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Laboratory Studies on Membrane Deoiling of Lecithin

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Abstract Deoiling of lecithin using a nonporous membrane was examined in a favorable solvent (hexane) medium with soy and rice bran lecithins. During the membrane process, the acetone insoluble (AI) content of soy lecithin increased from 63.2 to 81.0% in a single step batch operation. The membrane exhibited an excellent selectivity since phospholipid (PL) reverse micelles formed in the system were rejected almost completely due to low solubility probably aided synergistically by size exclusion. Diafiltration achieved greater oil removal from lecithin as reflected in terms of higher AI and PL contents in the deoiled lecithin. In discontinuous diafiltration, the PL content increased from 33.3 to 85.5% in rice bran lecithin (150% dilution to feed) and 56.6 to 85.7% in soy lecithin (200% dilution), respectively. The simulated continuous diafiltration run showed slightly greater PL content in soy lecithin (91.3%) compared to discontinuous diafiltration (89.7%) besides offering higher productivity. The membrane showed a color reduction of ~60% in soy lecithin but there was no improvement in rice bran lecithin due to the retention of degradation products. The proposed integrated membrane process with nonporous (deoiling) and nanofiltration (solvent recovery) membranes could be an attractive preposition besides being an acetone free process.

Keywords Acetone-free deoiling process · Nonporous membrane · Phospholipid · Rice bran lecithin · Soy lecithin

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Introduction

Lecithin refers to a complex mixture of phospholipids (PL), triglycerides and other substances such as glycolipids, free fatty acids and carbohydrates. Lecithin is obtained by water degumming crude vegetable oils and separating and drying the hydrated gums. It is the PL portion of lecithin that is mainly responsible for giving form and function to lecithin [1]. Lipids that are composed of two fatty acids and a phosphorus-containing region joined by ester linkages to a glycerol backbone are called PL. They are found in all living cells of animals and plants. Although the highest concentrations of PL occur in animal products, the major commercial source is the soybean, which contains 0.3–0.6% [1]. Nevertheless, PL from other vegetable sources, i.e., corn, cottonseed, linseed, peanut, rapeseed, rice bran, safflower and sunflower have also been studied and used. Lecithin is widely used in the food, pharmaceuticals and cosmetic industries.

Deoiling of crude lecithin is a prerequisite in making high-purity lecithin products including phosphatidylcholine (PC). Acetone has been the solvent of choice and currently used in the industry for the separation of glycerides and PL, based on the insolubility of PL and glycolipids in acetone. Eliminating solvent processing could maintain "relatively natural" characteristics in its products and avoid formation of condensation products such as mesityl oxide reported in the acetone-extraction process [1]. An alternative to acetone extraction is the treatment of lipid mixtures with supercritical gases or mixtures [2]. For deoiling of crude soy lecithin with pure CO_2, pressures as high as 60–100 MPa were required [3]. Besides, increasing viscosity of the lecithin during the deoiling process prevented the complete removal of the oil. The operating pressure was reduced to 8 MPa in

the temperature range of 40–55 °C when propane (80 wt%) was used as an entrainer along with CO_2 (20 wt%) to maintain the lecithin in a liquid state during extraction and made it possible to obtain an oil-free product. Deoiling was also demonstrated using supercritical CO_2 in the presence of a co-solvent such as ethanol and acetone at moderate pressures (17 and 20 MPa) at 62 °C [4]. However, supercritical fluid extraction (SCFE) involves capital intensive equipment owing to high pressure processing.

Deoiling of lecithin employing UF has been also reported [5, 6]. Commercial lecithin containing 40% triglyceride was dissolved to 10% solution in hexane and passed through a UF membrane (MWCO 20 kDa) in recycle mode to get deoiled lecithin containing 6% triglyceride content. Processing in diafiltration mode (25% lecithin in hexane as initial feed) with a lower MWCO (10 kDa) UF membrane could reduce triglyceride content to 3% in deoiled lecithin [5]. Another research group made a similar attempt with UF for deoiling lecithin followed by few more additional processing steps like bleaching and addition of tocopherols and tocotrienols in solvent medium before subjecting the retentate fraction to desolventization. Polyvinylidene fluoride membrane having a MWCO of 10–50 kDa was employed in the process and the deoiled lecithin obtained from the process contained >90% acetone insolubles (AI) [6].

In the last three decades, a large number of attempts have been made worldwide towards degumming, dewaxing, deacidifying and decolorizing edible oils using porous as well as nonporous membranes with and without using solvents [7]. The separation of a mixture of constituents in porous membranes is mainly based on size exclusion. While in the case of nonporous membranes, the separation is due to the solution-diffusion effect. Extensive studies carried out by our research group on processing vegetable oils using nonporous membranes have been reviewed recently [7, 8]. These studies showed that hydrophobic nonporous membranes possess very high selectivity to separate PL from undiluted as well as hexane diluted oils. The nonporous membranes tend to offer greater yield of PL compared to UF based membrane processes. In the present work, studies on deoiling lecithin were carried out using nonporous membranes with lecithins from soybean (common commercial source) and rice bran (another rich source of lecithin).

Theory

The transport in denser membranes is completely controlled by the solution diffusion mechanism in applications such as gas separation, pervaporation and vapor permeation [8] and also in the case of solute-solvent systems and liquid mixtures. The permeability in a nonporous membrane P_m is equal to

$$P_m = DS \tag{1}$$

where D is the diffusion coefficient and S the solubility. Besides solubility and diffusivity of the component in the membrane material, permeability also depends on the polarity of the component and coupling effect as well as the solubility of individual components in other permeating components including the solvent being used. In the present system, the PL molecules being amphiphilic tend to form micelles of a larger size in non-aqueous systems such as hexane–oil miscella since the PL content is well above the critical micelle concentration (CMC). So the separation/selectivity of the nonporous membranes will be also influenced by the size exclusion of the PL micelles.

The performance of the membrane process is assessed in terms of the selectivity of the membrane and productivity (permeate flux). In the present study PL rejection by the membrane was used as a measure to express the selectivity of the process. The percentage rejection (R_o) was determined assuming that it was constant during each batch of the experiment using the following equation:

$$R_o = \frac{100[\ln(C_R/C_F)]}{\ln(W_F/W_R)}(\%) \tag{2}$$

where C_F and C_R are the contents of each component in the feed and retentate (mg/kg oil), and W_F and W_R are the weights of the feed and retentate (kg oil), respectively.

Materials and Methods

Raw Materials

Laboratory grade soy lecithin was obtained from M/s Wako Pure Chemical Industries, Osaka, Japan and commercial grade soy lecithin was obtained from M/s Sakthi Soya Ltd., Coimbatore, India. Rice bran lecithin was prepared in the laboratory [9].

Chemicals and Solvents

PC, phosphatidylinositol (PI) and phosphatidylethanolamine (PE) standards were obtained from Sigma Chemical Company (St Louis, USA). HPLC grade solvents were procured from Qualigens Fine Chemicals (Mumbai, India). Hexane used in the experiments was of laboratory grade and purchased from Ranbaxy Fine Chemicals (New Delhi, India). All other chemicals and solvents were of analytical grade and obtained from reputed manufacturers in the country.

Membrane

Nonporous polymeric composite hydrophobic membrane, NTGS-2200 with polydimethylsiloxane as the active layer and polyimide as the support layer was used in the study (Nitto Denko, Kusatsu, Japan). The membrane was cut into a circular disc (7.5 cm diameter with 32 cm^2 effective area) and fitted in the membrane cell in such a way that the active surface comes into contact with the feed material.

Apparatus

Experimental runs were conducted in a self stirred flat membrane test cell (Model: C40-B, Nitto Denko) under a nitrogen atmosphere. Stirring was employed to minimize the concentration polarization effect and the speed was maintained at 1,200 rpm. As the membranes used in the study were nonporous membranes, an operating pressure of 2 MPa was employed by adjusting the pressure regulator of the nitrogen cylinder. Crude lecithin was diluted with hexane (1:9) to overcome its higher viscosity in the membrane process. Diafiltration was employed to improve the extent of deoiling from lecithin. All the experiments were conducted at room temperature.

The unit was operated in three modes of operation by charging the cell with a predecided quantity of lecithin–hexane mixture, namely, (a) batch operation (b) discontinuous diafiltration and (c) simulated continuous diafiltration (Fig. 1). In batch operation, the lecithin–hexane mixture was processed until a desired volume concentration ratio (VCR) was reached.

In the first step of the discontinuous diafiltration mode, the lecithin–hexane mixture was processed until a desired VCR was reached and stopped the run. Then the retentate fraction was diluted to its original volume with hexane and the experimental run was continued as before. This was continued until the desired number of steps of diafiltration was achieved.

During continuous diafiltration mode, the feed volume is maintained constant at any given time by compensating the permeation with a continuous dilution of the feed. Considering the practical difficulties in carrying out a continuous diafiltration during batch processing, a simulated run was conducted by stopping the run between small intervals (after 20% permeation) and adding equivalent amount of fresh hexane to the retentate before restarting the run. The experimental run was thus continued until the desired level of diafiltration was achieved.

Membrane Cleaning

The membrane was cleaned using hexane after every experimental run. The membrane was reused after recovering the original hexane flux with the cleaned membrane.

Analysis of Samples

Feed, permeate and retentate samples were analyzed after evaporating the hexane under a vacuum using a flash evaporator (at 45–50 °C for 40 min followed by 5 min flushing with nitrogen).

AI Content

AI content in crude and deoiled lecithin samples were determined using AOCS method Ja 4–46 [10].

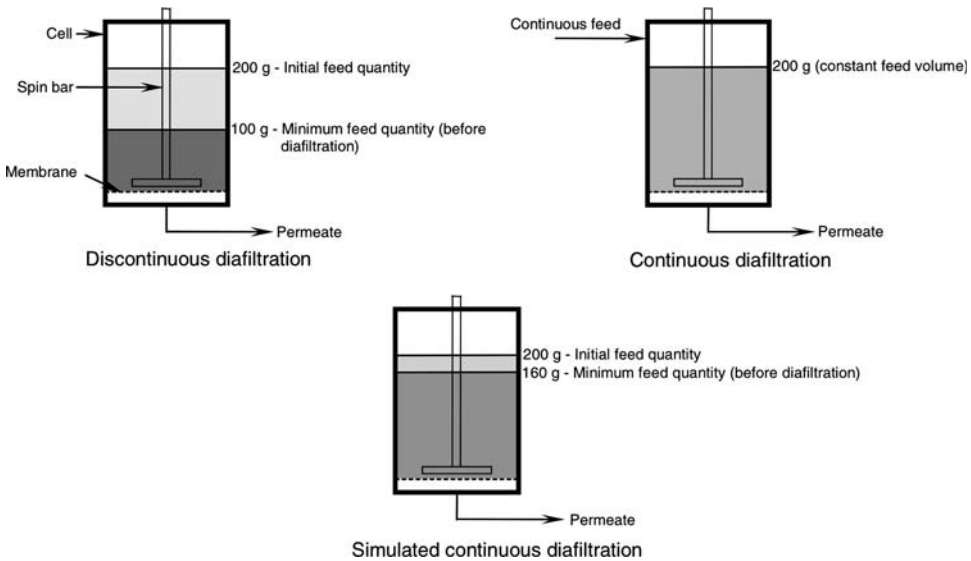

Fig. 1 Diafiltration in batch membrane cell

PL Content

Phosphorous content of the samples was measured after mixing with a known quantity of refined soybean or rice bran oil as the case may be, by the standard molybdenum blue method as per the AOCS method, Ca 12–55 [10]. The PL equivalent was calculated by multiplying the phosphorous content by a factor of 30 for soy lecithin and 31 for rice bran lecithin.

Individual PL Analysis

Individual PL (PC, PI, and PE) in lecithin samples were analyzed by normal phase HPLC using acetonitrile/methanol/phosphoric acid (780/10/9 v/v) as mobile phase [11]. HPLC details: column—Partisil—4.6 × 250 mm with 5 μm silica (Whatman International Ltd., Maidstone, England); LC-10AT HPLC pump, SCL-10A system controller, SPD-10A UV-VIS detector (Shimadzu, Kyoto, Japan). Measurement conditions: absorbance 205 nm, column temperature 25 °C, flow 1 mL/min and analysis time 40 min. Lecithin samples were dissolved in known amount of HPLC grade chloroform before analysis. The quantification of the individual PL was based on the standard curves obtained with HPLC standards of PC, PI and PE.

Color Estimation

The total color of the samples was estimated from the area under the absorption spectra between 350 and 800 nm [12]. The spectroscopic data were recorded using a UV-visible spectrophotometer (Model UV-160A, Shimadzu). Absorbance in the visible range was measured after dissolving the lecithin samples in hexane (5% w/v) and using a 10 mm cuvette with hexane as blank.

All the experimental runs were carried out in duplicate and practically no differences were observed (±2.0%). The mean values obtained are reported.

Results and Discussion

Efficacy of Nonporous Membrane for Deoiling Lecithin

Preliminary studies conducted to evaluate the efficacy of a nonporous membrane for deoiling lecithin revealed that PL were rejected to the extent of 97.5%. Consequently, AI content in soy lecithin increased by 28% from an initial level of 63.2 to 81.0% in a single step batch operation (Table 1). The nonporous membranes from the same series used in our earlier studies achieved almost complete degumming while processing crude vegetable oils in undiluted as well as hexane diluted systems [8, 13, 14]. In the present study with a lecithin–hexane system, the increase in AI content in the retentate fraction implied that the membrane possessed the required selectivity for the intended application.

Our earlier studies on processing hexane–oil miscella also showed that there is no selectivity between oil and hexane over a wide range of oil concentration in the miscella [15, 16]. Accordingly, in the present batch system the maximum removal of oil from the feed would be proportional to the amount of permeation. The level of AI content in the deoiled lecithin obtained in a single step processing was not very high. Lecithin with higher AI content (>95%) would be preferred in most of the applications owing to their greater purity and lower oil content. In order to improve the performance of the membrane process, a secondary run was conducted with the deoiled lecithin obtained from the primary run after suitable hexane dilution. As a consequence, the AI content improved from 81.0 to 89.6%, which improved further to 95.7% after a ternary run at a higher dilution (Table 1). AI measurement is a simple and rough measure of PL but also includes other minor substances such as waxes. When the AI content increased from 63.2 to 95.7%, the corresponding increase in PL content was from 57.7 to 89.7% in soy lecithin after three steps of processing (Table 1). The results revealed that diafiltration could be employed in the process. Diafiltration is a common method used to improve the yield as well as purity of target compounds in a membrane process. Therefore, subsequent studies were carried out employing diafiltration in order to achieve greater removal of oil from lecithin as well as to improve the PL content in the deoiled lecithin.

Deoiling of Lecithin During Discontinuous Diafiltration

The AI and PL contents of soy and rice bran lecithin samples during discontinuous diafiltration using nonporous membrane are presented in Table 2. As discussed in the earlier section, understandably oil removal increased with diafiltration and the quantity of oil removed was somewhat proportional to the ratio of permeate to feed in each step of

Table 1 Membrane deoiling of soy lecithin

Experimental description	Lecithin-solvent ratio (w/w)	VCR	AI[a] (%)	PL[a] (%)
Primary run	1:9	5.7	81.0 ± 0.3	–
Secondary run	1:9	5.1	89.6 ± 1.1	–
Ternary run	1:37	5.2	95.7 ± 0.9	89.7 ± 1.1

Lot–1: AI content—63.2% ± 0.7; PL content—57.7% ± 1.3

VCR volume concentration ratio

[a] In the retentate (hexane free basis). Values are expressed as mean ± SD of duplicate ($n = 2$) measurements

Table 2 Membrane deoiling of soy and rice bran lecithins during discontinuous diafiltration

Sample description	AI[a] (%)	PL[a] (%)	PL improvement (fold)
Soy lecithin (Lot-2)			
Feed	59.6 ± 1.0	56.5 ± 1.0	
Final retentate[b]	89.1 ± 1.4	85.7 ± 1.3	1.5
Rice bran lecithin			
Feed	–	33.3 ± 0.3	
Final retentate[c]	–	85.5 ± 1.4	2.6

Feed: 20 g of lecithin dissolved in 180 g of hexane

[a] Hexane free basis. Values are expressed as mean ± SD of duplicate ($n = 2$) measurements

[b] Retentate (25 g) obtained after four steps of diafiltration with 100 g of hexane addition in each step

[c] Retentate (25 g) obtained after three steps of diafiltration with 100 g of hexane addition in each step

diafiltration. During processing soy lecithin, the PL content improved from an initial level of 56.5 to 85.7% in the retentate fraction after four steps of diafiltration (200% dilution to feed). In the case of rice bran lecithin, the same level of PL (85.5%) could be achieved with three steps of diafiltration (150% dilution to feed). Further, the increase in PL content in rice bran lecithin was 2.6 fold while it was only 1.5 fold in soy lecithin in spite of a higher amount of hexane used during diafiltration. Initial PL content in the lecithin as well as the amount of solvent used in the process could affect the PL and oil contents in the deoiled lecithin. It is possible to increase the PL content further (above 90%) with a corresponding decrease in the oil content in deoiled lecithin by increasing the solvent volume during diafiltration. Continuous diafiltration is preferred to discontinuous diafiltration in many instances during plant operations. However, considering the practical difficulties in carrying out continuous diafiltration in a batch membrane cell, a simulated run was subsequently attempted.

Deoiling of Lecithin During Simulated Continuous Diafiltration

The AI and PL contents of soy lecithin samples during simulated continuous diafiltration are presented in Table 3. During the simulated run, the AI content in soy lecithin improved from an initial level of 63.2 to 95.7% in the retentate fraction after ten steps of diafiltration (200% dilution to feed) and the corresponding increase in the PL content was 91.3% from 57.7%. Continuous diafiltration resulted in higher PL content in the deoiled lecithin (91.3%) compared to discontinuous diafiltration (85.7%) for an equal amount of hexane dilution in the process (Table 2). Besides, continuous diafiltration of the lecithin

Table 3 Membrane deoiling of soy lecithin in a simulated continuous diafiltration run

Sample description	Weight (g)	Hexane addition (g)	AI[a] (%)	PL[a] (%)
Feed[b]	200	180	63.2 ± 0.7	57.7 ± 1.3
Intermediate feed	~190	~40[c]	–	–
Final retentate[d]	~30	0	95.7 ± 1.3	91.3 ± 1.4

[a] Hexane free basis. Values are expressed as mean ± SD of duplicate ($n = 2$) measurements

[b] 20 g of lecithin (Lot–1) dissolved in 180 g of hexane

[c] Hexane added during each diafiltration step

[d] Retentate obtained after ten stages of diafiltration

mixture helped in reducing the viscosity of the feed sample right from the start of the run and enabled a higher permeation rate (1.5 LMH) when compared to discontinuous diafiltration run (0.6 LMH), thus reducing the processing time.

Composition of Individual PL

The PL content in crude soybean and rice bran oils reported to be in the range of 1.5–2.1% [17] and 4–5% [18], respectively. The typical composition of individual PL in soy lecithin, PC, PI, PE and others are in the ratio of 28:25:17:30 [1]. The individual PL in soy and rice bran lecithins before and after membrane deoiling are presented in Table 4. PC, PI and PE together contributed to 57.3% (Lot-1) and 30.8% (Lot-2) of total PL in the soy lecithin and their composition was not altered much during membrane processing. In the case of rice bran lecithin, the contribution of PC, PI and PE was only 4.9% indicating the

Table 4 Individual PL contents in lecithin samples

Sample description	PL (%)	Individual PL (mg/kg)			PC + PI + PE (%)
		PC	PI	PE	
Soy lecithin (Lot–1)[a]					
Feed	57.7 ± 1.3	130,000	68,400	132,000	33.0 ± 1.5
Deoiled	91.3 ± 1.4	220,000	124,000	220,000	56.4 ± 1.6
Soy lecithin (Lot–2)[b]					
Feed	56.5 ± 1.0	82,000	23,300	68,700	17.4 ± 0.4
Deoiled	85.7 ± 1.3	124,000	32,500	91,000	24.8 ± 0.2
Rice bran lecithin[b]					
Feed	33.3 ± 0.3	9,150	5,220	2,090	1.6 ± 0.1
Deoiled	85.5 ± 1.4	42,500	14,000	10,800	6.7 ± 0.8

Values are expressed as mean ± SD of duplicate ($n = 2$) measurements

[a] Samples of simulated continuous diafiltration run

[b] Samples of discontinuous diafiltration run

greater presence of other PL. Besides, the composition of PL in the processed rice bran lecithin altered significantly during processing and the contents of PC, PI and PE together increased to 7.9%. PC has the highest hydration rate among the various PL followed by PI, PE and PA besides having the ability to encapsulate other PL [7]. In the case of rice bran lecithin used in the present study, PC content was too low (<3%). Therefore most of the less hydrating PL such as salts of PE and PA could exist as monomers, facilitating their permeation and consequently leading to the increase in the concentration of PC, PI and PE existing as reverse micelles, in the retentate fraction (deoiled lecithin).

Color of the Deoiled Lecithin

The visible spectra of soy lecithin samples (feed, permeate and deoiled lecithin) are shown in Fig. 2. The area under the absorbance spectra between 350 and 550 nm gives a rough measure of all pigments that exhibit absorption in the red-yellow region. The color of the lecithin improved after membrane processing as revealed by the reduction in the area of the spectra (~60%). The spectra of the permeate of soy lecithin was similar to the typical spectra of crude soybean oil [12]. Carotenoids (xanthophylls) are the predominant red/yellow pigments in crude soybean oil and have a characteristic absorption around 450 nm in the visible range. Our earlier study revealed that the nonporous hydrophobic membrane rejected oxygenated carotenoids (xanthophylls-lutein) to a greater extent while largely allowing the permeation of hydrocarbon carotenoids (β-carotene) in undiluted model systems owing to the nature of their polarity [8]. Another study revealed that the rejection of carotenoids in soybean oil reduced with increased hexane dilution of oil [15]. In the present study, carotenoids largely permeated through the membrane owing to the greater extent of hexane dilution involved in the process and as a result, the spectra of the deoiled lecithin did not show the presence of these pigments. In such systems, the solubility of individual compounds in the solvent is also important in addition to their solubility in the membrane material. Probably, the spectra of the retentate could be used as an indirect indicator of the oil present in the lecithin and a measure of performance of deoiling process. The color of the membrane deoiled soy lecithin was lighter while the conventionally processed lecithin by acetone extraction is generally darker without bleaching.

In rice bran oil Maillard browning products are also present, besides carotenoids and chlorophyll [18]. During membrane processing the color reduction in rice bran oil ranged between 43 and 53% for hexane diluted samples whereas it was 74% in the undiluted samples [13]. The color compounds present in rice bran oil may contribute for the color of its lecithin besides other degradation products formed during the process and storage. The visible spectra of rice bran lecithin indicated that carotenoids did not significantly contribute to its color (Fig. 3). Further, comparison of the spectra of feed and deoiled lecithin showed that the majority of the degradation products contributing to the color were retained by the membrane even under hexane diluted conditions. This is also reflected in the greater reduction in color of the permeate fraction. The results suggest that it may be necessary to include a conventional bleaching step in the processing of rice bran lecithin.

Improvement in PL Content in Lecithin by Nonporous Membrane

In all the experimental runs on deoiling lecithin described above, the AI content and so also the PL content in lecithin samples increased to a greater extent depending on their

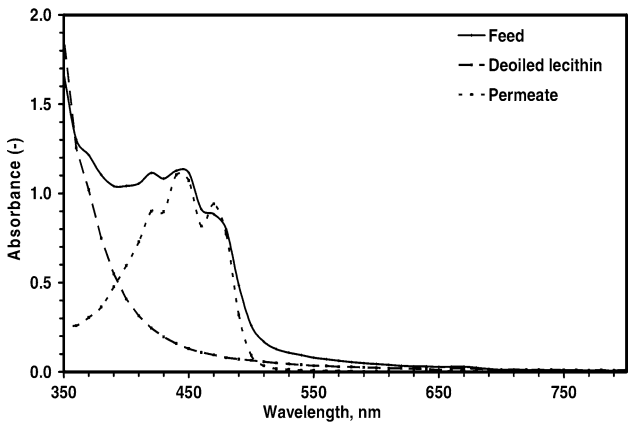

Fig. 2 Color reduction in soy lecithin during membrane deoiling process (simulated continuous diafiltration)

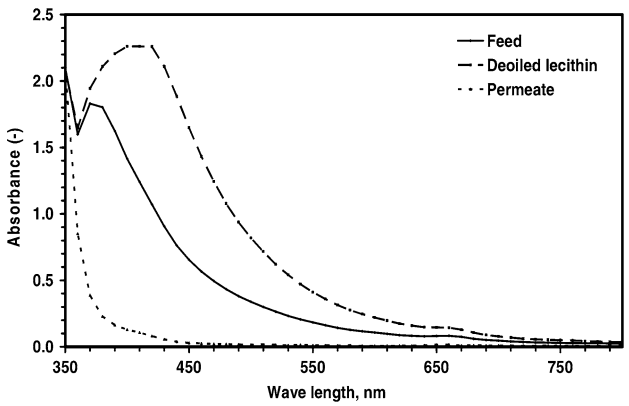

Fig. 3 Spectra of rice bran lecithin during the membrane deoiling process (discontinuous diafiltration)

initial levels as well as the conditions employed during membrane processing. PL are amphiphilic molecules containing hydrophilic polar heads and hydrophobic non-polar tails with an average molecular weight of around 700–800 Da. These surfactant molecules form reverse micelles with their hydrophilic polar heads oriented inward in non-aqueous systems such as vegetable oils and hexane–oil miscella. It has been reported that the size of the mixed micelles in soybean oil–hexane system is between 18 and 200 nm [7]. Accordingly, many researchers have employed a UF membrane typically with a MWCO of 20 kDa, for successfully degumming crude oils. High rejection of PL by nonporous membranes in undiluted [8] and hexane diluted oils [13, 14] was primarily attributed to its low solubility in the membrane material. In the case of hexane–oil miscella systems with PL content above CMC, size exclusion may provide a synergistic effect as the size of reverse micelles would be much larger [14]. Although the major constituents of crude oil and lecithin are the same, their concentrations are quite different in these two systems. In crude oils, the PL content varies from 1 to 5%, whereas PL is the major portion (~55–60%) in lecithin while the oil predominantly accounts for the rest. In the case of nonporous membranes, separation/permeation of components depends on their own solubility and diffusivity in the membrane material. In addition, it also depends on the coupling effect as well as the solubility of individual components in other permeating components including the solvent being used. All these factors are dependent on the concentration of individual components. In spite of the vast difference in the concentrations of major constituents, the nonporous membrane showed excellent selectivity for PL in lecithin–hexane system as in the case of oil–hexane system studied earlier.

Proposed Scheme

The proposed process for deoiling lecithin involves dissolving lecithin in hexane and processing through a nonporous membrane in diafiltration mode of operation, followed by desolventization of the retentate fraction by thermal evaporation of hexane under vacuum. A large amount of hexane (~44 L hexane/1 kg lecithin) is used in the process as dilution and diafiltration steps are involved in the process to obtain deoiled lecithin with a higher PL/AI content. The hexane need to be recovered and reused in the process. The energy requirement in the conventional thermal desolventization is very high as it involves a phase change and thus has a high impact on the process economics. Nanofiltration (NF) membranes could be used for hexane recovery and Raman et al. [19] reported 50% reduction in the energy required for evaporation of hexane. NF membranes exhibited ~85–90% rejection of triglycerides in hexane-oil mixtures [20] which may be reasonable enough for employing NF in the process. Therefore, a NF step has been incorporated for the recovery of hexane from the permeate stream of the nonporous membrane (Fig. 4) and the recovered hexane is recycled back in the nonporous membrane section for continuous diafiltration. The integrated membrane process as illustrated in Fig. 4 would be economically more attractive.

Processing lecithin by physical means using nonporous polymeric membranes under mild process conditions resulted in a product which is practically free from oil and the proposed process offers certain advantages over the known processes. For instance, acetone which is being used in the commercial process could lead to the formation of condensation products (mesityl oxide) if it is present in excess, especially when the lecithin is not sufficiently dry [1]. SCFE process proposed as an alternative requires very high pressures for processing [3] and involves capital intensive equipment. Nonporous membranes tend to offer greater yield compared to the UF based membrane process owing to their greater retention of PL including probably their monomers. These membranes showed substantial reduction in color in soy lecithin, but increased intensity of color in rice bran lecithin suggests the necessity of including a conventional bleaching step.

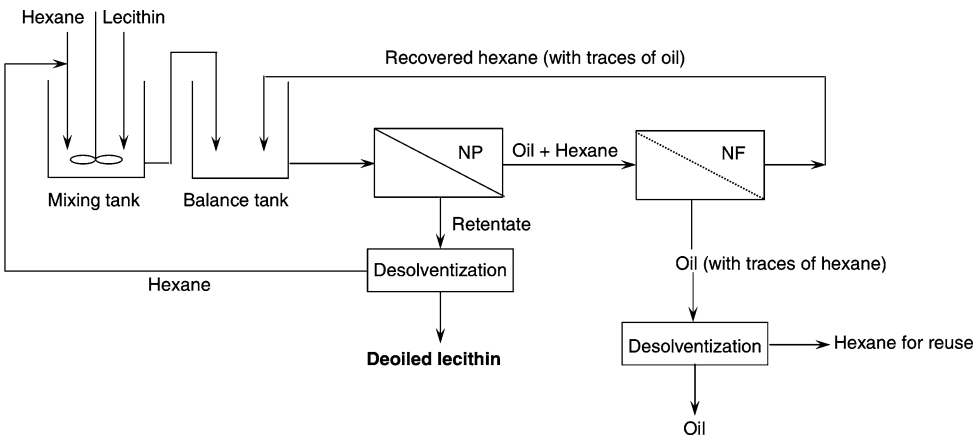

Fig. 4 Proposed scheme for deoiling lecithin

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