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Acetone-butanol-ethanol (ABE) Production from Cassava by a Fermentation-pervaporation Coupled Process

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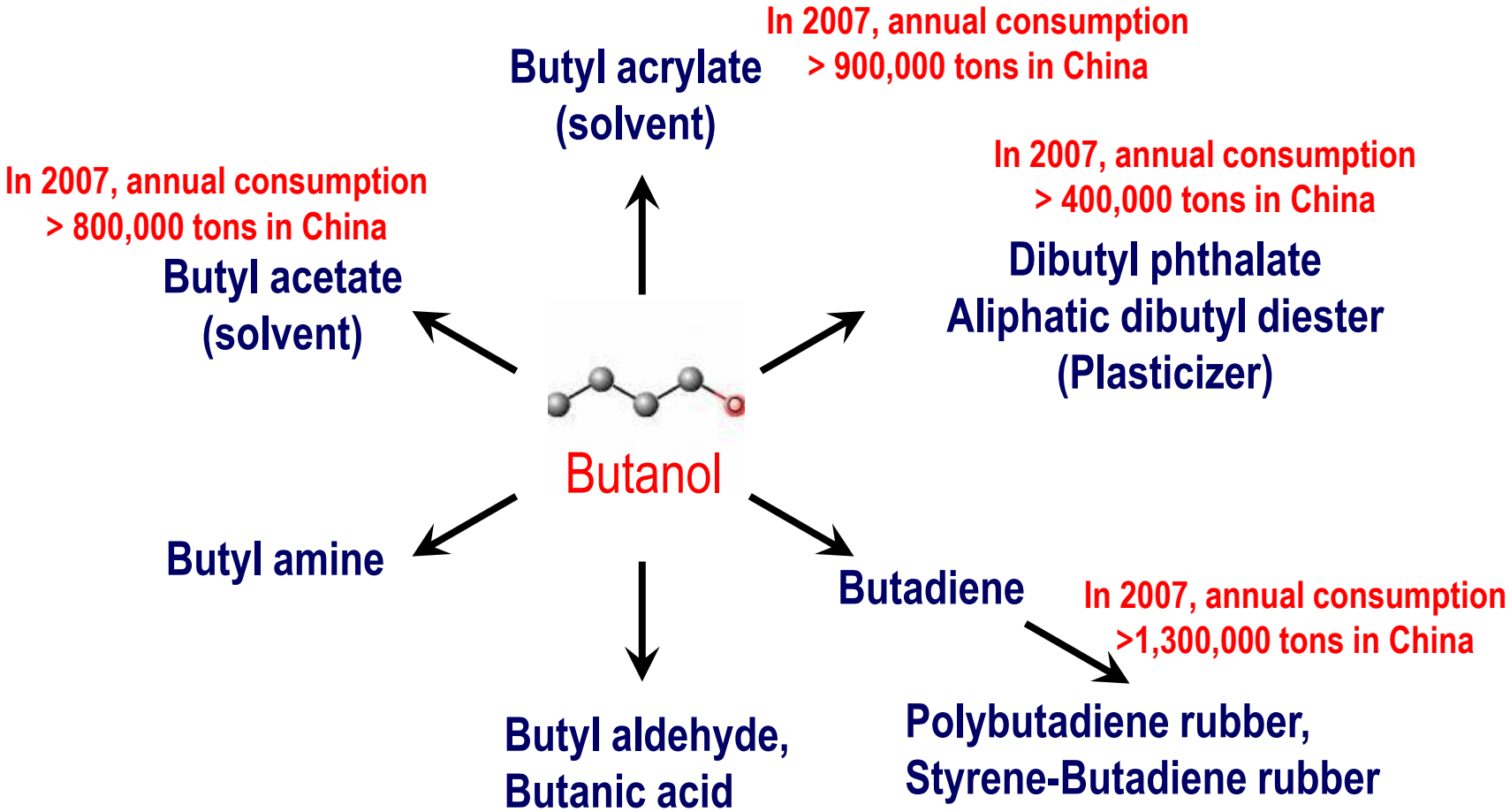
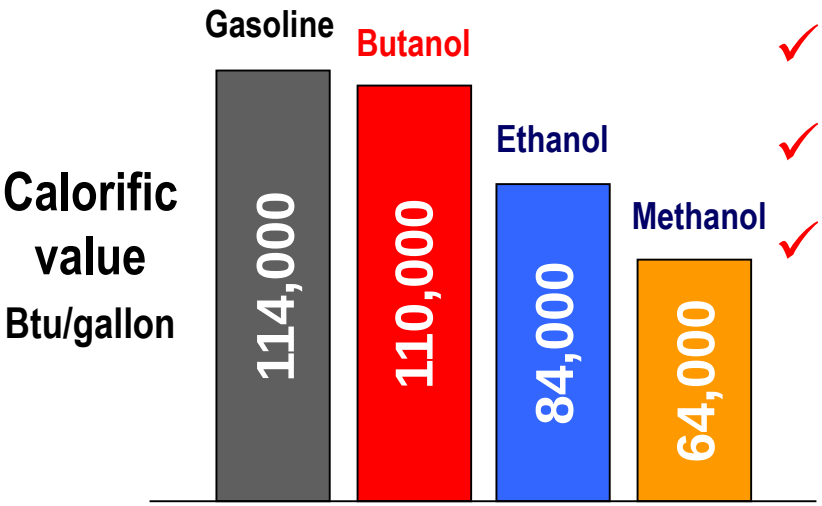
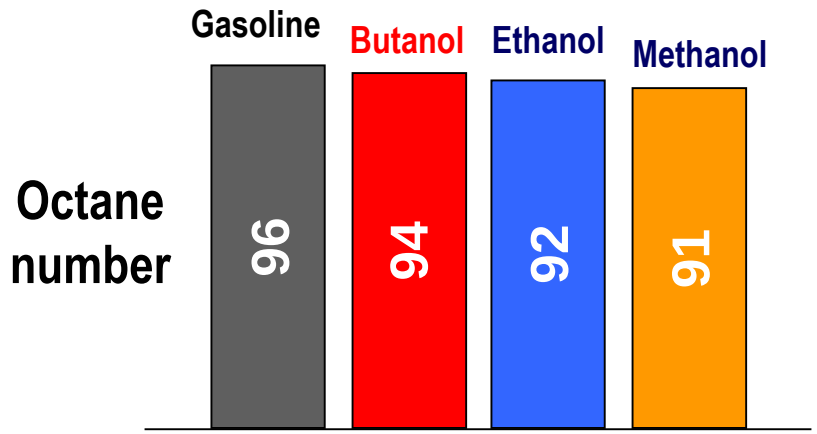
Butanol — An Important Platform Chemicals



Butanol — A Promising Biofuel with Huge Market





- ✓ weak hydrophility, low corrosion, easy to pipe
- ✓ mixing with gasoline at random proportion
- ✓ oxygen content similar to MTBE

Butanol-fuelled car driving 10,000 miles, DOE, 2005

Bottleneck in Industrial Fermentation—
Products Toxicity and Inhibition

- Low productivity

  Titer: normally <20 g/L

  Volume productivity:

  ~0.35 g/Lh

- High energy consumption

  Steam: 13 tons/ton ABE

- Large amount of wastewater

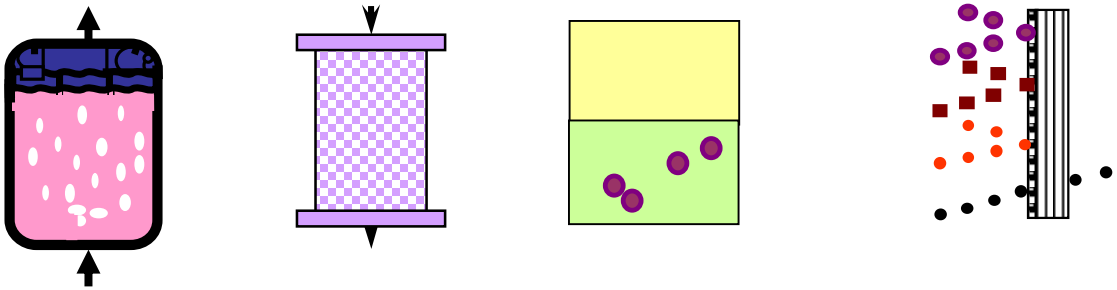
  50 tons wasterwater / ton ABE

Engineering Strategy : Developing Fermentation-*in situ* Separation Coupled Process

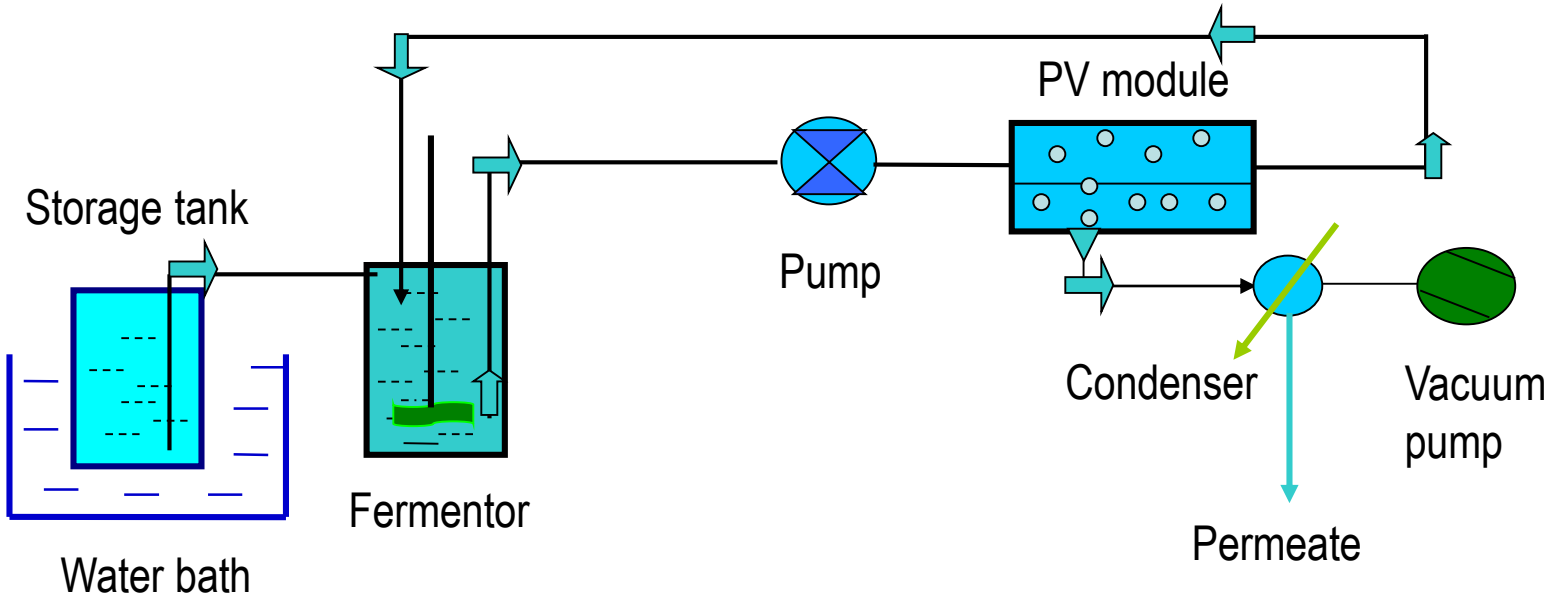
Comparison of in-situ Product Recovery Technologies

	Stripping	Adsorption	Extraction	Pervaporation
Capacity	Moderate	Low	High	Moderate
Selectivity	Low	Low	High	Moderate
Fouling	Low	High	Moderate	Low
Energy required （MJ/kg ABE）	21	33	14	9
Operational simplicity	High	Low	Low	High

Groot *et al.*, *Process Biochemistry* 27 (1992) 61-75



Fermentation-pervaporation Coupled Process



Schematic of fermentation-pervaporation process

Advantages:

- Low product inhibition
- High fermentation productivity
- Low separation energy consumption
- Low wastewater production

Key techniques:

- Development of PV membrane with high performance
- Optimization of the coupled process
- Module development & fouling control

Membrane Materials and Membrane Performance

Pervaporation membrane materials	Example
Polymeric materials	PDMS (α=30-45)、PTMSP(α=52-75)
Inorganic materials	Silicalite-1 (α=80-125)
Hybrid materials	Silicalite-1 filled PDMS (α=50-111)

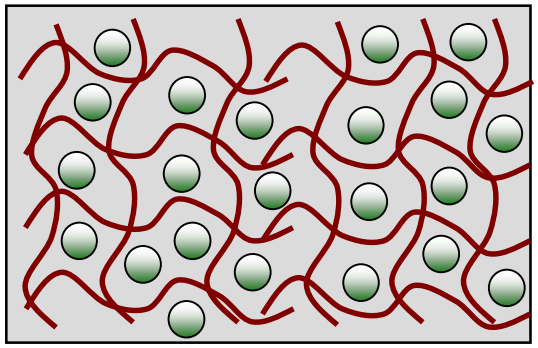
Problem and Solution in Preparation of Hybrid Membrane

Problem

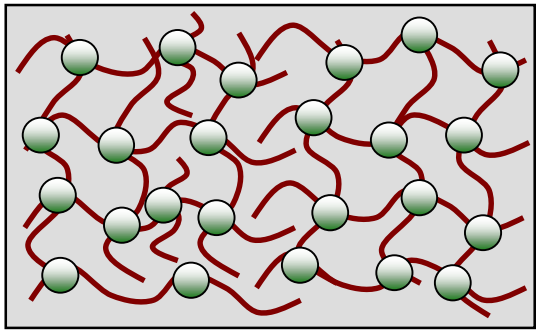
Silicalite flocculation in membrane

Decreasing the membrane selectivity

Decreasing the membrane strength when the silicalite loading was over 60%.



Conventional hybrid PV membrane

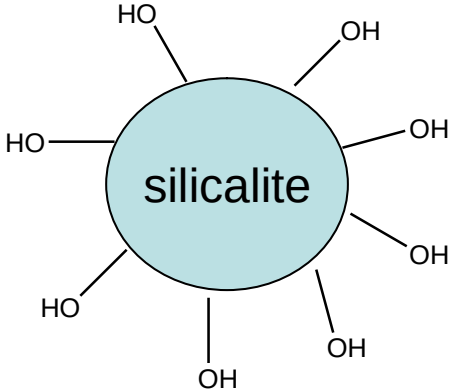


New hybrid PV membrane

Our solution

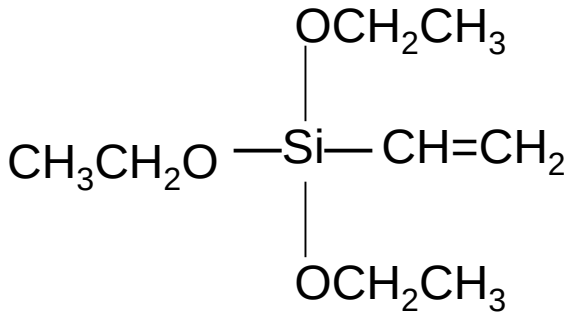
Modify the outer surface of the silicalite to improve the affinity between silicalite and polymer matrix

Surface Modification of Silicalite-1 Particles



Unmodified silicalite-1

+



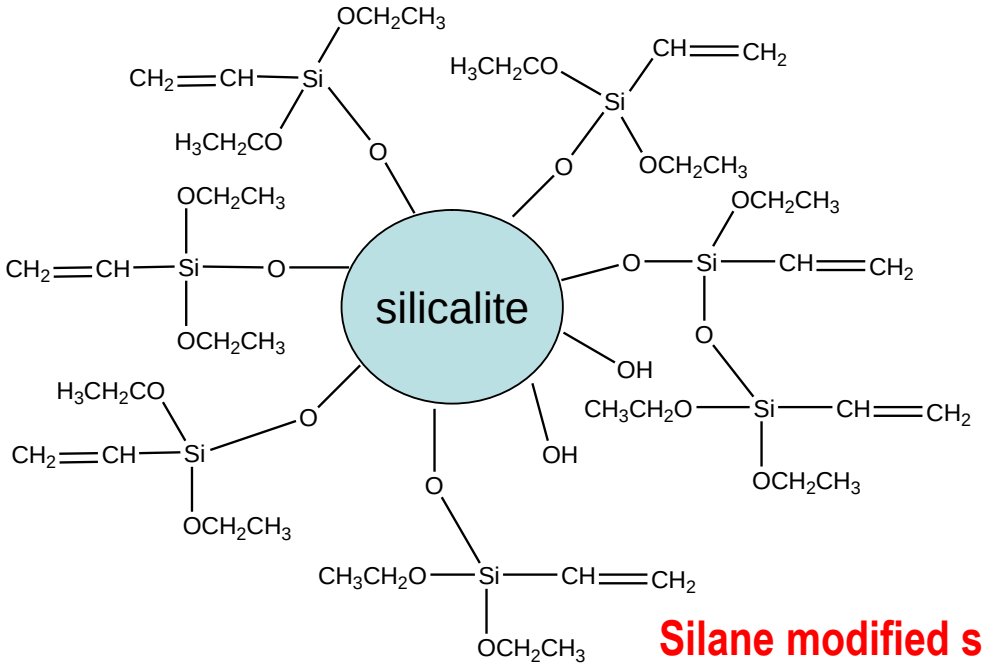
VTES(vinyltriethoxysilane)

1. Hydrolysis of the ethoxy groups

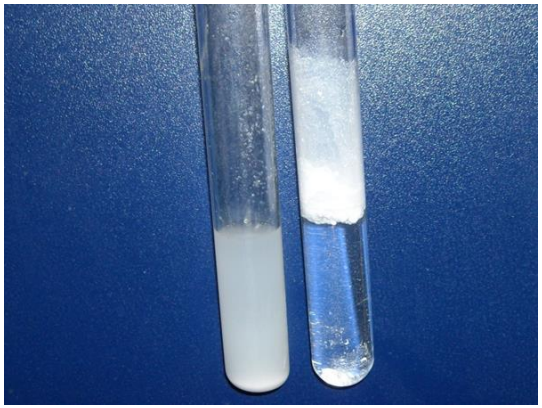
2. Condensation

a. with the silanol groups of silicalite

b. between adjacent silane molecules



Silane modified silicalite-1

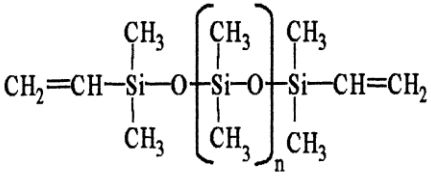


Contact angles:

38.1° (unmodified)

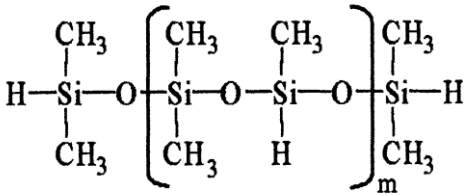
143.7° (modified)

Cross-linking Reaction of PDMS and Modified Silicalite-1



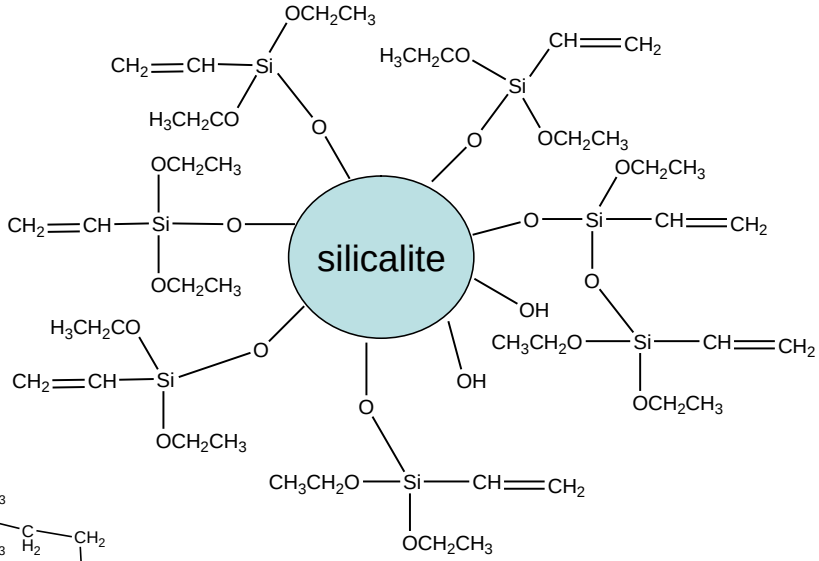
Prepolymer(**RTV615A**)

+



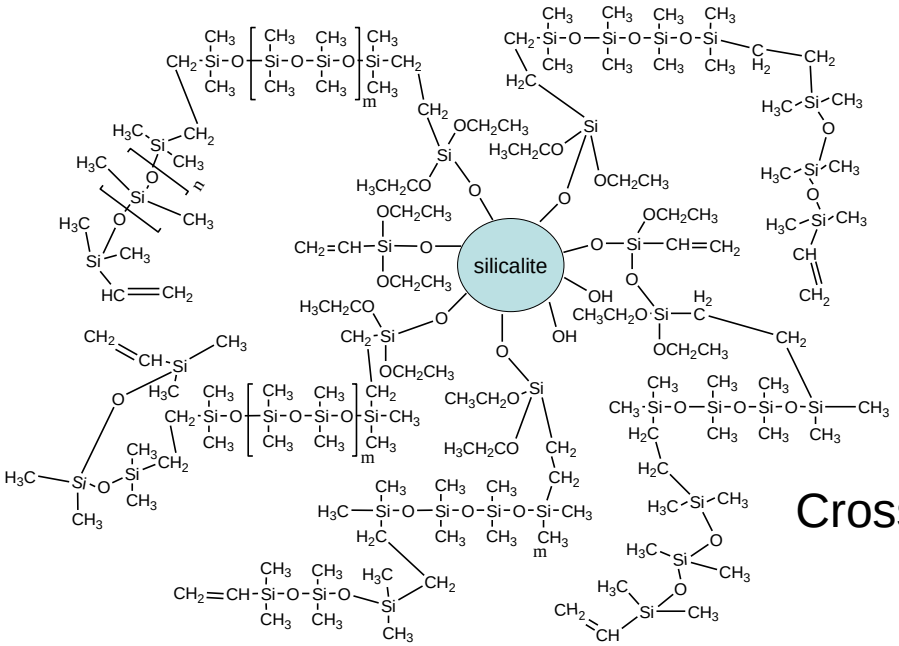
Crosslinker (**RTV615B**)

+



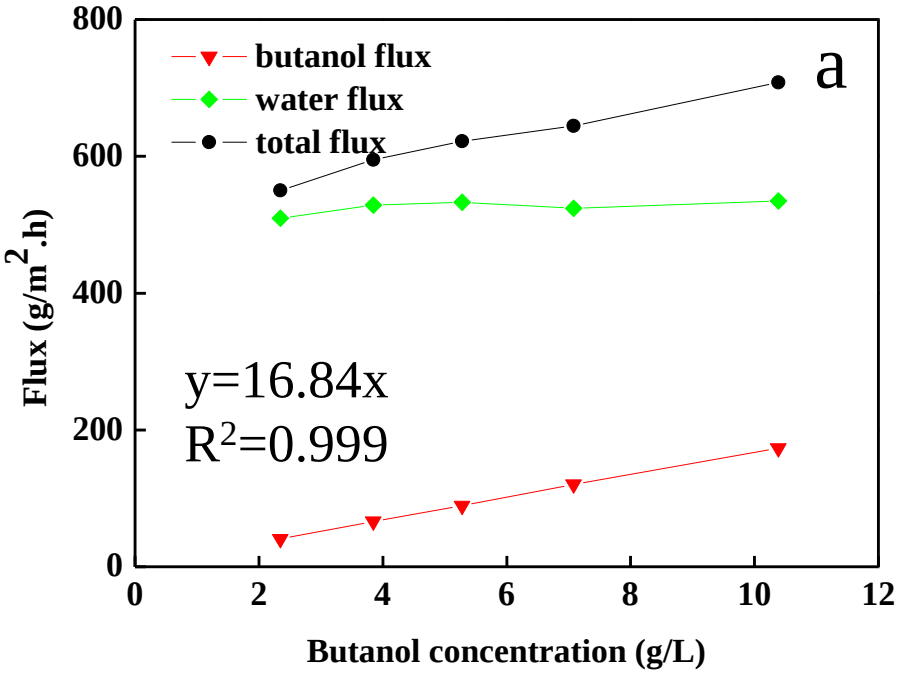
Silane-modified silicalite-1

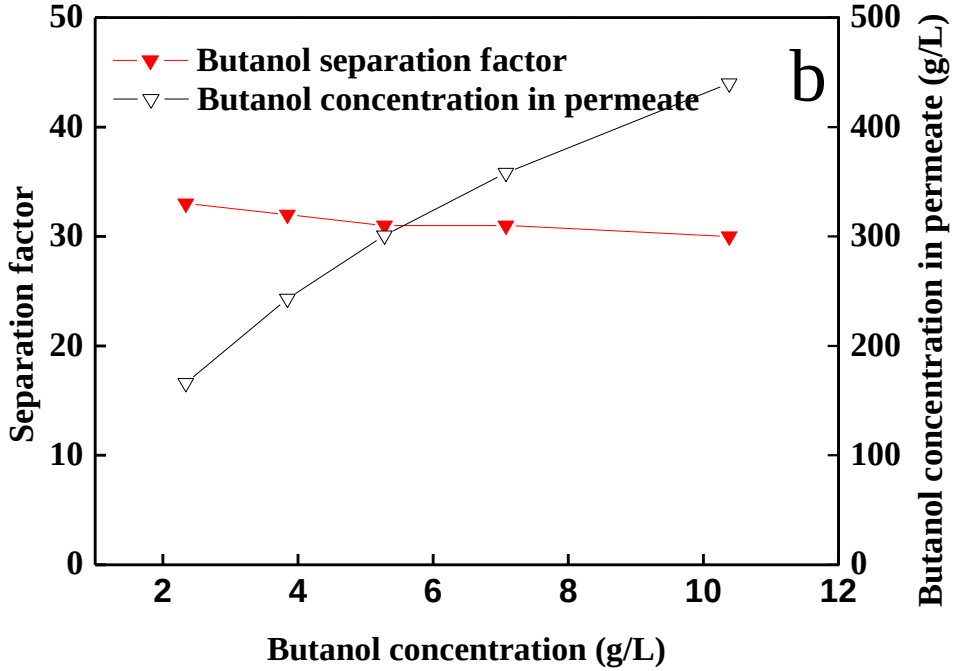
Pt-catalyst →



Crosslinked polymer network

Evaluation of Silicalite-1 PDMS/PAN Composite PV Membrane





Effect of butanol concentration on flux and separation factor using butanol/water model solutions at 37°C. (a) flux and (b) separation factor.

Experimental Setup for the Coupled Process

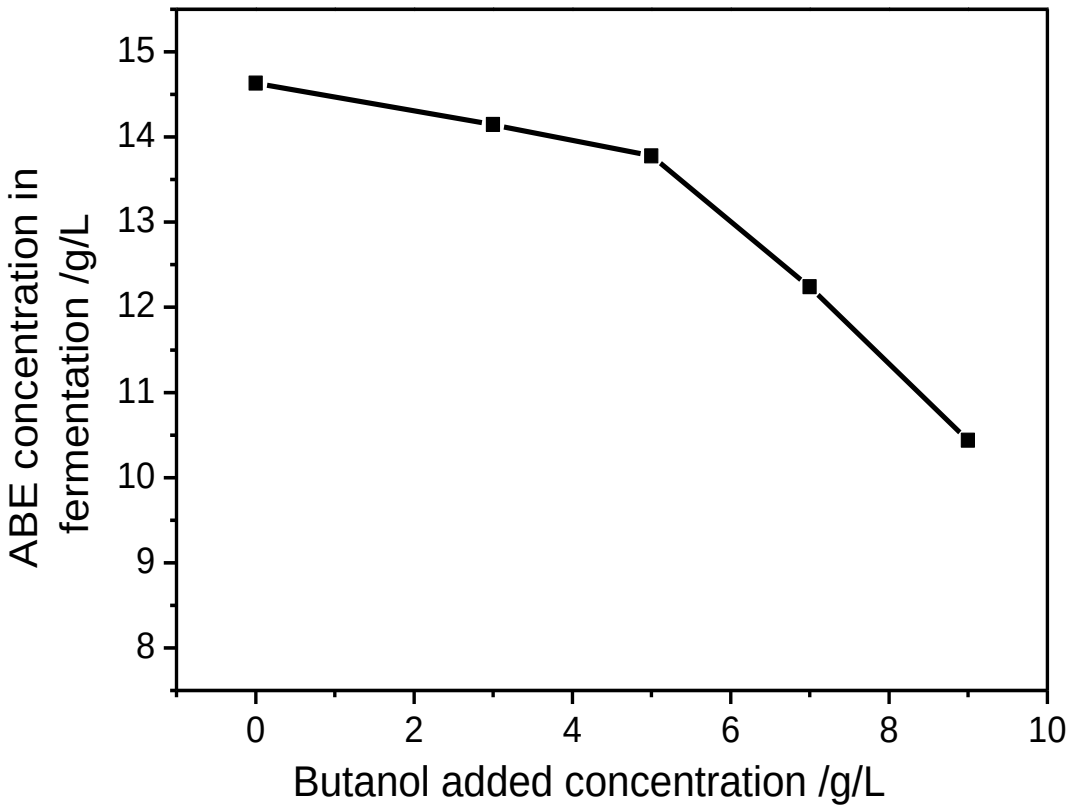
Membrane module

Fermentation-Pervaporation System

Batch ABE Fermentation from Cassava by *C. Acetobutylicum* ATCC 824 and DP217

Characteristics	Strains	
	ATCC 824	DP 217
Fermentation time (h)	72	60
Acetone (g/L)	3.04±0.18	3.74±0.01
Butanol (g/L)	5.67±0.05	9.53±0.03
Ethanol (g/L)	0.55±0.14	2.33±0.18
Total solvent (g/L)	9.26±0.35	15.60±0.24

Inhibition of Butanol



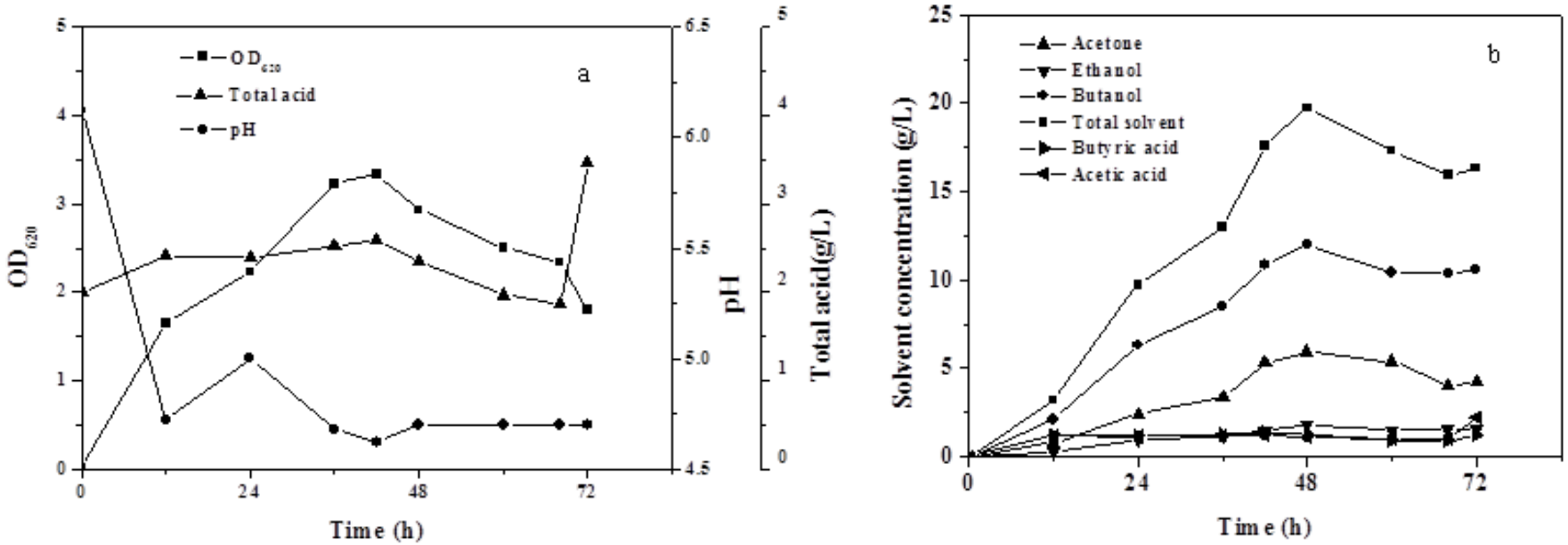
Effect of butanol on ABE production by *C. acetobutylicum*

The butanol inhibition concentration: >5g/L

7 g/L-13 g/L Butanol results in a 50 % inhibition of growth.

S. Y. Lee, J. H. Park, S. H. Jang, et al, Biotechnol. Bioeng., 101(2008)209 – 228

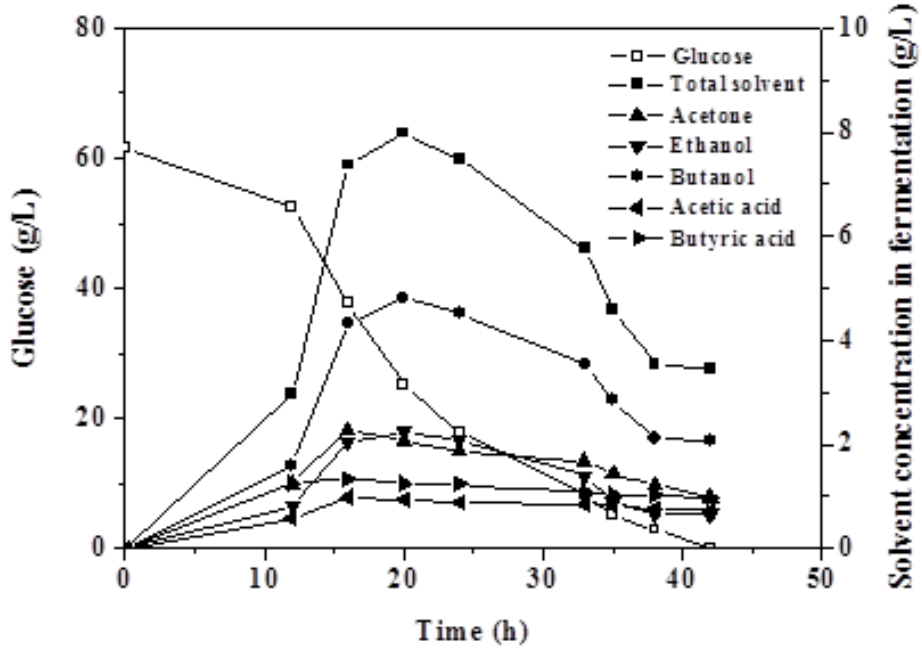
ABE Batch Culture with Optimized Medium

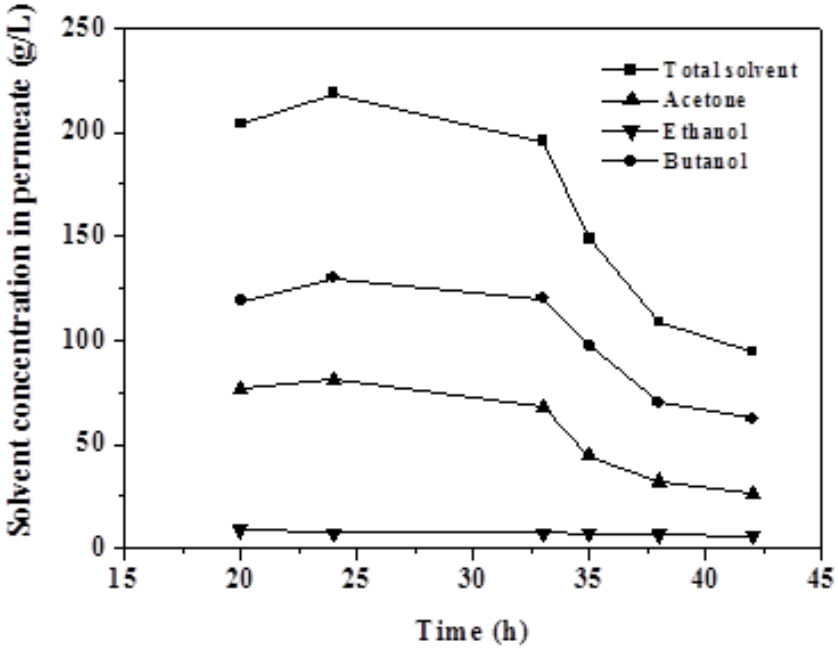


(a) OD_{620}, glucose concentrations and pH, (b) solvent and acid concentrations.

- Medium: 70 g/L cassava power + 2.17 g/L CSP + 0.01 g/L $FeSO_4 \cdot 7H_2O$
- Initial pH: 6.81
- The culture produced 20.14 g/L total solvent
- Acid concentration was above 1 g/L

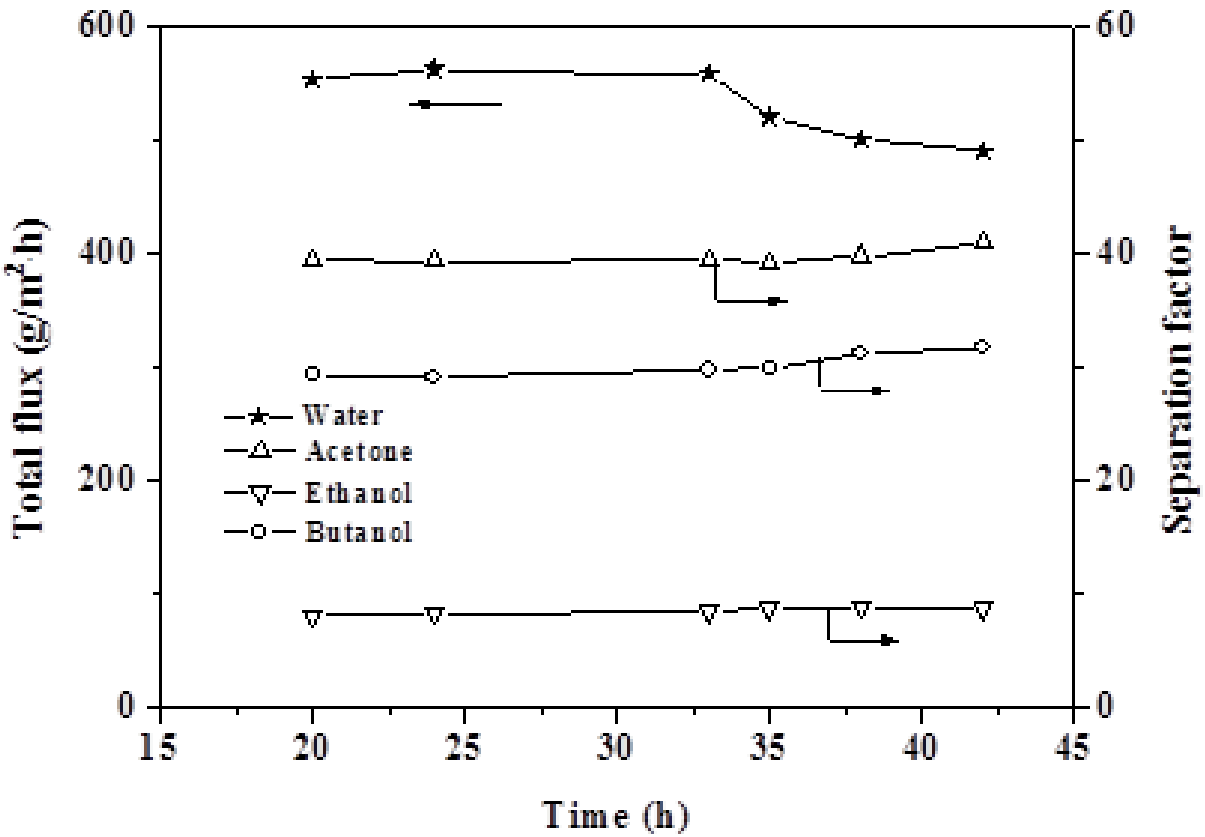
ABE Production in Batch Fermentations using Cassava with PV





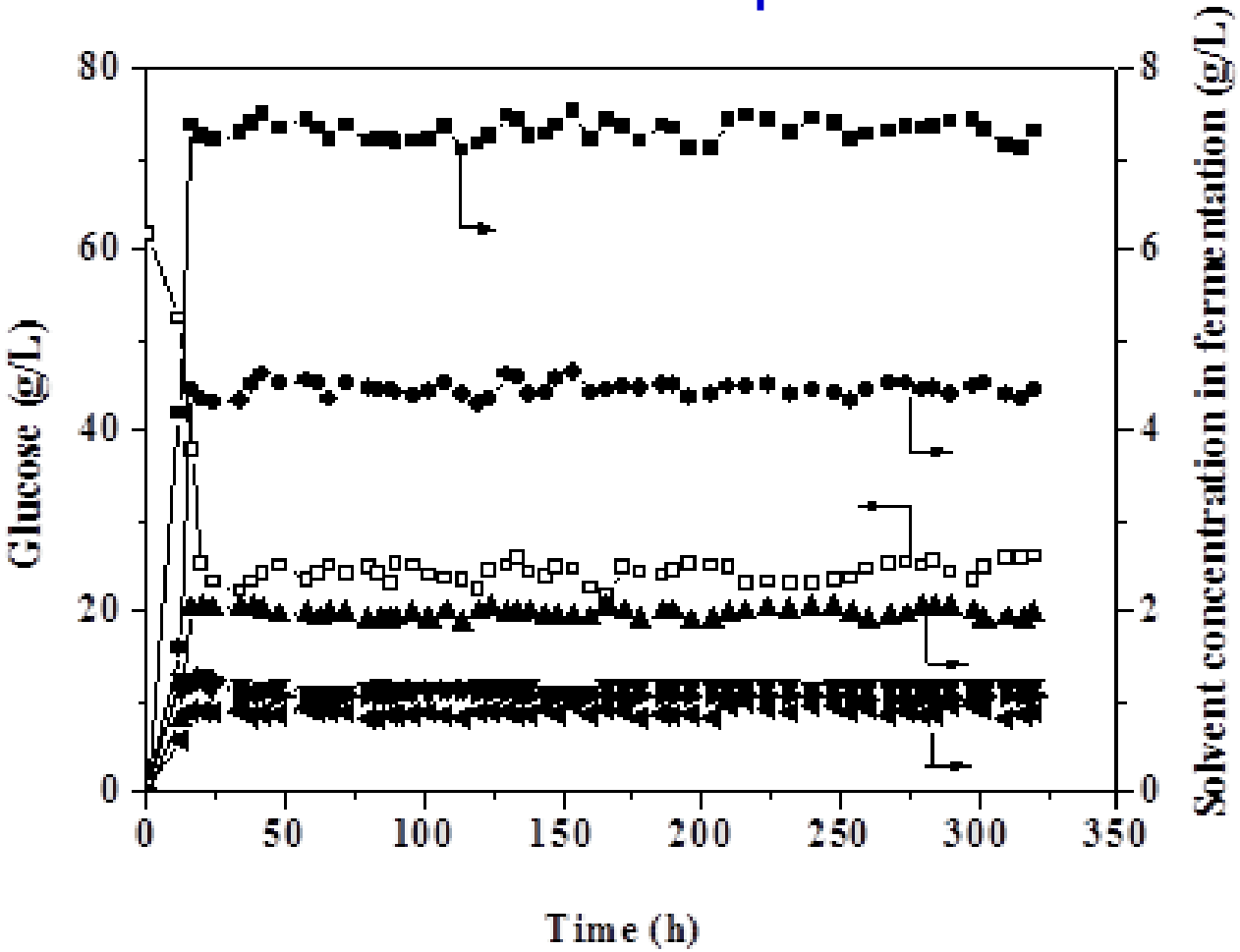
- PV operation started at the 16th hour when butanol concentration was 4.3 g/L
- More ABE was produced (21.78 g/L ABE, i.e., 7.36 g/L acetone + 12.95 g/L butanol + 1.47 g/L ethanol)
- Acid concentration was less than 1.0 g/L
- Higher productivity, higher yield, shorter fermentation time (42 h)

Performance of the Membrane in Batch Fermentation-PV Coupled Process



The performance of the membrane was very stable in terms of the flux and separation factor

Continuous ABE Production by Fermentations-PV Coupled Process



Glucose: 20-30 g/L

ABE: ~ 7.5 g/L

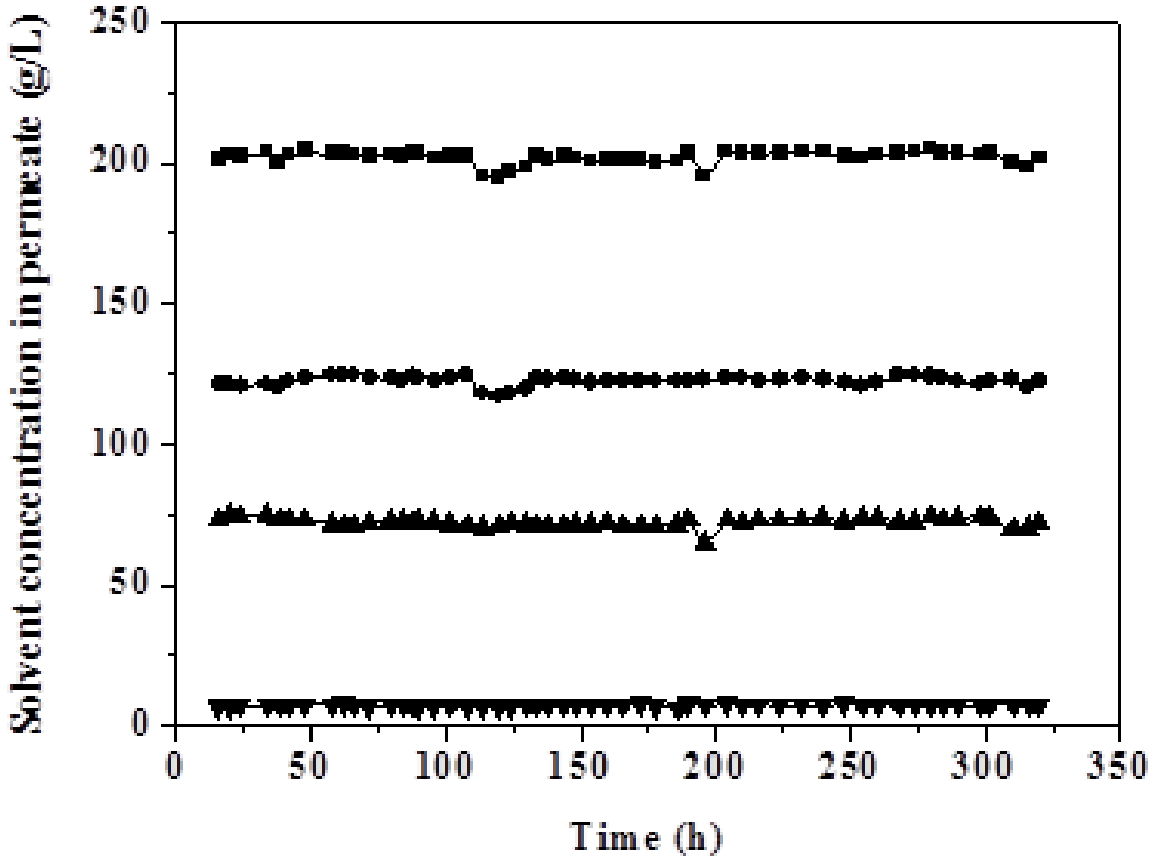
Butanol: ~ 4.5 g/L

Acetone: ~1.8 g/L

Ethanol: ~ 1.2 g/L

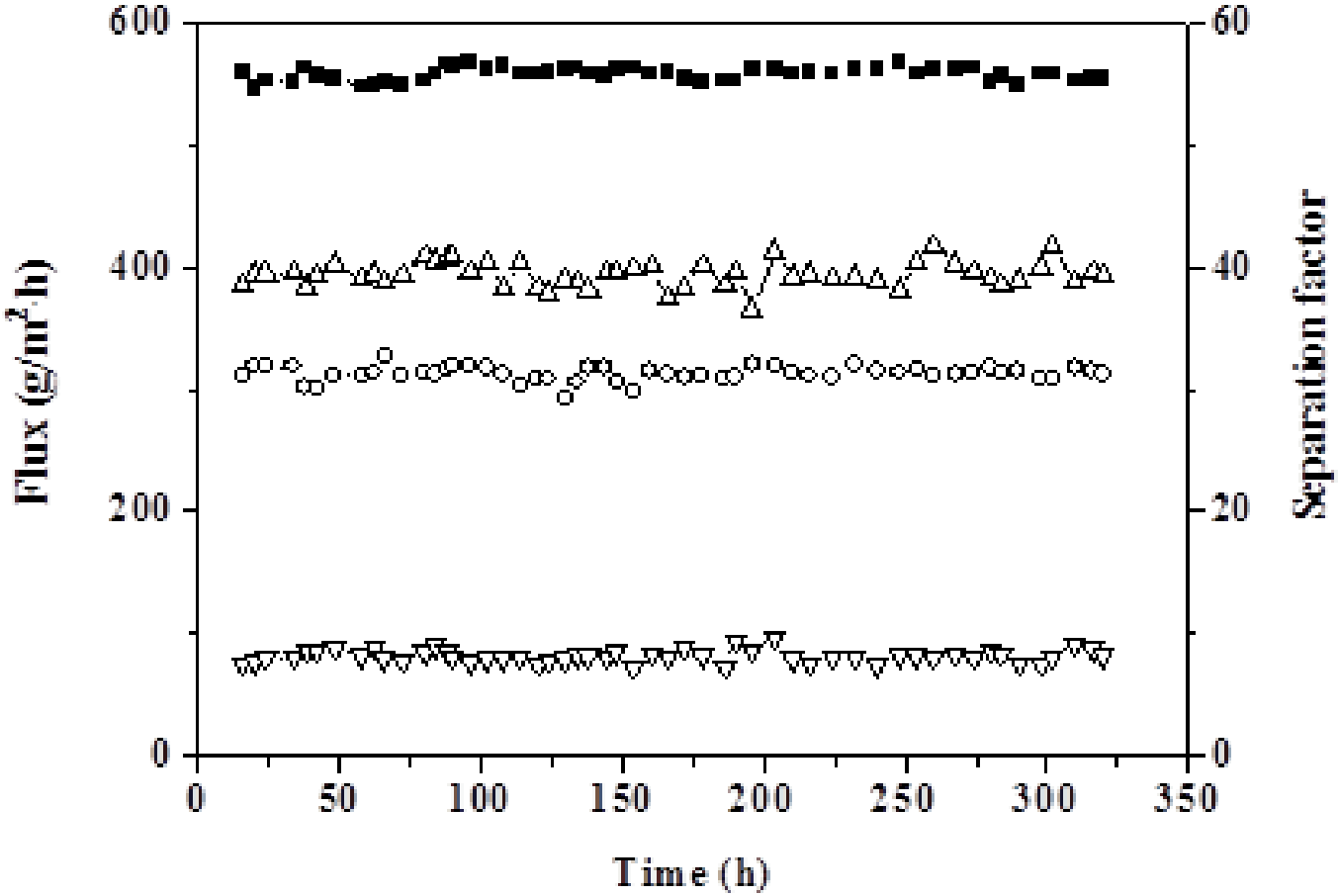
□ Glucose; ■ Total solvent concentration; ▲ Acetone; ▼ Ethanol; ● Butanol; ▸ Acetic acid; ◂ Butyric acid

Permeate Concentration in Continuous ABE Fermentations-PV Coupled Process



■ Total solvent ▲ Acetone; ▼ Ethanol; ● Butanolb

Membrane Performance in Continuous ABE Production by the Coupled Process



Average flux:

557 g/m2•h

Separation factor:

39.4 for acetone

31.2 for butanol

8.4 for ethanol

■ Total flux; Separation factor for △ Acetone ▽ Ethanol and ○ Butanol

Summary of Solvent Production by Fermentation with and without Pervaporation

Process	Solvent		Glucose utilization rate (g/Lh)
	Productivity (g/Lh)	Yield (g/g)	
Batch-PV	0.49	0.35	1.26
Continuous Coupling	0.76	0.38	2.02
Batch	0.42	0.33	1.00

Summary

- In ABE fermentation from cassava, it is technically feasible to eliminate the product inhibition by the fermentation-pervaporation coupled process. ABE could be effectively concentrated in the permeate.
- With the coupled process, the ABE yield could be increased, therefore, substrate can be utilized more efficiently.
- Developing PV membranes with higher selectivity and higher flux and optimizing the integrated process would further promote the economic and technical feasibility of the process.

Acknowledgements

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Thank You !