Evaluation of Surfactant-Aided Degumming of Vegetable Oils by Membrane Technology

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ABSTRACT: The first step in the process of vegetable oil refining is degumming, in which phospholipids and mucilaginous gums are removed that otherwise result in a low-grade oil. A membrane process is remarkably simple yet potentially offers many advantages in degumming. Studies were conducted on surfactant-aided membrane degumming with soybean and rapeseed oils in a magnetically stirred flat membrane batch cell with different types of microfiltration membranes. The reduction of phospholipids in soybean oil was in the range of 85.8–92.8% during the membrane process. The phosphorus content of membrane permeates of soybean oil was in the range of 20–58 mg/kg. Crude rapeseed oil contained higher amount of nonhydratable phospholipids and hence resulted in lower reduction in phospholipids, in the range of 66.4–83.2%. Addition of hydratable phospholipids could improve the efficiency of degumming in the membrane process without using any electrolyte, resulting in improvement of quality as well as quantity of the phospholipids.

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KEY WORDS: Degumming, lecithin, microfiltration, nonhydratable phospholipids, observed rejection, permeate flux, phospholipids, phosphatidylcholine, rapeseed oil, soybean oil.

Crude vegetable oil is processed into good-quality edible oil by a series of refining operations. The refining process removes or reduces, as much as possible, unwanted naturally occurring, as well as newly formed compounds, adjuncts, and introduced contaminants from the oil (1). Degumming, the first step in the refining process, removes phospholipids and mucilaginous gums. The presence of substantial amounts of phospholipids can lead to dark-colored oils, and they can also serve as precursors of off-flavors. Hence, the removal of nearly all of the phospholipids is very important for the finished oil quality.

Phospholipids are classified as hydratable and nonhydratable. The principal component of hydratable phospholipids is phosphatidylcholine (PC), whereas the nonhydratable phospholipids mainly consist of the calcium and magnesium salts of phosphatidic acid (PA) and of phosphatidylethanolamine (PE) (2). Water and acid degumming methods are commonly used in the industry. In the water-degumming process, the hydratable phospholipids are easily removed from the oil by treatment with water or steam, usually at higher temperatures (60–75°C). The resultant hydrated phospholipids become immiscible in the oil, and are separated, along with the gums, from the oil by settling, filtering, or centrifuging. During acid degumming, the hydratability of these salts is increased by addition of either phosphoric or citric acid. However, the lecithin obtained is inferior in quality. A number of acid degumming processes have been developed over the years such as the "superdegumming" and various other proprietary processes (3). Membrane degumming, countercurrent extraction with supercritical CO_2, and ultrasonic degumming have also been reported (2).

The membrane process is remarkably simple, offering many advantages over the conventional processes, namely, low energy consumption, ambient temperature operation, no addition of chemicals, and retention of nutrients and other desirable components (4). Many researchers have reported a micelle-enhanced ultrafiltration technique for degumming hexane–oil miscella (5–7). Lin *et al.* (8) have optimized a bench-scale degumming process for hexane–oil miscella using modified hexane-resistant membranes. Zhang *et al.* (9) screened 36 laboratory-made ultrafiltration membranes used for refining vegetable oils without added solvent, and one of the membranes achieved 93% separation of phospholipids in the pilot-scale. Our earlier studies showed that nonporous composite polymeric membranes selectively rejected phospholipids to the extent of 97.4–99.9%, the content being less than 240 mg/kg in the permeate without any pretreatment or dilution of crude oil with organic solvent (10–12). The near-complete removal of phospholipids indicated that the membranes rejected not only hydratable but also nonhydratable phospholipids (13). We reported that these membranes were also effective in rejecting pigments and oxidation products besides phospholipids while retaining tocopherols in the oil (14). However, the permeate flux needs improvement for industrial adoption.

Crude vegetable oils contain different types of phospholipids, namely, PC, phosphatidylinositol (PI), PE, PA and phytosphingolipids. PA and part of PE are present as Ca and/or Mg salts. Depending on the storage conditions of the oilseed, a part of the phospholipids can also be present as lyso- compounds. Among these different types of phospholipids, PC has the greatest hydration rate followed by PI. Hydrated PC furthermore can encapsulate 80% of other phos-

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pholipids (15). The level of PC naturally present in the crude oil is not sufficient for the complete removal of the phospholipids (which hydrate slowly) and therefore the effectiveness of the water degumming is generally low. Segers (16) reported that increasing the level of hydratable phospholipids in the crude oil improved the performance during the acid degumming process. However, there were no attempts to improve the performance by increasing the hydratable phospholipid content without the addition of any electrolyte. This approach, coupled with membrane technology, seems to offer a promising method. Hence in the present study, attempts were made to evaluate the efficiency of the membrane process, using porous polymeric membranes upon the addition of soybean lecithin, a natural surfactant, to the crude vegetable oils.

EXPERIMENTAL PROCEDURES

Materials. Crude soybean and rapeseed oils were kindly supplied by Nippon Lever B.V. (Shimidzu, Japan). Soybean lecithin was obtained from Wako Pure Chemical Industries, (catalog No. 124-00835; Osaka, Japan). Polyethylene microfiltration membranes with pore size of 30 nm were obtained courtesy of Tonen Chemical Corporation (Kawasaki, Japan). Hydrophobic polytetrafluoroethylene (PTFE) [pore sizes, 100 nm (catalog No. FVWP), 1000 nm (FAWP)] and polyvinylidene difluoride (PVDF) [pore size, 450 nm (HVHP)], and hydrophilic PTFE [pore size, 100 nm (JVWP)] microfiltration membranes were supplied by Nihon Millipore Co. Ltd. (Tokyo, Japan). The membranes were cut into circular discs (diameter 7.5 cm, effective area 32 cm^2) before being fitted into the membrane cell.

Feed preparation. A known quantity of lecithin was dissolved in 100 g of crude oil, to which a predetermined quantity of water was added. The mixture was agitated for 1 h using a magnetic stirrer before it was charged into the membrane cell.

Laboratory membrane unit. Experiments were conducted using a flat membrane test cell (model C40-B; Nitto Denko, Kusatsu, Japan) under a nitrogen atmosphere. The cell was placed on a magnetic stirrer, and the magnetic spin bar fitted into the cell provided the agitation. The cell and magnetic stirrer were placed in a thermostatically controlled incubator. Detailed description and schematic diagram of the experimental setup is given elsewhere (12). The required pressure was applied by adjusting the pressure regulator of the nitrogen cylinder. The unit was operated in batch mode by charging the cell with 100 g of crude oil. The pressure, temperature, and stirrer spin bar speed were maintained at 0.3 MPa, 40°C, and 400 rpm, respectively. Permeate was collected through a port beneath the membrane support and the experiment was stopped when permeate collection reached approximately 50 g.

Analyses. The phosphorus and calcium contents were determined using inductively-coupled plasma–atomic emission spectrophotometer; (model UOP-1; Kyoto-Koken Inc., Kyoto, Japan). Phosphatide or phospholipid equivalent was calculated by multiplying the phosphorus content by a factor of 30 (17). The magnesium content was determined using an atomic absorption spectrophotometer (model AA-781; Nippon Jarrel-Ash, Kyoto, Japan). Determination of individual phospholipids in oil samples was carried out by high-performance liquid chromatography (HPLC) using AOCS method, Ja 7b-91 (17).

Performance parameters. The performance of the degumming process was expressed in terms of percentage reduction of each phosphorus-related component (Ca and Mg) and phosphorus or phospholipid content in the processed oil. Percentage observed rejection and permeate flux are also included since the evaluation of the technique has been done using membrane technology.

The total reduction (TR) is the overall reduction of each component in the feed material compared to the processed oil. The effective reduction (ER) is the actual reduction of each component in the crude oil compared to the processed oil. The two parameters together give a better understanding of the role of added hydratable phospholipids in the degumming process than individually. The TR and ER were calculated as in Equations 1 and 2,

$$\mathrm{TR} = \frac{100(C_F - C_P)}{C_F}(\%) \quad [1]$$

$$\mathrm{ER} = \frac{100(C_C - C_P)}{C_C}(\%) \quad [2]$$

where C_C, C_F, and C_P are the contents of each component (mg/kg oil) in the crude, feed, and permeate oils, respectively.

The rejection is referred to as observed rejection to indicate that in a batch process the feed concentration constantly changes during the process. The observed rejection (R_o) for each permeate collected was determined using Equation 3 by assuming that rejection was constant during each batch of the experiment (18),

$$R_o = \frac{100[\ln(C_{R,f}/C_{R,i})]}{\ln(W_i/W_f)}(\%) \quad [3]$$

where $C_{R,i}$ and $C_{R,f}$ are the initial and final contents of each component in the retentates (mg/kg oil), and W_i and W_f are the initial and final weights of retentate (kg oil), respectively.

RESULTS AND DISCUSSION:

Optimization of lecithin and water requirement. The phospholipid rejections by microfiltration membranes with pore sizes of 10, 20, and 30 nm were 12.1, 9.8, and 8.7%, respectively, without any pretreatment of crude soybean oil (12). The low rejection of phospholipids indicated that most of the phospholipid reverse micelles formed in the system were smaller than the pore size of the membranes.

Present experiments conducted with crude soybean oil with 0.5 and 1.0% addition of water showed that polyethylene membrane (30 nm pore size) rejected phospholipids to the extent of 85.9 and 87.2%, respectively. The corresponding phosphorus contents in the permeates were 56 and 51 mg/kg. In the conventional water degumming process (centrifugal method), the phosphorus content of an oil of average quality is reduced to a range between 60 and 200 mg/kg.

TABLE 1
Phosphorus Contents of Crude, Feed, and Membrane-Processed[a] Soybean Oil

Sample description	Lecithin addition (%)	Water addition (%)	P (mg/kg)	Phospholipids R_0 (%)	Phospholipids TR (%)	Phospholipids ER (%)
Crude			368			
Feed	2.1	1	601			
Permeate			57	93.0	90.5	84.5
Feed	4.0	1	760			
Permeate			20	98.1	97.3	94.5
Feed	4.0	2	760			
Permeate			22	97.9	97.1	93.9
Feed	6.2	1	958			
Permeate			28	97.9	97.1	92.5

[a]Membrane: polyethylene (PE); pore size, 30 nm. R_0, observed rejection; TR, total reduction; ER, effective reduction.

In order to improve the performance further, the effects of the addition of small quantities of lecithin to the crude soybean oil apart from water added for hydration were investigated. Phosphorus contents of crude, feed, and permeate oils; total reduction (TR), effective reduction (ER), and observed rejection (R_0) of phospholipids for four different levels of lecithin and water addition are presented in Table 1. In all cases, the ER of phospholipids was high (84.5–94.5%). At a constant level of water addition (1%), when the lecithin addition was increased from 2.1 to 4.0%, the ER of phospholipids increased from 84.5 to 94.5% and phosphorus content in the permeate decreased from 57 to 20 mg/kg. However, when the lecithin addition was increased to 6.2%, there was a marginal decrease in the ER of phospholipids from 94.5 to 92.5% accompanied by a slight increase in the phosphorus content in permeate from 20 to 28 mg/kg. At a constant level of lecithin addition (4.0%), reductions in phospholipids and phosphorus content in permeates with 1 and 2% water addition were not significantly different. Hence, the addition of 4% lecithin and 1% water was employed for most of our studies on crude oil quality and evaluation of different types of membranes.

Effect of crude oil quality on degumming. The phosphorus, calcium, and magnesium contents and their reduction are presented in Table 2. The phospholipid contents of crude soybean and rapeseed oils used in the study were in the range of 0.84–2.0% and 0.79–1.13%, respectively, which were similar to the usual range of 1.5–2.1% in soybean oil (1) and 1.0–1.5% in rapeseed oil (19). During membrane processing

TABLE 2
Phosphorus, Calcium, and Magnesium Contents in Membrane Permeates of Different Grades of Crude Soybean and Rapeseed Oils[a]

Sample description	P (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	TR (%) P	TR (%) Ca	TR (%) Mg	ER (%) P	ER (%) Ca	ER (%) Mg
Soybean									
Crude	279	52	40						
Feed	810	80	83						
Permeate	20	16	6	97.5	80.0	93.0	92.8	68.9	85.6
Crude	302	52	46						
Feed	770	75	80						
Permeate	43	20	9	94.4	73.2	89.0	85.8	61.4	80.8
Crude	465	80	54						
Feed	896	126	82						
Permeate	44	41	11	95.1	67.3	86.8	90.6	48.7	79.8
Crude	666	98	77						
Feed	1190	127	107						
Permeate	58	41	18	95.2	67.9	83.4	91.3	58.3	76.7
Rapeseed									
Crude	263	150	40						
Feed	751	156	76						
Permeate	88	77	16	88.2	50.5	78.8	66.4	48.5	59.8
Crude	345	148	64						
Feed	848	160	95						
Permeate	94	73	24	88.9	54.3	74.8	72.8	50.6	62.7
Crude	375	128	62						
Feed	987	186	112						
Permeate	63	67	16	93.6	64.0	85.5	83.2	47.7	73.9

[a]Lecithin addition, 4%; water addition, 1%. Membrane, polyethylene; pore size, 30 nm. For abbreviations see Table 1.

TABLE 3
Reduction in Phospholipids in Industrially Water-Degummed Soybean Oils[a]

Sample description	Lecithin addition (%)	Water addition (%)	P (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	TR (%) P	TR (%) Ca	TR (%) Mg	ER (%) P
Degummed			219	67	43				
Feed	4.3	1.0	825	93	80				
Permeate			64	39	17	92.3	58.0	79.0	70.9
Degummed			141	92	38				
Feed	8.2	2.0	1080	159	103				
Permeate			62	63	18	94.3	60.3	82.8	56.0

[a]Membrane, polyethylele; pore size, 30 nm. For abbreviations see Table 1.

the rejection of phospholipids remained nearly constant, the values being 95.9–98.2 and 91.3–95.3% in soybean and rapeseed oils, respectively. In soybean oil, the ER of phospholipids remained more or less same, whereas the ER of phospholipids in rapeseed oil varied with the amount of phospholipids and the quality or grade of crude oil (Table 2). The phosphorus content in the permeate ranged from 20 to 58 mg/kg in soybean and 63–94 mg/kg in rapeseed oils.

The added lecithin contains relatively fast-hydrating phospholipids, and upon hydration membranes readily rejected them. This is evident from the fact that added lecithin was totally rejected when the experiment was conducted with refined soybean oil. The concentration of slowly or less hydratable phospholipids in the crude oil, namely, PE, PA, phytosphingolipids, and calcium and magnesium salts of PE and PA, may affect the ER of phospholipids and thereby the phosphorus content in the permeate. Magnesium was reduced to a greater extent than calcium content, implying that magnesium salts are relatively more easily hydratable than calcium salts of phospholipids. In rapeseed oil, the rejection of phospholipids was lower compared to soybean oil, probably because of the presence of greater amounts of nonhydratable salts in the crude oil as indicated by the higher contents of calcium and magnesium. The degumming performance depended not only on the total amount of phospholipids but also on the proportion and nature of nonhydratable phospholipids present in the crude oil.

Degumming performance with industrially water degummed soybean oil. Two different grades of degummed soybean oil, differing in phospholipid content, were treated according to the present membrane degumming process; and the reduction in phosphorus, calcium, and magnesium contents are presented in Table 3. The ER in phospholipid content was 70.9% when the lecithin and water additions were 4.3 and 1.0%, respectively. When these additions were nearly doubled for the degummed oil having the higher proportion of calcium and magnesium salts of phospholipids, the ER was only 56.0%. Furthermore, the permeates of the degummed soybean oils contained slightly higher amounts of phospholipids compared to the permeates obtained from crude oils (Tables 2,3). This may be due to the fact that the major portion of the phospholipids present in the water-degummed oil is very slow to hydrate. During the water-degumming process, readily hydratable phospholipids are removed, and the degummed oil will contain mainly nonhydratable phospholipids. The molar proportion (Mg + Ca)/P was reported to be greater after than before industrial water-degumming (20). The calculated molar proportion (Mg + Ca)/P values of the two grades of water-degummed oils were 0.5 and 0.9, whereas it was about 0.3 for the four different grades of crude soybean oils presented in Table 2. The higher proportions of calcium and magnesium to phosphorus contents also indicate greater amounts of nonhydratable phospholipids present in the industrially degummed oils, affecting the degumming performance. Hence, it is desirable to apply this membrane process directly to the crude oil rather than water-degummed oil from the standpoint of process economics.

Role of fast-hydrating phospholipids. The individual phospholipids in crude, feed, and membrane-processed oils and the reduction of PC and phospholipids are presented in Table 4. The hydration rates of different phospholipids, PC, PI, PE and PA, were reported to be in the magnitude of 100, 44, 16, and 8.5 on an arbitrary scale of 100 (15). Calcium salts of PE and PA had very poor hydration rates of less than 1 on the above scale. Segers and van der Sande (15) further reported that after hydration fast-hydrating phospholipids also had the ability to encapsulate other phospholipids. HPLC analysis of crude oils showed that the PC content was very low, 5.7 and 1.3% of the total phospholpids in soybean and rapeseed oils, respectively (Table 4), and probably not enough for the complete removal of total phospholipids. Slow-hydrating phospholipids, PE and PA, contributed 35–38% of the total phospholipids. Although PI content was not determined, it is expected to be somewhere between PE and PA. By taking all this into consideration, other lyso-compounds contributed about 37–46% of total phospholipids. Segers (16) had reported that increasing the level of hydratable phospholipids in the crude oil improved removal of impurities during acid degumming process. PA or PE becomes more hydratable in the oil due to their interaction with PC than by themselves (21). In the present membrane process, the quantity of fast-hydrating phospholipids is increased by adding lecithin before hydration; and subsequent membrane treatment resulted in higher reduction of phospholipids without use of any other electrolyte. To increase the PC content in the feed, PC-enriched lecithin was used in place of lecithin. PC-enriched

TABLE 4
Individual Phospholipids in Crude, Feed, and Permeate Oils[a]

Sample description	Lecithin addition (%)	Water addition (%)	Phospholipids (mg/kg) PE	PA	PC	Total	TR (%) PC	ER (%) Phospholipids
Soybean								
Crude			1272	2921	627	11010		
Feed[b]	1.3	1.0	—[c]	—	—	—		
Permeate			793	95	159	1410	—	87.2
Feed[b]	2.1	1.5	1549	4117	1925	16380		
Permeate			1197	332	23	1260	98.8	88.6
Rapeseed								
Crude			848	1414	86	6480		
Feed[d]	4.1	1.0	1083	5212	727	19890		
Permeate			939	1102	11	3240	98.5	50.0
Feed[b]	2.1	1.5	1028	2721	1361	12360		
Permeate			878	764	1	3090	99.9	52.3

[a]Membrane, polyethylene; pore size, 30 nm.
[b]PC-enriched lecithin addition.
[c]—not determined.
[d]Lecithin addition, PE, phosphatidylethanolamine; PA, phosphatidic acid; PC, phosphatidylcholine; for other abbreviations see Table 1.

lecithin was obtained by evaporating the ethanol-soluble portion of the acetone-insoluble fraction of soybean lecithin. When PC-enriched lecithin was used in the membrane experiments, the addition required could be reduced. In rapeseed oil, addition of 2.1% enriched lecithin and 4.1% lecithin gave more or less similar performance in terms of ER as well as phosphorus content in the permeate. In all the runs, the membrane rejected almost the entire quantity of PC, and TR was above 98.5%.

Performance of different membranes. The phosphorus, calcium and magnesium contents of crude oils, feed solutions, and the membrane permeates are presented in the Table 5. The microfiltration membranes made from different materials, namely, polyethylene, PTFE and PVDF, and having different pore sizes for a particular feed material exhibited very similar behavior in rejecting phospholipids. Hydrophobic membranes are generally preferred for nonaqueous applications such as oil processing. However, hydrophilic PTFE membranes with 100 nm pore size not only rejected phospholipids to the same extent but also had similar flux values as that of hydrophobic membranes having the same pore size. The permeate flux of soybean oil increased by three- to fourfold when the pore size of the membrane was changed from 30 to 100 nm. Above 100 nm pore size, there was apparently

TABLE 5
Rejection Performance of Different Types of Membranes[a]

Material[b]	Membrane Nature	Pore (nm)	Sample description	P (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	R_0 (%) P	Ca	Mg	Flux (kg/m^2·h)
			Soybean							
			Crude	279	52	40				
			Feed	810	80	83				
PE	Hydrophobic	30	Permeate	20	16	6	98.2	84.8	94.9	4.5
PTFE	Hydrophobic	100	Permeate	21	17	6	98.2	84.3	94.7	19.4
PTFE	Hydrophilic	100	Permeate	21	15	6	98.1	85.5	94.9	19.0
			Crude	302	52	46				
			Feed	1010	95	93				
PTFE	Hydrophilic	100	Permeate	36	22	11	97.4	82.0	91.1	17.3
PVDF	Hydrophobic	450	Permeate	38	22	10	97.3	82.5	92.0	16.4
PTFE	Hydrophobic	1000	Permeate	44	27	10	96.8	78.1	91.7	18.9
			Crude	666	98	77				
			Feed	1190	127	107				
PE	Hydrophobic	30	Permeate	58	41	18	96.5	74.7	87.5	4.2
PTFE	Hydrophobic	100	Permeate	57	39	17	96.5	76.2	87.8	13.4
			Rapeseed							
			Crude	345	148	64				
			Feed	848	160	95				
PE	Hydrophobic	30	Permeate	94	73	24	91.8	62.6	80.6	5.2
PVDF	Hydrophobic	450	Permeate	96	78	23	91.6	59.6	81.1	31.6

[a]Lecithin addition, 4%; water addition, 1%.
[b]PE, polyethylene; PTFE, polytetrafluoroethylene; PVDF, polyvinylidene difluoride; R_0, observed rejection.

TABLE 6
Performance During Semicontinuous Experiments with Soybean Oil

Expt.[a] no.	Crude oil (g)	Lecithin addition (g)	Water addition (g)	Sample description	P (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Ro (%) P	Ro (%) Ca	Ro (%) Mg	ER (%) P
				Crude	279	52	40				
A_1	100	4.4	1.0	Feed	—[b]	—	—				92.8
				Permeate	20	—	—	—	—	—	
A_2	50	0.0	0.0	Feed	—	—	—				74.4
				Permeate	71	—	—	—	—	—	
A_3	50	0.0	0.0	Feed	—	—	—				26.2
				Permeate	206	—	—	—	—	—	
B_1	100	4.1	1.0	Feed	745	80	75				90.0
				Permeate	28	26	6	97.3	74.6	94.2	
B_2	50	1.1	0.5	Feed	384	63	50				89.1
				Permeate	30	28	10	94.2	62.8	84.4	
B_3	50	1.1	0.5	Feed	384	63	50				85.8
				Permeate	40	36	15	92.4	51.2	76.7	
C_1	100	4.1	1.0	Feed	770	75	80				84.6
				Permeate	43	20	9	95.9	79.2	91.8	
C_2	50	0.0	1.0	Feed	—	—	—				85.6
				Permeate	40	24	11	—	—	—	
C_3	50	0.0	1.0	Feed	—	—	—				84.8
				Permeate	42	28	13	—	—	—	

[a]Subscripts 1, 2, and 3 denote the order of batch run in each semicontinuous experiment.
[b]—, not determined; membrane, polyethylene; pore size, 30 nm. For abbreviations see Tables 1 and 5.

no change with soybean oil in the permeate flux. Rapeseed oil gave higher permeate flux than soybean oil, and the increase was about 1.2- and 1.9-fold with membranes having pore sizes 30 and 450 nm, respectively. The permeate flux obtained appears to be suitable for industrial adoption. The rejection of phospholipids was dependent on the type and quality of the crude oil as well as composition of phospholipids present in the feed.

Semicontinuous trials on membrane degumming with soybean oil. The results from a few semicontinuous trials, conducted in order to reduce the quantity of hydratable phospholipids required in the membrane process and the performance indicators, namely ER and percentage rejection, are presented in Table 6. During the trials, after 50 g of oil had permeated through the membrane, the cell was depressurized, and 50 g of fresh crude oil was added to the retentate before the unit was restarted. This step was continued to obtain three permeates. The phosphorus contents in the first three successive permeates collected were 20, 71, and 206 mg/kg, and the corresponding ER of phospholipids were 92.8, 74.4, and 26.2%, respectively. The gradual decrease in ER of phospholipid is probably due to unavailability of sufficient water for hydration of the phospholipids present in the fresh crude oil added. In another trial, addition of 1.1 g of lecithin, 0.5 g of water, and 50 g of crude oil after each permeate collection improved the performance. The phosphorus contents in the first three permeates were 28, 30, and 40 mg/kg, and the corresponding ER of phospholipids were 90.0, 89.1, and 85.8%, respectively. In yet another trial, the addition of 1 g of water along with 50 g of crude oil after each permeate collection resulted in consistent performance. The phosphorus contents in the first three permeates were 43, 40, and 42 mg/kg and the corresponding ER of phospholipids were 84.6, 85.6, and 84.8%, respectively. The addition of water increased the availability of water for hydration of phospholipids present in the subsequent feed and resulted in consistent reduction of phospholipids in the successive runs.

Segers (16) had reported that increasing the level of hydratable phospholipids in the crude oil improves the oil purification in the conventional acid degumming process. From the present findings, it is evident that the addition of hydratable phospholipids increased the efficiency of degumming in the membrane process by enhancing the encapsulating ability even without using any electrolyte. This approach will lead to improvements in quality as well as the quantity of the lecithin obtained in the process. Our evaluation of this approach has been carried out on a dead-end membrane filtration cell. A few runs on centrifugation studies also gave similar results. The information gained from our studies could enhance our understanding of degumming process, which consequently may lead to simpler crude oil refining. However, for commercial exploitation, further investigation is required on pilot- scale membrane units as well as other conventional separation operations like centrifugation.

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