Influence of Hydrodynamics on Osmotic Evaporation Performance

Mathilde Courel, Gilbert Marcel Rios, Manuel M. Dornier, Max Reynes

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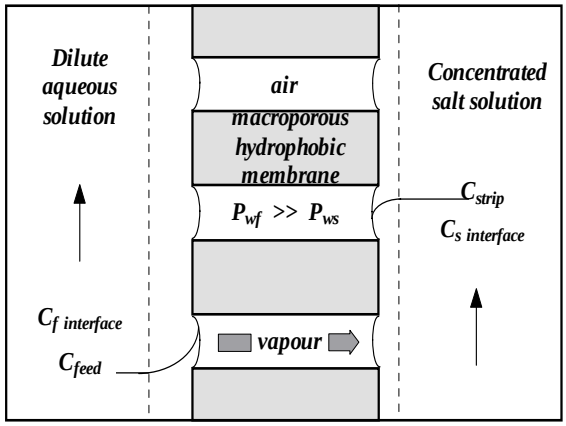
M. Courel[1,2]; G.M. Rios[2]; M. Dornier [1]; M. Reynes [1]

1. CIRAD-FLHOR : Centre de coopération internationale en recherche agronomique pour le développement ; BP 5035, 34032 Montpellier Cedex 1 ; tel. 33 04 67 61 44 85, fax : 33 04 67 61 44 33, e-mail : courel@cirad.fr
2. LMPM : Laboratoire des Matériaux et Procédés Membranaires, UMR 5635, Place Eugène Bataillon, 34095 Montpellier Cedex 5 ; e-mail : rios@crit.univ_monpt2.fr

Il manque les titres de figures

Introduction

Osmotic evaporation (OE) is a recent membrane technology that was patented by Deblay in 1991 [1] allowing concentrating fragile aqueous solutions such as fruit juices [2]. OE consists of extracting water from an aqueous stream by means of a concentrated salt solution. The liquids are circulated along the 2 faces of a macro porous hydrophobic membrane. Because of its hydrophobicity the polymer cannot be wetted by the liquids; vapour-liquid interfaces are thus formed at each extremity of the pores that contain air at atmospheric pressure (Fig. 1). The presence of salt depresses the vapour pressure of the brine and results in creating a vapour pressure gradient between dilute and salt solution.



Mass transfer and hydrodynamics

The mass transfer mechanism can be decomposed in 3 steps: the water is transported from the bulk feed through a concentration boundary layer to the membrane surface where it evaporates. The vapour is transferred across the membrane under the influence of a vapour pressure gradient and condenses at the surface of the strip solution. The water then passes through a diluted brine boundary layer to the bulk stream. The evaporation flux can be summarized by the following equations:

$$N = K \cdot \Delta P_w \qquad 1/K = [1/(1/k_f + 1/k_m + 1/k_s)]^{-1}$$

The molar flux N is proportional to the bulk vapour pressure gradient ΔP_w ; K is the overall permeability of the system that can be expressed in terms of mass transfer resistances respectively in the feed (k_f), in the strip solution (k_s) and in the membrane (k_m).

The vapour transfer across the membrane has been widely studied for membrane distillation process and the same theory can be applied for OE. The porous polymer filled with air can be considered as a stagnant air film opposing resistance to the diffusion of water vapour. According to the type of membrane used, other resistances coming from the porous structure ie Knudsen diffusion or Poiseuille viscous flow might be taken into account.

Table 1 - OE fluxes obtained by various authors; T = 35-40°C; water or dilute fruit juice; NaCl or CaCl2 aqueous solutions; flat sheet PTFE or hollow fibre PP membranes.

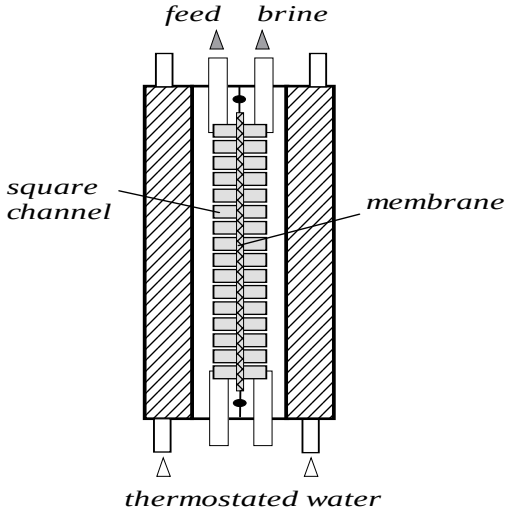
REFERENCE	MENGUAL [3]	GODINO [4]	GOSTOLI [5]	SHENG [6]	HOGAN [7]
Geometry	stirred cell	stirred cell	stirred cell	plate & frame	hollow fibre
Hydro-dynamics	200 rpm	50 to 350 rpm	1200 rpm	5.8 to 12.0 $l.min^{-1}$	0.085 to 0.255 $m.s^{-1}$
Flux ($l.h.m^{-2}$)	0.39; 3.90?	2.95 to 4.20	max 2.7	1.25 to 1.80	1.30
Shear effect on flux	∞ agitation + 40 to 50 %	+ 7 fold + 30 %	no polarisation	+ 2 fold + 36 %	+ 3 fold no effect

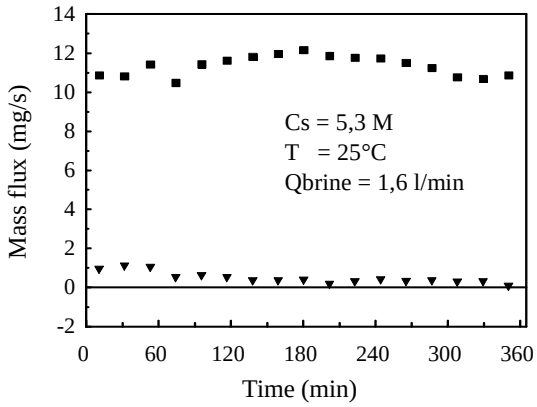
Concentration polarisation can play a significant role in the performance of OE systems. The resistances offered by the liquid films bounding either side of the membrane may cause severe flux decay. Mass transfer across boundary layers is generally supported by the film theory [3][4][5][6][7]. The phenomenon of concentration polarisation is intimately linked to the hydrodynamics of the process. The data summarized in table 1 show that according to the module geometry and the liquid hydrodynamics used by the various authors, the concentration polarisation on brine side varies from 0 effects to 50% flux reduction.

Taking into account these considerations, a new module was designed to try and increase the flux performances and to study the hydrodynamics of OE.

Materials and methods

The design of a new laboratory scale module is shown in Fig. 2. The fluids are circulated into square channels evenly distributed so that the velocity of the fluids is identical on the whole membrane surface. The membrane is sandwiched between the 2 symmetrical half cells with a surface area of 40 cm^2. A commercial TF200 flat-sheet membrane from Gelman company was used for this work (pore diameter = 0.2 μm; porosity = 60%; thickness = 165 μm) made of a thin PTFE layer supported by a PP net. Distilled water was extracted by calcium chloride aqueous solutions of 5.5 +/- 0.05 $mol.l^{-1}$ at a temperature of 25 +/- 0.2 °C. The concentration of the brine was maintained constant by using a large volume of solution and controlled by density measurements. The recirculation flow rates of the 2 solutions were controlled with rotameters with an accuracy of 2 %.





Results

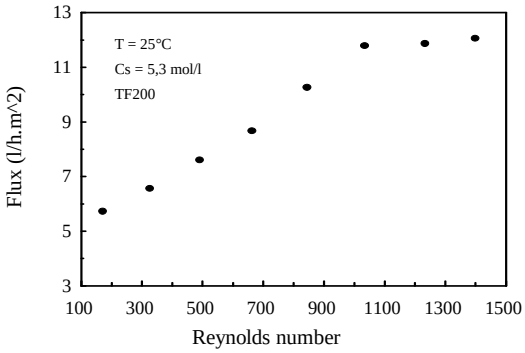
Flux measurement procedure

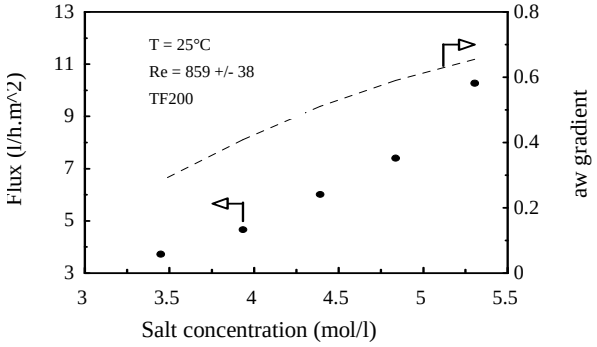
The kinetics of each OE experiment was followed by recording the weight loss of the water reservoir from an electronic balance. The slope of the kinetic curve was calculated by least square regression to give the corresponding OE flux with an accuracy of less than 1 %. The noise introduced by the circulating fluids was measured and attained a maximum of 4 % of the OE signal (Fig. 3). The maximum stability was achieved between 180 and 360 minutes and this time interval was used to calculate the mean characteristic flux of an experiment. Reproducibility tests indicated that the OE flux could be measured under standard conditions with an accuracy of 10% within a 95% prediction interval.

Effect of circulation flow rate and concentration of the brine

One of the objectives of this work was to estimate the maximum flux attainable under specific temperature and brine concentration conditions. Using water and $CaCl_2$ 5,3 M, the flow rate of the brine was varied from 0,3 to 2,7 l.min-1 covering a range of Reynolds numbers from 170 to 1400 corresponding to a laminar flow regime. The results presented Fig.4. indicate evaporation fluxes from 5,7 to 12,0 $l.h^{-1}.m^{-2}$ which is much higher than the performances reported in the literature. The OE flux increases with brine flow rate because of increased Reynolds number and decreased boundary layer resistance. Concentration polarisation in the brine affects significantly the flux as a 9 fold flow rate increase results in a 100% flux increase.

Another set of experiments was conducted at constant brine flow rate and temperature and the salt concentration was varied from 3.45 to 5.30 $mol.l^{-1}$. The results shown in Fig.5 indicate the flux dependence on the driving force which is related to the water activity of the salt solution.





Conclusions

Considering the low osmotic evaporation fluxes reported in the literature as well as the lack of information about the hydrodynamic aspect of this technique, a new laboratory scale OE module was developed. A series of experiments was carried out with pure water and $CaCl_2$ solutions varying the flow rate and the concentration of the brine. The OE fluxes obtained in this work showed a significant improvement towards the results published by various authors. In spite of important concentration polarisation in the brine, the relative high fluxes can be attributed to high mass transfer coefficients achievable in the new lab-scale OE module.

References

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