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A pilot-plant test on desalination of soy sauce by nanofiltration

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ABSTRACT

A pilot-plant test on desalination of soy sauce was performed with spiral-wound nanofiltration (NF) membrane modules. NF270 was found to be the most suitable for desalination of soy sauce due to its high permeate flux, though the rejection of amino nitrogen slightly decreased with increasing operation temperature. Soy sauce permeate was further concentrated to yield light-color soy sauce by Desal-5 DK, another membrane with higher rejection of organic matter but lower permeate flux than those of NF270. Glutamic acid and aspartic acid in soy sauce had highest retention by NF270 while glycine passed through membrane most easily. Under constant transmembrane pressure (TMP) condition, the mode that diluted soy sauce was directly concentrated to eligible product was found to be the most suitable one in terms of processing time and operation cost. Productivity for low-salt soy sauce decreased significantly in the early stage of operation and then kept constant for a long-term operation. With application of a composite cleaning agent containing alkali, surfactant and enzyme at a low concentration for a short duration, the flux of the severely fouled membrane could be completely recovered, suggesting that it could be feasible to produce low-salt soy sauce by NF technology.

1. Introduction

Soy sauce, a traditional Oriental food condiment, normally contains a high concentration of sodium chloride (NaCl, 18–20%, w/v). For the sake of health, part of NaCl needs to be removed from the raw soy sauce [1]. In previous studies [2–4], nanofiltration (NF) technology has been applied successfully to the desalination of soy sauce at laboratory-scale. With dead-end filtration at constant permeate flux, Luo et al. [4] found that, with NF270, the combination mode of dilution–concentration–diafiltration could be the most suitable for desalination of soy sauce. However, when desalination of soy sauce by NF is applied in commercial production, it is likely to be operated in tangential flow at constant transmembrane pressure (TMP). Although the dead-end filtration at constant permeate flux has obvious advantages in the rapid evaluation of membranes performance and well understanding of separation mechanism [5,6], the results cannot be used directly in the design and operation of conventional tangential flow filtration process, the most commonly applied process in industry. Tansel et al. [7] found that ions rejections by NF in dead-end mode were always lower than that in cross flow mode because of the difference in shear force. And membrane fouling in constant TMP mode was also dissimilar to that in constant flux mode [8,9]. Thus many disparities will occur when membrane processes scale up from laboratory. Therefore, a pilot plant test on NF-filtration of soy sauce is required in order to industrialize this concept.

In industrial scale production, the cost resulted from membrane fouling and cleaning is significant in membrane process [10,11]. Since soy sauce is a concentrated mixture comprising protein, amino acid, peptide, saccharide, organic acid, NaCl, etc., a severe permeate flux decline during desalination process could be expected due to combined fouling [12], as found in membrane filtration of other complex effluents like fruit juice [13], diary ultrafiltration (UF) permeate [14], and wastewater [15,16]. Li et al. [17] reported that concentration polarization and cake formation were the dominant fouling resistance for ceramic microfiltration of raw soy sauce. In NF of soy sauce, low molecular weight solutes such as amino acid and glucose could also block the membrane pores by adsorption, thus decreasing the membrane permeability. Although an alkali aqueous solution could effectively recover the flux in microfiltration of raw soy sauce [18], this cleaning procedure might not be efficient for cleaning the fouled NF membranes by soy sauce due to their different fouling mechanisms. Therefore, understanding the fouling tendency and finding an appropriate cleaning approach are essential to the application of low-salt soy sauce production by NF.

In this work, desalination of soy sauce by NF at pilot plant scale was investigated with spiral-wound membrane modules under constant TMP conditions. Based on our previous laboratory scale work [4], the objective of the present pilot scale study was to

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develop an optimum operation mode for industrial production of low-salt soy sauce by NF, with focus on the effect of different operating parameters on permeate flux. The fouling tendency and cleaning method for desalination of soy sauce by NF were also examined. The outcome of the present work would serve as a valuable guide for process design and practical operation in subsequent industrial application.

2. Materials and methods

2.1. Soy sauce and chemicals

Soy sauce was directly taken from a local food plant in Foshan, Guangdong Province, China. Raw soy sauce was pretreated by sedimentation, centrifugation and ultrafiltration (UF) at industrial scale, and the soy sauce after UF was pumped into NF-system for further processing.

All chemicals used for cleaning and sterilizing were of food grade, provided by the local food plant. The proprietary liquid composite cleaning agent was composed of alkali, surfactant and enzyme, and 0.3% (w/v) concentration (pH ≈ 10) was used in the present work.

Fig. 1. Photograph of the pilot equipment.

2.2. Equipment and membrane modules

A homemade NF pilot device was used in the experiments, equipped with a 100 L capacity feed tank, as shown in Fig. 1. Fig. 2 shows the schematic diagram of NF-system. Two multistage pumps (CRN3-36, Grundfos, Denmark) were furnished for feeding and cleaning, respectively. Pressure was measured by both digital and analogue manometers, and, as TMP reference value, the mean value between the inlet and outlet of membrane module was taken, and pressure drop never exceeded 0.9 bar. Experiments ran at a constant TMP of 24 bar except elsewhere stated. Operation temperature was controlled at 30 ± 1 °C by circulating water except for cleaning procedure. Crossflow rate and permeate flux were determined by rotameters.

As can be seen in Fig. 1, this pilot device can simultaneously run three NF spiral-wound modules with two UF tubular modules as pretreatment, but in the present study, only one of pressure vessels loaded with a NF module was used for each test. The NF membrane modules of NF270-4040 and Desal-5 DK-4040 were supplied by DOW-Filmtec and GE-Osmonics, respectively. They consisted of a spiral-wound aromatic polyamide membrane with a total effective area of 7.6 m^2. The molecular weight cut-off of the membranes was about 150 Da [19].

2.3. Experimental procedure

First, new membrane modules were rinsed by pure water for 1 h at a TMP of around 0.3 bar, and the permeate was discharged. In order to compare with the results of laboratory scale tests, diluted soy sauce (soy sauce:pure water = 1:1) was added into feed tank and then concentrated to its original volume. Subsequently, the desalted soy sauce was further concentrated to meet the Super Class quality standards defined in China National Standards GB18186-2000, GB2717-2003 [20] (first stage); meanwhile, NF primary permeate was further concentrated to yield light-color soy sauce, which could meet the Class II quality standards [20] (second

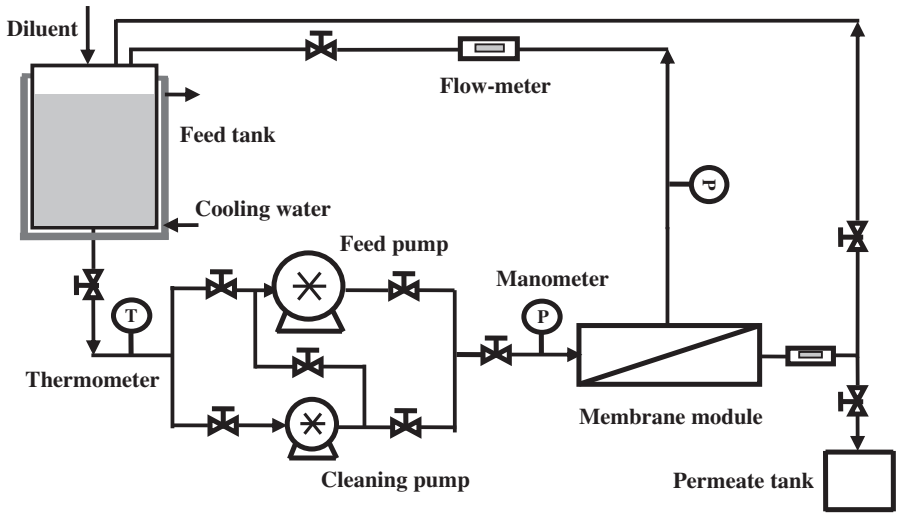

Fig. 2. Schematic diagram of the NF system.