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A rotating disk ultrafiltration process for recycling alfalfa wastewater

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ABSTRACT

Rotating Disk Membrane (RDM) module with ultrafiltration (UF) was an effective alternative method to treat alfalfa wastewater and realize protein recovery and agricultural irrigation water production. The effects of membrane and operational conditions (rotating speed, temperature and transmembrane pressure (TMP)) on filtration behavior were investigated using full recycling tests. High molecular weight cut off (MWCO) membrane, rotating speed, temperature and TMP improved flux behavior and productivity, but reduced separation performance. Moreover, the increases of membrane MWCO, temperature and TMP also led to elevation of irreversible fouling. Then series of concentration tests were conducted at various operational conditions and the filtration behavior was studied. High temperature could improve flux behavior and productivity significantly. Hermia's blocking model was used to study fouling process, and identify the main fouling mechanism. These results from laboratory-scale tests provide a useful guide for protein recovery and agricultural irrigation water production in alfalfa wastewater treatment and provide a useful guide for UF process operation in industrial scale.

1. Introduction

Leaf protein is an important protein for animals and human consumption industrially obtained from alfalfa juice. Due to abundant sources, high nutritive value and absence of animal cholesterol, the alfalfa juice containing high protein content has been recognized as an effective source of high quality leaf proteins [1]. The alfalfa processing plants, like most other food industries, generate a large amount of wastewater during the procedures for alfalfa harvest, plant extrusion and machine cleaning, composed of diluted alfalfa juice [2,3]. This effluent results in both water eutrophication and nutrient loss when it is discarded without effective treatment. In fact, alfalfa wastewater contains a large amount of leaf protein, which has a high nutritive value (absence of animal cholesterol and 50% hydrophilic proteins) [4–6]. Therefore, alfalfa wastewater can be recognized as resource recovery for protein recycle and agricultural irrigation water production. A number of methods have been used to separate and concentrate leaf proteins from alfalfa juice, such as organic solvent fractionation [7], crystallization [8], heating [9], centrifugation [10], molecular sieve chromatography [11] and ion exchange [12]. With the promotion of cyclic economy in recent years, resource reutilization has become the goal of wastewater treatment. However, most separation methods cannot satisfy the requirements for reuse. Besides, they have various intrinsic disadvantages, such as low separation efficiency, high energy cost, damage of nutritive proteins, complex operation and high investment [13], which limit their industrial applications.

Membrane especially ultrafitration (UF), as shown in Fig. 1, provides a promising method to produce concentrated retentate, which has high protein concentration and can be precipitated by coagulation to obtain feed supplement for animals [1,14], or can be treated by anaerobic digestion to collect renewable energy sources (H_2 and CH_4) [15], while the permeate by membranes can be further filtrated by membrane to produce reusable water [16,17], or can be used for agricultural irrigation [1]. Therefore, membrane is regarded as an economical and environment-friendly process for treatment of alfalfa wastewater. However, during membrane filtration process of protein solution, serious flux decline caused by membrane fouling and concentration polarization occurred [18,19], increasing the operation cost and restricting its sustainable operation and industrial application.

In order to control flux decline, various strategies have been proposed to reduce membrane fouling and concentration polarization, such as the operating below "critical flux" [20], modification of membrane surface [21], feed pretreatment [22], improvement

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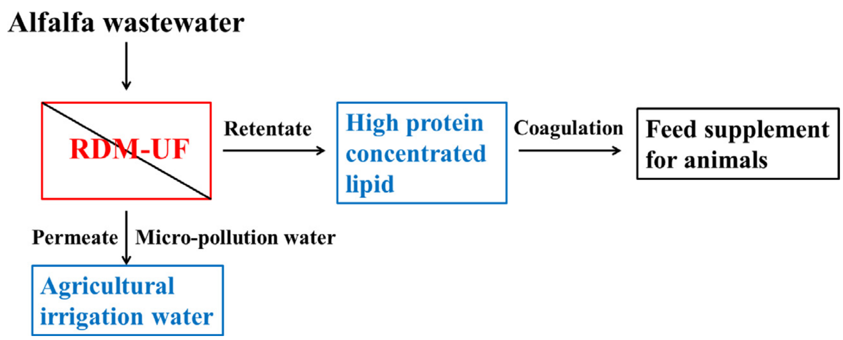

Fig. 1. Schematic diagram of a UF process for alfalfa wastewater treatment and resource recycling.

of filtration module [18] and membrane cleaning [23]. But most of fouling control strategies exhibit the insurmountable shortcomings, for example, feed pretreatment needs additional treatment and has high operation cost [24], modification of membrane surface has a short duration and is not stable [21], operating below "critical flux" gives a low permeate flux and affects productivity [20] and membrane cleaning requires high operating cost [23,25]. Therefore, the selection and application of flux decline control strategies are multi-stages and need a global consideration.

The configuration of membrane modules strongly influences the hydrodynamic, which determines shear rate on membrane surface and affects flux behavior, fouling control and separation performance. Our laboratory utilizes a rotating disk membrane (RDM) shear-enhanced filtration module which can be operated at a high shear rate ($4.43 \times 10^{-5}\ s^{-1}$) [26,27]. Our RDM module 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 [1]. Because it can reduce concentration polarization effectively, solute rejection and permeate flux keep increasing with transmembrane pressure (TMP) [28], thus permits to concentrate wastewater to a very high concentration and provides a very valuable tool for resources recovery of wastewater treatment. Zhang et al. [1] compared dead-end, cross-flow and RDM filtration modules for the filtration of alfalfa juice, and showed that the RDM filtration module was the best with regards to permeate flux and selectivity. Operating at an optimized hydraulic condition (feed flow rate = 75.81 L/h, TMP = 7.00 bar and rotating speed = 2250 rpm) calculated by response surface methodology, RDM module obtained a highly concentrated retentate and a permeate with low total protein concentration (below 5 mg/L) from model dairy wastewater, because high shear rate on membrane surface could increase protein rejection, improve permeate flux and enhance wastewater concentration factor [29]. Therefore, RDM module exhibits many advantages in wastewater treatment and proteins recovery.

In this study, the RDM module with UF for the pretreatment of alfalfa wastewater was proposed and examined, aiming at realizing recovery of protein in retentate, and agricultural irrigation water production by permeate. The effects of selection of UF membranes and optimization of operation conditions (rotating speed, temperature and TMP) on the solutes rejection, flux behavior, separation performance and permeability recovery after membrane cleaning were investigated. Based on the optimized operation condition, a series of concentration tests were conducted and the fouling mechanism was investigated. Besides, membrane pore blocking model was utilized to describe the fouling mechanism. The outcome could be used in membrane process development for pretreatment of alfalfa wastewater, protein recovery and production of agricultural irrigation water from alfalfa wastewater.

2. Materials and methods

2.1. Test fluid

Alfalfa wastewater 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 wastewater was centrifuged at 4000 rpm for 10 min using a Sigma 3–16 P device for separating the insoluble materials. The main characteristics of wastewater are shown in Table 1.

2.2. Experimental set-up and membranes

A rotating disk module (RDM), shown in Fig. 2, was used for alfalfa wastewater filtration. A flat membrane, with an effective area of 176 cm^2 (outer radius R_1 = 7.72 cm, 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, 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, USA), and the data was collected automatically by a computer. Permeate was collected in a beaker placed on an electronic scale (B3100P, Sartorius, Germany) connected to a computer in order to measure the permeate flux.

Six commercial UF membranes fabricated by MICRODYN-NADIR Membrane Corporation, Germany were selected in this investigation owing to their strong antifouling performance and

Table 1
Main characteristics of alfalfa wastewater.

Index	Alfalfa wastewater
COD (g L^{-1})	147.5
TN (g L^{-1})	0.48
Crude protein (g L^{-1})	3.0
Dry matter (g L^{-1})	66.4
Ash (g L^{-1})	19.01
Turbidity (NTU)	550
Conductivity (ms cm^{-1})	10.70
pH	5.91
Soluble matter (°Brix)	7.01
Density, ρ (g ml^{-1})	1.18
Protein percentage of dry matter (%)	4.52