Biopolymer Membranes For Greywater Filtration

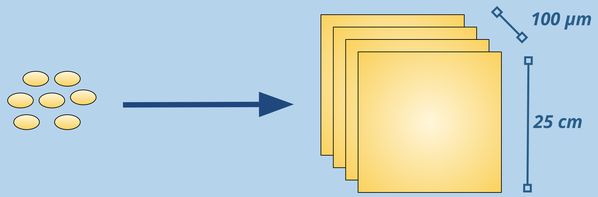
Homa Keshmiri, Alexandra Lam, Christine Ogunsola, Amanda Schroeder, Melody Simmons
Department of Chemical & Biomolecular Engineering, University of Maryland - College Park, MD

A. James Clark School of Engineering

Introduction

Lightly contaminated wastewater from household activities like laundry and dishwashing can be efficiently reused for agriculture and irrigation through localized filtration systems without requiring excessive purification standards. Membranes are a leading technology in greywater treatment due to their compact design, low cost, and effectiveness in removing small solids and pathogens. However, current membranes rely on petrochemical materials and toxic solvents, raising environmental and health concerns.

Our project addresses these issues by **producing sustainable CTA/Chitosan composite biopolymer flat sheet membranes** using an environmentally friendly solvent called NMMO. This design targets sustainability, performance, and scalability.



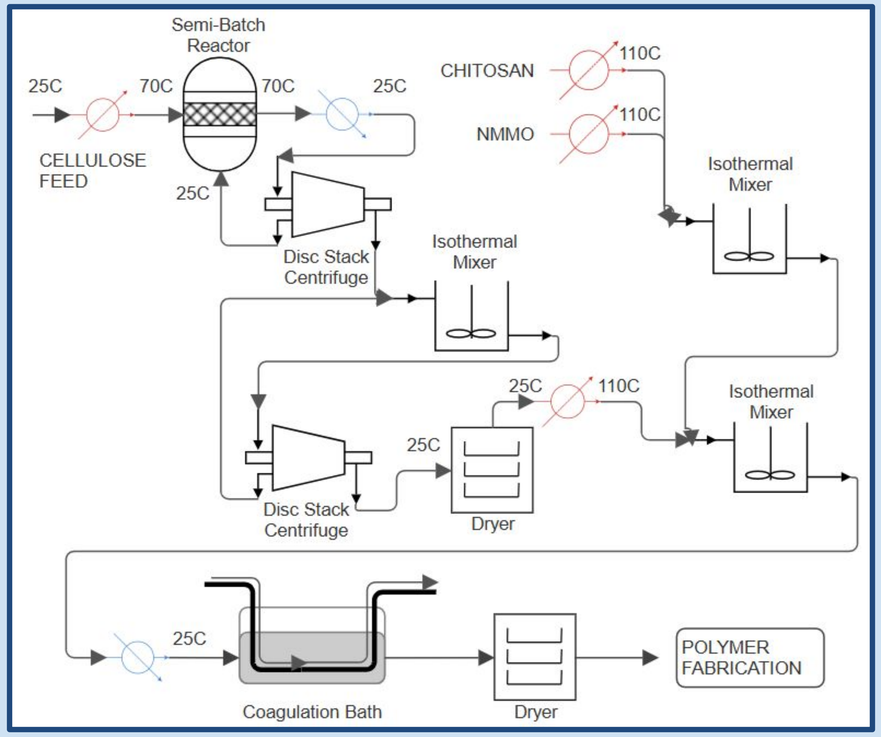


Figure 1. Process Flow Diagram of CTA production

Key Reactions

1. **Acetylation reaction:**
   $C_6H_{10}O_5$ ***(cellulose)*** + $3(CH_3CO)_2O$ ***(acetic anhydride)*** → $C_6H_7O_2(OCOCH_3)_3$ ***(CTA)*** + $3CH_3COOH$ ***(acetic acid)***
2. **Hydrolysis of Acetic Anhydride (during washing):**
   $(CH_3CO)_2O + H_2O \rightarrow 2CH_3COOH$
3. **Potential Side Reactions (to be avoided):**
   NMMO + $(CH_3CO)_2O$ → esterified NMMO (undesired)
   NMMO + H_2SO_4 → degraded NMMO (acid-catalyzed degradation)

Economics

Goal: 400,000,000 membranes per year
Price: $0.13 per membrane, $135 per pack

Initial Investment ($)	$17.4 M
Production Cost (RM, Utility, Operations, etc.) ($/yr)	$49.3 M
Sales ($/yr)	$51.4 M
Net Profit ($/yr)	$1.22 M
Return On Investment (%)	7.02%
Payback Period (yr)	4.81

Methods

Aspen Plus V14 Simulation Software was used to model all units, process streams and exchangers
Aspen Economic Analyzer estimated cost and utility requirements
Python was used to code a proportional integral temperature controller
By Hand calculations were performed to model process optimization parameters, solubility requirements, and other complex system properties.

Process Overview

1. **Cellulose Acetylation:** Cellulose reacts with excess acetic anhydride in acetic acid solvent (in the presence of sulfuric acid catalyst) to produce solid CTA
2. **CTA Purification::**
   Centrifuge 1- removes liquid solvent from solid CTA
   Centrifuge 2- water is added to remove acetic anhydride and sulfuric acid
3. **Polymer Solution Synthesis:** High shear mixers dissolve chitosan and CTA in NMMO under PI temperature control
4. **Phase Inversion:** Removes polymer from polymer solution through precipitation with water

Safety & Environmental Considerations

- Acetic acid and acetic anhydride flammability:
  - Reactor sealed and operated in inert N_2 atmosphere
  - Pressure and temperature controller
- Sulfuric acid reactivity with water:
  - Humidity sensor
  - N_2 inert environment
- NMMO autocatalytic runaway rxn above 120°C:
  - PI Temperature controller
- Dispose small quantities of acetic anhydride, acetic acid, and sulfuric acid with hazardous waste facility
- Air and water waste streams pass US regulation emission requirements to release
- Distill out NMMO/water mixture and recycle back into process (savings of $131 M/yr)

At an industrial scale, phase inversion is a continuous process where the polymer solution is poured onto a roll of support layer, immersed in a coagulation bath, and then rolled out of the bath as seen in Figure 2.

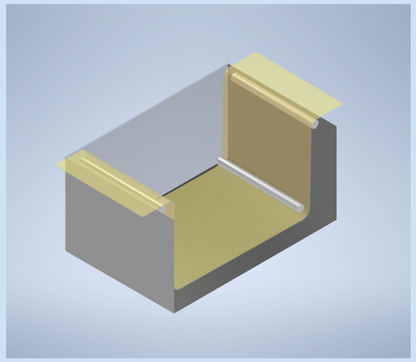


Figure 2. Coagulation bath for phase inversion unit

Process Optimization

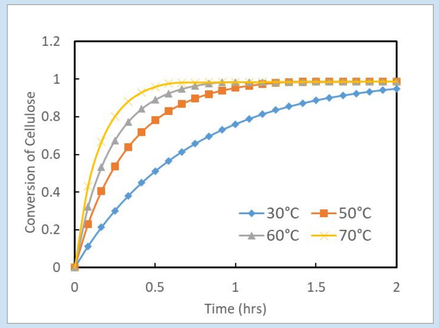


Figure 3. Reactor temperature optimization

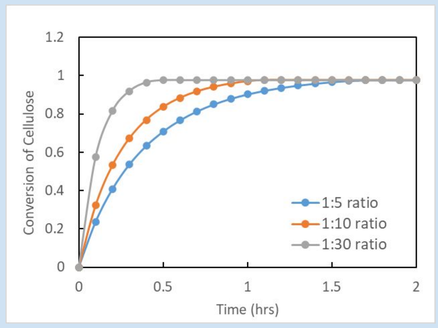


Figure 4. Reactor solvent ratio optimization