Recovery of aroma compounds from dairy products by pervaporation

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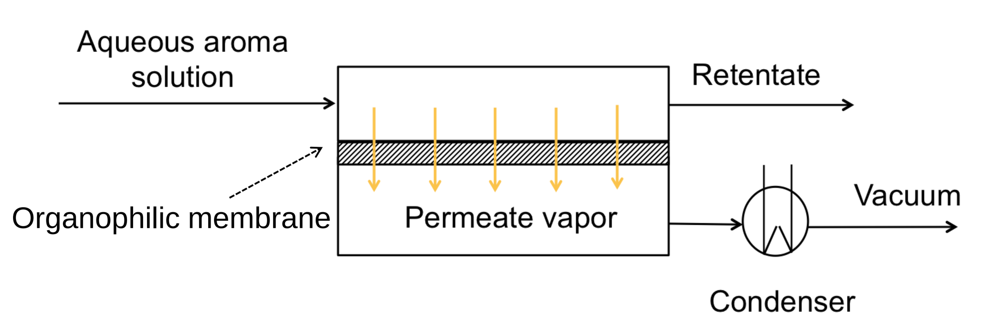
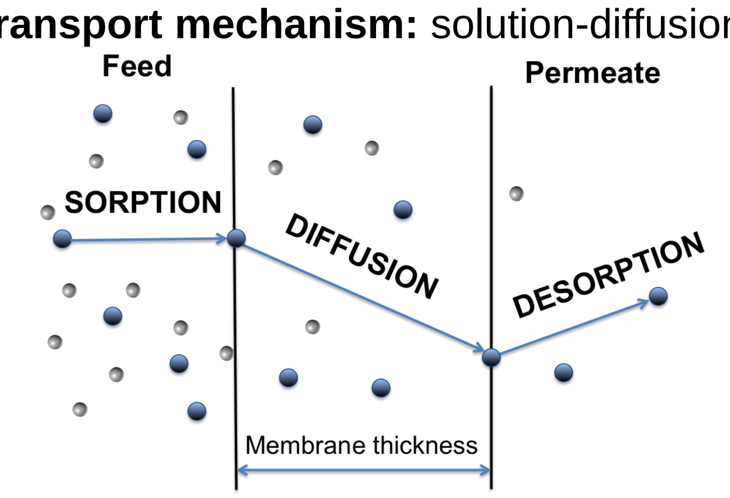
Background

- During processing of dairy products, volatile aroma compounds may be lost due to evaporation or thermal degradation.
- **Traditional methods** of recovery of aroma compounds: distillation, gas stripping, solvent extraction. But they involve high temperature, high energy consumption or introduction of other chemicals.
- **Pervporation** - no damage to aromas, no additives, good selectivity to aromas.

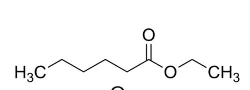
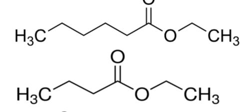
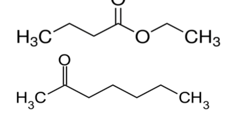
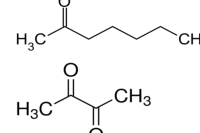
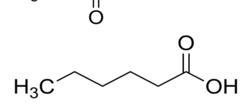
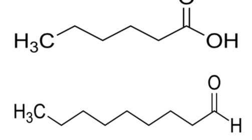
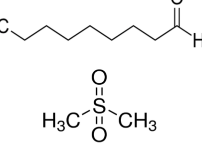
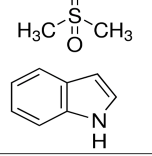


- **Mass transport mechanism:** solution-diffusion model

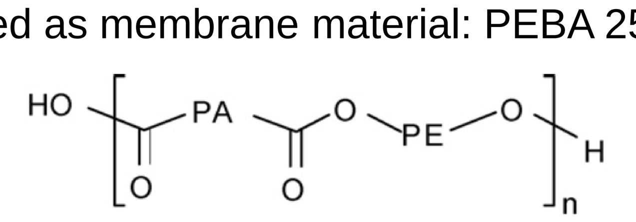


Motivation

Investigate the effectiveness of pervaporation on recovery of aromas from dairy solutions.

Aroma compounds	Formula	Odor	MW (g/mol)	T_B (°C)	Solubility in water 25 °C (g/kg)
Esters					
Ethyl hexanoate		Pineapple	144	228	0.46
Ethyl butanoate		Pineapple	116	120	5.75
Ketones					
2-Heptanone		Banana	114	151	4.3
Diacetyl		Buttery	86	88	250
Acid					
Hexanoic acid		Goat	116	206	10.82
Aldehyde					
Nonanal		Grass	142	191	0.096
Sulfur compound					
Dimethyl sulfone		Hot milk	94	240	Miscible
Aromatic compound					
Indole		Jasmine	117	253	1.9

Polymer used as membrane material: PEBA 2533



Characterization of PV performance

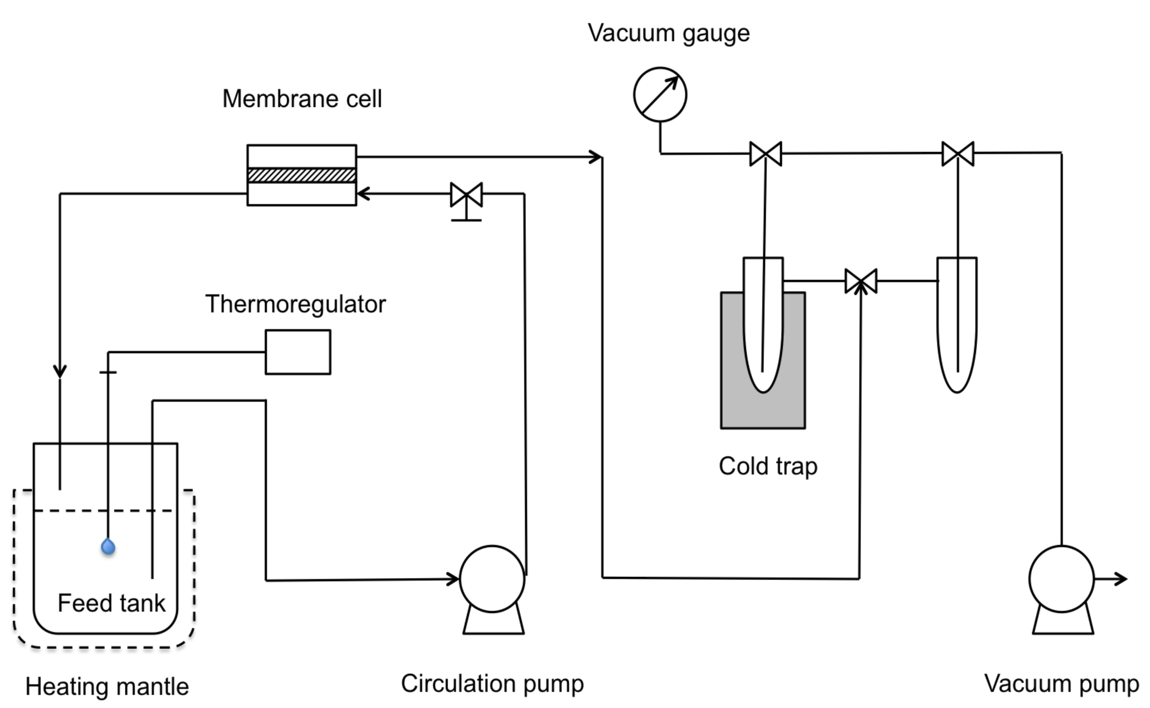
- Permeation flux (J_i), g/(m^2.h) $J_i = N_i/A$
- Enrichment factor (β) $\beta = Y_i/X_i$

N_i: permeation rate, g/h

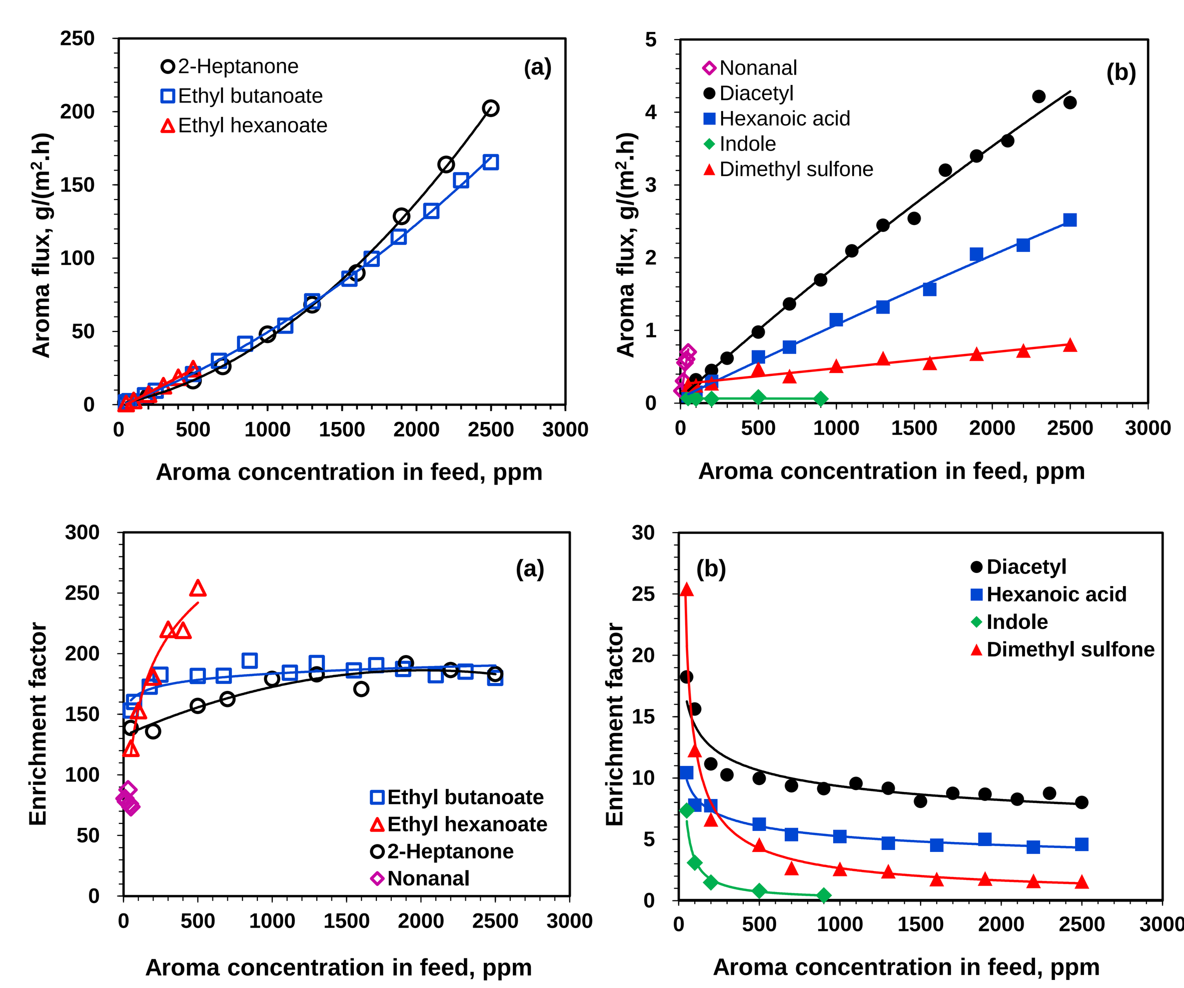
X_i: Aroma concentration in feed, g/g

Y_i: Aroma concentration in permeate, g/g

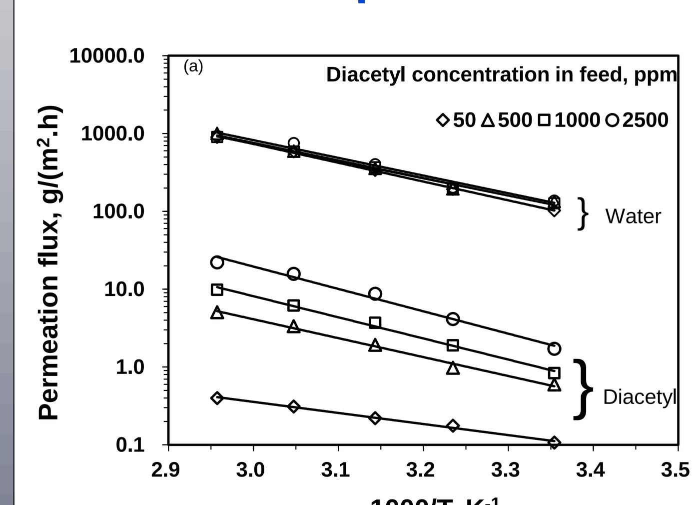
Pervaporation setup



Effect of feed concentration



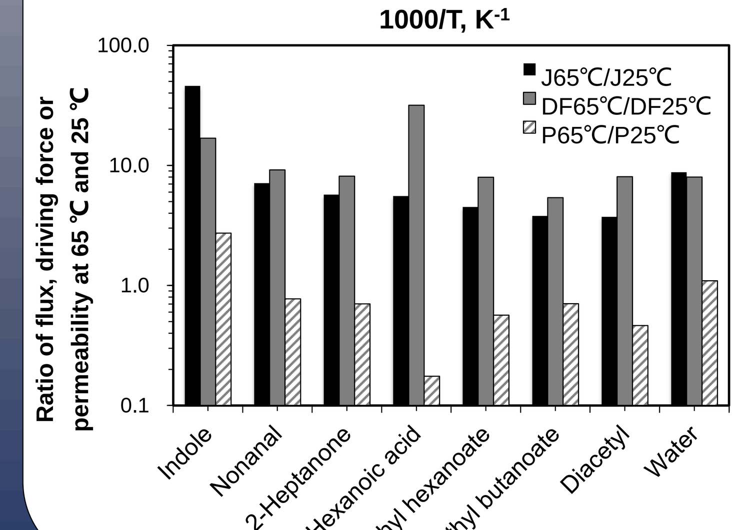
Effect of temperature



Arrhenius-type equation:

$$J_i = J_{0i}\exp\left(-\frac{E_{Ji}}{RT}\right)$$

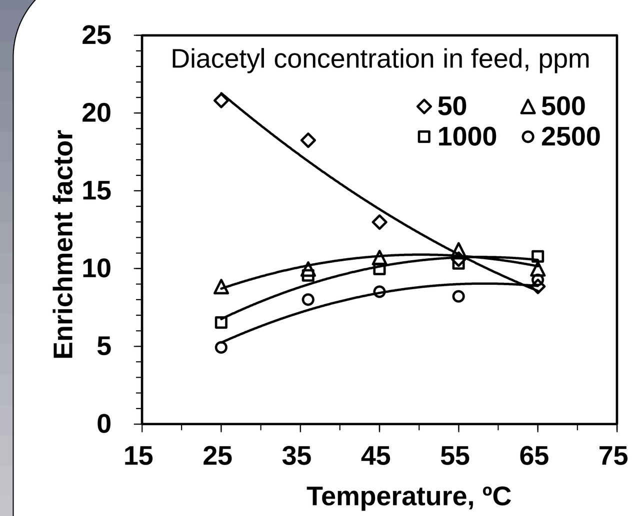
J_0: preexponential factor for flux, g/(m^2.h);
R: universal gas constant，J/(K.mol);
T: absolute temperature, K.



$$P_i = \frac{J_i l_i}{\gamma_i X_i p^{sat} - Y_i p^p}$$

Permeation driving force

l_i: membrane thickness, μm
γ_i: activity coefficient
p^{sat}: saturated pressure, Pa
p^p: permeate pressure, Pa



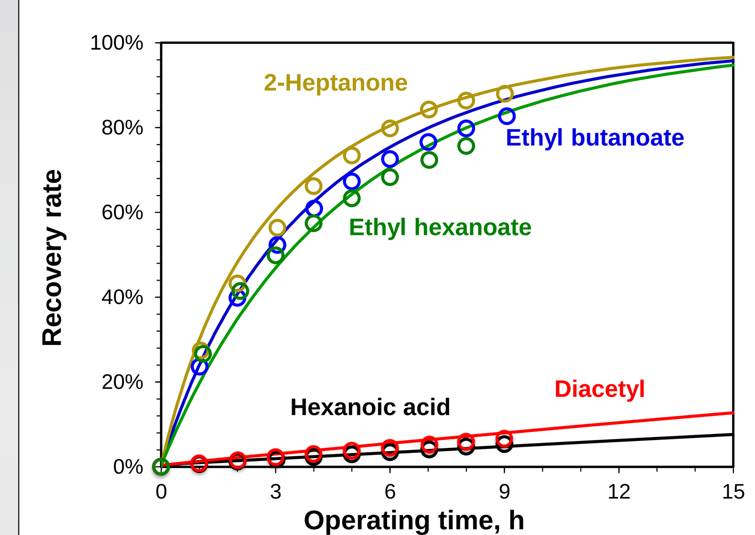
C_a, ppm	Diacetyl-water			
	E_{Ja}	E_{Pa}	E_{Jw}	E_{Pw}
50	27.3	-16.4	45.2	1.6
500	46.6	3.1	43.3	-0.3
1000	52.0	8.6	42.4	-1.2
2500	55.0	11.6	43.5	-0.1

Batch pervaporation

Feng and Huang's model (well mixed binary feed):

$$t = \frac{F_0}{A}\int_X^{X_0}\frac{Y exp\left(-\int_X^{X_0}\frac{dX}{Y-X}\right)}{J(Y-X)}dX$$

t: operating time, h;
F_0: initial feed amount, g;
A: membrane area, m^2;
X_0: initial aroma concentration in feed, g/g

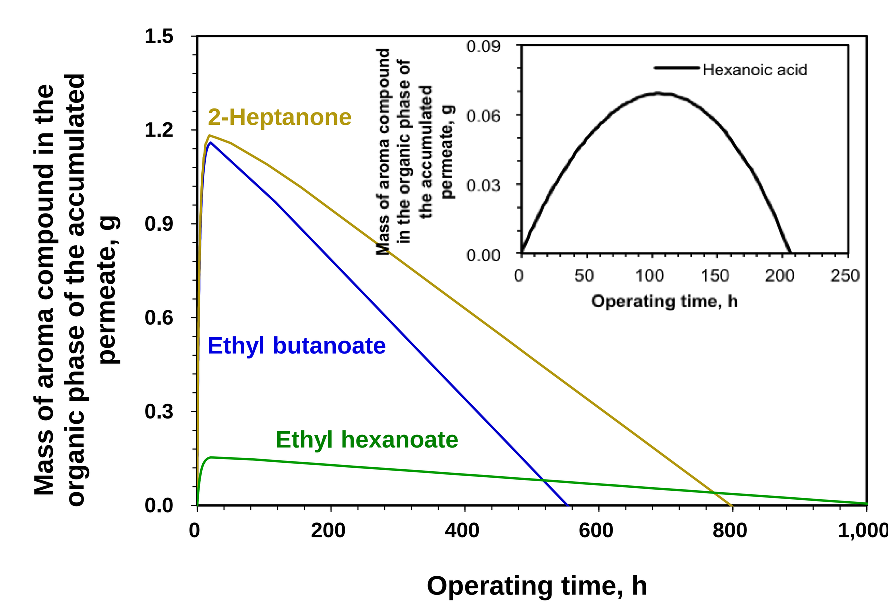


Initial feed amount: 500 g; Initial feed conc.: 320 ppm for ethyl hexanoate; 2500 ppm for other aromas; Temperature: 36 ℃

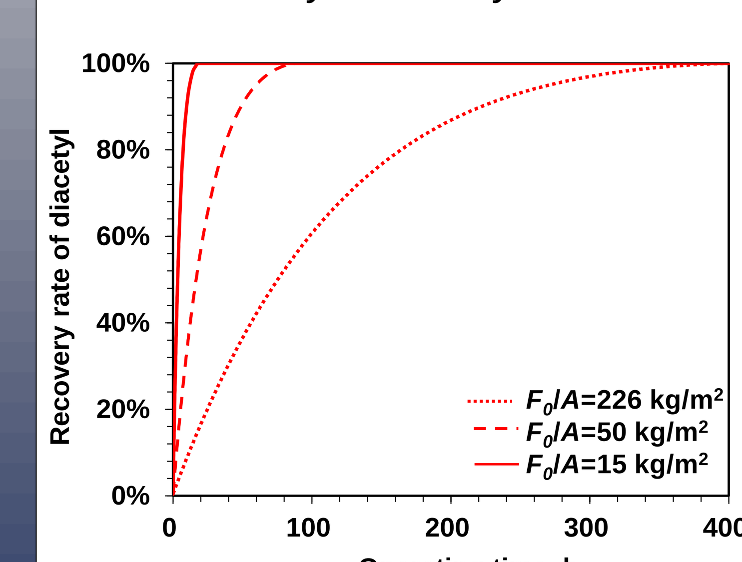
When aroma concentration in accumulated permeate reaches aroma solubility in water, phase separation occurs.

$$M_o = \frac{F_0\left((X_0+X_0S_o-S_o)-(X+XS_o-S_o)exp\left(-\int_X^{X_0}\frac{dX}{Y-X}\right)\right)}{1-S_oS_w}$$

S_o: aroma solubility in water, g/g; S_w: water solubility in aroma, g/g.

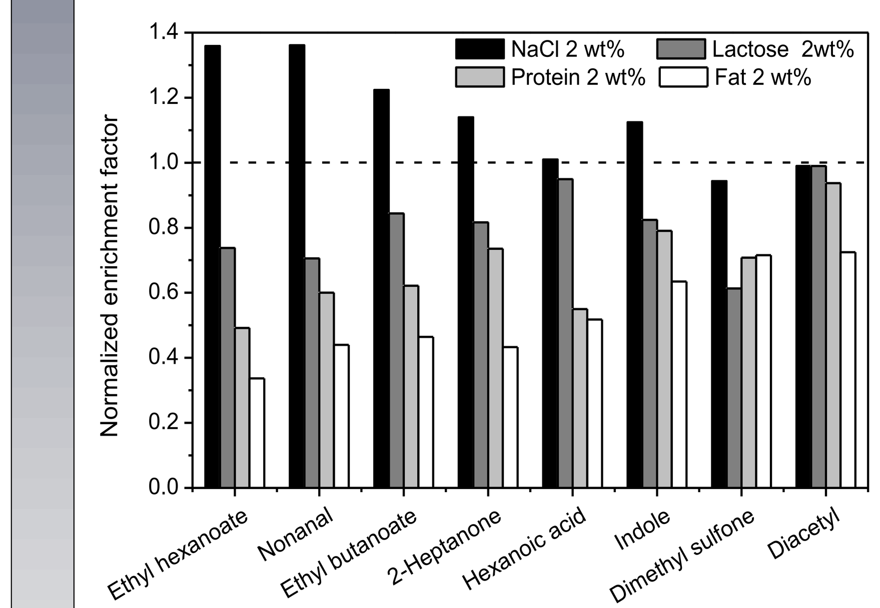


The ratio of initial feed mass (F_0) and membrane area (A) affect recovery efficiency.



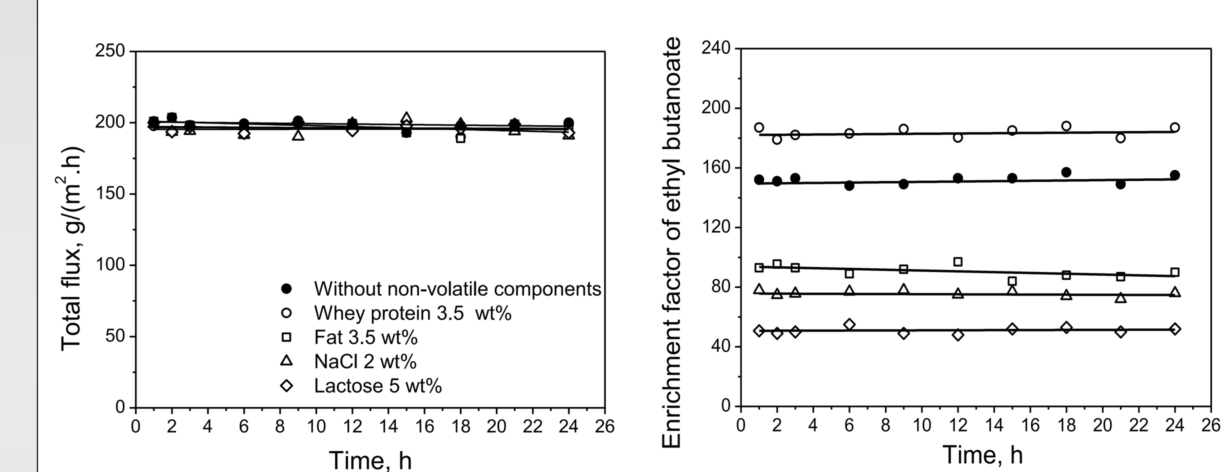
To achieve a 100% recovery,
F_0/A = 226 kg/m^2, t = 381 h;
F_0/A = 50 kg/m^2, t = 84 h;
F_0/A = 15 kg/m^2, t =17 h.

Effect of non-volatile dairy components on PV



In general, lactose, whey protein or milk fat in feed solutions negatively affected the pervaporative recovery of aroma compounds. NaCl positively influenced the recovery of more hydrophobic aroma compounds.

No concentration polarization or membrane fouling with the presence of lactose, whey protein, fat and NaCl was observed.



Conclusions

- 1. With an increase in feed aroma concentration or temperature, aroma fluxes increase rapidly.
- 2.The recovery of aroma compound from its aqueous feed solution is influenced by F_0/A for a given period of batch operating time.
- 3. Lactose, whey protein and milk fat in feed negatively affect the pervaporative recovery of aroma compounds, due to the hydrophobic interaction between these non-volatile compounds and aromas. NaCl positively influences the recovery of more hydrophobic aroma compounds.

Reference

- Feng, X., Huang, R.Y.M., 1992. Separation of isopropanol from water by pervaporation using silicone-based membranes. J. Membr. Sci. 74, 171–181.
- Parliment, T.H., McGorrin, R.J., 2000. Critical flavor compounds in dairy products, in: Flavor Chemistry: Industrial and Academic Research. American Chemical Society, Washington, D.C., pp. 44–71.

Acknowledgements

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