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Leaf protein concentration of alfalfa juice by membrane technology

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ABSTRACT

Membrane technology (microfiltration (MF) and ultrafiltration (UF)) of alfalfa juice was studied as an alternative method to conventional leaf protein concentration. Three types of filtration modules (dead end filtration using laboratory Amicon cell (DA), dynamic cross filtration using rotating disk module (CRDM) and dead end filtration using rotating disk module (DRDM)) were used to investigate concentration efficiency of MF and UF with full recycling tests and concentration tests. Rotating speed and transmembrane pressure (TMP) improved flux behavior, but higher permeate flux caused by higher rotating speed reduced leaf protein rejection of MF. The strong rotating shear effect and open flow channel structure of CRDM could control concentration polarization and membrane fouling, therefore, it gave the best flux behavior, least flux decline, best clarification effect, smallest irreversible fouling and highest permeability recovery in membrane cleaning. However, the best leaf protein rejection was obtained by DRDM, because of high shear rate and "secondary filtration" of fouling layer created by closed flow channel structure. Besides, CRDM showed the highest productivity and best potential for industrial application. These results from laboratory-scale tests can be very useful for concentrating leaf protein from alfalfa juice and serve as a valuable guide for process design in industrial scale.
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1. Introduction

As a common perennial vegetable, alfalfa has been widely cultivated as a forage crop in Europe and North America and represents about 32 million hectares in the worldwide [1]. After drying green crop, alfalfa is utilized as raw material for the production of fodder pellets for cattle, due to its high feed value and high crude proteins content (about 2600 kg/ha) [2]. During the pellet production process, the green crop of alfalfa is chopped and pressed before drying, while much alfalfa juice is generated. This green extracted juice containing high proteins content has been recognized as an effective source of high quality proteins for animals and human consumption, because of abundant sources, high nutritive value and absence of animal cholesterol [3]. Alfalfa leaf protein includes about 50% hydrophilic proteins and 50% lipophilic proteins [2]. Hydrophilic proteins have high digestibility and a balanced aminogram, which possesses significant functional properties, such as emulsifying, jellifying and foaming agents [4–6].

In order to recover protein in alfalfa juice, numerous protein separations and concentration technologies have been used to concentrate and produce leaf proteins for food industry of alfalfa juice. According to different separation mechanisms, they can be divided into three categories: (1) difference of solubility [7–9]: salting, organic solvent fractionation, chromatography, crystallization, heating and centrifugation; (2) differences of molecular size and shape [2,10]: molecular sieve chromatography and membrane; (3) difference of charge: ion exchange [11]. However, most conventional separation and concentration methods have various intrinsic disadvantages, such as high energy cost, low separation efficiency, damage of nutritive proteins, complex operation and high investment, which limit their industrial applications.

As a promising separation method, membrane technology has wide applications in food industry and water treatment, including manufacturing of vegetal extracts and juices, meat and fish products, sugar, alcoholic and non-alcoholic beverages, dairy effluent treatment and dairy products [7]. A few previous studies [7,10,12,13] used UF to separate and concentrate crude protein from waste leaf extraction juice. However, during the concentration process, serious flux decline caused by membrane fouling and concentration polarization occurred, increasing the operation cost and restricting its sustainable operation and industrial application.

For the purpose of controlling flux decline, various strategies have been utilized to eliminate membrane fouling and decrease concentration polarization, such as the modification of feed characteristic and membrane surface [14–16], optimization of operation [17], choice of filtration modules [18] and membrane cleaning [19].

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At the same time, different strategies may also affect separation efficiency, production quality and membrane cleaning and reuse [17,20]. Therefore, a suitable flux decline control strategy cannot only sustain the flux behavior of whole filtration process at a high level, but also improve separation efficiency and permeability recovery in subsequent membrane cleaning.

The configuration of membrane modules (i.e., dead-end, cross-flow and shear-enhanced) strongly influences the flux behavior and fouling evolution [21]. The shear rates of dead-end and cross-flow modules are produced, respectively, by a stirring effect and an increase the tangential fluid velocity along the membrane. Shear-enhanced modules can create a high shear rate on the membrane surface by a moving part such as a rotating membrane, or a disk rotating near a fixed circular membrane or by vibrating the membrane either longitudinally or torsionally around a perpendicular axis, inducing dispersion of solutes on the membrane surface and elimination of membrane fouling [22]. Therefore, it outweighs the conventional cross-flow membrane filtration process in excellent effluent quality, stable permeate flux, low concentration polarization and high retention and has been successfully implemented in many fields of research and engineering such as wastewater treatment [18], medical engineering [22] and food engineering [23] as well as biotechnological separations [24].

The objective of the present work is to investigate the application of membrane technology (MF and UF) to separate and concentrate leaf protein from alfalfa juice. In order to control flux decline, three types of filtration modules (DA, DRDM and CRDM) were chosen and compared. The focus of this work is to (1) discuss the effect of TMP and rotating speed on flux behavior and separation efficiency in full recycling tests; (2) investigate concentration efficiency, flux behavior and membrane cleaning in concentration tests. The experiments should be useful for evaluating the membrane performance of concentrating leaf protein from alfalfa juice and understanding the process efficiency, separation performance, flux behavior, and membrane fouling in various filtration modules.

Table 1
Main characteristics of alfalfa juice.

Index	Alfalfa juice
Crude protein (g L^{-1})	21
Chlorophyll a (mg L^{-1})	12.38
Chlorophyll b (mg L^{-1})	20.82
Dry matter (g L^{-1})	86
Ash (g L^{-1})	21
Turbidity (NTU)	600
Conductivity (ms cm^{-1})	9.29
pH	5.8
Soluble matter (°Brix)	8.1
Density, ρ (g ml^{-1})	1.20
Protein purity (%)	24.4

2. Materials and methods

2.1. Test fluid

Alfalfa juice provided by Luzéal, Pauvres, France, was pre-filtered by a mesh of 0.4 mm pore size and mixed, then stored at the temperature of −20 °C until further use. In order to prevent serious membrane fouling, before experiment the juice was centrifuged at 4000 rpm for 10 min using a Sigma 3-16P device for separating the insoluble materials. The main characteristics of alfalfa juice are shown in Table 1.

2.2. Filtration modules

2.2.1. Dead end filtration using Amicon cell (DA)

The dead-end filtration Amicon 8200 cell (Millipore, Billaica, USA) was used for alfalfa juice filtration. As shown in Fig. 1, the internal diameter of the cell is 6.35 cm and maximum volume is 180 mL. The membrane was located at the bottom of the cell. The effective membrane area is 3.17×10^{-3} m^2. A constant pressure was provided by filling the cell with nitrogen gas and maximal pressure could reach 6 bar, while permeate was collected in a tube placed on an electronic scale in order to calculate the permeate flux.

2.2.2. Dynamic cross filtration using rotating disk module (CRDM)

A rotating disk module (RDM), shown in Fig. 2, was used for alfalfa juice filtration. A flat membrane, with an effective area of 176 cm^2 (outer radius R_1 = 7.72 cm, and inner radius R_2 = 1.88 cm), was fixed on the cover of the cylindrical housing in front of the disk. The disk equipped with 6 mm-high vanes, which can generate very high shear rates on the membrane, at rotation speeds up to 2500 rpm. The module was fed from a thermostatic and stirred tank containing 12 L of fluid by a volumetric diaphragm pump (Hydra-cell, Wanner, USA). The peripheral pressure (Pc) was adjusted by a valve on outlet tubing and monitored at the top of the cylindrical housing by a pressure sensor (DP 15–40, Validyne,

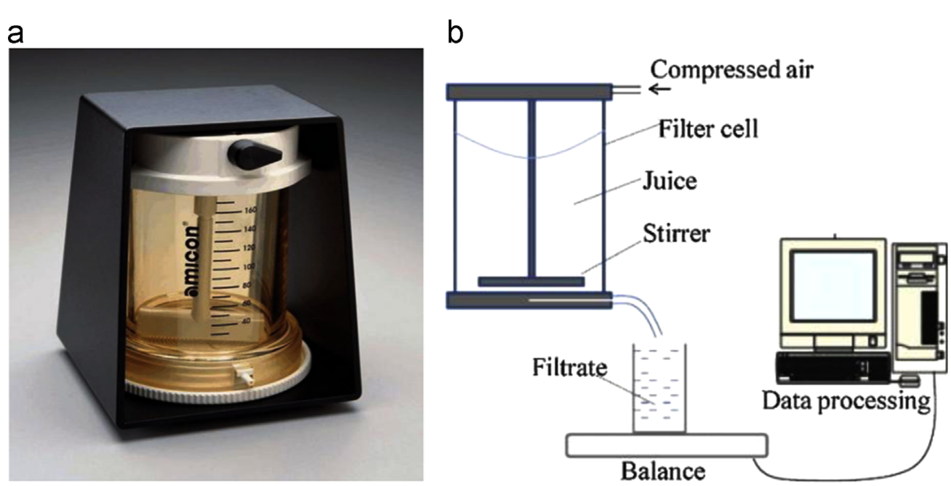

Fig. 1. (a) Photo of dead end filtration cell and (b) schematic representation of DA.

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