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Review

Current and future applications for nanofiltration technology in the food processing

*Fakhreddin Salehi**

Faculty of Food Science & Technology, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

ABSTRACT

The increase in energy costs and the demands for products with greater nutritional value and of processing procedures less toxic to the environment are attractive factors for transferring membrane processing to food industries. Nanofiltration (NF) technology is still evolving, finding more and more applications in food processing and appears as an important alternative to conventional methods. The purpose of this review is to present the recent development and future potential of NF processes in the food industry. Recent research has highlighted the potential for NF use in wide ranging, including water softening, wastewater treatment, vegetable oil processing, beverage, dairy and sugar industry. NF has been established as greater separation efficiency, successfully reduces the wastewater, done under low temperatures, reduction in number of processing steps and presents a promising choice toward the achievement of cost effective process. NF carries quite distinctive properties such as pore radius and surface charge density which influences the separation of various solutes.

Keywords: Beverage; Dairy; Drinking water; Sugar industry; Vegetable oil; Wastewater treatment

1. Introduction

Membrane separation processes are used to concentrate or fractionate a liquid to yield two liquids that differ in their composition. It stands out as alternatives to conventional processes for the chemical, pharmaceutical, biotechnological and food industries (Cassano et al., 2003; Baker, 2004; Jiao et al., 2004; Ravanchi et al., 2009; Aroon et al., 2010; Lau et al., 2012). In many cases the low energy consumption, reduction in number of processing steps, greater separation efficiency and improved final product quality are the main attractions of these processes (Cheryan, 1998; Baker, 2004; Aroon et al., 2010; Cuartas-Uribe et al., 2010; Lau et al., 2012). NF can also be applied for more challenging applications, involving fractionation rather than purification. The nature of the membrane controls which components will permeate and which will be retained, since they are selectively separated according to their molar masses or particle size (Cheryan, 1998). It is well known that NF membranes can be used for salt fractionation since the rejection of monovalent salts is lower than that of multivalent salts (Tanninen et al., 2006; Hilal et al., 2007). An extreme case of charge-induced separation is the observation of negative rejections of monovalent ions in the presence of multivalent ions or polyelectrolytes (Van der Bruggen et al., 2003; Ting et al., 2007). NF appears as an important alternative to conventional methods of food processing.

This review summarizes the recent developments and future potential of NF membrane processes in the food industry that appear to have great potential in the production of high quality food, including water softening, wastewater treatment, vegetable oil processing, beverage industry, dairy industry and sugar industry.

2. Membrane

The separation performance of a membrane is influenced by its chemical composition, temperature, pressure, feed flow and interactions between components in the feed flow and the

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* Tel.: +98 1714426432; fax: +98 1714426432.
E-mail address: FS1446@yahoo.com

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membrane surface. The four major pressure driven membrane processes are ultrafiltration, reverse osmosis, microfiltration and nanofiltration; brief general descriptions of the membrane processes used in the food industry are provided in this section.

2.1. Pressure driven membrane processes

A hydrostatic pressure gradient is the driving force used to achieve the desired hydrodynamic flow through the membrane (and through a deposited layer that may develop during the filtration process). In some cases, concentration gradients or electrical potential gradients may also be used as additional driving forces (Cheryan, 1998; Baker, 2004). Four pressures driven membrane processes are distinguished in practice:

2.1.1. Microfiltration (MF)

MF is a membrane process that involves the use of membranes with a pore size of 0.2–2 μm, and can selectively separate particles with molecular weights of >200 kDa. MF uses pressures lower than 0.2 MPa and separates molecules between 0.025 and 10 μm. MF is primarily used to separate particles and bacteria from other smaller solutes (Baker, 2004; Hua et al., 2007).

2.1.2. Ultrafiltration (UF)

UF involves the use of membranes with a molecular weight cut off (MWCO) in the range of 1–300 kDa and a pore size of ~0.01 μm. UF uses pressures greater than 1 MPa and used to separate colloids like proteins from small molecules like sugars and salts (Baker, 2004).

2.1.3. Nanotiltration (NF)

NF lies between the separation characteristics of reverse osmosis (RO) and UF process which is widely used for several applications such as water softening and wastewater treatment. The pore size of the NF is in the range of 0.5–1 nm. It concentrates, fractionates or purifies aqueous solutions of organic solutes with molecular weight between 100 and 1000 Da and mixture of monovalent/multivalent salts and uses pressures between 1 and 4 MPa (Baker, 2004; Salehi et al., 2011). Since, the NF membrane carries negative charge at the surface, positive charged ions will be attracted and negative charge will be repelled due to Donnan effect. The most successful NF models are those based on the combination of the extended Nernst–Planck equation with the Donnan steric equilibrium. These models have been typically solved by using iterative procedures based on the Runge–Kutta method (Vezzani and Bandini, 2002; Kumar et al., 2013). Most NF membranes are composite materials supported by polymer substrate and manufactured in a spiral wound design as opposed to a flat sheet or tube geometry. The predominant model used today for industrial applications is the spiral configuration. Polyamide (PA) is used as the thin film membrane layer in NF membranes (Baker, 2004; Hong et al., 2006).

2.1.4. Reverse osmosis (RO) or hyperfiltration

RO membranes are characterized by a MWCO of ~100 Da, and the process involves pressures 5–10 times higher than those used in UF. It uses pressures between 4 and 10 MPa and concentrates particles with molar masses below 350 Da and this technique reject nearly all solutes and desalinate water (Baker, 2004).

2.2. Operational parameters

The main physical operational parameters that affect the permeate flow rate are: pressure, temperature, viscosity and density of the feed fluid, and the tangential velocity (Scott, 2003).

The viscosity can be controlled by two factors: solids concentration in the feed and temperature (Hwang and Kammermeyer, 1998). An increase in feed concentration alters the viscosity, density and diffusivity of the feed solution, causing a decrease in permeate flow rate (Satyanarayana et al., 2000). An increase in temperature results in a decrease in fluid viscosity and increase in molecular mobility, that is, in diffusivity. For its part, an increase in tangential velocity increases the permeate flow rate by provoking greater turbulence, causing a dispersion in the solute molecules concentrated on the membrane surface, reducing the thickness of the gel layer (Cheryan, 1998; Cheng and Lin, 2004). There is a linear relationship between flow rate and the inverse of the solvent viscosity for NF and UF membranes, indicating that the main mass transport mechanism in these systems is convection (Tsui and Cheryan, 2004).

3. Water softening

In the past few years, increasing water scarcity and deteriorating water quality are becoming growing problems in many regions of the world (Loo et al., 2012). NF and RO are used for a wide range of applications, such as the purification of water to produce potable water (mainly sea and brackish water desalination), rejection of pesticides and the production of ultrapure water for the semiconductor industry (Ghaemi et al., 2012). During the last decade, the interest in the use of membrane processes in general and NF in particular has emerged in wastewater treatment as well as drinking water and process clean water production (Table 1). This growth can be explained by a combination of (1) growing demand for water with high quality, (2) growing pressure to reuse wastewater, (3) better reliability and integrity of the membranes, (4) lower prices of membranes due to enhanced use, and (5) more stringent standards, e.g. in the drinking water industry (Van der Bruggen et al., 2008; Greenlee et al., 2009).

Further improvements can be achieved through the introduction of NF as RO pretreatment process. Since NF retains turbidity, microorganisms, hardness, the most part of multivalent ions, and 10–50% of monovalent species, as a consequence, the osmotic pressure of the RO feed is decreased thus allowing the unit to operate at higher recovery factors. Coupling RO and NF for seawater desalination, a global recovery factor of 52% can be obtained (higher than that of a typical RO operation which is in the range of 35–40%) (Macedonio et al., 2007). Moreover, the integrated NF–RO process is more environmentally friendly, because fewer additives (antiscalants and acid) are needed (Van der Bruggen and Vandecasteele, 2002).

Oh et al. (2000) developed a membrane process that uses an NF module coupled to a stationary bicycle to generate energy required for pressurizing the feed. However, fouling of the membranes results in a reduction in water flux, which leads to higher treatment costs. Membrane fouling also limits the water recovery, i.e. the ratio of permeate to feed stream, to values of about 80% in the drinking water industry (Nederlof et al., 2005; Amoudi, 2010; Sutzkover-Gutman et al., 2010). Nilson and DiGiano (1996) reported that the hydrophobic fraction of natural organic matter in surface water caused almost all