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Concentration of cranberry juice by osmotic distillation process

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ABSTRACT

An osmotic distillation (OD) system was implemented to concentrate cranberry juice at laboratory scale. The experimental setup allows the circulation of cranberry juice (*Vaccinium macrocarpon Ait.*) and an osmotic agent with flow rates varying from 0.5 to 1.5 L min^{-1} at temperatures between 30 and 40 °C. The osmotic agent selected in this study was a concentrated $CaCl_{2(aq)}$ solution with concentrations ranged from 30% to 50% w/w.

The transmembrane flux of water vapor was ranged between 0.25 and 1.21 L h^{-1} m^{-2}. The comparative low content of TSS in cranberry juice allows obtaining fast water removal from 500 mL of juice, achieving concentrations from 8.6 to 48 °Brix in 18 min. The total phenolic content was preserved after concentration.

A mass transfer model was developed to explain the concentration kinetics of the juice. The solution simulations allow obtaining a maximum deviation of 32% between experimental and simulated values of transmembrane water flux.

1. Introduction

In order to optimize the storage conditions and transportation costs, fruit juices are generally concentrated by vacuum evaporation. However due to thermal effects, this process involves changes in the organoleptic properties of products. The traditional evaporation process allows obtaining concentrations up to 45–71 °Brix, while the increasing of viscosity is limited by the rising of the temperature while the process takes place. The fouling reduces the heat transfer rate, that is why the surfaces of evaporation must be cleaned regularly to insure the efficient working of the evaporator. The selection of an adequate system must be considered if these devices are apt to concentrate fruit juices at high concentration levels and low costs (Cissé et al., 2011; Hernandez et al., 1995).

Osmotic distillation (OD) is an interesting alternative process for the concentration of thermosensible solutions. This process has been used for concentrating liquid foods, such as milk, fruit and vegetable juices, instant tea and coffee because it works under room pressure and temperature, preserving the nutritional characteristics of foods (Hogan et al., 1998). Moreover, using concentrated brine as extracting phase allows decreasing the loss of aromatic compounds from the juice to be concentrated to the brine keeping then a good level of organoleptic properties (Vaillant et al., 2001; Cissé et al., 2005). This isothermal concentration method can be applied to fruit and vegetable juices whose properties may be altered by thermal treatments. Thus, a product with nutraceutical properties is an ideal candidate to be concentrated with this technique (Romero et al., 2003b).

The concentration of cranberry juice (*Vaccinium macrocarpon Ait.*) of OD is theoretically and experimentally analyzed in this study. The high commercial value of this product could justify the implementation of a system of re-concentrating the brine used as an extracting solution to receive the evaporated water from the juice. The low evaporation flux and the regeneration of the diluted brine represent the main technical and economic barriers of this process for concentrating the majority of liquid foods. These particular conditions have motivated this work in order to analyze the performance of the OD process for the concentration of cranberries juice, identifying the main operation variables. In our knowledge it is the first work published concerning the application of osmotic distillation for the concentration of the cranberry juice.

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Nomenclature

A	activity (dimensionless)
A	surface area for mass transfer (m^2)
$D_{w\text{-}air}$	diffusion coefficient of water in air ($m^{2}\ ^{-1}$)
J	mass transfer flux (mol m^{-2} s^{-1})
G_z	Graetz number (dimensionless)
K	mass transfer coefficient (mol m^{-2} s^{-1})
P	pressure (Pa)
P_w	partial pressure of water (Pa)
P_w^*	partial pressure of pure water (Pa)
R	universal constant of gases (8.314 J mol^{-1} K^{-1})
Re	reynolds number (dimensionless)
Sc	schmidt number (dimensionless)
Sh	Sherwood number (dimensionless)
T	temperature (K)
X	molar fraction (dimensionless)

Greek letters

Γ	activity coefficient (dimensionless)
E	porosity (dimensionless)
Δ	membrane thickness (m)
T	membrane tortuosity (dimensionless)

Subscripts

1	refers to the feed solution-membrane interface
2	refers to the membrane-brine interface
Av	refers to average diameter of the fibers
B	refers to the bulk of the phase
ID	refers to internal diameter of the fibers (lumen)
OD	refers to outside diameter of the fibers (shell)
W	refers to water

Superscripts

(1)	refers to feed solution boundary layer
(2)	refers to membrane pores
(3)	refers to receiving phase (brine) boundary layer
E	refers to extractant phase (brine)
F	refers to feed solution

2. Concentration of cranberry juice by means of osmotic distillation

2.1. Principle of the osmotic distillation process

Osmotic distillation is a membrane process applied to concentrate solutions under isothermal conditions. In this process, an aqueous solution can be concentrated by an osmotic gradient using an aqueous osmotic agent with low water activity (i.e. concentrated brine). Fig. 1 shows an outline describing the principle of the process where a macroporous and hydrophobic membrane separates both solutions. In this figure, three regions may be identified in the proximities of the membrane: (I) the boundary layer of the feeding solution to be treated; (II) the membrane pore filled with gas; (III) the boundary layer of the osmotic agent. The OD is an evaporative process where simultaneous mass and heat transfer is observed with its respective concentration and temperature profiles. The temperature profile can be explained by a temperature polarization phenomenon, which involves a latent heat transfer through the membrane. This latent heat transfer decreases the temperature at the evaporation interface and increases the temperature at the condensation interface. The interfaces formed by the liquid phases and the gas retained in the pores are considered in thermodynamic equilibrium. Thus, taking into account the volatile condition of the components to be transferred, the driving force generated by the mass transfer through the porous medium is the difference in vapor pressure between both interfaces. The solutions to be concentrated in the majority of the studies on OD (Ali et al., 2003; Alves and Coelhoso, 2006; Courel et al., 2001; Romero et al., 2003a; Petrotos and Lazarides, 2001; Cassano and Drioli, 2007; Cassano et al., 2007; Jiao et al., 2004; Bélafi-Bakó and Koroknai, 2006; Koroknai et al., 2006) contain a low concentration of non-volatile solutes from moderate to high molecular weight (carbohydrates, polysaccharides, carbolic acid salts and proteins), which have limited stability at high temperatures and pressures. In a previous work, Romero and coworkers (Romero et al., 2003a) analyzed the effect of the boundary layers on the concentration and temperature polarization phenomena, developing an algorithm that solves the equations attached to the simultaneous mass and heat transfer for flat sheet membrane modules.

2.2. Properties of cranberry juice

Cranberry, *V. macrocarpon Ait*., is a specie that grows wild in United State of America. This country is the leading world producer followed by Canada and Chile (Buzeta, 1997). The interest of consumers is based on its low calories content, high vitamins content, minerals and fiber percentage (Buzeta, 1997). The use of concentrates of this juice, in liquid and pill form has become massive because of its medicinal properties, such as being anti-microbial, anti-carcinogenic, analgesic and anti-inflammatory (Wu et al., 2008). These properties are attributed to the main nutrients in cranberry represented by phenolic compounds (Wu et al., 2009). Cranberries are rich in phenolic antioxidants with redox properties that allow them to act as hydrogen donors and singlet oxygen quenchers (Lin et al., 2005; Kwon et al., 2007). Recent studies have shown anthocyanins, proanthocyanidins, and phenolics from cranberries are active components in molecular mechanism behind various health benefits of cranberries (Lin et al., 2005; Guo et al., 2007; Apostolidis et al., 2008; Wu et al., 2009).

This study used diluted samples of cranberry juice concentrate made by OceanSpray®. The concentrate is prepared from depectinized, filtered juice derived from properly matured, cleaned cranberries. It is concentrated under low temperatures and vacuum, and the essence fraction is returned (OceanSpray, 2013). The main components of this product are shown in detail on Table 1.

3. Experimental procedure

The cranberry juice concentrated in these experiments was obtained from OceanSpray®. Commercial concentrated juice was used in experiments in order to obtain constant quality, concentration of sugars and phenolic content for all samples to be concentrated by OD. Concentrated juice with initial 50 °Brix was diluted up to 8.6 °Brix. This concentration was chosen because it was verified as an average value of sugar concentration in fresh juice in previous tests.

The experimental device used in this study is constituted by a system with two independent circuits for the circulation of the solutions: one for the solution to be treated (water or cranberry juice) and the other for the concentrated brine used as osmotic agent. Both circuits have peristaltic pumps connected to graded