses a 1000-L bioreactor and key utilities with the specific aim of fermenting PS to ethanol under real, industrial conditions

Through a collaborative agreement between SU and PAMSA, this mobile demonstration plant was constructed by an engineering firm in Cape Town and commissioned at the Sappi Tugela pulp and paper mill in Mandeni, KZN in August 2023. Over the past two years, SU has also partnered with the CSIR and made substantial progress in developing an industrial process for converting PS into ethanol under industrial conditions.

METHODOLOGY

Activities at the mobile plant focused on demonstrating ethanol production from two types of PS tested during this period viz. sludge from virgin wood in 2024, and sludge from recycled fiber in 2025. Figure 1 illustrates the process employed in the preparation of PS for simultaneous saccharification fermentation (SSF).

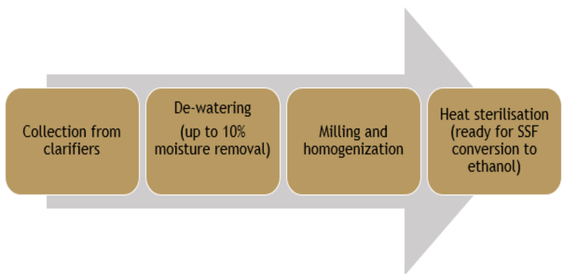

Figure 1: Process employed in the preparation of industrial amounts of PS.

MAIN RESULTS

Data from bench-scale laboratory experiments showed that PS can retain traces of microbial contamination even after sterilization. A patented sterilizer vessel that feeds sterilized PS directly into the fermenter at regular intervals was designed and constructed as part of the demonstration plant. Table 1 shows that the sterilizer vessel reduced contaminants in the PS by up to 99%.

Table 1: Effect of PS decontamination in the sterilizer vessel

PS source	Microbial load before sterilization (CFU/g)	Microbial load after sterilization (CFU/g)
Virgin fiber	$1{,}8 \times 10^4$	2.7×10^1
Recycled fiber	7.2×10^4	0.5×10^1

Figure 2 shows the best performing SSFs with both PSs. A yield of 69% was achieved with virgin fiber PS while recycled fiber PS gave a yield of 74% of the maximum theoretical ethanol concentration.

To improve the SSF process capability while reducing reliance on expensive enzymes, advanced yeast strains were investigated. Use of a xylose-metabolizing and enzyme-secreting consolidated bioprocessing (CBP) yeast lowered enzyme dosages to 53% of what was used in the SSF with the industrial yeast Ethanol Red®.

When the physical properties of the two PS types were compared, it was evident that recycled fiber PS contained less lignin and higher ash content than virgin fiber PS. Virgin fiber PS had higher cellulose and hemicellulose, both of which can be converted into simple sugars for the fermentation of ethanol. The impact of these differences in physical characteristics affected the operational requirements, as well as the PS feeding strategy in the fed-batch fermentation.

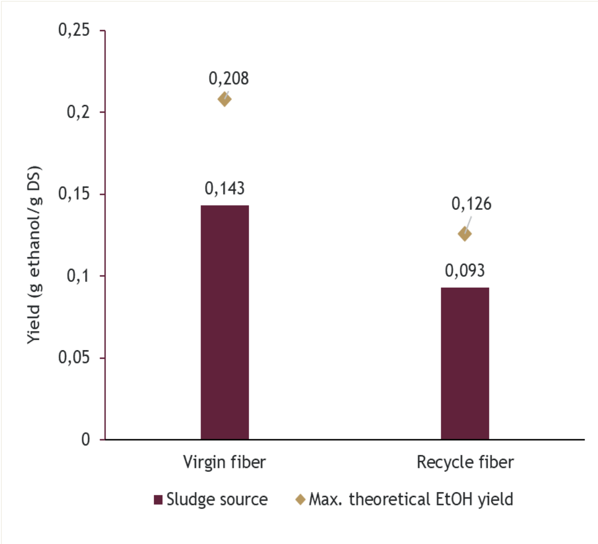

Figure 2: A plot comparing the best fermentations using virgin fiber PS and recycled fiber PS

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The SSF targets the enzymatic degradation and fermentation of the hemicellulose and cellulose fractions of PS. As these polymers retain substantial amounts of water, their bioconversion is expected to enhance dewaterability. This was confirmed by demo plant results: where up to 70% of the initial moisture was removed, and the fermented solids were successfully pressed to below 20% (w/w) moisture.

These findings underscore that certain process limitations and optimization opportunities only become apparent under real industrial conditions, highlighting the mobile demonstration plant's critical role in generating insights unattainable at laboratory scale.

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