Towards the Recovery of valuable chemicals through Forward Osmosis (FO)

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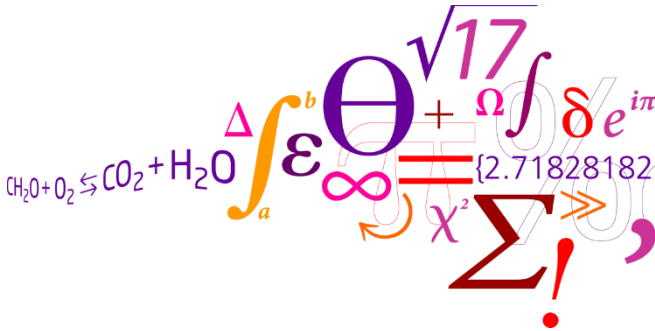

DTU Environment
Department of Environmental Engineering

Overview

1. Ceit-IK4
2. Introduction
3. Objective
4. Material and Methods
5. Results and Discussion
6. Conclusions

Ceit-IK4


A Coruña
Gijón
Santander
San Sebastián
FRANCE
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Vigo
Ponferrada
Soria
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Barcelona
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Segovia
Guadalajara
MADRID
Teruel
Castellón
Palma
Maó
PORTUGAL
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Toledo
Valencia
Badajoz
Albacete
Ibiza Town
Córdoba
Alicante
MEDITERRANEAN SEA
Huelva
Seville
Granada
Cartagena
Mojácar
Málaga
Almería
Cádiz
Marbella
Gibraltar
ALGERIA
MOROCCO
0 25
kilometres

Ceit-IK4

- Ceit is an independent, private, non-profit[1] RTO (Research and Technology Organization)
  - Created in 1982 by the University of Navarra
  - Associated with the University
  - Supported by the Basque Government as part of the Basque network of Science, Technology and Innovation
- Ceit's mission is to serve society and industry by
  - developing research projects
  - training young researchers

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Introduction

ANAEROBIC DIGESTION

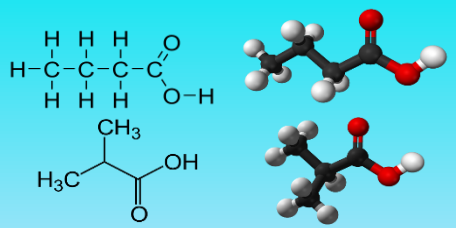
- Mature technology
- Biogas market
- Legislation

BIOREFINERY

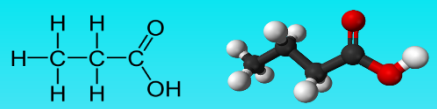
- VFA production
- Experimental phase
- Application

  (Pure form & mixtures)

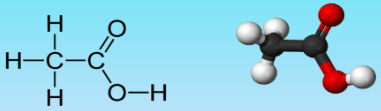
Butyric



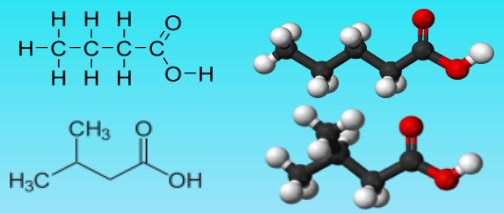
Propionic



Acetic



Valeric



Introduction

VFA market

Carboxylic acids	Chemical formula	Market size (tonnes/year)	Price per tonne (USD, $)
Formic	$HCOOH$	30,000	800–1,200
Acetic	CH_3COOH	3,500,000	400–800
Propionic	CH_3CH_2COOH	180,000	1,500–1,650
Butyric	$CH_3(CH_2)_2COOH$	30,000	2,000–2,500
Caproic	$CH_3(CH_2)_4COOH$	25,000	2,250–2,500

Chemical

WWTP

Biofuels

Biomaterials

Animal Feed

Introduction

Methodology

Industrial wastewater

Paper
Meat
Winery
Biodiesel

Sludge
Solid waste

Dairy
Slaughterhouse
WWTP
OFMSW

Laboratory scale

- Acidogenic potential
- pH: acid & alkaline
- T: 35˚C y 55˚C

Pilot scale

- Batch and continuous
- Mono fermentación
- Co-fermentación

Motivation of the stay

+

Motivation of the stay

Anaerobic fermentation

Raw waste

Soluble fraction

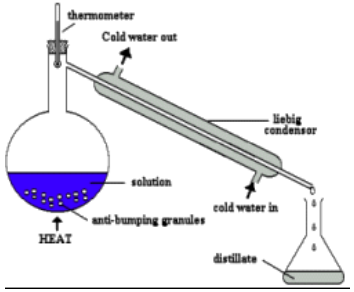
Valuable bioproducts

Motivation of the stay

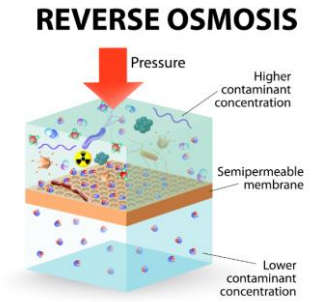
Downstream options

Solvent extraction

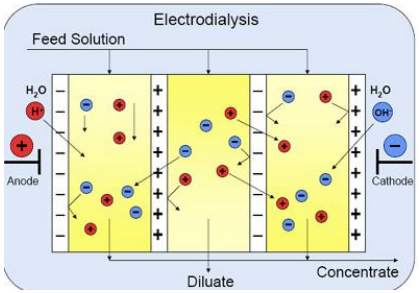
Distillation



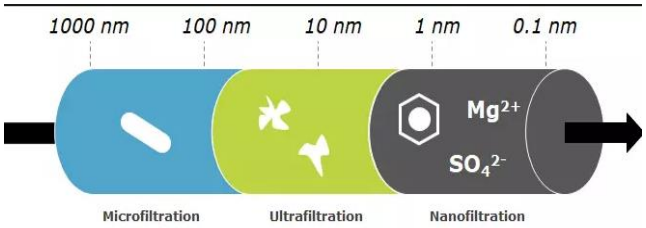
Membrane technologies



Electrodialysis



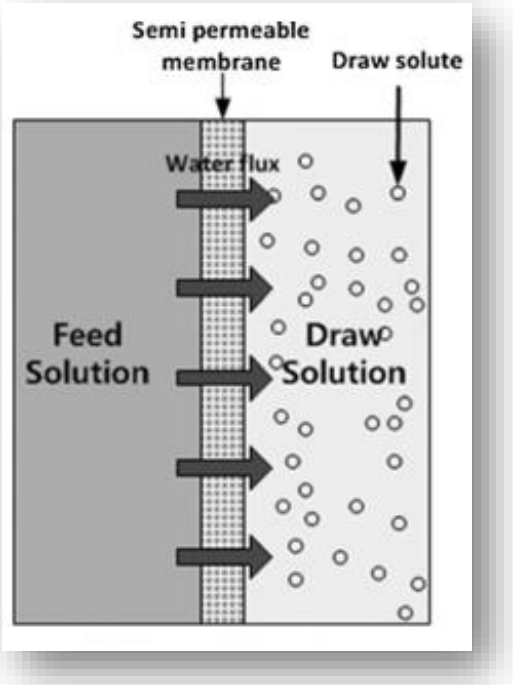
Nanofiltration



FORWARD OSMOSIS?

Motivation of the stay

FORWARD OSMOSIS (FO)

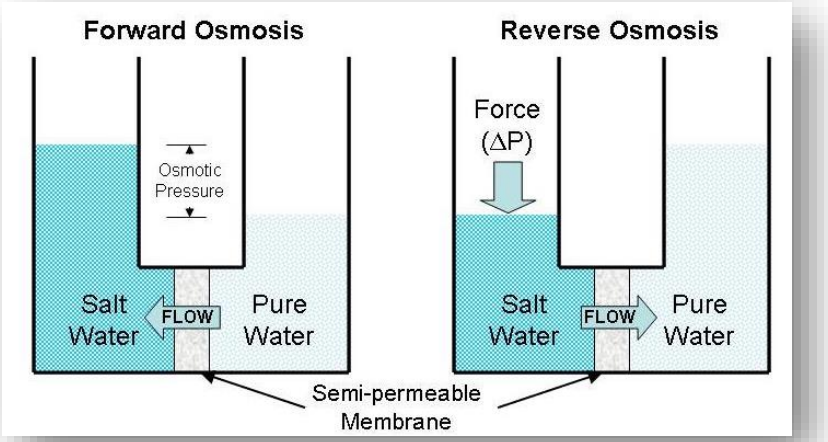


P1 < P2

Driving force = ΔP osmotic pressure

Advantages

- ✓ Low energy requirement
- ✓ Lower fouling propensity
- ✓ Higher water recovery



Overview

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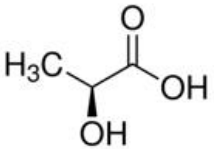
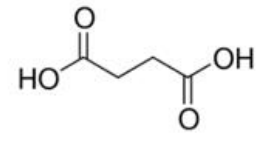
Objective

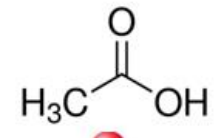
1. Application of FO technology with Synthetic mixtures



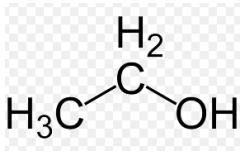
Lactic acid



Succinic acid



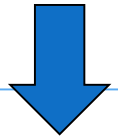
Acetic Acid



Ethanol

pH 3

pH 7



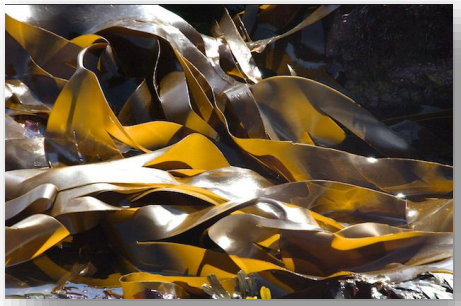
Flat sheet

Hollow fibre

Objective

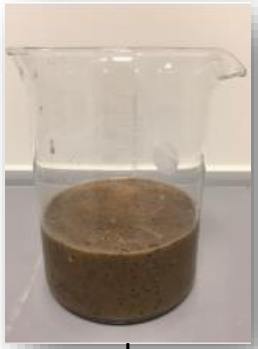
2. Application of FO with real fermentation broths

Macroalgae



1. **Succinic Acid** broth

Biopulp



Enzymatic hydrolysis + Fermentation

2. **Lactic acid** broth

Fermentation

3. **Ethanol** broth

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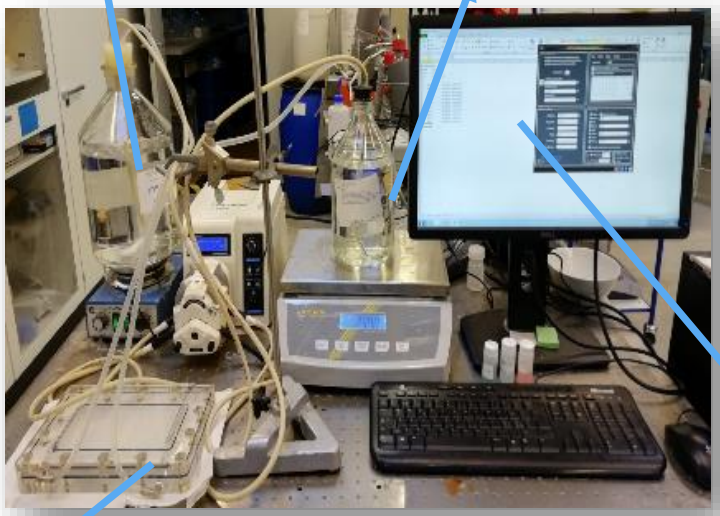
Material and Methods

Synthetic FO experiments

Membrane Characteristics		
	Flat sheet	Hollow fibre
Membrane area	0.014 m^2	0.3 m^2
Company	FTSH20	Aquaporin

Draw solution

Feed: 20 g/L



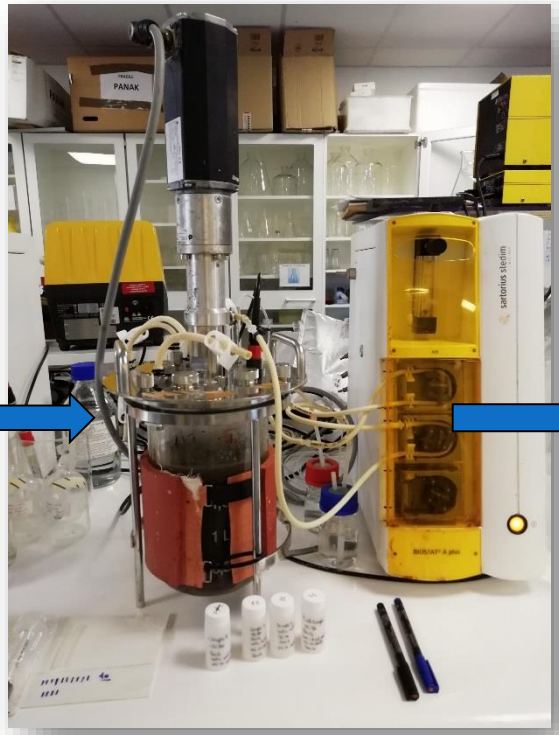
Mass transfer

Weight change measurement (Feed)

Material and Methods

Fermentation tests

Inoculation of
Lactobacillus Delbrueckii



Number of tests: 3

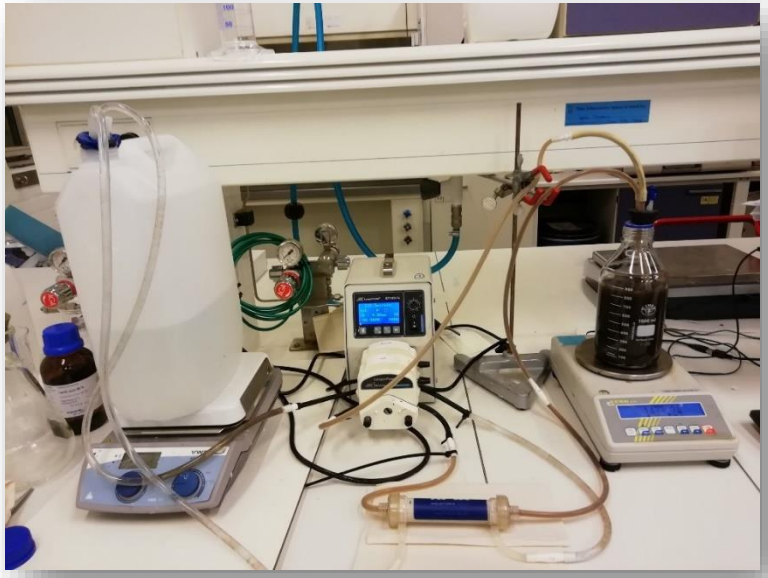
Substrates:

- Diluted biopulp 1:1 (ethanol production)
- Hydrolized biopulp (lactic acid prod.)

Soluble fraction for FO tests

Material and Methods

Real broth FO tests



- Water flux L/m^2 h
- Conductivity change: mS/cm
- Osmotic Pressure change: mOsmol/kg
- Composition: HPLC, VFA (Feed, DS)

Feed solution (1L)

- Lactic Acid broth
- Succinic Acid broth
- Ethanol broth

Process conditions

- Room T
- No pH adjustment
- Draw solution (4L):
  - NaCl 1.5 M
  - NaCl 5 M
- Duration: 1h

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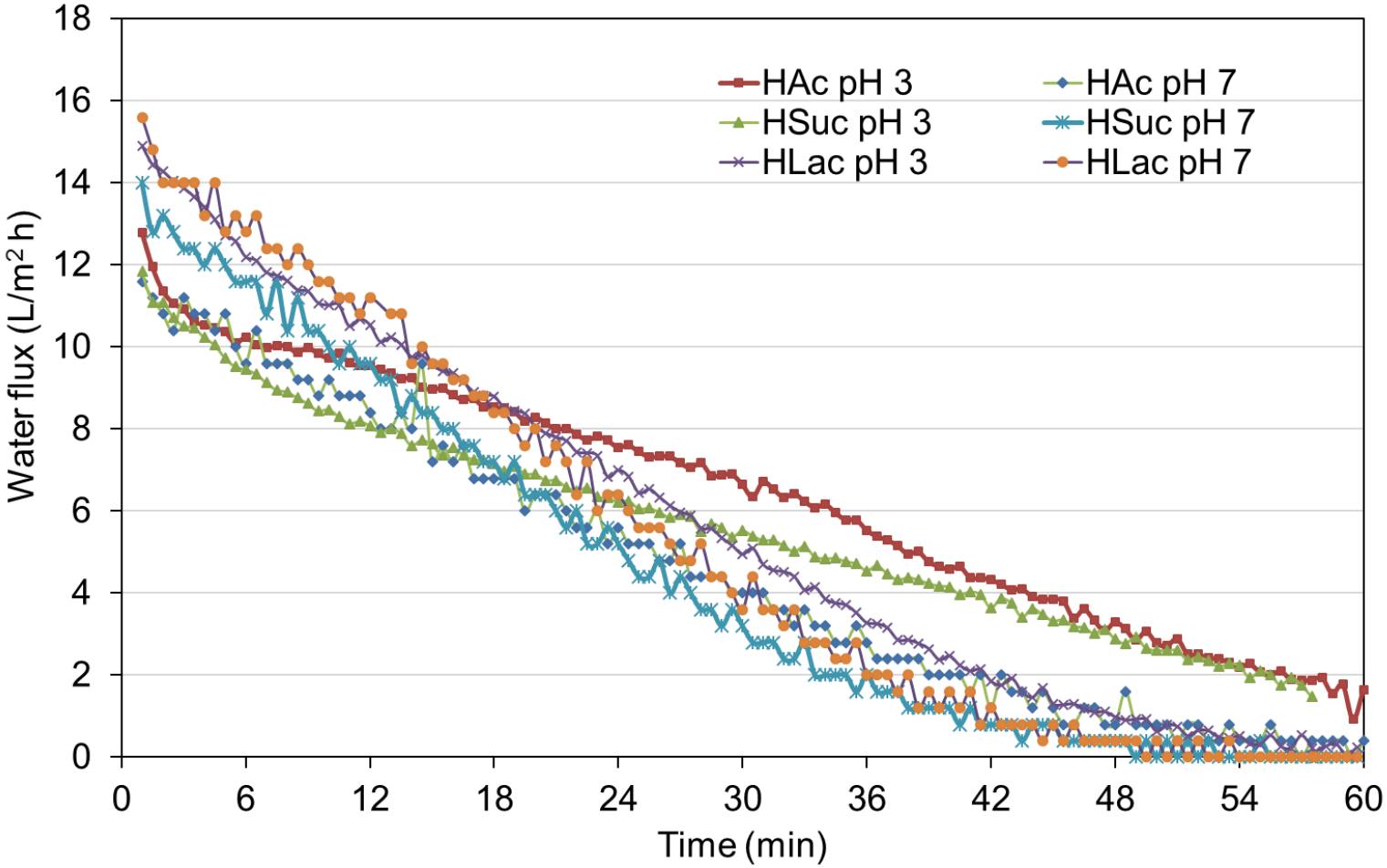
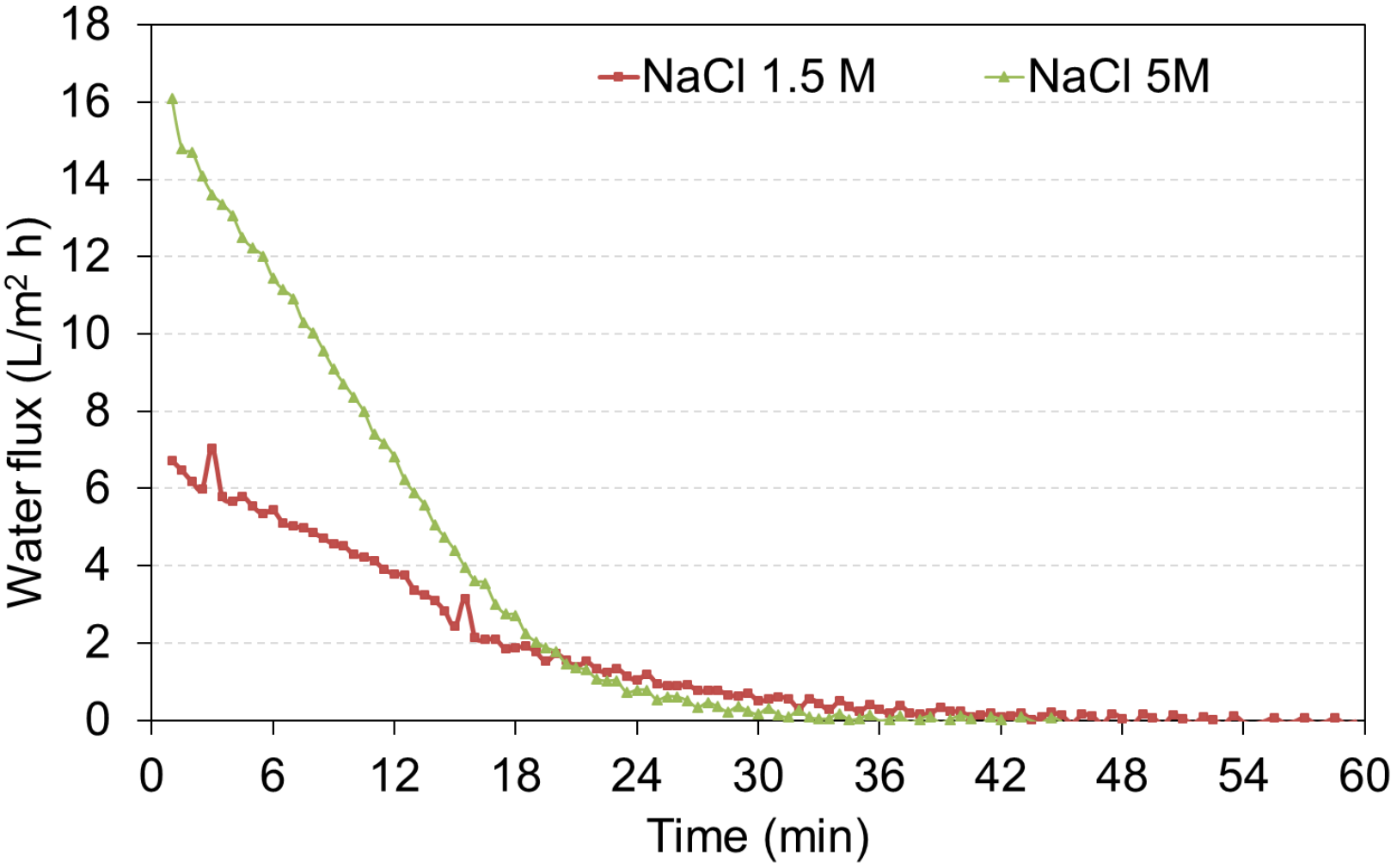
Results and Discussion

Example of decline in the water flux; Effect of pH and chemical



Results and Discussion

Example of the effect of DS concentration



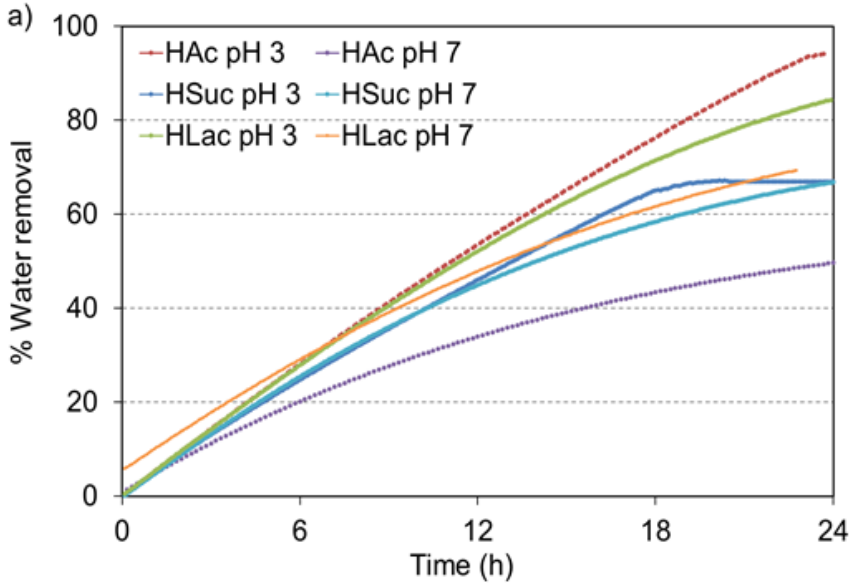
Results and Discussion

1. FO SYNTHETIC TESTS RESULTS

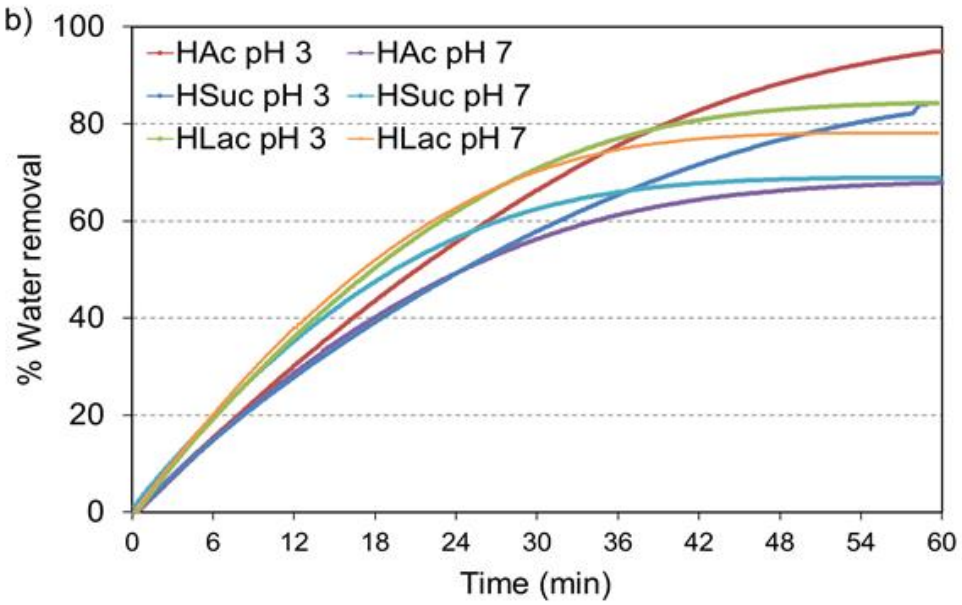
Results and Discussion

1. SYNTHETIC TESTS: Percentage of water removal from the Feed

Flat sheet results



Hollow fibre results

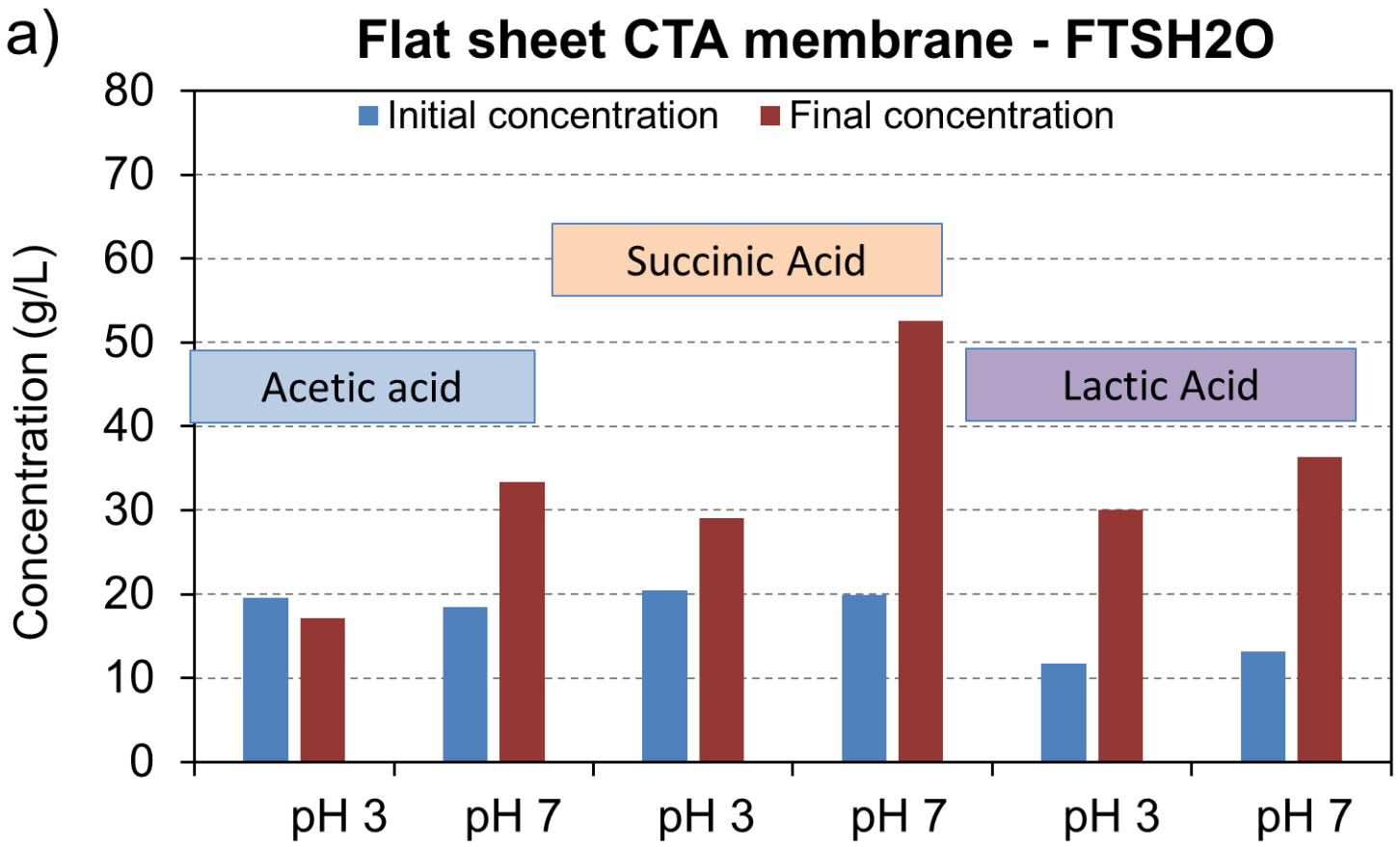


Observation

- Higher water removal with hollow fibre > 65%
- Higher water removal at pH 3
- Hac > HLac > HSuc

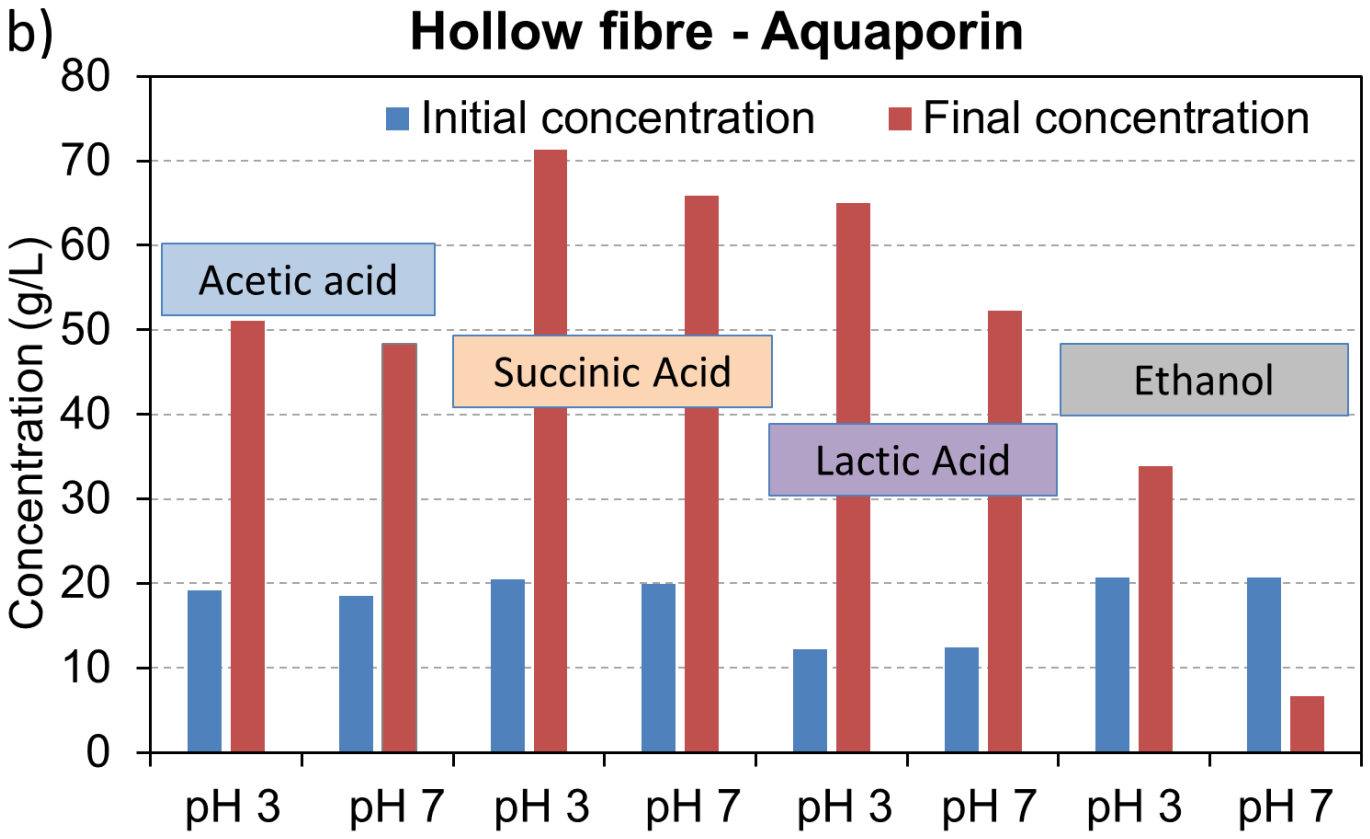
Results and Discussion

1. SYNTHETIC TESTS: Flat sheet membrane up-concentration



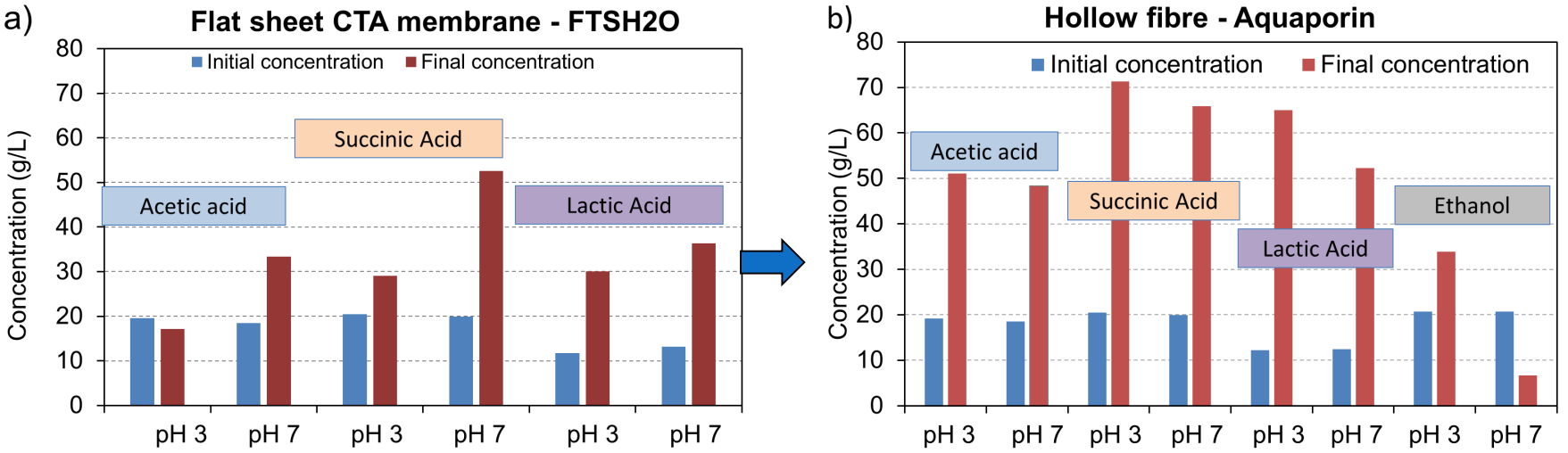
Results and Discussion

1. SYNTHETIC TESTS: Hollow fibre membrane up-concentration



Results and Discussion

1. SYNTHETIC TESTS: Comparison of flat sheet and hollow fibre

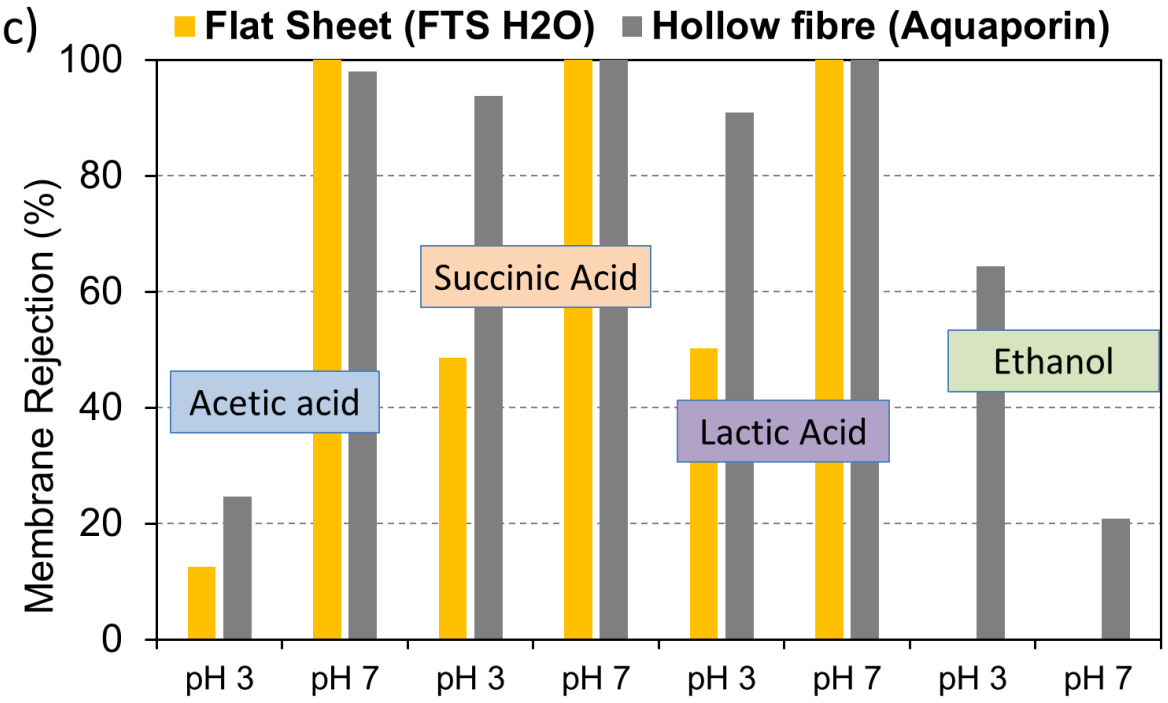


Hollow fibre membranes

- A higher water flux
- Higher up-concentration potential (between 1.6 – 5.3 times)
- HSuc > HLac > HAc > Ethanol

Results and Discussion

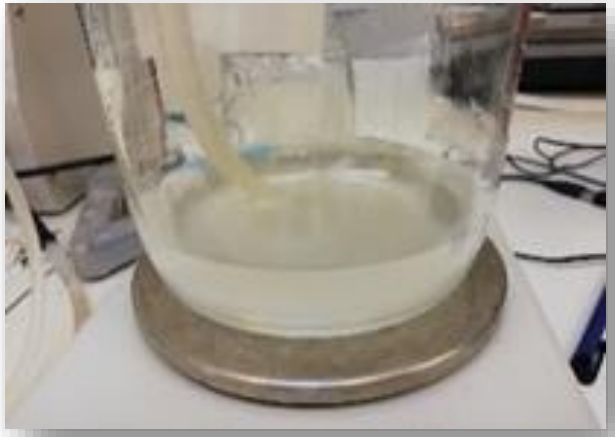
1. SYNTHETIC TESTS: % rejection of solute



- 100% rejection rate of the solute at pH 7 (except ethanol)
- Better performance of Hollow fibre at pH 3 than flat sheet
- Poor rejection of HAc at pH 3

Results and Discussion

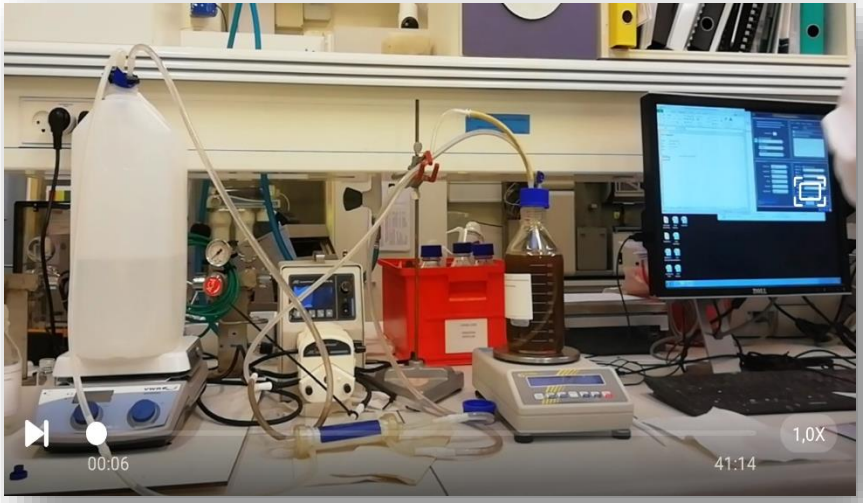
1. SYNTHETIC TESTS: best result for Succinic Acid



320 mL of a saturated solution of Succinic Acid

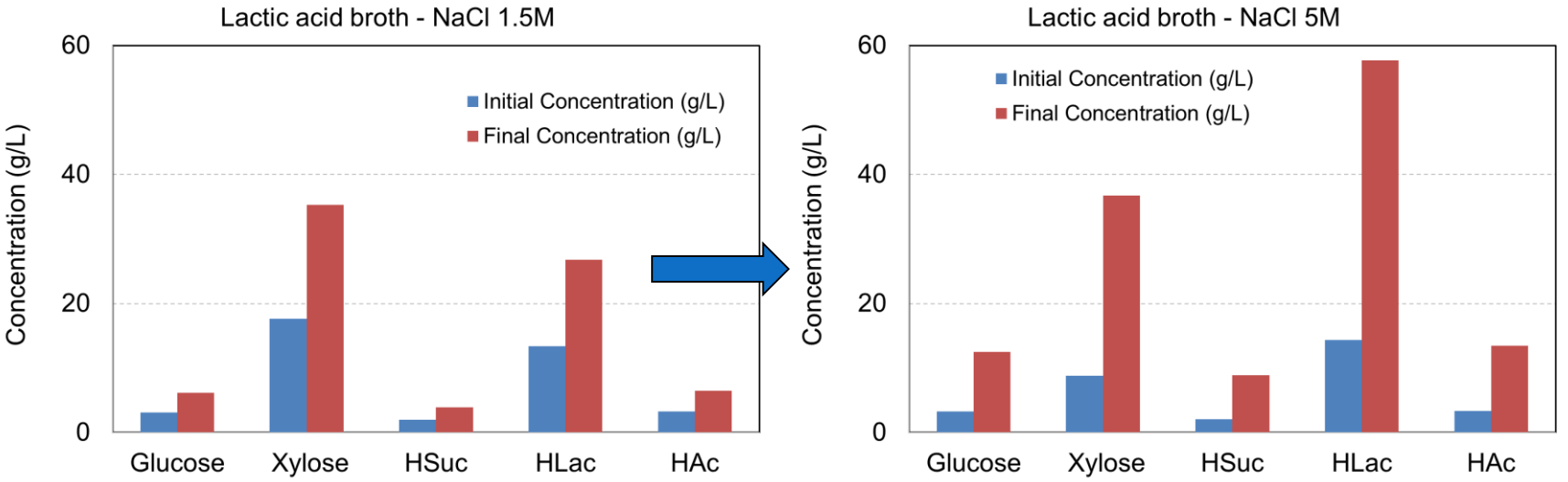
Results and Discussion

2. FO test results with real fermentation broths



Results and Discussion

2. Real Fermentation broths: a) Lactic acid broth, pH = 5.90

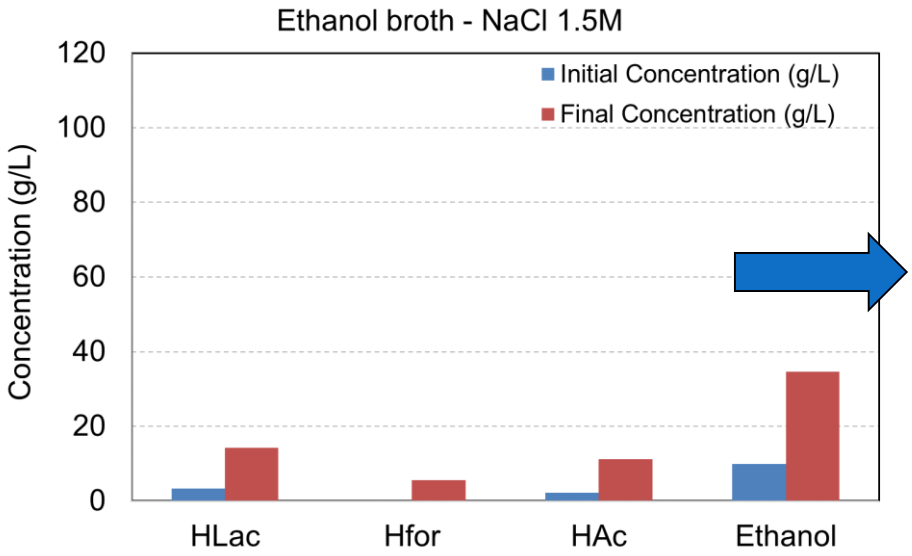


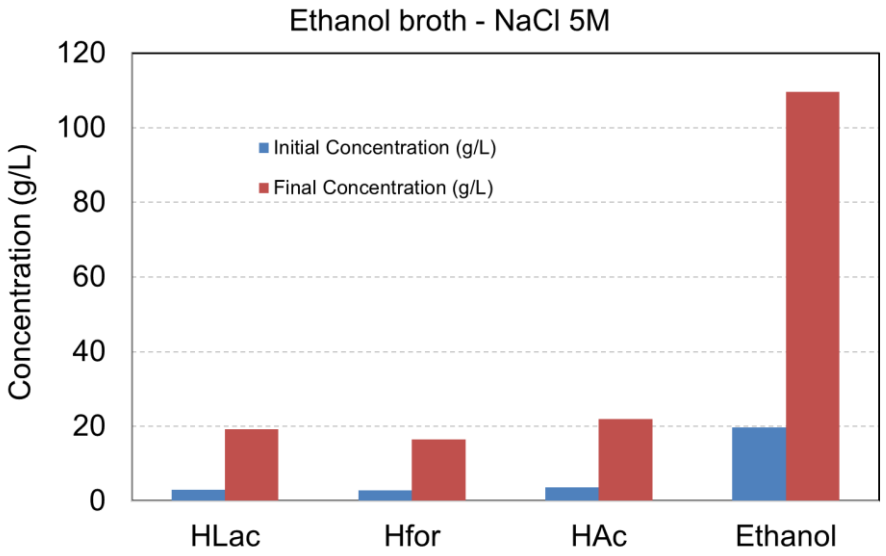
57.7 g/L of Lactic Acid

Membrane rejection = 100%

Results and Discussion

2. Real Fermentation broths: b) Ethanol broth, pH = 7.10



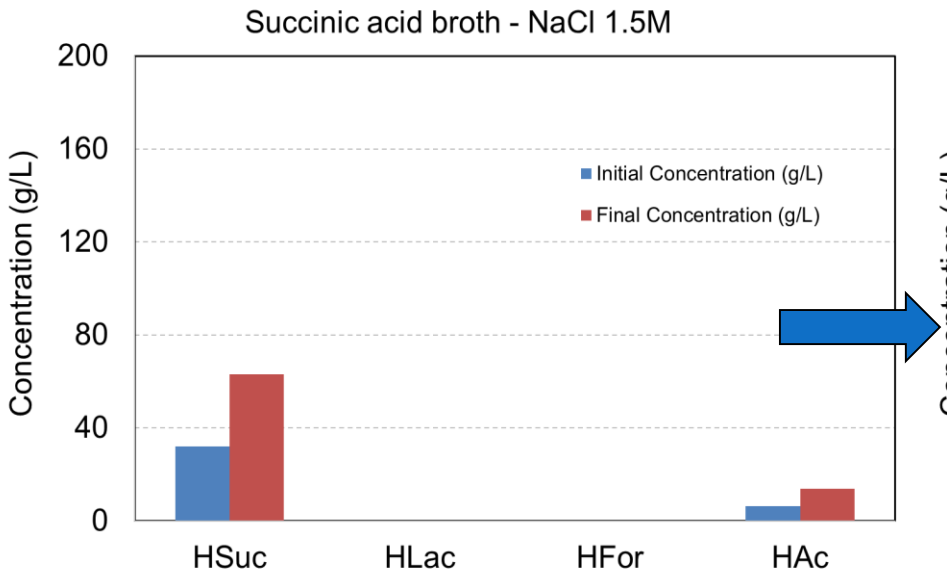


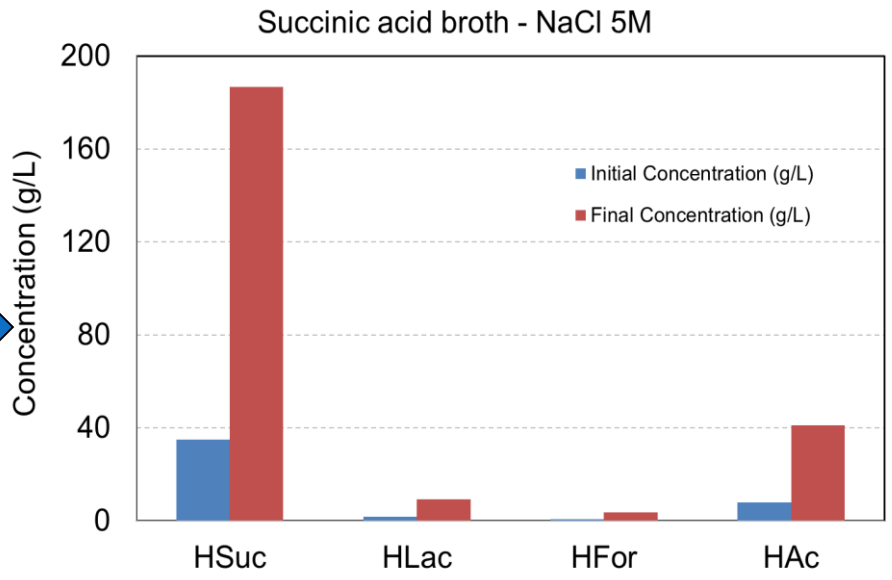
109.6 g/L of Ethanol

Membrane rejection = 100%

Results and Discussion

2. Real Fermentation broths: c) Succinic acid broth, pH = 7.50





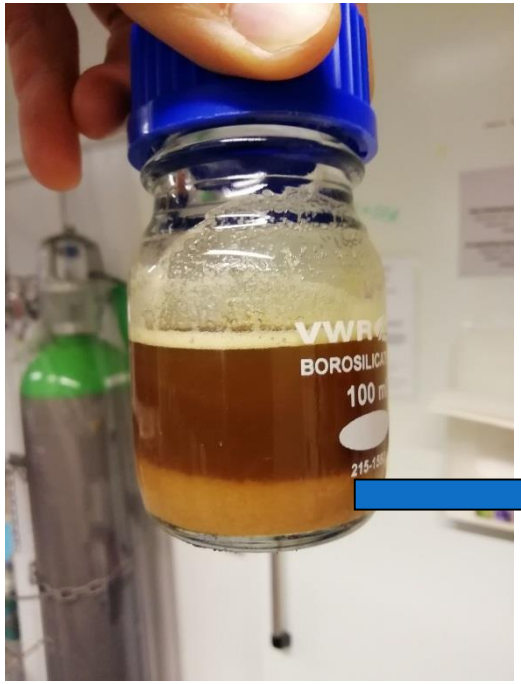
186.8 g/L of Succinic Acid

Membrane rejection = 100%

Results and Discussion

2. Real Fermentation broths: a) Succinic acid cristallization

- pH: 3 (+ HCL)
- Time: 12 h
- 4 ℃



Succinate salt precipitation

Purity of the product?

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Conclusions

- FO technology was succesful for the scope of the study.
- The target chemicals: HSuc, HLac and HAc can be up-concentrated with 100% rejection at pH 7, during synthetic FO tests.
- Hollow fibre membranes showed benefits in terms of water flux, water removal and solute rejection rate.
- The application of hollow fibre membranes with real fermentation broths was succesful.
- The results with real broths were enhanced with 5M NaCl.
- 58 g/L of Hlac, 110 g/L ethanol and 186.8 g/L of succinic acid could be obtained.
- Cristallization could be the following step for HSuc recovery.
- FO could be a potential base technology in future downstream processes at local biorefineries.

Thank you!!!

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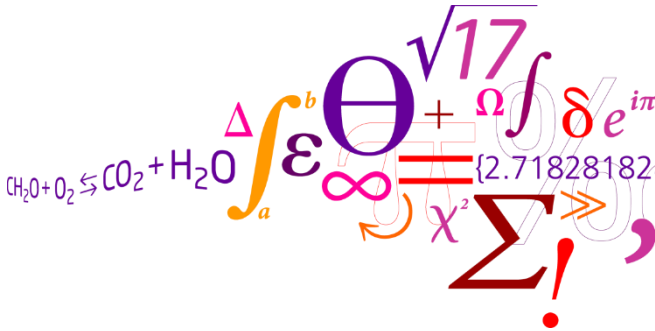

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