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Research Paper

Extraction of Vancomycin Antibiotic from Water using Green Emulsion Liquid Membrane Based on Sunflower Oil

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Keywords

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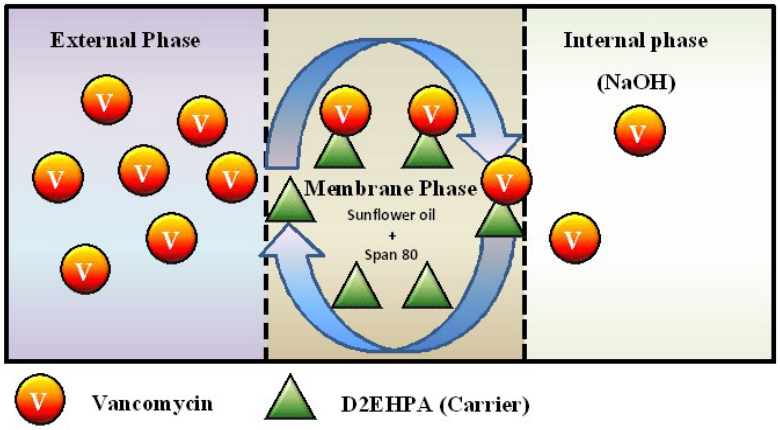
Highlights

- A green method was introduced for removing Vancomycin from water.
- Sunflower oil was employed in preparing ELM.
- Carrier (D2EHPA) facilitated extraction of drug was successfully conducted.
- ELM prepared by sunflower oil was able to completely remove Vancomycin from water.

Graphical abstract



Abstract

The toxicity and carcinogenic effect of many drugs including antibiotics have brought up an environmental worry in the recent years. The current study examined a green emulsion liquid membrane (ELM) as an environmentally-friendly method for extracting Vancomycin antibiotic from its aqueous solutions. The main value of the idea is to reduce environmental risks of employing common unsafe organic solvents applied as diluent in the ELM process. For this purpose, the raw sunflower oil was employed to prepare ELM. An organic phase including the sunflower oil (diluents), Span 80 (emulsifier) and bis(2-ethylhexyl) phosphoric acid (D2EHPA) carrier were mixed with internal aqueous phase (stripping phase) containing NaOH. The results confirmed that almost 100% of Vancomycin was successfully extracted at the optimum conditions affecting parameters for preparing the membrane. The extraction percentage and emulsion stability were acceptable for the feeds with wide range of pH from 5-9 and NaCl concentration from 0-5 g/L. Moreover, a recovery percent of ~70% was achieved for the captured Vancomycin when the emulsion was broken.

1. Introduction

The presence of antibiotics in aquatic ecosystems and their probable risks in the environment have attracted especial attention in the last decade. Studies have shown that there are different concentrations of antibiotics in the urban wastewaters especially when expose to the hospital wastes, pharmacy wastewater treatment plants, rivers, surface, and ground water. Since a small amount of antibiotic drug is absorbed into the body, it can be easily found in the urine and feces and can enter into the aqueous environments via the urban wastes [1]. The yearly intake of antibiotics is between 100 to 200 thousand tons for human use [2]. Also, agriculture also utilizes equal or larger amounts [3,4]. The presence of antibiotics in the environment has been proved in the literature [5]. The increasing resistance of bacteria to the antibiotics may transfer to the other kinds of them when such medicines temporarily discharged to the environment [1,2]. The researchers proved the existence of low amounts of antibiotics in water and their toxicity [6] due to bioaccumulation [7,8].

Vancomycin is a glycopeptide antimicrobial agent which has been used

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for over 30 years for the treatment of severe infections by gram-positive organisms [9,10]. Because of the increasing resistance of bacteria (such as staphylococci) to the beta-lactam antibiotics, the importance of Vancomycin existence in the environment has increased [9,11].

The effluent from the pharmaceutical industries can be extracted and recovered by variety of methods, such as biological and chemical treatments, coagulation-flocculation processes, adsorption, membrane filtration, ion-exchange, electrochemical decomposition, and etc. [12,13]. However, these methods are not adequately efficient for the removal of any organic compounds [14,15]. The incomplete removal of pharmaceuticals results in environmental risks when the wastes discharged to the environment without efficient removal of such substances. From the literature, the removal efficacy of bioremediation and physicochemical processes reaches the maximum yield of 60% [16,17]. Similarly, the UV irradiation was poorly acted because of its inferior oxidation ability [18]. On the other hand, the elevated costs of advanced oxidation processes was assumed as a weak point of these methods [8,15,19-21]. Recently, the liquid emulsion membrane (ELM) method has been introduced as a simple and effective method for the separation of low amounts of various organic/inorganic compounds from the aqueous solutions. First using of ELM process was reported by N. Li in 1968 for the separation of hydrocarbons [22]. According to the literatures, ELM separation technique suggests some advantages compared with the other commonly used ones such as facile operation, great efficiency and selectivity, simultaneous removal and reclamation process [23, 24]. The ELM is defined as an emulsion based liquid-liquid extraction in which the emulsion membrane is dispersed into the feed solution having the target substances. Through the carrier assisted ELM process, the carrier in the organic phase reacts with solute in the feed phase to transfer the solute-carrier complex into the internal phase. The target substance is then transferred into the stripping phase via a chemical reaction with a stripping agent existed in the internal phase. The essential weak point of ELM might be the poor stability of the emulsion leading to the swelling of the emulsion micelles, their breakage , and decrease in the ELM extraction efficiency [25].

Another essential factor in the ELM process is the diluent type. A desirable diluent should possess low viscosity and the least miscibility with aqueous phase. Being non-toxic, non-corrosive, low cost and highly capable to selectively extract the desired species are the other characteristics of a suitable solvent in ELM process [26]. The most of ELM processes apply liquid light alkanes such as kerosene (C8-C17) [27-30], heptane [31], and hexane [32-34] which are known as toxic, non-degradable, volatile and flammable compounds. Although the high efficiency of solute extraction is achievable for the abovementioned diluents, they are not environmentally safe. Therefore, to ensure the environmental safety of ELM process along with lower risk of secondary pollution caused by these solvents, the green solvents can be replaced. The edible vegetable oils are considered as the green diluents for the ELM process in extracting various compounds (Table 1).

There are also reports referring drug extraction using the ELM process in the recent studies [24,44,45] in which the diclofenac, amoxicillin, and tetracycline were removed by ELM based on commonly used hydrocarbon diluents. Considering the probable health risks of applied alkanes and their derivatives, vegetable oil has been introduced as one of the suitable replacements for the commonly used petroleum-based solvents in the ELM process. The various sources herbal oils, including palm, soybean, corn, coconut, peanuts, and sunflower might be utilized for this purpose [14]. Based on our knowledge, removing antibiotics through a green ELM process has not been reported. Accordingly, the current study examines the utilization of edible oil in ELM formulation for the elimination of Vancomycin from aqueous solution. Vancomycin was selected due to having large molecule structure which might potentially make the extraction more difficult. All the main affecting parameters such as surfactant portion, internal phase composition, the time needed for emulsification, contact time for extraction, carrier agent concentration, volume ratio of the internal phase to the organic phase (I/O), volume ratio of the emulsified membrane to the feed phase (TR) as well as the emulsion breakage were studied to obtain the best conditions of drug extraction using the green ELM.

2. Materials and methods

2.1. Chemicals

Vancomycin powder for infusion with the chemical structure depicted in Figure 1 was obtained from Exir Pharma Co, Iran. NaOH, di-(2-ethylhexyl) phosphoric acid (D2EHPA, 95%) was from Merck, Germany. Span 80 surfactant was purchased from Merck, Germany as well. The raw home-extracted sunflower oil prepared by a local producer in Kermanshah, Iran was used as the diluent without any purification. The sunflower seeds were compressed to obtain raw oil and no treatment operation was conducted on the extracted oil. This means that the oil contains all the usual components of pristine sunflower oil. Also, all the other chemicals were used without further purification.

2.2. ELM preparation and separation process

The solution prepared as the internal phase contained different concentrations of NaOH (0.01 to 0.2 M) in distilled water as the stripping agents. The organic phase creating the membrane was prepared by adding the certain amount of Span 80 as the emulsifier and D2EHPA as the carrier in the organic solvent. The emulsion was created by dropwise addition of the internal phase solution into the sunflower oil under the fast stirring (3000 rpm) for 10 min. In addition to observations, it was found in many literatures that the procedure resulted in a stable emulsion. For all the experiments a fresh emulsion was prepared each time. For extraction of target substance (Vancomycin), 20 ml of the prepared green ELM was added into the 200 mL vessel containing Vancomycin aqueous solution, and the mixture was stirred by magnetic stirrer at 350 rpm for 60 min. The sampling was performed with a syringe during the certain time intervals after the agitation beginning. At the end of the contact time, the mixtures were decanted into the separation funnel and left for about 30 min to achieve a complete phase separation. The breakage of emulsion was also tested. This was conducted by detecting the volume of emulsion prior to the extraction and comparing with the volume after that. The antibiotic concentration in water was determined using the spectrophotometric method. The double repeated experiments were conducted to investigate different variables (stripping solution, emulsifier and carrier concentrations, contact time, I/O ratio, and TR. The studied variables and their values are illustrated in Table 2.

2.3. Feed phase preparation

As mentioned before, Vancomycin is widely used for the treatment of serious infections by gram-positive organisms. Due to the existence of this antibiotic at low concentrations in real wastes, the feed phase was synthetized by dissolving Vancomycin powder for injection in distilled water to produce a 1 mg/L of Vancomycin solution (The existence of more than 1000 ng/L of this antibiotic has been reported in the literature [46]). It is worth mentioning that Vancomycin possesses relatively large molecules compared with other drugs extracted by ELM. Therefore, it is a favorable choice to examine the ability of unconventional diluent (raw sunflower oil) in the ELM based extraction of similar antibiotics and drugs.

Table 1
List of reported results for contaminant removal using nontoxic oil liquid membranes.

Vegetable oil organic solvent		Solute	Extraction (%)	Reference
Diluent	**Carrier**			
Paraffin oil	-	Cationic dye	> 95%	[35]
Palm oil	tricaprylmethylammonium Chloride(TOMAC)	Cr(VI)	97%	[36]
Palm oil	tridodecylamine (TDA)	Reactive dye	90%	[37]
Rice bran oil	Aliquat 336	lactic acid	> 95%	[38]
Palm oil	-	Phenol	~ 90%	[39]
Corn oil, canola oil, sunflower oil, soybean	tributylphosphate (TBP)	Cu(II)	100%	[40]
Palm oil	tri-n-octylmethylammonium chloride	Cr(VI)	99%	[41]
Sunflower oil, Corn oil, palm oil	Aliquat 336	Cd(II)	98.6%	[42]
Rice bran oil	tridodecylamine (TDA)	Cr (VI)	~ 97%	[43]

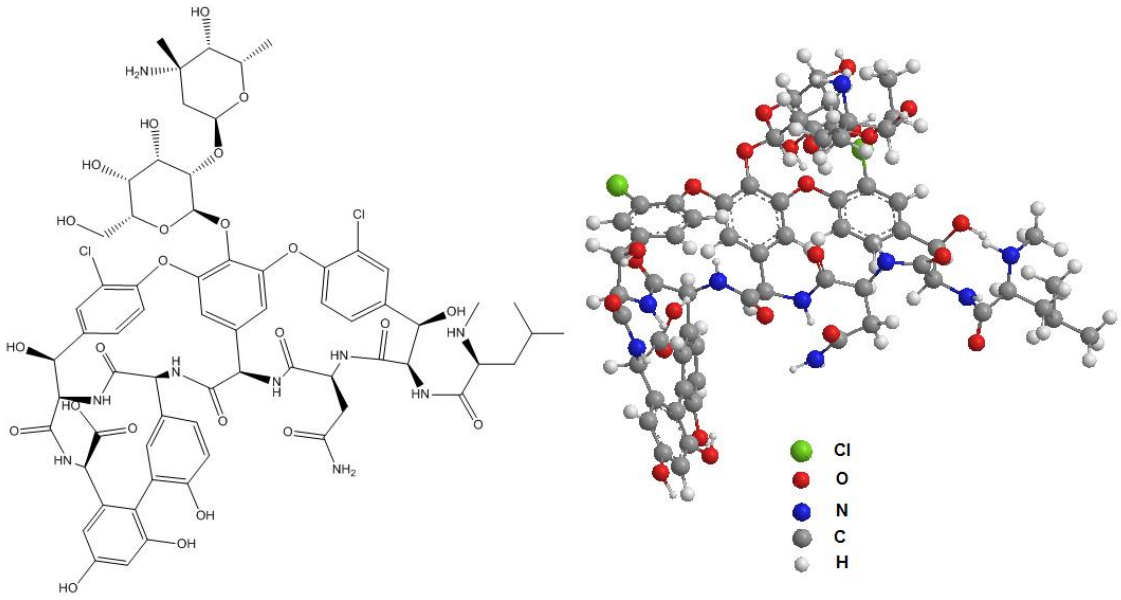

Fig. 1. 2D and 3D chemical structure of Vancomycin.

The real pharmaceutical wastes might contain various substances making the feed conditions different from the synthetic waste on account of pH and ionic strength. Accordingly, the effect of pH and concentration of salt also were examined. 5, 6, 7 and 9 pHs and 0, 0.1, 1 and 5 g/L NaCl were applied to discover the extraction efficiency in various feed conditions.

2.4. Analysis method

The amount of Vancomycin was determined by Spectrophotometric method (PG instruments, UK, Model: T80 ++) at 280 nm wavelength. For determination of Vancomycin concentration in the treated water, sampling of treatment mixture was conducted using a syringe and then the settled aqueous phase was examined using UV spectrophotometer. The Vancomycin recovery efficiency of the prepared ELMs also was explored via breaking the emulsion after treatment stage and measuring the concentration of Vancomycin trapped in membrane phase. In this case, the emulsion was let to be isolated from the mixture and then poured in a container to be shocked by agitation at 100 rpm and 50°C. After the demulsification process, the concentration of extracted Vancomycin was measured. The employed equations for calculating Vancomycin removal, membrane breakage, and recovery percent were as stated in Eqs. (1-3), respectively:

$$Extraction\ (\%) = \frac{C_i - C_f}{C_i} \times 100\% \quad (1)$$

$$Breakage\ (\%) = \frac{V_i - V_f}{V_i} \times 100\% \quad (2)$$

$$Recovery\ (\%) = \frac{C_{int}}{2TRC_i} \times 100\% \quad (3)$$

where, C_i and C_f are the Vancomycin concentration in initial feed solution and its final concentration after treating with green ELM, respectively. V_i is the volume of emulsion prior to the extraction and V_f is the final volume of emulsion after that. C_{int} is the concentration of Vancomycin in the internal phase after extraction and *TR* is the treatment ratio i.e., the volume ratio of the emulsion to the external phase.

3. Results and discussion

3.1. Emulsion characterization

In the green ELM processes, the preparation of a stable emulsion as well as the study of optimal conditions to obtain a stable emulsion is very vital. Figure 2 shows the emulsion stability and Vancomycin extraction versus the emulsification time (5- 12 min). The experiments were conducted by the distilled water as the external phase and the detailed conditions depicted in Figure 2. For less than 7 min duration of emulsification process, the emulsion is not stable enough and would break during the extraction process. As previously reported, the insufficiency of emulsification time will result in a higher rate of emulsion breakage due to the swelling of globules [35,39]. The swelling phenomenon decreases extraction efficiency. Having a larger size leads to coalescence of the droplets and subsequently more breakage. In contrast, for a long emulsification time, despite having smaller globules and high mass transfer surface, the enhanced internal shearing stress caused by a large number of small droplets in volume unit resulted in a partial decrease in extraction efficiency. Also, the longer emulsification time makes a thicker the emulsion. A highly viscous emulsion leads to a slower extraction rate based on literature [47]. Consequently, emulsification duration of 10 min with the breakage rate of 5% and the drug extraction of 100% was selected for subsequent experiments. The emulsion appearances after various times are shown in Figure 3. As it can be observed, the emulsion is stable until 40 minutes, after which instability converted into biphasic form. The results indicated that the sunflower oil produced a stable emulsion.

3.2. Influence of surfactant content

Surfactant concentration is the other imperative factor on the ELM stability, the extraction rate, and the emulsion breakage. The consequence of surfactant concentration on the efficacy of Vancomycin extraction as well as the emulsion breakage is depicted in Figure 4. The operating parameters were constant and same as those used formerly and the emulsification time was equal to 10 min. The results imply that the cleavage of emulsion as well as the static resistance of emulsion strongly depends on the surfactant concentration. Based on the Figure 4, higher surfactant concentration (up to 5%) enhances the stability of emulsified membrane as well as the extraction rate. The formation of larger emulsions at lower concentrations (1%) decreases the rate of extraction. In fact, by enlarging the dimensions of emulsion globules, the amount of the mass transfer rate is reduced. This caused by that the insufficient surfactant amount which affects complete encapsulation of the entire internal phase leading to emulsion breakage. When the Span 80 concentration was elevated, the created micelles became smaller, predictably. Increasing the surfactant content to 5% increases the viscosity of the prepared ELM, which produces the mayonnaise-like emulsion with a decreased rate of mass transfer [33,35]. Although, a high amount of surfactant can increase the swelling probability because of the high osmotic pressure. Hence, the surfactant concentration was fixed at 3 wt.% for the later experiments.

Table 2
The evaluated parameters in the Vancomycin extraction using ELM process.

Parameter	range
Emulsification time (min)	5, 7, 10, 12
Surfactant concentration (%wt)	1, 3, 5
Contact time (min)	2, 5, 7, 9
Carrier concentration (M)	0.02, 0.03, 0.05, 0.06
Treatment ration (TR)	1:3, 1:5, 1:7
I/O ratio	1:2, 1:1, 2:1
Internal phase concentration (M)	0.01, 0.05, 0.1, 0.2

3.3. Influence of contact time

Figure 5 indicates the Vancomycin removal and emulsion stability by different contact times. According to this figure, the Vancomycin extraction percentages were not meaningfully altered. The Vancomycin removal was more than 95% for 5 min, 7 min, and 9 min. This can be well explained by Fick's second law of diffusion. Accordingly, a final equilibrium would be prevailed between the dissolved compound in the feed phase and the extracting solvent [48]. Therefore, too much contact time would not be effective to extract additional Vancomycin. However, the results for the breakage of emulsion is some different. As it can be seen, the breakage ratios decreased from 24% to 11% when the contact time altered from 5 to 2 min. In fact, the globule size became smaller by increasing the contact time and hence, it the stability of the emulsion promotes. By additional increment in contact time up to 7 min, the breakage percent has gradually increased, and the 43% breakage occurred at the 9th minute. This is because of lengthening the extraction time, by which more water enters into the internal phase of emulsion leading to the rupture of the emulsion [49]. From the results, 5 min of extraction time would be the appropriate time for achieving the minimum breakage and efficient extraction of Vancomycin into the internal phase.

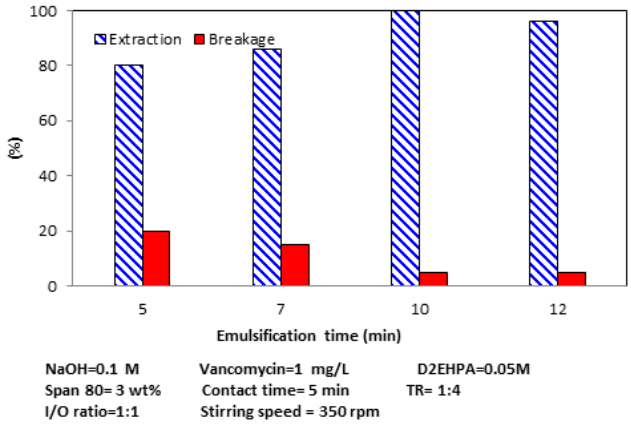

Fig. 2. Emulsion stability and extraction performance at various examined emulsification times.

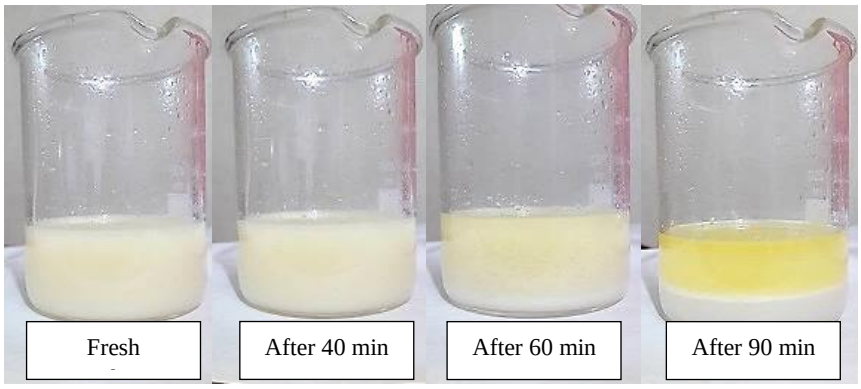

Fig. 3. Emulsion appearance by the time passage at the same experimental conditions of Fig.2.

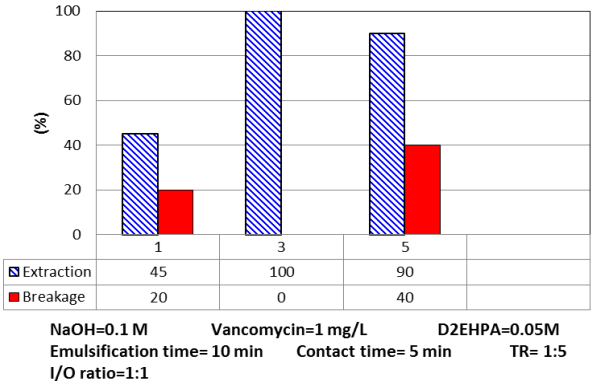

Fig. 4. Emulsion stability and extraction performance at the different surfactant concentrations.

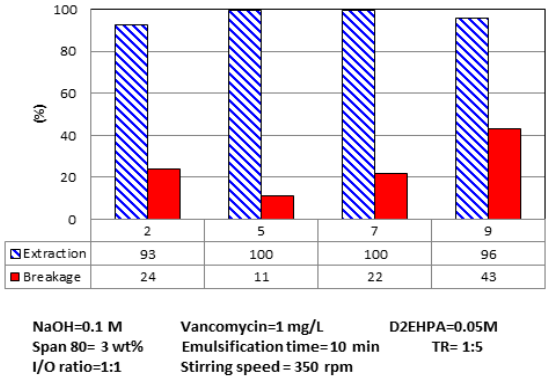

Fig. 5. Emulsion stability and extraction performance vs. contact time.

3.4. Influence of carrier agent concentration

The alteration of extraction efficiency and emulsion stability versus the concentration of D2EHPA as the carrier agent is illustrated in Figure 6. It was indicated that increasing the quantity of the carrier limits the extraction rate via inducing some effects on the viscosity of membrane phase. Actually, higher carrier amount enhances the fluidity of resultant emulsion and hence a diluted membrane phase is created [50,51]. According to the results, the extraction percentage linearly increased from 45% to 100% when the concentration of D2EHPA reached to 0.05 M. Also a significant decrement from 35% to 15% in the emulsion breakage was observed when the concentration of D2EHPA was increased. This means that a more stable ELM system has been produced. At the same time, further increase of the concentration above 0.05 decreased the emulsion stability. Reduction of the extraction efficiency originated from the decrement of the membrane phase viscosity as a result of a high carrier concentration. Furthermore, the ELM process might be influenced by the acidic or basic media of the membrane solution leading to the hydrolysis of both surfactant and carrier. This results in the decrease of emulsion stability and Vancomycin extraction into the membrane phase. Moreover, it was reported that the osmotic swelling and higher emulsion breakage would be occurred when using an excessive concentration of carrier [52]. Hence, 0.05 M D2EHPA was selected to be used for the subsequent investigations.

3.5. Influence of treatment ratio (TR)

The volume ratio of the emulsion to the external phase (TR) plays a key role in the amendment of the mass transfer surface. Based on the results, the Vancomycin removal efficiency increased from 95% to 100% when changing the treatment ratio from 1:3 to 1:5, and became constant around 88% at treatment ratio 1:7 (Figure 7). It is anticipated that declining the volume of the emulsion relative to the feed phase reduces the extraction efficiency. Then again, with an increased TR, the interface of the emulsion and the feed phase gets broader. As a result, the operation expenditures would rise. The stability of the emulsion does not seem to be affected by TR. The same result has been reported before for the emulsion breakage which was not expressively influenced by TR amount [53]. Since the swelling percentage was around 10% with the highest amount of TR, it cannot cause noteworthy changes in the emulsion stability. Thus, TR was fixed at 1:5 to provide a desirable scattering of the emulsified membrane phase in the feed phase as well as the proliferation in the separation rate.

3.6. Influence of I/O ratio

The I/O ration i.e., the volume ratio of the internal phase to the organic phase also has effects on the extraction rate and the emulsion stability (Figure 8). Three 1:2, 1:1 and 2:1 ratios were examined. As it is obvious, the emulsion stability and the extraction rate increases with changing the ratios from 1:2 to 1:1 because the amount of internal phase is not enough for separation at the ratio of 1:2. The further increase of the internal aqueous solution volume (more than the 1:1) decreases both the speed and efficiency of extraction and increases the emulsion failure. This might be explained by the elevated viscosity of emulsion as well as the expanded internal droplets as a result of high volume of the internal phase [54]. The expanded internal droplets decrease the interfacial interaction zone between the emulsion and feed solution leading to inferior extraction efficiency. Additionally, the volume of membrane solution must be adequate for surrounding whole the internal phase solution [55]. Besides, when the emulsion stability decreases from 1:1 to 2:1, breakage of around 44% occurs due to internal phase leakage. Therefore, to achieve a uniformly dispersed emulsion, 1:1 volume ratio was picked.

3.7. Influence of internal phase concentration

Figure 9 depicts the effect of NaOH concentration on the rate of extraction, and the emulsion membrane stability. From this figure, the increasing concentration of NaOH from 0.01 to 0.1 M has positive effect on the extraction efficiency; however, the higher concentrations lead to a destructive effect. Conversely, the breakage reduced from 20% to 10%. The elevated concentration gradient between external and internal phases because of high amount of stripping agent might be the main reason. As a result, the solute transports from the external phase into the internal phase. According to Figure 9, the extraction of Vancomycin increase at 0.1 M, where the water transfer is the lowest because the ion concentrations are rather the same on both sides of the membrane. Employing the internal phase concentration more than 0.1 M resulted in reduction of Vancomycin extraction to 86%. This can be explained by water leakage from the external phase into the internal phase due to the high concentration of ions which makes an osmotic pressure [56]. An increased water leakage decreases the drug extraction in this case.

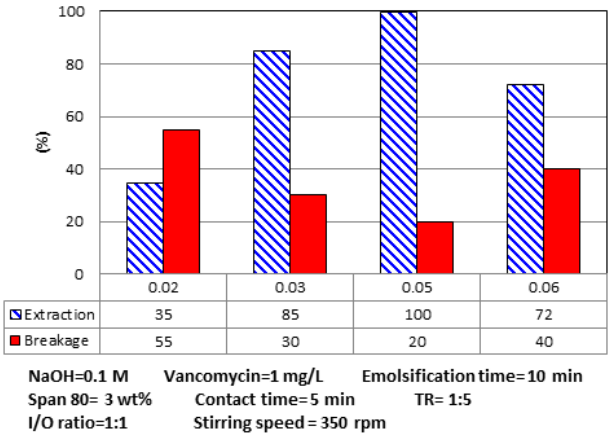

Fig. 6. Emulsion stability at the various concentrations of carrier agent.

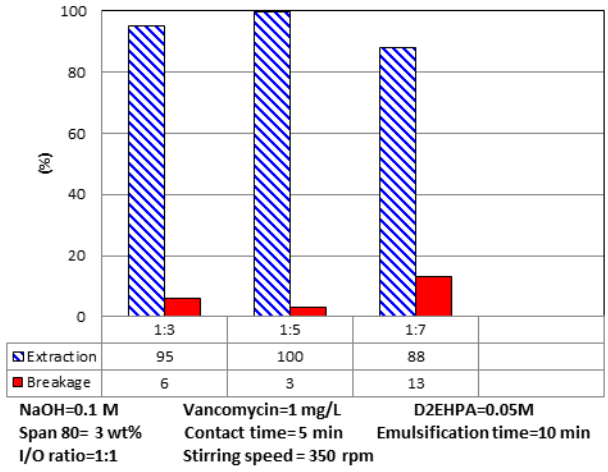

Fig. 7. Effect of TR on the emulsion stability and extraction performance.

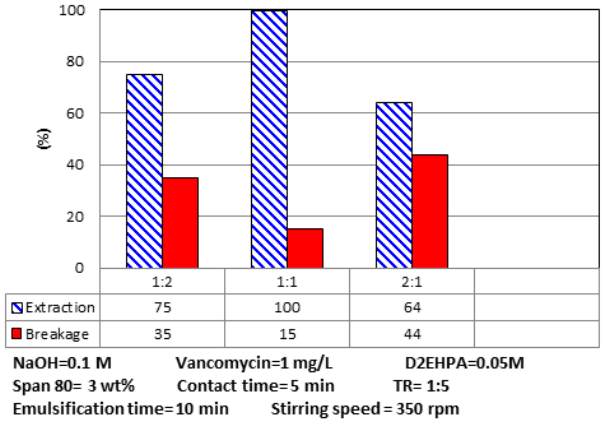

Fig. 8. Emulsion stability and extraction performance at different examined I/O volume ratio.

3.8. Effect of feed pH

According to Figure 10, the external phase pH significantly influenced the extraction rate and emulsion stability. Vancomycin was better extracted by increasing the pH from 5.0 to 6.0; however, there is a slight decrease in both extraction efficiency and emulsion stability by changing pH from 6.0 to 7.0. The observed decline in Vancomycin extraction attributes to the swelling of emulsion which increases the breakage rate. Actually, the osmotic pressure difference originated from lower proton concentration in feed phase sucks water into the internal phase and swells the emulsion droplets. It is interesting to know that defined green ELM has a great potential to extract Vancomycin from the feed with higher proton concentration. Additionally, the partially decreased extraction at higher proton concentration might be due to competition of proton to enter the internal phase instead of the targeted vancomycin molecules. Therefore, at 6 pH, the maximum extraction and emulsion stability was achieved.

Further increment of pH to 9 led to more emulsion breakage and subsequently lower drug extraction. The elevated OH^- concentration might be responsible for destruction of emulsion globules. About 20% lower extraction of Vancomycin might be still desirable for some special conditions suggesting that the green ELM prepared by sunflower oil acts acceptable in a wide range of feed pH.

3.9. Effect of feed ionic strength

Vancomycin extraction and stability of the emulsion might be affected by ambient ionic strength especially in a real wastewater. Hence, feed solutions with different concentrations of NaCl from 0 to 5 g/L were also examined. According to the results in Figure 11, by adding 0.1 g/L NaCl, the extraction efficiency did not change significantly; however, it derived more breakage in the emulsion. The existence of ions in the external phase can either compete with vancomycin in entering into the emulsion and decrease the emulsion stability [57]. At an elevated salt concentration (1–5 g/L), the extraction efficiency was more significantly decreased as it could be predicted; however, the extraction is still noticeable in the highest tested NaCl concentration which refers to the applicability of prepared green ELM in the presence of high amounts of dissolved salts.

3.10. Recovery and regeneration of the emulsion

The extract recovery was examined for the best performed membrane composition. By breaking the emulsion in the case of highest Vancomycin removal, about 70% of drug was recovered. This means that partial impregnation of ELM components with target along with incomplete emulsion breakage during recovery process could decrease the determined Vancomycin entered into the internal phase. Based on the Eq.3, the recovery percent is influenced by TR which implies that using higher amount of emulsion phase can decrease the recovery percent. Hence, finding an optimum TR helps to control the final extracted target after the demulsification.

To determine the optimal set of variables assuming the economic profits of the prepared green membrane, the emulsion was re-prepared form the broken emulsion at the optimal conditions. For this purpose, the recycled emulsion of the second stage was carried out under the favorable conditions for the liquid membrane preparing process. As shown in Figure 12, the percentage of extraction and failure was insignificantly different from the first stage. The third stage was prepared using the second phase emulsion in optimal conditions. The results show that the usefulness of the recovered membrane still was noticeable. Therefore, it can be concluded that the prepared membrane shows proper reusability as well as the high Vancomycin extraction proficiency.

4. Conclusions

The feasibility of employing sunflower oil as a diluent for preparing a green ELM was evaluated for removing an unsafe pharmaceutical from aqueous solution for the first time. The obtained results certified that the ELM preparation using the nontoxic, biodegradable diluent (sunflower oil) successfully led to production of a green ELM formulation to fully extract an antibiotic from aqueous solution. The conditions for obtaining the most efficient emulsion were 3 wt.% of Span 80, 0.05 M D2EHPA, I/O equal volume ratio, the treatment ratio of 1:5, and NaOH at 0.1 M as the internal aqueous phase. By these values, the extraction efficiency of 100%, recovery percent of 70%, and 10% breakage were achieved. In comparison to the few similar works in removing drugs by ELM [24,44], it can be claimed that replacement of hazardous organic solvents like dichloromethane (with inhalation hazard) and normal hexane (with limited allowed exposure time) by green edible sunflower oil successfully resulted in similar outcomes. As a general judgment, sunflower oil can be a good replacement as a green diluent for being utilized in ELM process for Vancomycin antibiotic removal from aqueous solution and might be applicable for the other antibiotics and drugs as well.

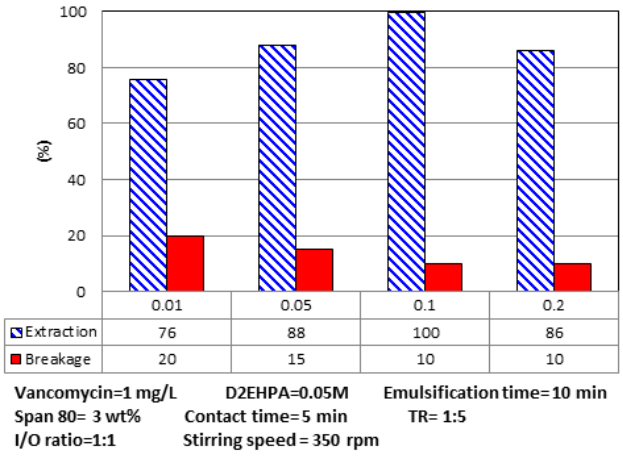

Fig. 9. Emulsion stability and extraction performance in various internal phase concentrations.

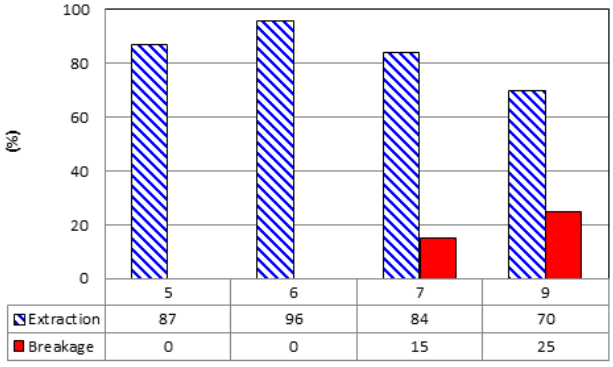

Fig. 10. Vancomycin extraction and emulsion breakage in various pHs (the other variables remained constant and equal to optimum amounts).

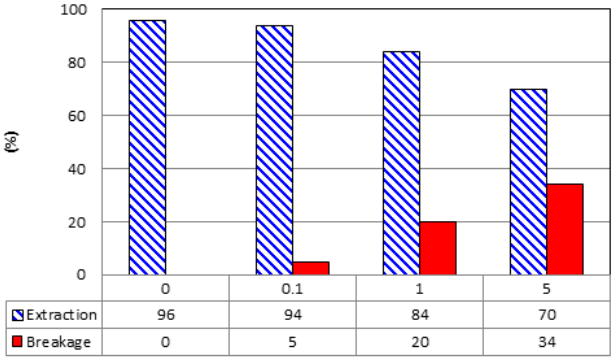

Fig. 11. Vancomycin extraction and emulsion breakage in various ionic strengths (the other variables remained constant and equal to optimum amounts).

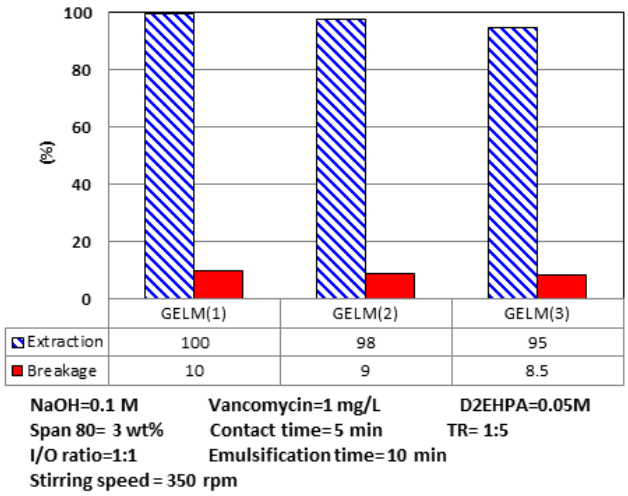

Fig. 12. Emulsion stability and extraction performance of the reused emulsion for 3 usages in row.

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