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ScienceDirect
Journal of Food Engineering 80 (2007) 317–326
JOURNAL OF FOOD ENGINEERING
www.elsevier.com/locate/jfoodeng

Reconcentration of spent solutions from osmotic dehydration using direct osmosis in two configurations

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Received 12 January 2006; received in revised form 31 May 2006; accepted 1 June 2006
Available online 25 July 2006

Abstract

The main objective of the present study is to evaluate direct osmosis as a process to reconcentrate osmotic dehydration spent solutions. The reconcentration is performed using two modes: off-site (during which osmotic and stripping solutions are brought into contact in a membrane module) and on-site direct osmosis (the osmotic solution is reconcentrated at the same time as the osmotic dehydration process takes place).

During the off-site direct osmosis Desal5-DK membrane performed the best, giving for 40, 50 and 60 °Brix fluxes of 3, 1.9, 1.7 kg/m^2 h, respectively, first because of its properties and, second, because it is not very thick, which reduces the mass transfer resistance between the solutions. The low water fluxes obtained when on-site direct osmosis was used (0.06 and 0.023 for 40 and 50 °Brix, respectively), can be attributed mainly to the low driving force and problems related to stirring and the design of the membrane support.

The apples osmodehydrated during the on-site direct osmosis were used in the sensory analysis. The panellists indicated that the apples that were osmodehydrated using the reconcentrated solution had best overall taste.

Keywords: Osmotic dehydration; Direct osmosis; Sucrose solution; Membrane characterisation

1. Introduction

Osmotic dehydration (OD), which involves partial dehydration of water-rich foodstuffs, is a very promising food pre-treatment. OD involves soaking foods (fruit, vegetables, fish and meat) in a hypertonic (osmotic) solution i.e., concentrated sugar, salt, alcohols or soluble starch solutions, which partially dehydrates the food (Erle & Schubert, 2001; Mújica-Paz, Valdez-Fragoso, Lopez-Malo, Palou, & Welti-Chanes, 2003). During the process, two major simultaneous counter-current flows occur: the solute is transferred from the solution into the food and water flows out of the food into the solution, which is stronger than the previous one. Osmodehydration results in extended shelf-life, fewer aroma losses in dried and semi-dried foodstuffs, reduction of the freezing load and/or the possibility to freeze the food without causing unwanted textural changes and dripping during thawing (Petrotos & Lazarides, 2001).

OD process efficiency is strongly affected by the osmotic solution (OS) properties. One of the basic factors in the choice of OS is the water loss/solid gain ratio, because of its importance in the promotion/reduction of impregnation (Sacchetti, Gianotti, & Dalla Rosa, 2001). The osmotic solution must have low a_w, acceptable taste and be harmless for health. Sweet solutions (sucrose, glucose, fructose, corn syrup, sorbitol) are often used for fruit processing and salty ones (NaCl, $CaCl_2$) for vegetable, meat and fish

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doi:10.1016/j.jfoodeng.2006.06.003

processing. To make OD more viable economically, spent solutions from other processes may be used e.g., cheese whey was used to osmodehydrate bell peppers (Torreggianni, Forni, Erba, & Longoni, 1995). Managing OS is the bottleneck of the OD process and it restrains industrial implementation. Thus, from the process and economic point of view it is necessary to find an effective recycling method. If the OS concentration remains high, the effectiveness of dehydration and the hygienic state of food (low water activity) are guaranteed (Gianotti, Sacchetti, Guerzoni, & Dalla Rosa, 2001). Preserving substances added to the OS and waste reduction are also important. Binary (water–sugar) solutions can be reconcentrated by heat or by adding dry sugar, but those methods are not viable in complex solutions (Raoult-Wack, 1994), first because of the thermal spoilage of heat-sensitive compounds and second, because it is impossible to calculate the exact quantity of the reactants to be added. So far, all the studies about OS management have focused on the development of plants that require minimal OS quantities or the application of heat treatments combined with coarse filtration or acid precipitation (Dalla Rosa & Giroux, 2001).

As for the membrane filtration applied in the present study to reconcentrate OS, it has not been experimentally evaluated and suggestions are only made. Romero Barranco, Brenes Balbuena, García García, and Garrido Fernanández (2001) suggested ultrafiltration as a method for regenerating the spent brines of table olives. The authors pointed out the savings in energy consumption compared with evaporation, and lack of groundwater contamination by elimination of evaporation ponds as main advantages of ultrafiltration. Gekas, Baralla, and Flores (1998) in a state of the art about the application of membrane technology in the food industry, indicated nanofiltration as a method to separate solutions from scalding and OD process, due to the possibility of separation of ions and micromolecules.

The only experimental attempt documented in literature of membrane separation for OS recycling was carried out by Proimaki and Gekas (2000). These authors proposed a novel system to concentrate OS using a direct osmosis process. In that system the sucrose solution was reconcentrated by a sucrose solution of higher concentration. The drawback of the mentioned study was the design of the experimental set-up that impeded to obtain accurate results. The system proposed by Proimaki and Gekas was the origin of the on-site OS reconcentration by direct osmosis investigated in the present work.

In the present study direct osmosis (DO) was a method chosen to reconcentrate the osmotic dehydration spent solutions. DO is a membrane contactor process, during which the concentration phenomena takes place across the hydrophilic membrane placed between the concentrated solution (feed) and the stripping solution with lower water activity. The water activity gradient between the feed and the stripping solution is the driving force of the process. Since higher driving force than during the pressure driven processes is obtained higher concentrations of viscous solutions e.g.: sugar solution and juices can be obtained, which reduces the investment costs. The DO was used so far to concentrate grape juice (Popper, Camirand, Nury, & Stanley, 1966), tomato juice (Petrotos, Quantick, & Petropakis, 1998) and to improve aroma attributes of red radish concentrate extracts (Rodriguez-Saona, Giusti, Durst, & Wrolstad, 2001). Also industrial DO equipment designed by Osmotec, Inc. is available.

In this study direct osmosis is studied in two modes: off-site and on-site. During off-site direct osmosis (off-site DO), osmotic and stripping solutions are brought into contact in a membrane module. During on-site direct osmosis (on-site DO), however, the osmotic solution is reconcentrated at the same time as the osmotic dehydration process takes place. Off-site DO was performed using nanofiltration (NF) membranes and NaCl as the stripping solution (SS), while on-site DO was performed with a microfiltration membrane and hypertonic sucrose solutions. Therefore, the main objective of the present study was the reconcentration of highly viscous osmotic dehydration spent (sucrose) solutions using direct osmosis in two modes.

2. Materials and methods

2.1. Off-site direct osmosis

2.1.1. Preliminary studies for selection of stripping solution and membrane configuration

As a first step to carry out off-site direct osmosis, small-scale studies about membrane retention, coordination and the effect of SS concentration on the water flux were performed. In these studies small methacrylate modules were used. The modules consisted of two compartments of similar size, with a membrane placed between them (Fig. 1). The volumes of SS and feed were 120 ml each and the active membrane area was $1.35 \times 10^{-3}\,m^2$. During the experiments different concentrations of NaCl as SS were applied and the membrane used was Desal5-DK.

2.1.2. Membranes and experimental set-up

To study the relation between water transport and membrane type, membranes of various densities, thicknesses and configurations were used. The experiments were carried out using two flat sheet membranes (Desal5-DK, GE Osmonics and MPF-34, Koch Membrane) and two tubular membranes (AFC99, PCI Membrane and MPT-34, Koch Membrane). The MPT-34, MPF-34 and Desal5-DK membranes are NF membranes, the most selective of which is Desal5-DK. The AFC99 membrane is a reverse osmosis membrane with 99% rejection of NaCl. The properties of the other NF membranes are listed elsewhere (Warczok, Ferrando, López, & Güell, 2004). The experimental set-up used is presented in Fig. 2.

2.1.3. Experimental procedure

The solutions were prepared from commercially available sucrose and the concentrations tested were 5, 20, 40,