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Application of osmotic membrane distillation for reconcentration of sugar solutions from osmotic dehydration

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Abstract

In the current study osmotic membrane distillation (OMD) was applied to reconcentrate osmotic dehydration spent sucrose solutions. The OMD experiments were performed at constant temperature of 35 °C, using PTFE membrane. During the experiments sucrose solutions of different concentrations (30–60 °Brix) were partially dehydrated using 50% (w/w) $CaCl_2$ and 24.6% (w/w) NaCl as stripping solutions. $CaCl_2$ as more efficient stripping solution was then used to reconcentrate spent solutions obtained from osmotic dehydration (OD) of apples. After experiments sucrose and reducing sugars presence in stripping solutions was analyzed and $CaCl_2$ and NaCl presence was checked in sucrose and OD solutions. As far as feed solutions up to 60 °Brix were considered the water flux in OMD depended mainly on water activity in the stripping solution and the concentration of sucrose solution. However, for the feed solutions of 60 °Brix its viscosity was the determinant factor during the process. For OD spent solution water flux was lower due to the presence of suspended solids. Stripping solutions and sucrose solutions analysis showed that ions or sugars were retained and mainly water was transported through the membrane.

Keywords: Osmotic membrane distillation; Sucrose solution; Osmotic dehydration

1. Introduction

In the food industry membrane separation became a key process for concentration, fractionation and purification of liquid food and for wastewater treatment. Its advantages, such as: low operation temperature, no special chemicals required, uncomplicated operation and possibility of automation, makes membrane separation a very good alternative to traditional methods for liquid food treatment. So far, in the food industry, only pressure driven processes are widely applied, but their characteristics restrained the application to diluted solutions treatment. Thus, membrane processes have to be combined with traditional thermal treatments, resulting in deterioration of aroma, taste and colour of the final product. For that reason, finding a method to process concentrated solutions is a very challenging objective. In the present study, osmotic membrane distillation was applied to reconcentrate sucrose solutions from osmotic dehydration of foodstuffs. Osmotic dehydration (OD) is a process which involves partial dehydration of water-rich foodstuffs by soaking them in a hypertonic aqueous solution of various edible solutes (e. g. sucrose, NaCl). OD is a common method to improve food quality and stability, to modify its functional properties and to reduce energy required for dehydration [1]. During the process two major simultaneous counter-current flows occur: transfer of solute from the solution into the food, and water flow out of the food into the solution. Osmodehydration results in food extended shelf-life, reduction of aroma losses in dried and semidried foodstuffs, reduction of the freezing load and/or possibility to freeze the food without causing unwanted textural changes and dripping during thawing [2]. Despite of OD advantages and its simplicity, the industrial application is bottlenecked by OD spent solution management.

To solve this problem, there are attempts to apply different separation techniques. The osmotic membrane distillation (OMD) is a membrane contactor technique which applies a microporous, hydrophobic (e.g. PTFE, PVDF and PP) membrane. Both sides of the porous membrane are in contact with two aqueous solutions of different water activity, e.g. OD sugar solution and concentrated salt solution. The water activity difference between the two liquid phases translates into a vapor pressure difference across the membrane. OMD is a technique that allows concentration of solutions at constant temperature under atmospheric pressure. The OMD allows to treat very viscous solutions, e.g. concentrated sugar solutions, and also

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guarantees gentle operation conditions (low temperature) which is important for food processing. Inorganic salts (NaCl, $CaCl_2$, $MgCl_2$ and $MgSO_4$) or organic solvents (glycerol and polyglycerol) can be used as stripping solutions. The adequate selection of the stripping solution is crucial for the process efficiency. The properties that the stripping solution should exhibit to be used in OMD are: high solubility in water (low water activity), low volatility and viscosity, high superficial tension and non-toxicity [3].

The latest studies on OMD for juice concentration emphasize the high quality of the obtained final product, combined with low capital investment and low energy consumption [4]. Cassano et al. [5] designed an integrated juice concentration process with OMD as the final filtration step preceded by ultrafiltration and reverse osmosis. The quality of the final product was much better than the quality of the product obtained with traditional thermal processes. Both aroma and color were similar to those of the fresh juice, and also the total antioxidant activity was maintained. Very high juice concentration (from 25–20 up to 60–66 TSS/100 g) achieved during the OMD was another advantage of this process [5].

Comparing OMD with membrane distillation (MD) of orange juice, Alves and Coelhoso [6] observed that water flux was more than 50% lower in MD process, what was attributed to the thermal polarization effects during the MD process. Regarding the aroma retention, the OMD also yielded in a much better retention of orange juice aroma.

In the current study, osmotic membrane distillation was evaluated as an alternative method for reconcentration of an osmotic dehydration sucrose solution.

2. Materials and methods

2.1. Osmotic membrane distilation experiments

The OMD experimental set-up was a polymethacrylate cell with two symmetrical compartments. The volume of both compartments was 140 ml. The stripping solution and the sucrose solution in OMD cell were separated by a hydrophobic, symmetric, polytetrafluoroethylene membrane (Type 11806, Sartorius) with a nominal pore size of 0.45 μm and thickness of approximately 80 μm. This membrane is resistant to high temperatures (up to 200 °C), presents very good chemical compatibility (with acids, bases and solvents) and is permanently hydrophobic. The membrane active area was 1.25×10^{-3} m^2. Sealed OMD cell was connected to a feed tank on one side and to a calibrated glass pipette on the other (Fig. 1).

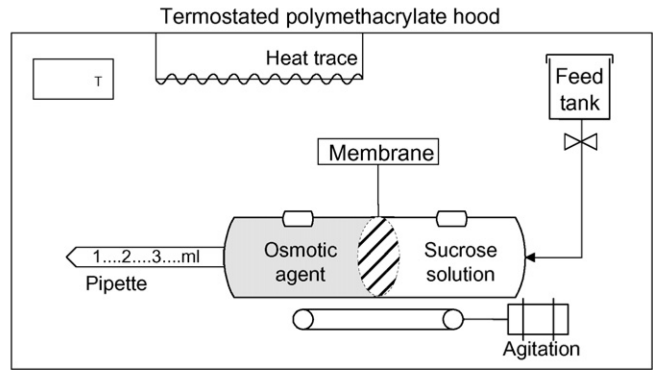

Fig. 1. Experimental set-up used during osmotic membrane distillation experiments.

Both compartments were hermetically sealed, so the volume of solution passing through the pipette was equal to the volume of water transferred through the membrane from the sucrose solution to the stripping solution.

Both solutions were constantly agitated at 400 rpm. The OMD set-up was placed inside a polymethacrylate hood and maintained at a temperature of 35 °C. The experiments lasted 3 h and water flux was measured throughout the entire run.

As stripping solutions $CaCl_2$ (POCH, Poland) and NaCl (Standard, Poland) were chosen. The initial concentration of the stripping solutions was 50 and 24.6% (w/w) for $CaCl_2$ and NaCl, respectively. The chosen concentrations guaranteed high driving force for the OMD process. At 50% (w/w) concentration, a $CaCl_2$ solution presents the lowest water activity, for higher concentrations the decrease of water activity is negligible but the viscosity increases significantly. The NaCl concentration was close to the saturation point (26.4% w/w).

After analysis of water fluxes obtained with both stripping solutions, $CaCl_2$ was used to reconcentrate sucrose solution from apples OD. Properties of stripping solutions and sucrose solution are listed on Table 1.

The presence of sucrose and reducing sugars in the stripping solution was analyzed using analytical assay (GAB Sistemática Analítica S.L., Spain) [9]. The presence of $CaCl_2$ and NaCl was checked in sucrose and stripping solutions using complexometric titration with EDTA solution and a potentiometric method, respectively (Manual de Análisis y Control de Vinos y Alcoholes). Total soluble solids (sugars) concentration was measured with a refractometer (RL1, PZO Poland). All experiments were run in duplicate and the sample analysis was done in triplicate. For each experiment a new membrane sample was used.

Table 1
Properties of sucrose, $CaCl_2$ and NaCl [7,8]

	Sucrose				$CaCl_2$	NaCl
Concentration (°Brix)	30	40	50	60	–	–
Concentration (% (w/w))	30	40	50	60	50	24.60
Dynamic viscosity (10^{-3} Ns/m) 35 °C	2.1	3.8	8.5	27.4	43.02	1.3
Osmotic pressure (bar) 25 °C	32	51	82	131	2121	356
Water activity at 25 °C	0.971	0.955	0.936	0.898	0.214	0.772