Utilizing Cotton Pulp from Baby Diapers for Bioethanol Production

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Introduction

Disposable baby diapers belong to an important group of products that are being used throughout infancy due to their high efficiency and ease of use. They are thrown away after one use, creating a huge waste management problem (Kordecki et al. 2022). Used baby diapers are challenging to manage as they are a waste stream that constitutes 3.3% of municipal waste which is remarkable in quantitative terms. It has been estimated that about 4600-4800 diapers are used during the first three years of a baby's life and globally 250 million of them are thrown away every day. Disposable diapers are made of wood pulp, cotton, viscose rayon and many polymers such as polyester, polyethylene and polypropylene (Li et al. 2024). In addition to containing polymers, they contain organic waste as well. The used diapers are therefore a complex waste consisting of both solid and organic parts that cannot be included in any recycling/utilization flow of the urban waste management networks developed to date. Their components can be used after separation and appropriate pretreatment for the recovery and reuse of polymers and for the production of biosolvents mainly from the cotton content (Ichiura, Nakaoka, and Konishi 2020).. The scope of this study was to investigate a valorisation pathway for the diaper cotton pulp after its layers separation.

Materials and Methods

The composition of a dry diaper was estimated in % w/w dry basis as: 35.88% Pulp, 30.48% Super Absorbent Polymer (SAP), 12.91% Non-Woven Polypropylene (PP), 4.61% Adhesives, 0.72% Polypropylene Films, 2.17% Non-Woven PolyEthylene Terephtalate (PET), 12.68% Laminate PP/PE and 0.55% Elastics. Polymers can be easily recovered by separation using an acetone or ethanol solution, while SAP requires a more complicated treatment using sodium chloride (NaCl) in order to achieve its dehydration and return to its original form (Chazovachii et al. 2021). The pulp has a high cellulose (74.31% w/w) and hemicellulose (20.27% w/w) content, therefore it seems as a suitable substrate for the production of fermented sugars and biosolvents such as bioethanol via saccharification and alcoholic fermentation.

All chemicals utilized were of analytical quality. Novozymes (Denmark) kindly supplied us with CelliCtec3, a cellulololytic enzymatic formulation. The activity of CelliCtec3 was quantified as 171.7 FPU/mL (Zhong et al. 2022). Saccharomyces cerevisiae (dry baker's yeast) was used for ethanol production. For the determination of sugars and ethanol produced during the enzymic hydrolysis and alcoholic fermentation processes, HPLC (HyperREZ™ XP Carbohydrate H^+) analysis was employed. All analyses were conducted in duplicate.

Experimental procedure

To achieve separation of the diaper layers, a square segment of a clean diaper is excised and subjected to immersion in a pure acetone or ethanol solution for 24 hours.

Due to the high percentage of cellulose content of the cotton pulp, a series of experiments were carried out in 50mL boro-bottles. The solid loading is 3% w/w for all the experiments to maintain comparability of results.

For optimal cellulose breakdown, the solution is pretreated as follows:

a) Hydrothermal pretreatment using an autoclave (ISOLAB Laborgerate GmbH) at 121ºC for 30 minutes.
b) In a water bath at 90°C for 75 minutes.

Three different solvents are tested: NaOH (0.1M, 0.2M, 0.3M), H_2SO_4 (1% v/v), and H_2O. Following pretreatment, enzymatic hydrolysis was conducted for 48 hours at 50°C with three different cellulase loadings: 200 μL/g cellulose, 400 μL/g cellulose, and 500 μL/g of cellulose. Finally, at a temperature of 35°C, Saccharomyces cerevisiae was added at a loading of 2% w/w, and alcoholic fermentation was carried out for 24 hours. Upon completion of the process, the degradation percentage of the solid cotton pulp was calculated.

Results

After immersion of the diaper in the acetone and ethanol solutions, distinct layer separation was observed as acetone dissolved the adhesive binding among the layers. It is noteworthy that SAP did not absorb any acetone and retained its crystalline structure.

The saccharification performance in all tests and the ethanol production and solids degradation performance for the two optimal processes are presented in the tables below.

Solvent	Concentration of solvent	Cellulase Load (μL /g cell.)	Saccharification Yield Autoclave	Saccharification Yield Water Bath
NaOH	0,2 M	500	55%	44%
H_2SO_4	1% v/v		8%	1%
H_2O	-		11%	2%

Table 1. Solvent selection experiments results.

NaOH Concentration	Cellulase Load (μL /g cell.)	Saccharification Yield Autoclave	Saccharification Yield Water Bath
0.1 M	500	3%	5%
0.2 M		44%	55%
0.3 M		68%	85%

Table 2. Experiments for the selection of the optimal concentration of NaOH.

Cellulase Load (μL /g cell.)	NaOH Concentration	Saccharification Yield Autoclave	Saccharification Yield Water Bath
200	0.3	60%	76%
400		83%	61%
500		68%	85%

Table 3. Experiments for the selection of the optimal concentration of cellulase for the enzymatic hydrolysis.

NaOH Concentration	Cellulase Load (μL /g cell.)	Yeast load (w/w)%	Ethanol Production Yield Autoclave	Degradation of solids
0.3 M	400	2	50%	92%

Table 4. Ethanol yield and Degradation of solids for the Autoclave pretreatment method.

NaOH Concentration	Cellulase Load (μL /g cell.)	Yeast load (w/w)%	Ethanol Production Yield	Degradation of solids
0.3 M	500	2	31%	80%

Table 5. Ethanol yield and Degradation of solids for the Water Bath pretreatment method.

Conclusions

To sum up, the overall performance of the method on the process of the diaper's layer separation is considered to be quite satisfactory, with the use of acetone and ethanol solutions.

Regarding the saccharification, ethanol production, and solids' degradation experiments, maximum yields of 85%, 50%, and 92%, respectively, were achieved. These outcomes demonstrate the feasibility of utilizing cotton pulp from diapers, with considerable scope for optimization. Further optimization is needed to enhance both the initial solids loading and the reaction kinetics of ethanol production.

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