**Process Intensification of the Hydrolysis of Cellulosic Fiber Wastes Using Membrane Bioreactors for Catalyst and Enhancer Recycle**

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**Highlights**

* Recycled paper fibers are enzymatically hydrolyzed using cellulases.
* Surfactants are necessary to combat inhibition activity of mineral particulates.
* Better kinetics and yields are achieved using membrane separation in an MBR.
* Process modeling enables optimization of the operation of the MBR.

**1. Introduction**

Mixed office waste paper (MOW) and other grades of fine and packaging paper are widely reused to produce recycled tissue and packaging paper. Recycled pulp is made by dispersing the wastepaper in water and removing the ink and mineral particles by air flotation. However, fiber fragments also float and are rejected in the waste streams and up to 60% of such wastes can be such cellulosic particles. Furthermore, as fibers are recycled multiple times, they become brittle and fragment during pulp preparation. The fragments are a hindrance to paper manufacture. They clog the paper mats and wires during dewatering and drying, significantly slowing down the paper machine reducing the production rate. Modern paper machines are operated at very high speeds (in excess of 60 mph) and any hindrance can have significant impact on profitability. Recycled pulp fines also reduce bonding within the paper sheets and reduce the strength and quality of the final product. However, the rejection of such pulp fines into the waste stream increases the waste volume and its organic load imposing large disposal costs to the paper mills, negatively impacting the environment and the sustainability footprint of the paper products. Reduction of this waste stream through its utilization presents a great opportunity.

In recycled paper mills, these waste fines are usually rejected into the rejects stream which is eventually dewatered and the solids landfilled. However, there is increasing pressure on landfilling due to environmental degradation and increasing costs of transportation. Therefore, any effort to reduce the volume of these solid wastes can be economically attractive with a positive impact on the environment. Waste fibers (WF) represents an attractive biomass due to its cellulosic fibers content and the fact that its structure is feasible for bioconversion without pretreatment. Waste Fiber composition is diverse depending on the substrate and pulping and paper making processes but is mostly composed with 40-65% of sugars, 10-40% of ash and low portion of other materials such as lignin, plastics, or synthetic fibers [[1-3](#_ENREF_2)]. These waste fibers are advantageous because the biomass particle size has already been reduced to the micrometer range (in fiber diameters) and the fact that the bulk of the lignin has been removed in the wood pulping process itself. However, high ash content in the WF inhibits the ability to convert its carbohydrates and reduces the productivity of processes. The heterogeneity of paper sludge results in low product concentration by limitation of solid loading ]. Among the fillers, calcium carbonate (CaCO3) is reported as the strongest inhibitor reducing enzymatic activity effecting on hydrolysis yield by pH drift. The inhibitory effect of CaCO3 could also be potentially related to non-productive enzyme binding. The affinity of CaCO3 is much higher towards enzyme more than the affinity of clay, and precipitated calcium carbonate (PCC) shows much higher binding affinity than ground calcium carbonate (GCC) ].

**2. Methods**

Samples of waste fibers were procured from a recycled linerboard-manufacturing mill (RF). A synthetic model of this waste rejects was also prepared in the laboratory by grinding a sample of unbleached softwood kraft pulp (UKP) fibers. This was mixed with different quantities of clay and precipitated calcium carbonate. The hydrolysis was carried out in hydrolysis flasks placed in a shaking incubator (Reciprocal Shaking Bath 51221080, Precision Scientific Co., Denver CO) and hydrolyzed at 50°C up to 72 h at 130 rpm. The cellulase enzyme used was commercially available Cellic CTec2 (Novozymes USA) in 5% consistency using 0.05M sodium acetate buffer (pH 5). The hydrolyzate was removed after fixed time and samples withdrawn and analyzed with HPLC or NMR. For the calcium ion solution test, the PCC was dissolved in the prepared sodium acetate buffer and acetic acid was added to bring the pH to 5 (SU). The solid residue was filtered on Whatman filter paper #1 and the filtered solution was supplied for UKP hydrolysis to measure the effect of dissolved calcium ions. Tween 80 (Amresco®) was selected for non-ionic surfactant test for this study.

A continuous membrane bioreactor configuration was set up and used for experiments.

**3. Results and discussion**

**Figure 1.** Hydrolysis of fibers as a function of enzyme concentration in FPU. Effect of surfactant.

The continuous separation of sugars as hydrolysis products from the reaction vessel allows faster kinetics and a reduction in the size of the reactors. Optimization of the reaction conditions by kinetic modeling is currently underway.

**4. Conclusions**

A membrane bioreactor is able to improve yields and kinetics of the enzymatic hydrolysis and also enable enzyme and promoter recycling, contributing to effectiveness and economical production costs of the process.

**References**

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