PROCESS INTENSIFICATION WITH MEMBRANE TECHNOLOGY

Heleen De Wever, VITO, Belgium
Ludo Diels, VITO/Antwerp University, Belgium
VITO IN NUMBERS

» 784 employees
» 34 nationalities

» HQ in Mol, Belgium. Offices in Ostend, Berchem, Ghent, Genk
» Subsidiary in China and Qatar

» More than 400 patents worldwide

» 1000 research projects

» More than 500 research partners

» 230 scientific articles in 2016

» 170 mio € turnover in 2016
Integration of separation & conversion targeting more efficient processing

Separation & Conversion Technology

- Membrane technology
- Electroseparation
- Extraction
- Organic Solvent Filtration
- Bioconversion
- Electroconversion
- Chemical conversion
- Techno-economic assessment
- Analysis
POTENTIAL APPLICATIONS OF MEMBRANES FOR PROCESS INTENSIFICATION

- Remove inhibitors from pre-hydrolysis;
- Fractionate black liquors
- Concentrate lignin
- ...

- Enzyme/catalyst recovery
- Hydrolysate purification
- Solvents recovery
- Impurities removal
- (Bio)process integration
- ...

- Separation based on MW, affinity, polarity...
- Solvent recovery
- Impurities removal

**lignocellulosic feedstock**

**conversion**

**separation & purification**

**materials**

**consumer**

**pre-treatment**
Membranes in upstream processing/pretreatment
CASE: DESALINATION OF ORGANIC FEED STREAM

Concept capacitive deionisation (CDI) - Membrane capacitive deionisation (MCDI)

Source: http://pubs.rsc.org/en
Source: http://www.biotechserv.com
CASE: DESALINATION OF ORGANIC FEED STREAM

Conventional chemistry

Glucose
Sucrose
Starch
PURE

Sustainable chemistry → challenge = desalination

Biomass hydrolysate
IEX
+ proven technology
- use of chemicals
- regeneration stream = waste

Alternative
Biomass hydrolysate
MCDI
+ no extra chemistry
+ no waste, but concentrate
+ low voltages = cost ↓
+ innovative technology

MCDI

3650 µS/cm
Na = 800 mg/l
K = 201 mg/l
Cl = 1210 mg/l

1300 µS/cm
Na = 185 mg/l
K = 39 mg/l
Cl = 259 mg/l

200 µS/cm
Na = 32 mg/l
K = 7 mg/l
Cl = 66 mg/l

Performance:
Na and K elimination 95%
Water (& sugar) recovery 82%
Energy use 2,7 kWh/m³ 0,03 kWh/kg sugar

WCIB2017 7
Integration of bioconversion and membrane processes
CASE: HIGH CELL DENSITY FERMENTATION

Challenge: increased productivity in lactic acid fermentation

Approach

» Perform fermentations in continuous mode

» Couple UF membranes to axenic organic acid fermentation to increase the concentration of bacterial cells and hence the volumetric productivity → membrane bioreactor (MBR)

» Optimize on 1st generation feedstock

» Demonstrate on 2nd generation feedstock
CASE: HIGH CELL DENSITY FERMENTATION

Challenge: increased productivity in lactic acid fermentation

What VITO did

» Develop and couple semi-automated UF membrane modules to organic acid fermentation
» MBR tests run at industrially relevant conditions in terms of lactate titers, use of lime, test duration
» Continuous operation under sterile conditions for several weeks
» Demonstrate techno-economic feasibility

Productivity of 30 g/L/h (27 x compared to batch and 6 x compared to continuous mode)
86 g/kg lactate titer
Complete consumption of C5 and C6 carbohydrates (not obtained in batch/continuous mode)
Flexible semi-automated set-up for long-term testing

Also applicable on:
» Other fermentation reactions
» Combination of membranes with enzymatic reactions
» Biocatalyst immobilization: simultaneous bioconversion and fractionation
**IN-SITU PRODUCT RECOVERY (ISPR)**

**Product inhibition or/and degradation...**

Substrate ➔ Bioconversion ➔ Products

... are drivers for **in situ product recovery (ISPR)**

**Diagram:**

- **Product is inhibitory**
  - YES ➔ **Product is unstable**
  - NO ➔ **Product is volatile**

**Product is volatile**
- YES ➔ Gas stripping, Adsorption, Pervaporation, Extraction, Vacuum fermentation
- NO ➔ **Product is charged (pH > pKa)**
  - YES ➔ Electrodialysis, Ion exchange, Crystallization
  - NO ➔ Adsorption, Extraction, Crystallization

**Tested on:**
- Solvents
- Organic acids
- Aroma compounds
- Chiral products
- Etc...

*Source: Van Hecke et al. (2014)*
**CASE: IN-SITU PRODUCT RECOVERY OF SOLVENTS**

*Challenge: improve productivity biobutanol fermentation*

### Challenges in traditional fermentation
- Cost of substrate
- Product toxicity:
  - Low product titers
  - Low productivity

→ High purification costs
→ High waste water volumes
→ Energy-intensive separation

### Integration with pervaporation
- Using a membrane-based ISPR recovery technique for continuous, selective withdrawal of aceton-butanol-ethanol from medium
- Integration of organophilic pervaporation with Clostridial fermentation

### Benefits
- Productivity x 2.5 by removal product inhibition
- Fermentor cost ↓
- Water footprint -50%
- Steam consumption -50%
- Applicable to (fed)-batch & continuous processes
CASE: *IN-SITU PRODUCT RECOVERY OF SOLVENTS*

*Step 1: Optimization at laboratory-scale on C6, then C5/C6 sugars*
*Step 2: Preliminary techno-economic evaluation*

Lab-scale demonstration unit @ VITO
PDMS membrane / continuous fermentation
*C. acetobutylicum* ATCC 824
Step 3: Demonstration at pilot-scale on C6 sugars

In collaboration with:

Bio Base Europe Pilot Plant

CASE: IN-SITU PRODUCT RECOVERY OF SOLVENTS
**Case: In-situ Product Recovery of Solvents**

**Step 4:** Fed-batch & continuous tests on 2nd generation feedstocks with proprietary strains

The ButaNexT project has received funding from the European Union Horizon 2020 Research and innovation Programme.
CASE: PROCESS INTENSIFICATION IN MACROCYCLISATION REACTIONS

Proof-of-concept studies:
- Successful head-to-tail cyclisation (lactone)
- Successful side chain-side chain cyclisation with unstable product (peptide)

Benefits for production:
- 5 x productivity in existing batch reactor
- Similar productivity in downsized batch reactor
- Shorter time to market in product development stage (no need for pilot scale)
- Reduced production costs
Membranes in downstream processing
CASE: SOLVENT SWAP

Purification modified sugar

NMP removal from modified sugar (~1000 Da)

- Extraction/evaporation → residual NMP > 3%
- Nanofiltration Diafiltration with water

NMP < 0.1%

- Project started at VITO
- Lab-scale using Inopor 0.9 nm membrane
- 6 months of piloting at VITO on 5 m² scale

- Now implemented at a scale of 2 x 24 m²
- Product loss < 0.1%
- 100% re-use of permeate
International collaboration
VITO ACTIVITIES IN AN INTERNATIONAL CONTEXT

1. Identify and develop products & services

2. Bring products & services to the market we target

3. Act as facilitator

⇒ Industry/society transition
⇒ Set up value chain - develop market
⇒ Coordinate - Flanders/EU and global
⇒ Apply/develop VITO technology - where appropriate
⇒ Develop unique VITO position
⇒ Beyond science - LCA/policy advice
EXAMPLE: BIOAROMATICS FROM LIGNIN → PRESENTATION TOMORROW
Join us: biorizon.eu/community → tomorrow
BUSINESS MODELS FOR INNOVATION

Contract Research & Strategic Collaboration
- Trajectory for feasibility studies
- Techno-economic assessment support

Collaborative Projects
- Demonstration of innovative technologies
- Process & product development
- IP creation

Other Valorisation Models
- Licensing
- Spin-off / Joint-venture
- Risk participation and benefit sharing
- VITO as R&D partner
VITO ACTIVITIES IN AN INTERNATIONAL CONTEXT
Applications for membrane technologies in biorefineries: successful examples presented but many more applications possible and case studies available.

High potential for process intensification: combination with (bio)processes can lead to increased productivity, reduced process flows, decreased energy consumption, improved yield.

Evaluate case by case where/how membranes can be implemented in clever and optimal way.

Develop, scale up and implement through international collaboration.
THANK YOU FOR YOUR ATTENTION

www.vito.be

sustainablechemistry@vito.be - heleen.dewever@vito.be