

Development and validation of a theoretical model for osmotic evaporation



A.L. Peñaranda-López^a, J.C. Martínez-Alvarado^a, C.J. Muvdi-Nova^b, B. Torrestiana-Sánchez^{a,*}

^a Food Research and Development Unit, Instituto Tecnológico de Veracruz, Av. M. A. de Quevedo # 2779, Veracruz Ver. 91897, Mexico

^b CICTA, Universidad Industrial de Santander, Cra 27 calle 9, Bucaramanga, Santander, Colombia

HIGHLIGHTS

- The developed model fairly predicts the vapor permeation flux and sugar concentration kinetics during osmotic evaporation.
- According to the model the highest resistance to heat and mass transfer is found in the feed side of the membrane.
- The variables having the most important effect on flux are temperature and the brine concentration
- The model predicted anisotropy in the polarization of both temperature and concentration in both sides of the membrane.
- Prediction with viscous solutions should take into account the increased mass transfer resistance among the fibers.

ARTICLE INFO

Article history:

Received 10 September 2015

Received in revised form 17 January 2016

Accepted 29 January 2016

Available online xxxx

Keywords:

Osmotic evaporation

Theoretical model

Cassava starch hydrolysates

ABSTRACT

In this work, a mathematical model developed to describe the heat and mass transfer over time during the osmotic evaporation process is reported. The model predicted the vapor permeation flux and sugar concentration kinetics with error values of $\leq 36\%$ and $\leq 16\%$ respectively, during the evaporation of glucose–water solutions up to 50°Brix. Predictions of the model were experimentally validated in the range of vapor permeate flux values between 0.4 and 2 kg m⁻² h⁻¹. According to the model the variables having the most important effect on flux were temperature and the brine concentration. It also indicates anisotropy in the polarization of both temperature and concentration between the feed and brine sides of the membrane and points out that the heat and mass transfer phenomena occurring in the feed side of the membrane are the mechanisms controlling the process. The model was also used to describe the experimental flux and concentration kinetics of cassava starch hydrolysates. Deviations between predictions and data obtained with cassava starch hydrolysates are attributed to the high viscosity of this feed and to the increased mass transfer resistance among fibers inside the module.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

The concentration step in food processing is often a primary requirement for product development. Concentration of fruit juices and syrups is currently carry out by vacuum evaporation under operating conditions established according to the needs of every process. However, the main drawbacks of vacuum evaporation are the high energetic costs and the thermal degradation of sugars due to the relatively high operating temperatures. Hence, there is a need to find new innovative and easy to operate concentration technologies to overcome such limitations. Osmotic evaporation (OE) is a membrane concentration process which operates under mild conditions (low pressure and temperature) preserving the sensorial product's properties (i.e. taste and color) [1]. This process has been mainly used to concentrate clarified juices since it keeps almost constant their physicochemical, biochemical and aromatic properties [1–8].

However, few models have been reported describing the mass and energy transfer in OE [9–11]. Most of these models assume that the process runs in steady state and they have been validated using pure water as the feed solution. In addition, the mass and energy transfer is described by a resistance in series model, which indicates based on experimental evidence that flux depends significantly on temperature, brine nature and its concentration. Nagaraj et al. [10] compared two different brines and found that calcium chloride induced higher transmembrane flux than sodium chloride at all concentrations tested. They also pointed out the strong effect of temperature on water flux. Otherwise, Valdes et al. [11] used the phenomenological equations of mass and energy transfer proposed by Romero et al. [9] and found that brine concentration was the main factor affecting process performance. This result was in accordance with the model for transient sucrose concentration, proposed by Alves & Coelho [12], who observed that water flux increased significantly with increments on brine concentration. Recently, Zambra et al. [13] developed a mass transfer model to describe the concentration kinetics of cranberry juice during osmotic evaporation. They reported a maximum deviation of 32% between experimental and

* Corresponding author.

E-mail address: btorrest@itver.edu.mx (B. Torrestiana-Sánchez).

Nomenclature

a	Water activity
A	Area [m ²]
C_p	Heat capacity [J·kg ⁻¹ ·K ⁻¹]
d_h	Hydraulic diameter [m]
D_w	Diffusion coefficient [m ² ·s ⁻¹]
D_{wv}	Water vapor diffusion [m ² ·s ⁻¹]
h	Heat transfer coefficient [W·m ⁻² ·K ⁻¹]
H	Membrane width [m]
ΔH	Latent heat of vaporization [J·kg ⁻¹]
J_w	Mass transfer flow [kg·m ⁻² ·s ⁻¹]
k	Mass transfer coefficient [kg·m ⁻² ·s ⁻¹]
k_m	Mass transfer coefficient of the membrane [kg·m ⁻² ·s ⁻¹ ·Pa ⁻¹]
k_B	Boltzmann constant [1.3807 * 10 ⁻²³ J·K ⁻¹]
k^T	Thermal conductivity [W·m ⁻¹ ·K ⁻¹]
K_K	Knudsen diffusion [kg·m ⁻² ·s ⁻¹]
K_M	Molecular diffusion [kg·m ⁻² ·s ⁻¹]
m	Mass flow [kg·s ⁻¹]
M	Molecular weight [kg·mol ⁻¹]
P	Pressure [Pa]
P^S	Saturation pressure [Pa]
P_{Alm}	Average logarithmic pressure [Pa]
Q_{wv}	Heat transfer flux [W·m ⁻²]
Q	Flow rate [L·min ⁻¹]
r	Pore radius [m]
R	Gas constant [J·mol ⁻¹ ·K ⁻¹]
T	Temperature [K]
TSS	Sugar concentration [°Brix]
V	Tank volume [m ³]
v	Velocidad lineal [m·s ⁻¹]
x	Mass fraction
z	Membrane length [m]

Subscripts

F	Feed side
m	membrane
B	Brine side
W	Water
1	Boundary layer in the feeding side
2	Boundary layer in the brine side
0	initial

Greek letters

ε	Porosity
δ	Thickness [m]
σ	Mean collision diameter [m]
λ	Mean free path [m]
φ	Association parameter for water
μ	Dynamic viscosity [Pa·s]
γ	Activity coefficient
ρ	Density [kg·m ⁻³]
τ	Tortuosity
ϑ	Molar volume of the solute [m ³ ·kgmol ⁻¹]

Dimensionless numbers

K_n	Knudsen number
Pr	Prandtl
Nu	Nusselt
Re	Reynolds
Sc	Schmidt
Sh	Sherwood

simulated values for the transmembrane water flux. In this work, a theoretical model describing both, mass and heat transfer in the OE process is proposed and validated for glucose–water solutions. This model was also used to explain the concentration kinetics of cassava starch hydrolysates, which to our knowledge, have not been reported before.

2. Model development**2.1. Mass transfer**

Osmotic evaporation involves the concentration of a solution using a hydrophobic membrane and an extractive phase, which can be a brine or a saturated organic solution (Fig. 1). The hydrophobic membrane separates the solution to be treated and the brine. During the process, water vapor is transported through the pores from the solution of higher water activity (aqueous solution) to the solution of lower activity (brine) where it finally condenses.

The driving force of the process is a differential of vapor pressure induced by an activity gradient between the two solutions employed [2].

Water mass balance in the feed and brine tank are described by the following differential equation:

$$\frac{d(\rho_F V_F)}{dt} = -J_W \cdot A_m \quad (1)$$

$$\frac{d(\rho_B V_B)}{dt} = J_W \cdot A_m \quad (2)$$

where, J_W is water vapor flux and A_m is the mean value of the contact surface area along the membrane.

Through the z length of the membrane, the mass balance in the feed and brine sides is respectively:

$$\frac{dm_F}{dz} = -J_W \cdot H \quad (3)$$

$$\frac{dm_B}{dz} = J_W \cdot H \quad (4)$$

where, m_F and m_B are the water mass flow in the feed and the brine respectively, z is the length and H is the membrane width.

2.1.1. Mass transfer in the membrane

Mass transfer in the membrane is driven by a water vapor pressure difference induced by the activity gradient of the two solutions used:

$$J_{Wm} = k_m \cdot \Delta P_W \quad (5)$$

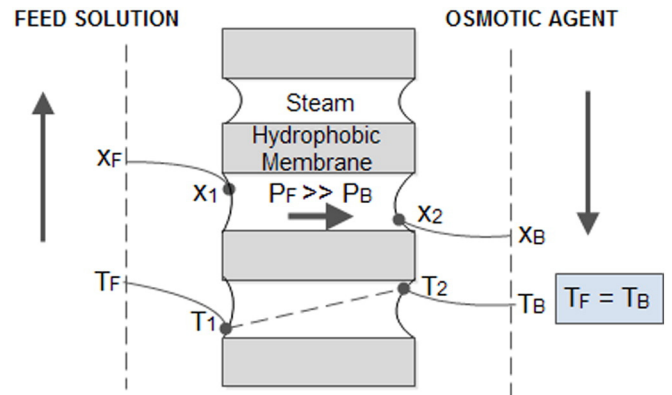


Fig. 1. Transport phenomena with the concentration and temperature profile through the membrane in the osmotic evaporation process.

Download English Version:

<https://daneshyari.com/en/article/622804>

Download Persian Version:

<https://daneshyari.com/article/622804>

[Daneshyari.com](https://daneshyari.com)