Poly(ether block polyamide) membranes for recovery of propyl propionate from aqueous solution by pervaporation

By:
M. Mujiburohman and X. Feng
Chemical Engineering Department
University of Waterloo

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Outline:

- Background
- Research Objectives
- Theory
- Experimental Results
- Conclusions

Background

Aroma compounds have a significant role in:

Food industry

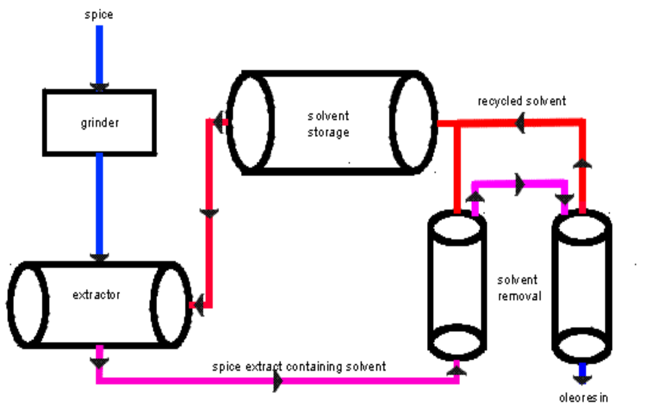
Pharmaceutical industry

Cosmetics

A wide variety of aroma compounds is available in natural sources, especially in plants;

- renewable
- low cost in raw material

Conventional technologies to recover natural aroma compounds:

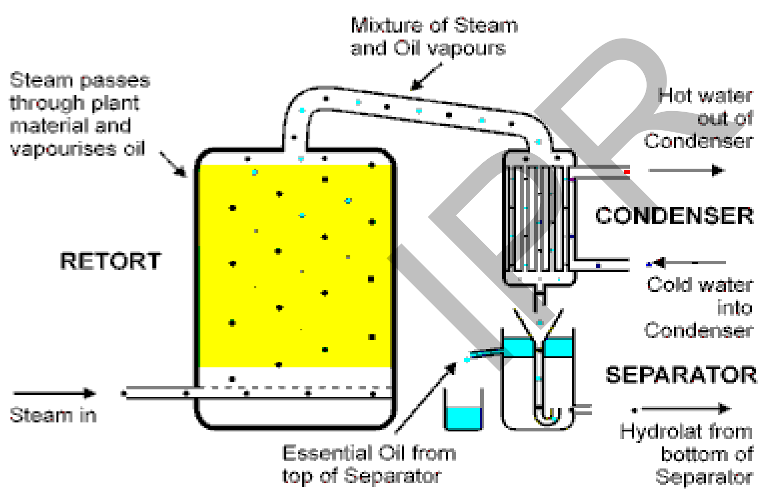


Extraction method

It requires:

- a selective solvent

- subsequent separation between solvent and the desired component; the final product might be contaminated

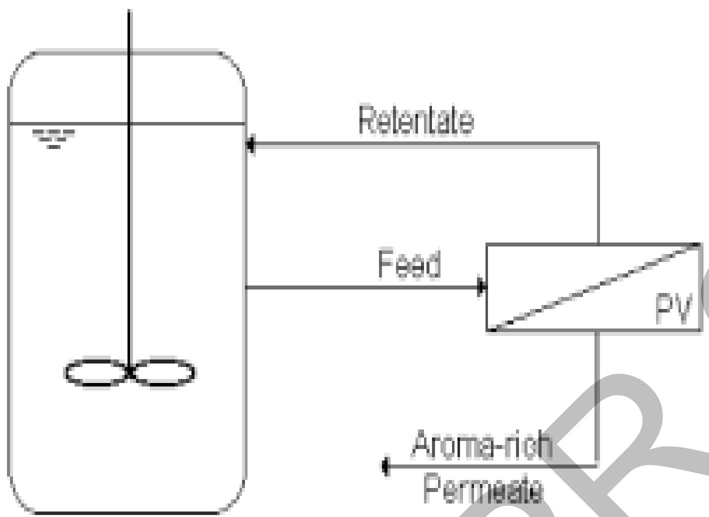


Distillation method

High energy consumption; at a high operating temperature the natural properties of aroma compounds can be destroyed; oxidation may arise

Pervaporation (PV)

(a Promising Separation Technology)



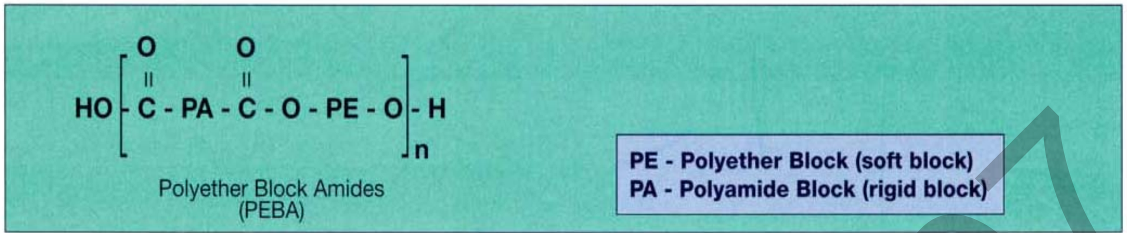
Using selective membranes, PV can recover or concentrate the natural aroma compounds

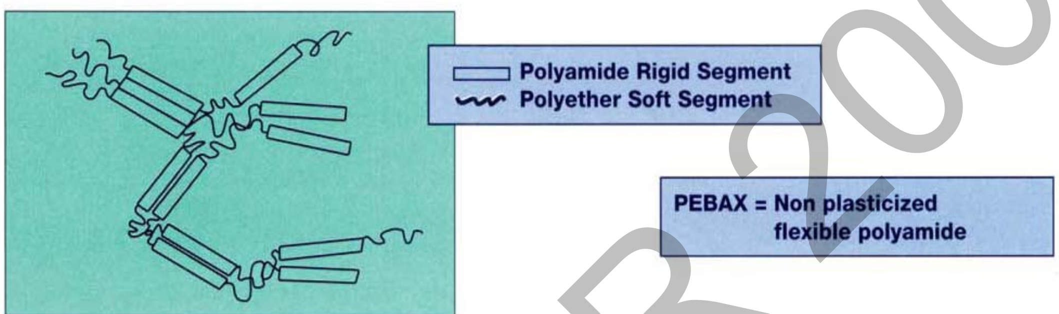
No entrainer is needed (thus no contamination); high selectivity and low energy consumption

Due to: the good market and availability of aroma; the promising performance of PV

→ Investigation on recovery of natural aroma compounds using membranes is attracted attention

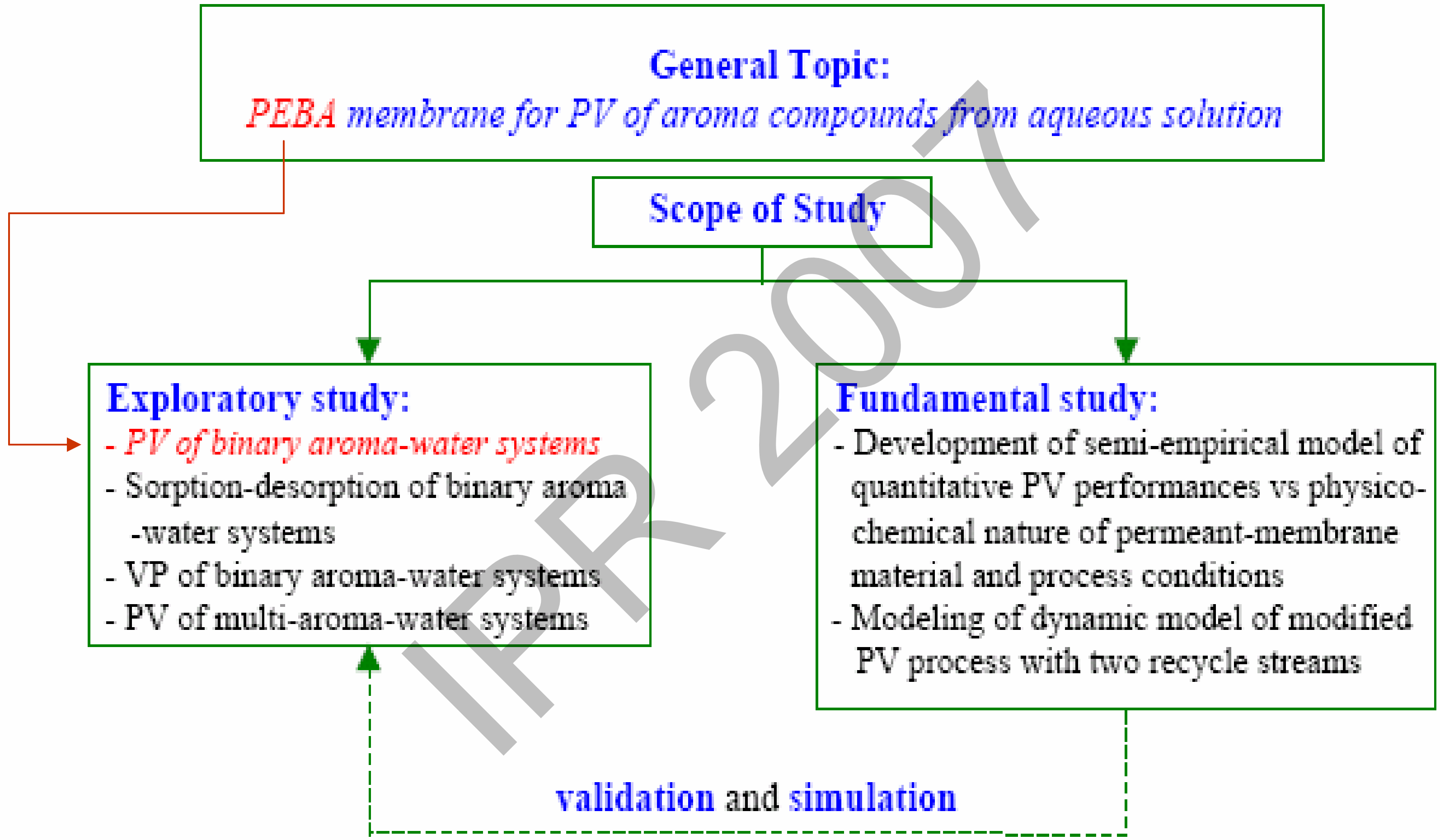
Membrane Material (PEBA Polymer)





offers favorable membrane-forming properties, good chemical resistance and thermal – mechanical stabilities

→

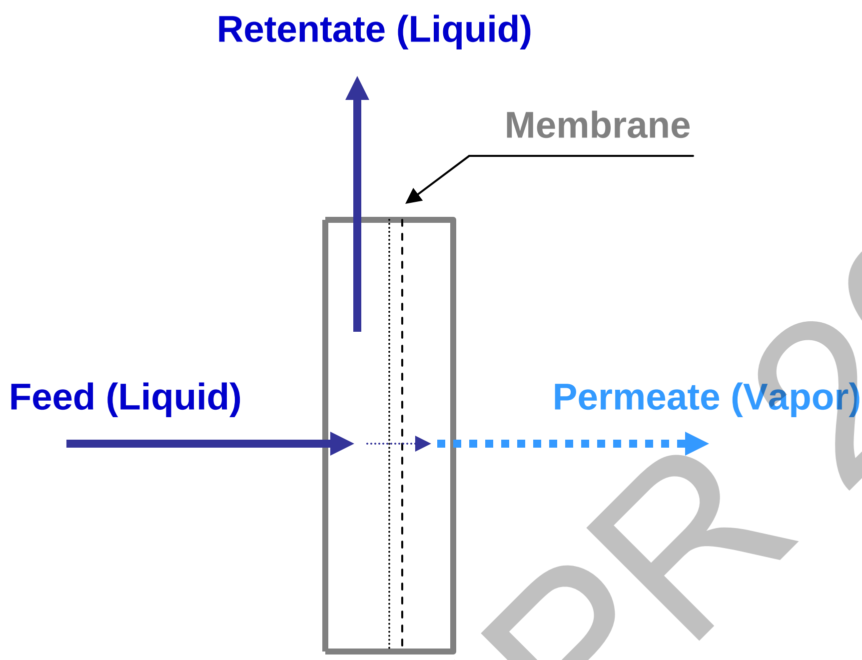

General Topic:
PEBA membrane for PV of aroma compounds from aqueous solution
Scope of Study
Exploratory study:
- PV of binary aroma-water systems
- Sorption-desorption of binary aroma -water systems
- VP of binary aroma-water systems
- PV of multi-aroma-water systems
Fundamental study:
- Development of semi-empirical model of quantitative PV performances vs physico-chemical nature of permeant-membrane material and process conditions
- Modeling of dynamic model of modified PV process with two recycle streams
validation and simulation

Research Objectives:

In this work the aroma compound is represented by propyl propionate ($C_6H_{12}O_2$ an ester compound) which has fruity flavor and is present in some fruits, with the aims to:

investigate the PV performances of PEBA membrane in attempt to concentrate propyl propionate from dilute aqueous solution, as an effect of process conditions (feed concentration and operating temperature)

Theory
PV



PV refers to two words "permeation" and "vaporization", to emphasize the fact that permeant undergoes phase change from liquid to vapor during its transport through the membrane

Characteristics (Performances) of PV

- Permeation Flux

$$J = \frac{Q}{At}$$

- Selectivity

$$\beta = \frac{c'}{c} \qquad \alpha = \frac{\left(\frac{c'_A}{c'_B}\right)}{\left(\frac{c_A}{c_B}\right)} = \frac{c'(1-c)}{c(1-c')}$$

Q = amount of permeant
A = area of membrane
t = operating time

β = enrichment factor *α* = selectivity
c', *c* = mass fraction (concentration) of permeant in permeate and feed side

Process Conditions

Essentially, the separation performance of PV is determined by the physicochemical nature of the membrane material and the species to be separated, the structure and morphology of the membrane and the **process conditions**

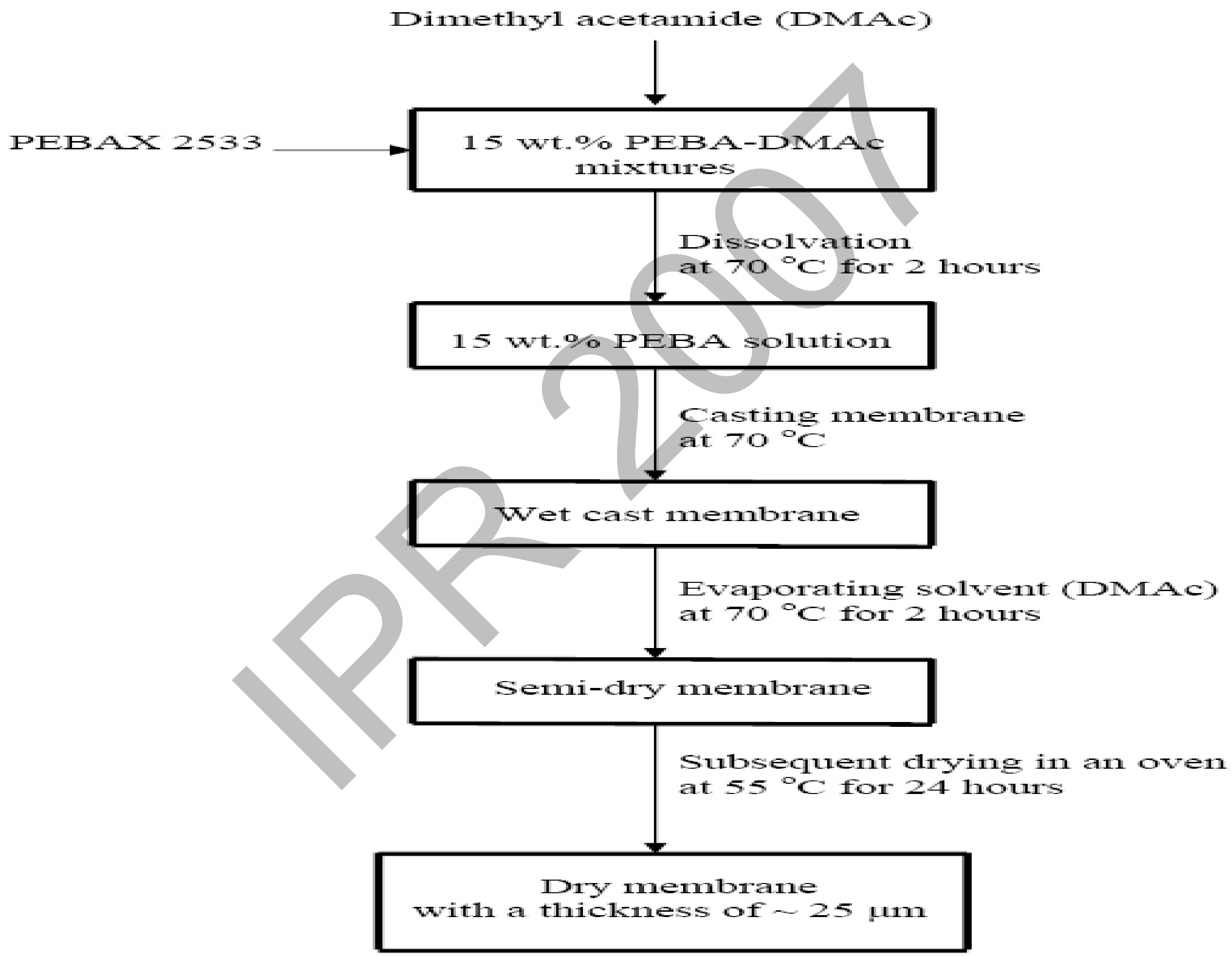
- Feed Concentration
- Temperature

} to be studied

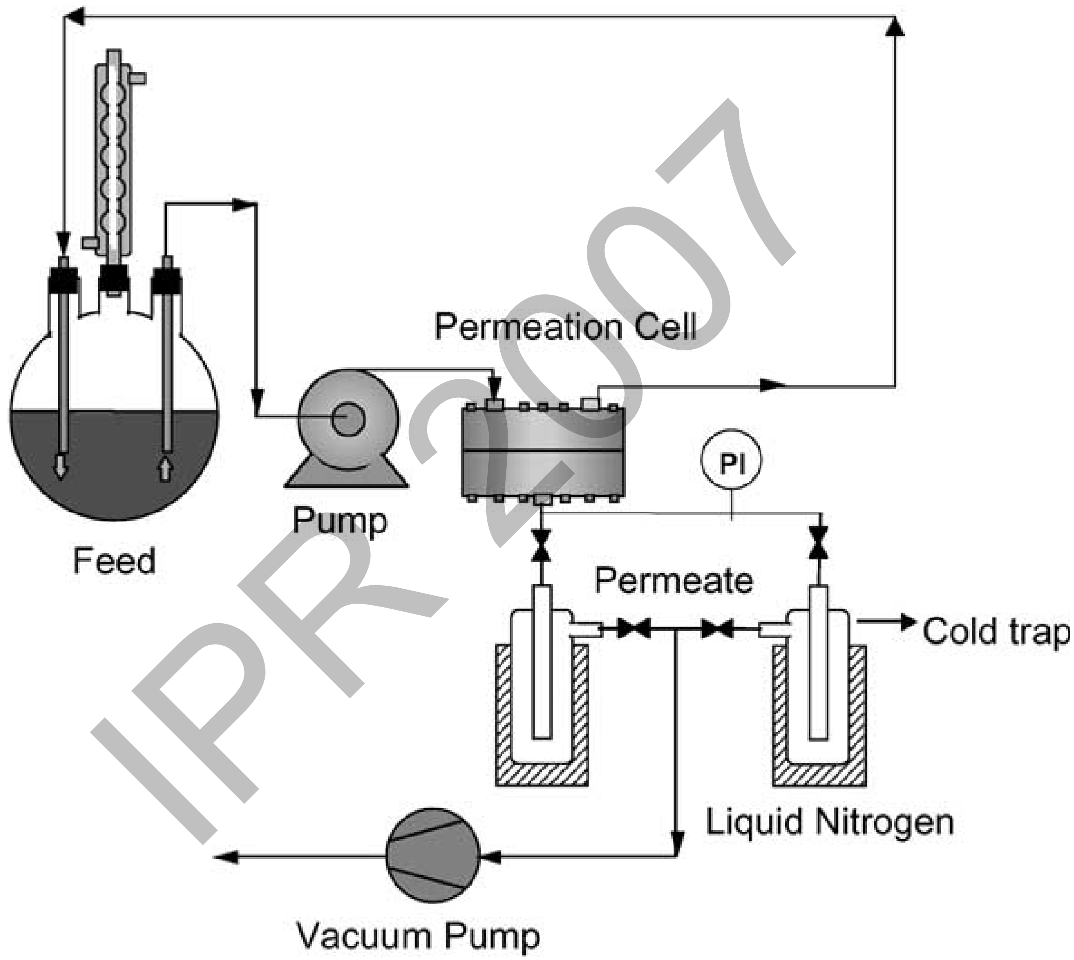
- Pressure
- Feed flow

Experimental Results

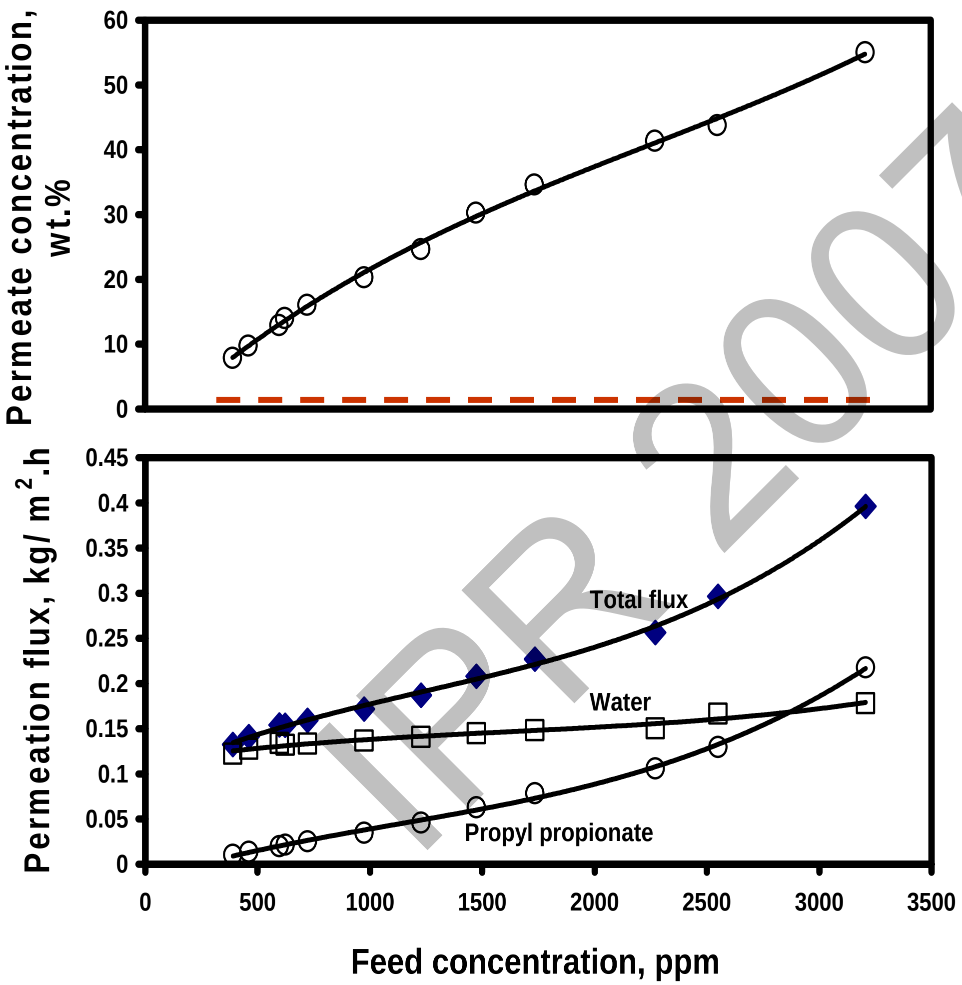
- Preparation of PEBA Membrane by solution-casting technique



- PV Equipment



I. Effect of Feed Concentration

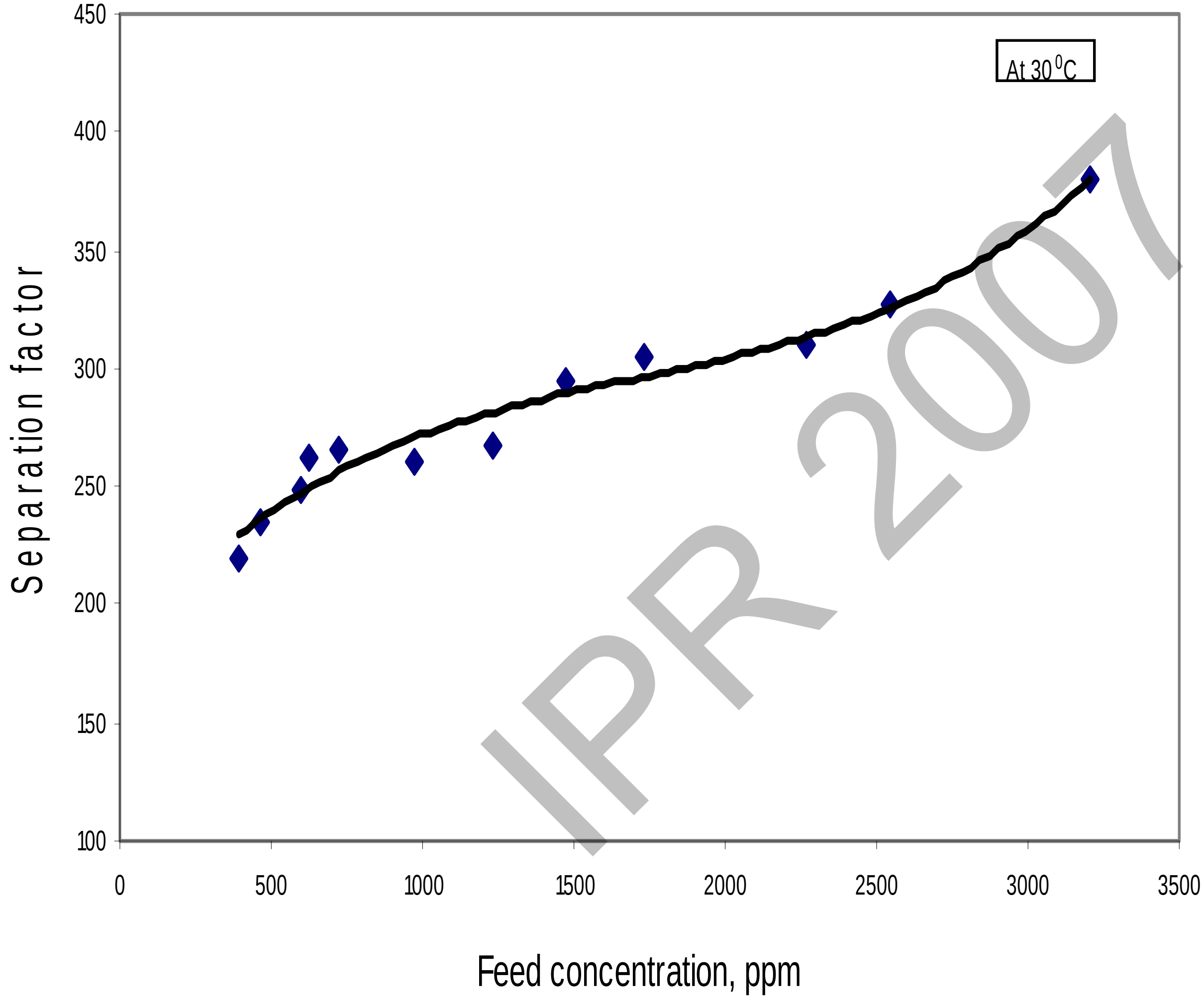


The permeate concentrations >>> solubility limit

(- - - - - - - - = 0.56 wt.%)

Factors:

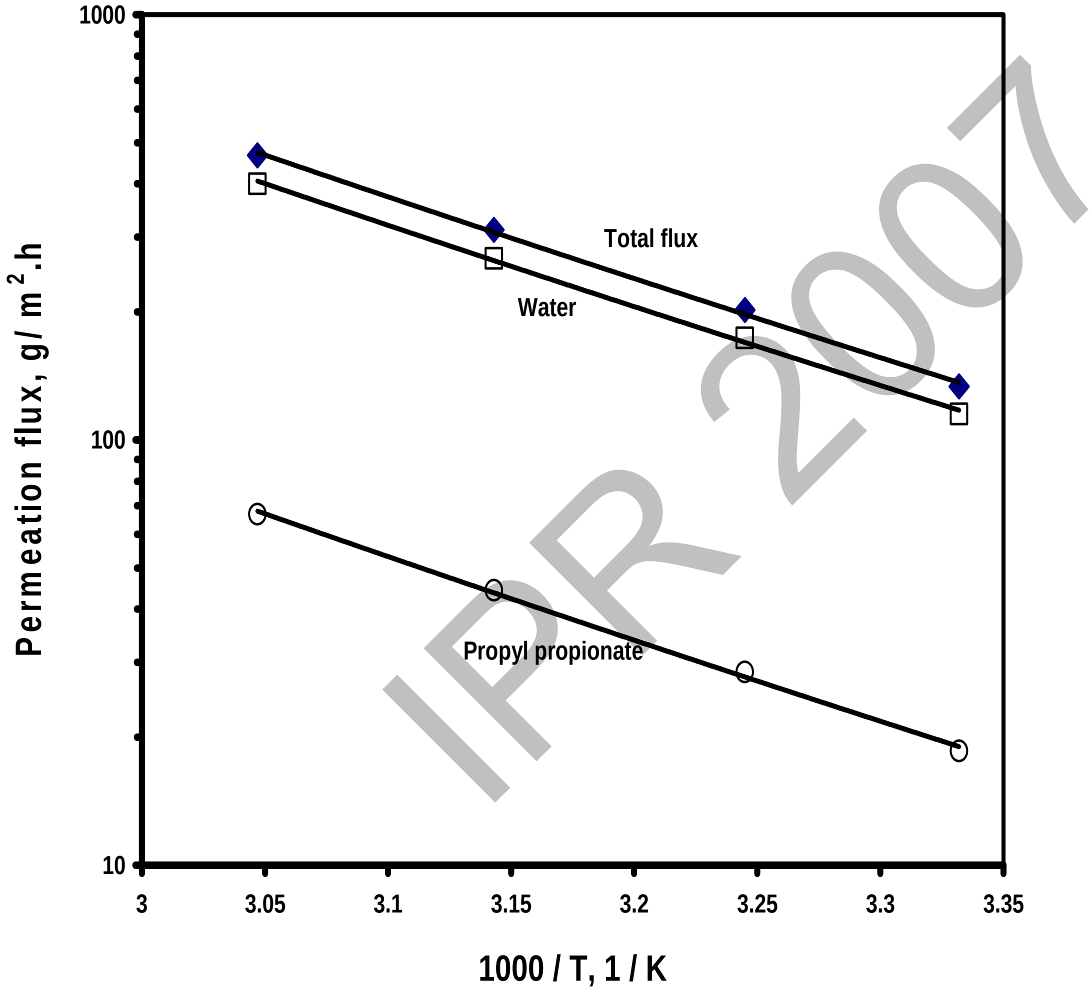
- Hydrophobicity
- Driving force effect
- Swelling effect



The separation factor (selectivity): 220-380

PEBA is a promising membrane material

- Effect of Operating Temperature



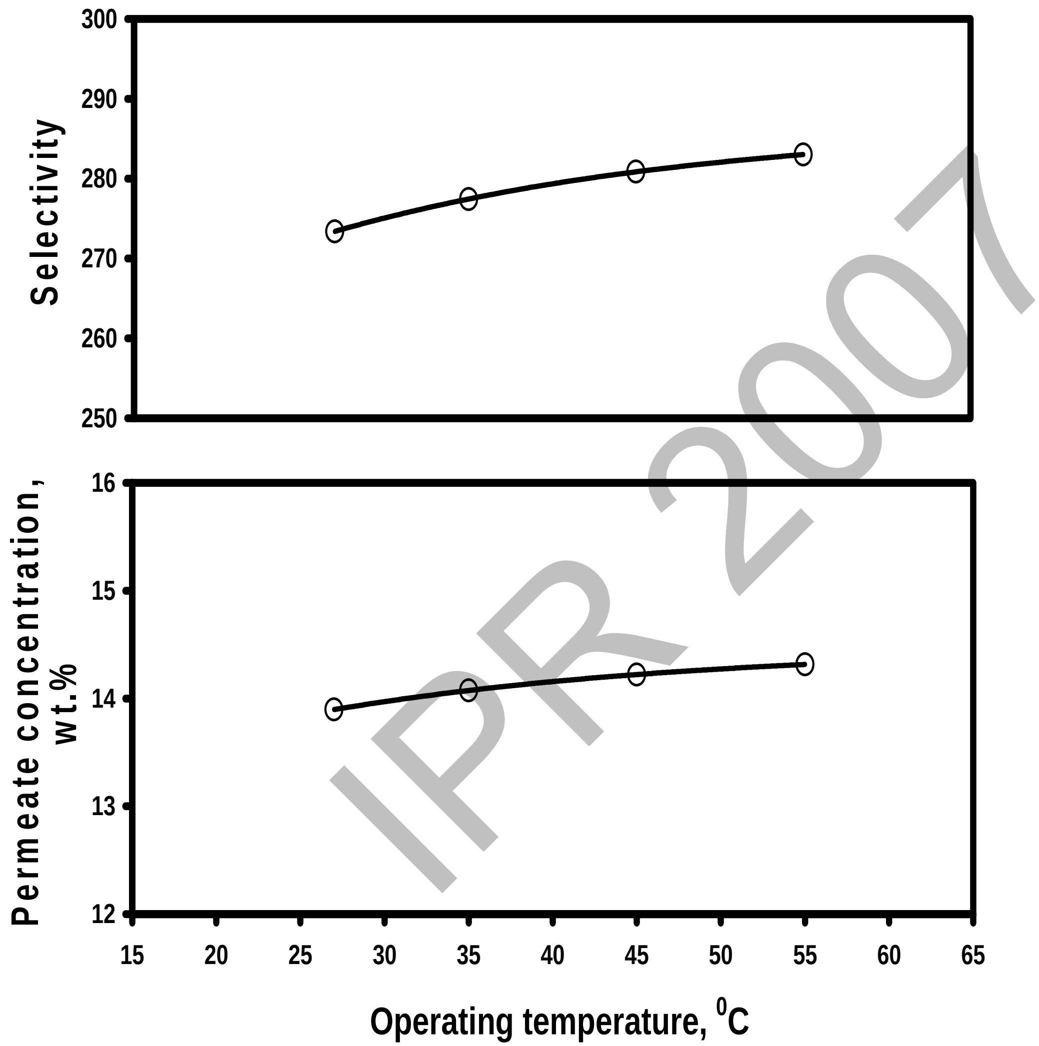
Increase in temperature

↓

Thermal motion, amplitude and frequency of polymer chain to jump increase

↓

Free volume increases



The separation factor (selectivity): 273-283

The permeate concentrations >>> solubility limit (0.56 wt.%)

Conclusions

- PEBA is a selective polymeric membrane for recovery of aroma compound (propyl propionate) from aqueous solutions
- The feed concentration affects significantly the permeation flux and selectivity; at 30^0C and in the feed concentration range of 390-3,200 ppm, the permeation rate was 0.13-0.40 kg/ m^2.h and the separation factor was 220-380
- The operating temperature strongly affects the total flux, but the selectivity is slightly affected; in a temperature range of 27-55^0C at a feed concentration of 700 ppm, the permeation rate was 0.13-0.47 kg/ m^2.h and the separation factor was 273-283
- The temperature dependence of total and partial permeation fluxes follows an Arrhenius type of expression

Acknowledgements

- *NSERC*
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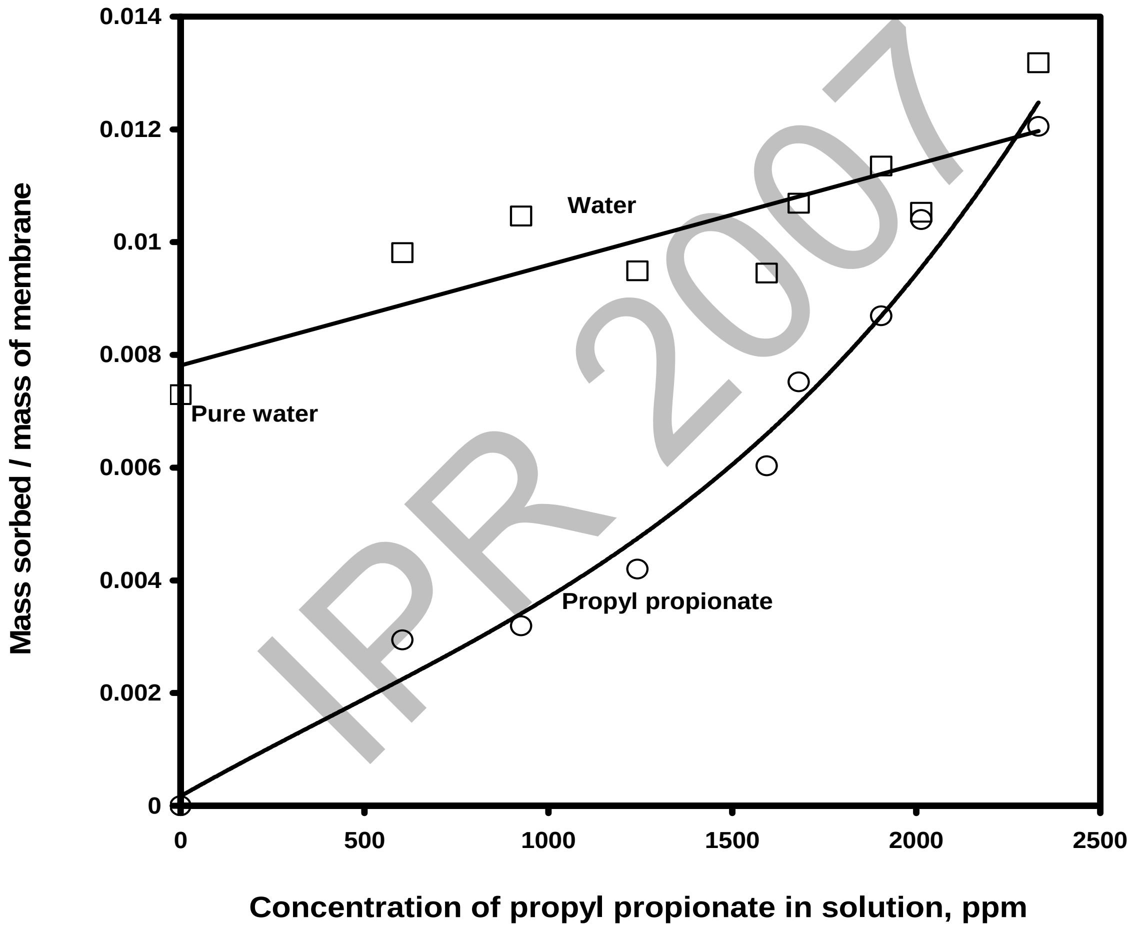
Aroma & Fine Chemicals, Ltd – UK

Supporting slides …

Solubility and Diffusivity
(Sorption-Desorption Experiments)

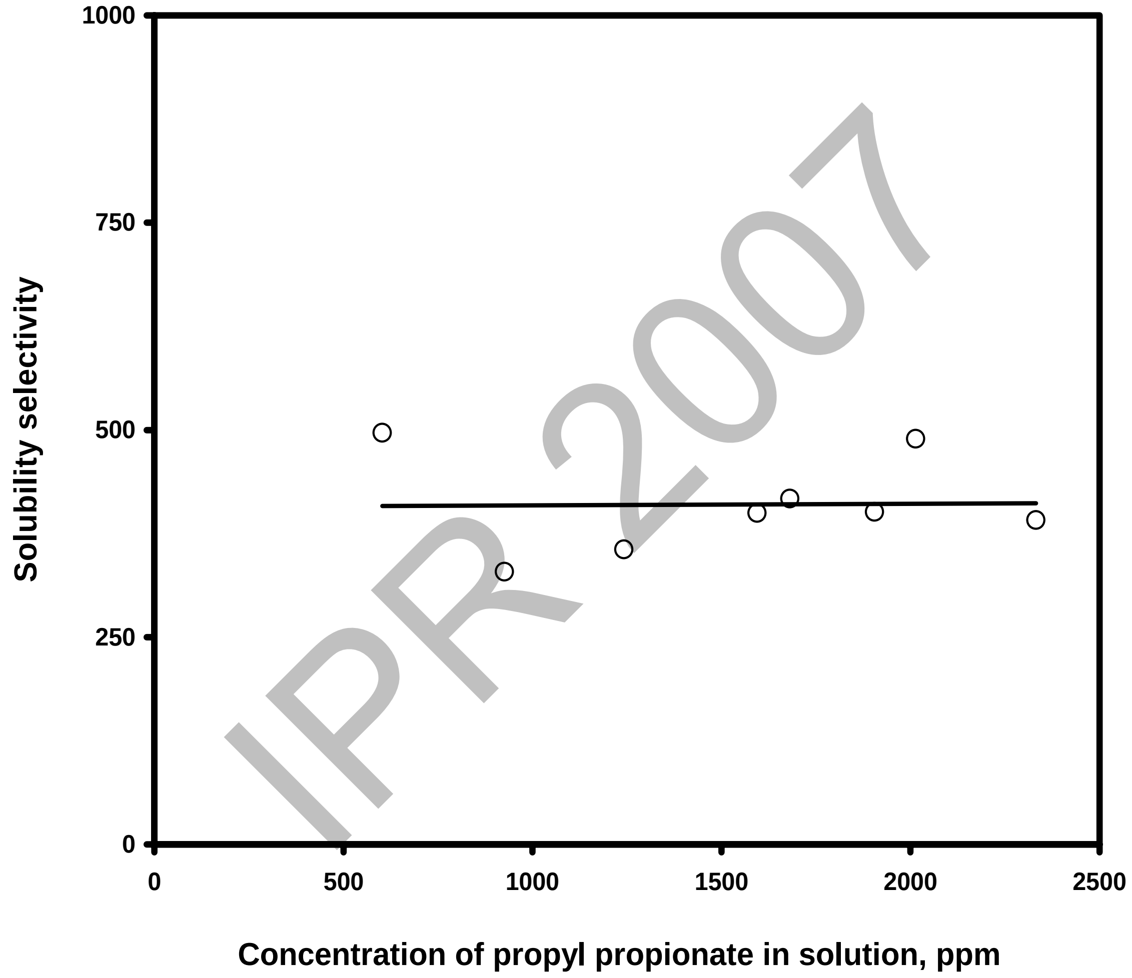


- Solubility selectivity

$$\alpha_S = \frac{\dfrac{X_p}{(1 - X_p)}}{\dfrac{c}{(1 - c)}}$$

X_p = mass fraction of permeant sorbed inside the membrane

c = mass fraction of permeant in the solution



1000
750
500
250
0
0
500
1000
1500
2000
2500
Solubility selectivity
Concentration of propyl propionate in solution, ppm
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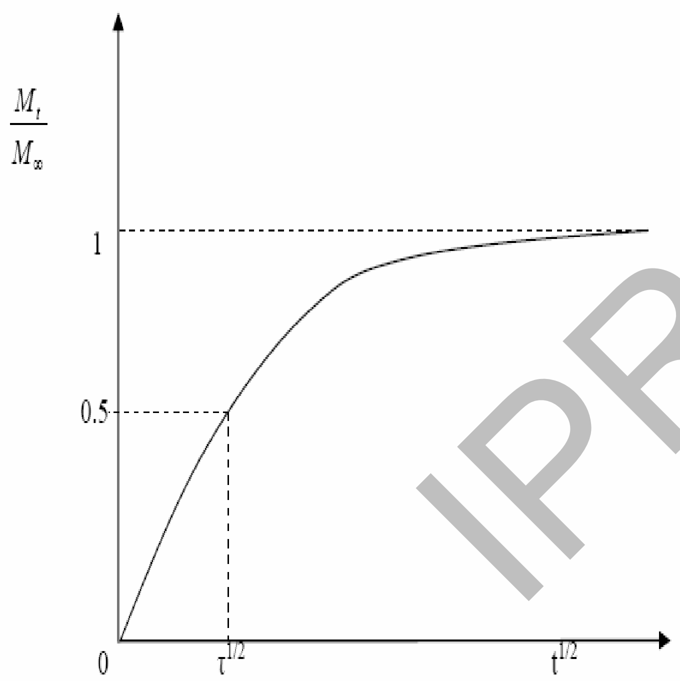
Measurement of Diffusivity

- Time-Dependent Sorption Method

Based on the data of sorption experiment

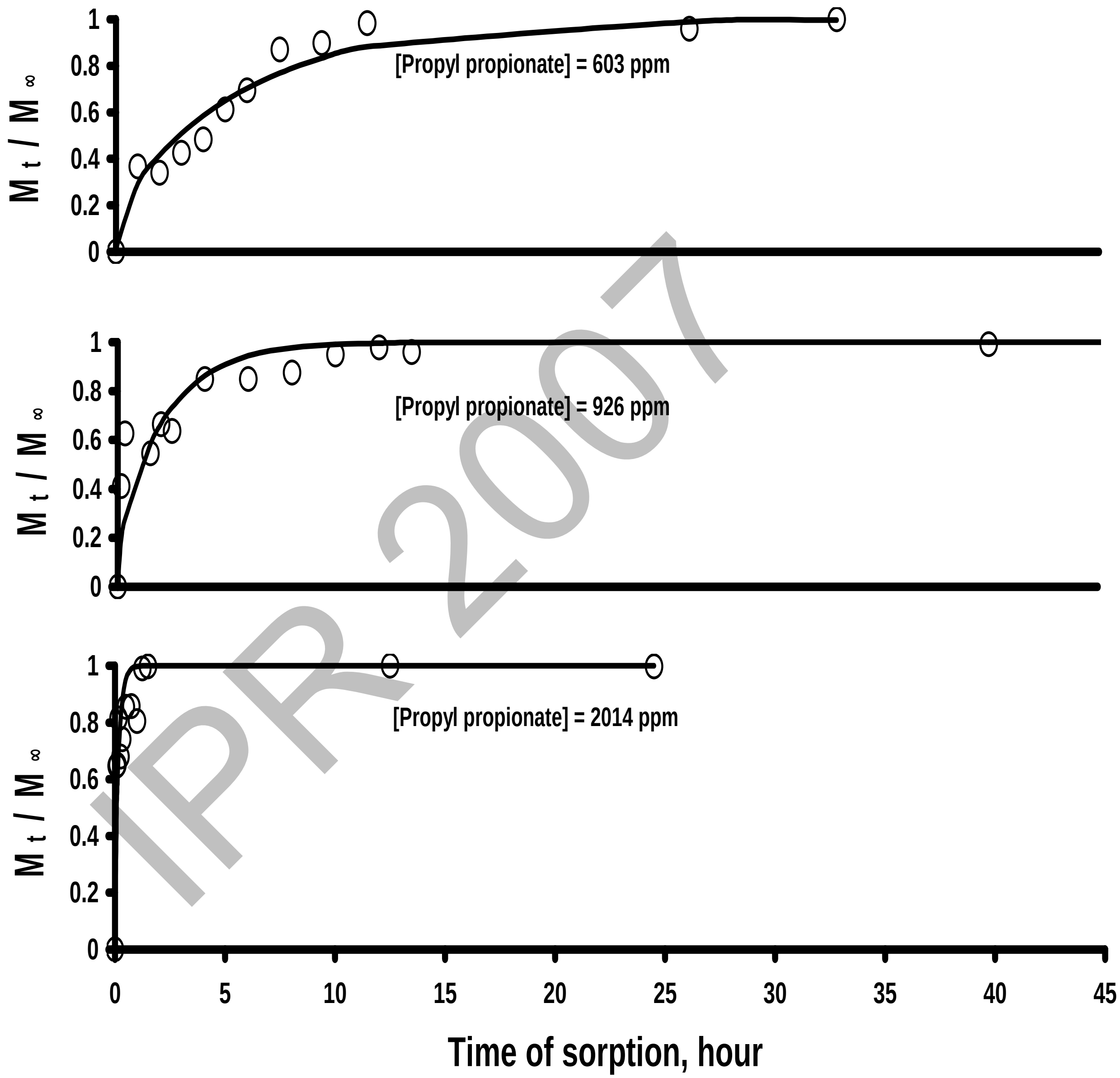


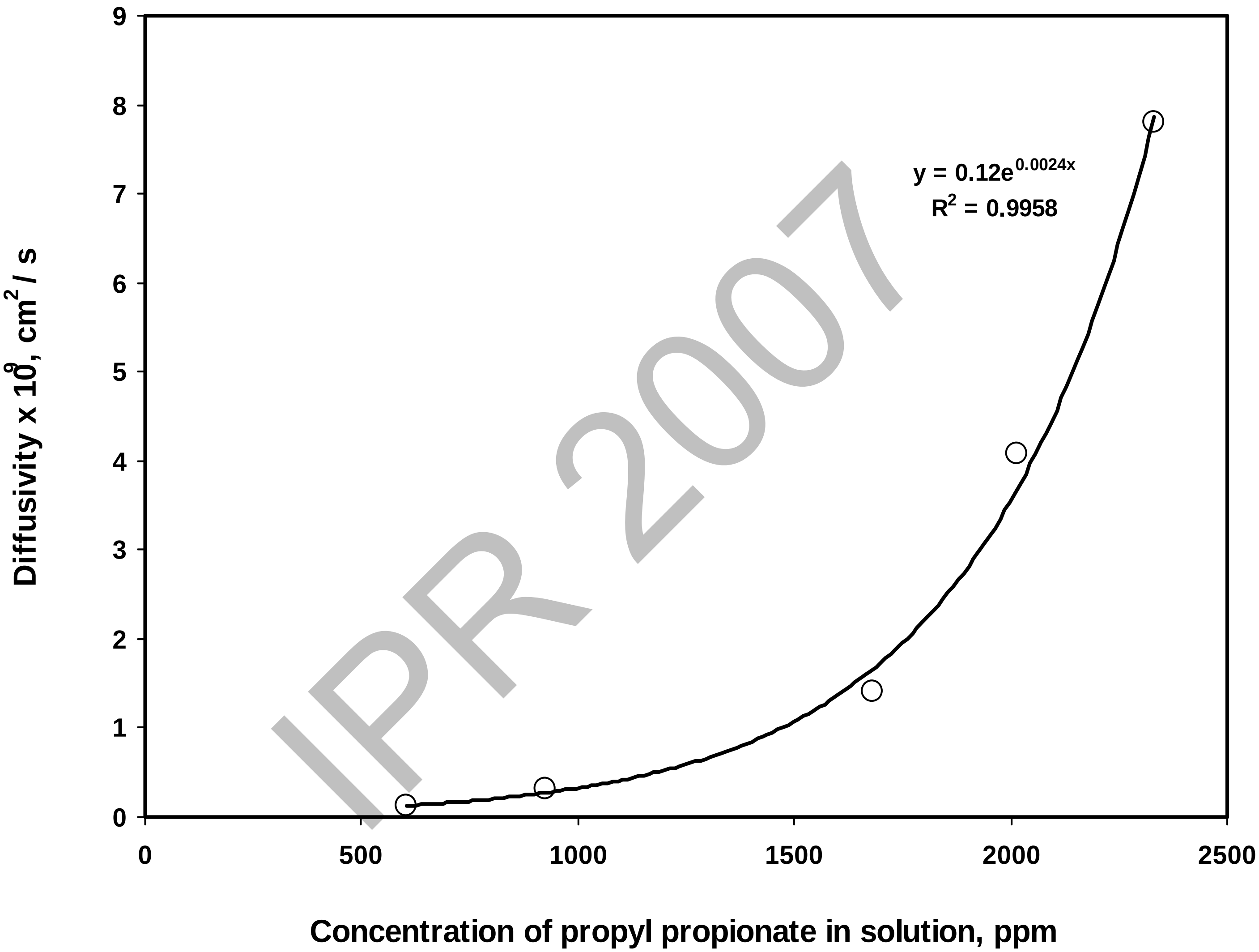
$$\frac{M_t}{M_\infty} = \frac{4}{l}\left(\frac{D}{\pi}\right)^{1/2} t^{1/2}$$

$$D = \frac{0.04919}{\left(\frac{\tau}{l^2}\right)}$$

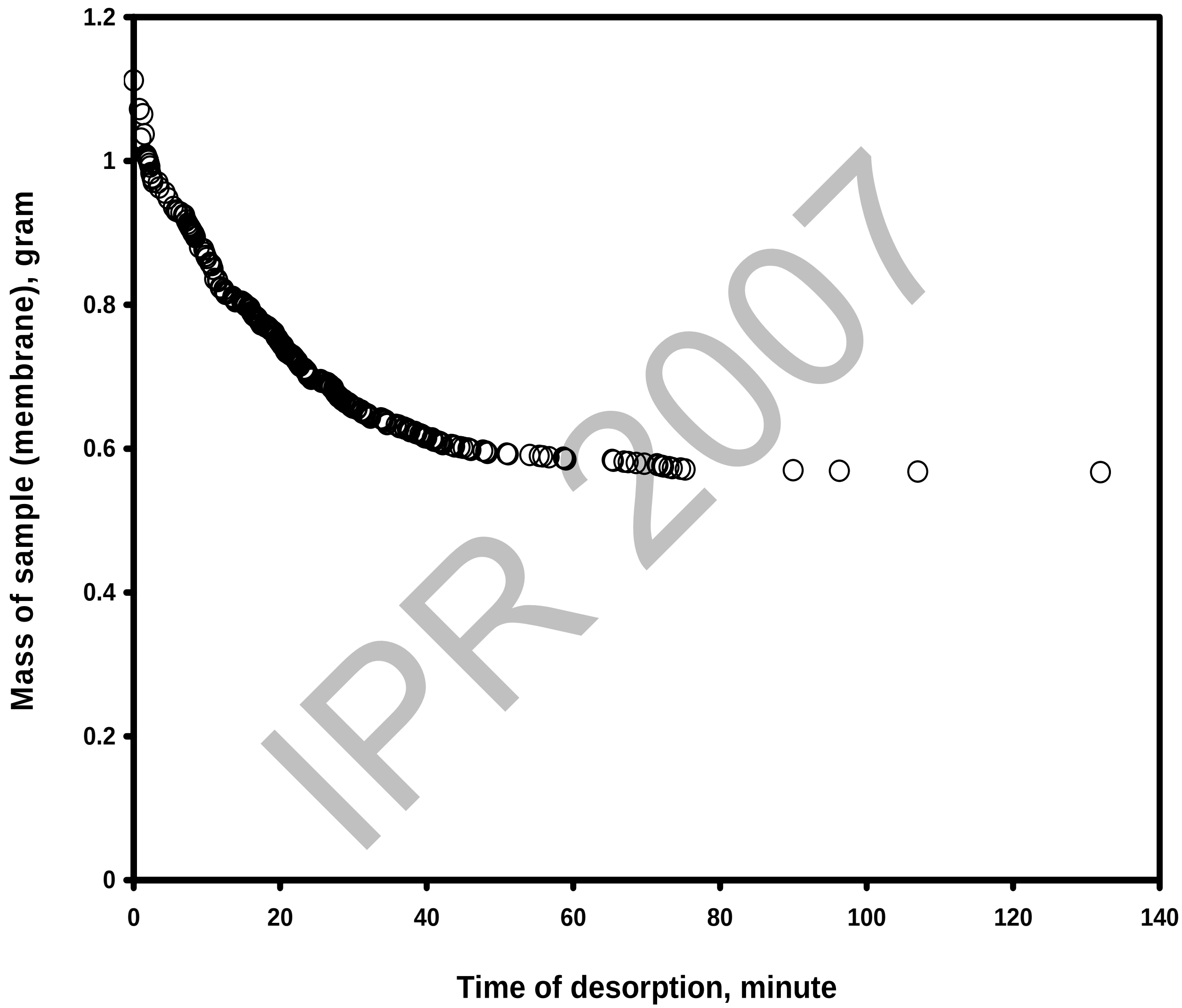
$$\frac{M_t}{M_\infty} = 1 - \sum_{n=0}^{\infty} \frac{8}{(2n+1)^2 \pi^2} \exp\left[\frac{-D(2n+1)^2 \pi^2 t}{4l^2}\right]$$

Sorption Kinetics





Diffusivity x 10^9, cm^2 / s
9
8
7
6
5
4
3
2
1
0
500
1000
1500
2000
2500
y = 0.12e^0.0024x
R^2 = 0.9958
Concentration of propyl propionate in solution, ppm


Mass of sample (membrane), gram
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
120
140
Time of desorption, minute
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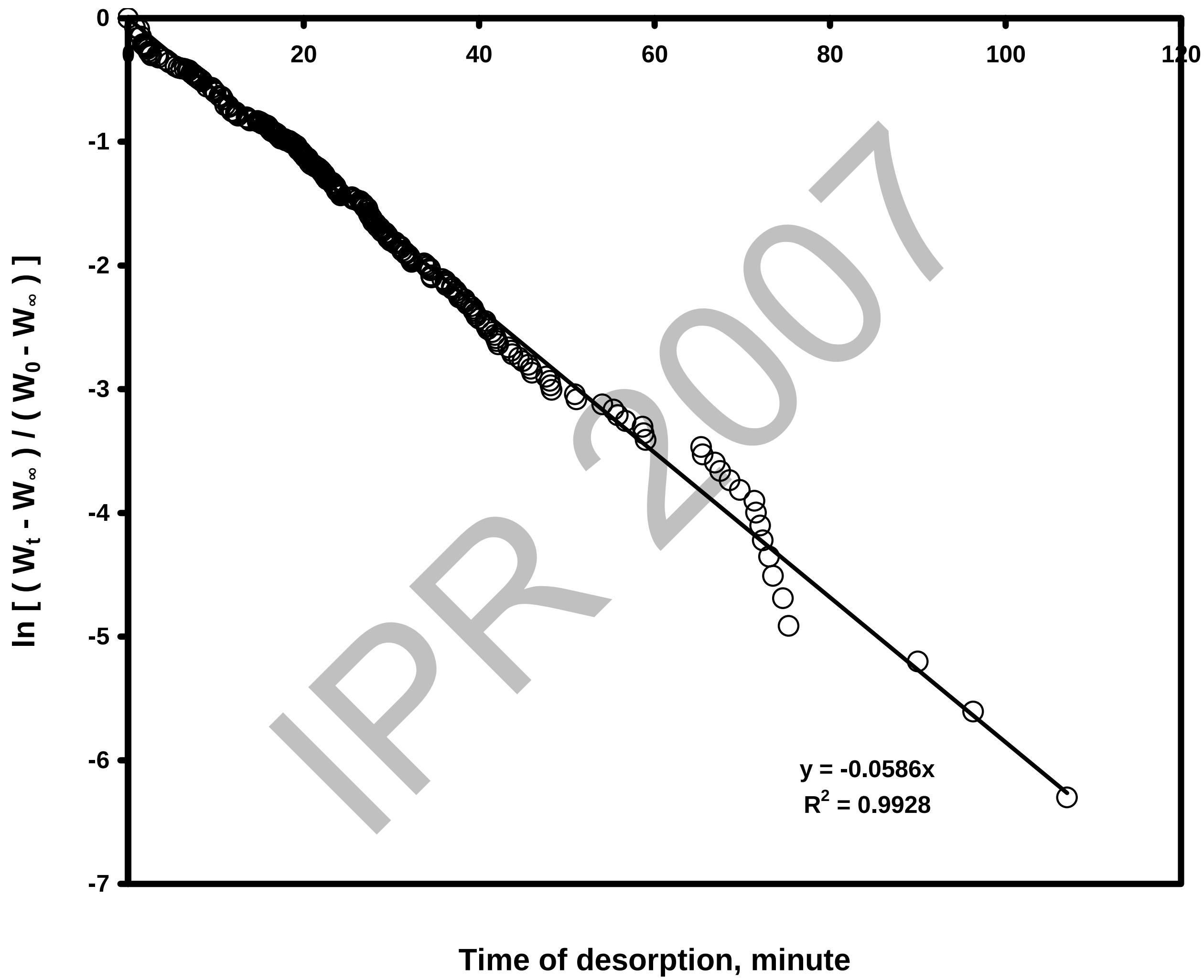

0
-1
-2
-3
-4
-5
-6
-7
0
20
40
60
80
100
120
ln [(W_t - W_∞) / (W_0 - W_∞)]
y = -0.0586x
R2 = 0.9928
Time of desorption, minute

Transport Mechanism in PV

- Solution-Diffusion Model

(widely used model)

The movement of permeant from feed side to permeate side undergoes three consecutive steps:

(1) Sorption from bulk liquid to the membrane surface of the feed side

(2) Diffusion through the membrane

(3) Desorption from the membrane surface to the permeate stream