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Removal of Acetaminophen Residues from Wastewater by Bulk Liquid Membrane Process

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Abstract

The removal of Anit-Inflammatory drugs, namely; Acetaminophen (ACTP), from wastewater by bulk liquid membrane (BLM) process using Aliquat 336 (QCl) as a carrier was investigated. The effects of several parameters on the extraction efficiency were studied in this research, such as the initial feed phase concentration (10-50) ppm of ACTP, stripping phase (NaCl) concentration (0.3,0.5,0.7 M), temperature (30-50^{o}C), the volume ratio of feed phase to membrane phase (200-400ml/80ml), agitation speed of the feed phase (75-125 rpm), membrane stirring speed (0, 100, 150 rpm), carrier concentration (1, 5, 9 wt%), the pH of feed (2, 4, 6, 8, 10), and solvent type (CCl_4 and n-Heptane). The study shows that high extraction efficiency for ACTP of about 97% was achieved by a bulk liquid membrane at 50 ppm initial concentration of feed; stirring speed of feed phase 130 rpm; stirring speed of membrane phase 100rpm; 0.5 M NaCl concentration; carrier concentration 1wt%; volume ratio of 200ml feed:80ml membrane; feed pH of ACTP is 6, and 50˚C. The transport kinetics was evaluated using a kinetic model with two consecutive first-order irreversible reactions. The kinetics of (ACTP) transport by bulk liquid membrane was investigated at the best experimental conditions. The activation energy values of the extraction and stripping processes were 1.733 and 1.826 kJ.mol^{-1}. The activation energy confirms that the transport process from solutions is controlled by diffusion.

Keywords: Anti-inflammatory drugs, Acetamionphen (ACTP), Bulk liquid membrane, Wastewater treatment, Aliquat 336.

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1- Introduction

The chronic toxicity of pharmaceuticals present to nature and human beings in the aquatic environment has recently become extremely concerning. The use of prescription medications, or over the counter medicines, is measured at thousands of kilograms a year worldwide. Such compounds may be discharged as metabolites or in unchanged form into the water, then deposited in the aquatic ecosystem, and can contaminate aquifers and underground water.

Acetaminophen (ACTP) is a commonly used drug in the group of anti-inflammatory non-steroidal medicines.

These are commonly used to treat menstrual pain, inflammation, fever, rheumatoid arthritis, and migraines. The active substance of pharmaceuticals is among the most important pollutants on the WHO list [1].

The potential influence on human health and environmental impact of acetaminophen is identified to occur at high concentrations of a microgram per liter and is eliminated effectively by wastewater treatment plants (WWTPs) for the most part. It was found in European wastewater effluents to have a concentration of up to 6 μgL^{-1}, in US natural waters up to 10 μgL^{-1}, and in Tyne River, the UK over 65 μgL^{-1}[2]. The maximum concentration for acetaminophen in one of the Iraqi cities (Basra) was found to be 23.99 μg L^{-1} [3].

Different techniques have been used for the recovery or removal of organic compounds contained in wastewater, such as coagulation, activated carbon adsorption, electrochemical methods, UV irradiation, volatilization, sedimentation and filtration, photocatalysis, or Fenton oxidation. Such processes, however, are of limited efficiency and significant concentrations persist in treated waters [4].

Recently, bulk Liquid Membrane (BLM) has gained significant attention and has proven to be an efficient extraction method for pollutants removal from wastewater, as well as being an effective method for concentrating, isolation and regeneration. Liquid membranes are also of considerable significance from an environmental engineering perspective when understanding the transport mechanisms principle [5].

There is no documented work on extracting ACTP from contaminated water through BLM to the best of our knowledge. So a protocol for the recovery of acetaminophen from aqueous solutions was developed using BLM. The parameters to achieve high efficiency of ACTP removal by bulk liquid membranes (BLM) were evaluated.

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2- Experimental Work

The solutions of membrane phase were prepared by dissolving the carrier Aliquat 336 (Kunshan Yalong Trading Co. Ltd, China) in carbon tetrachloride (BDH Chemicals Ltd Poole). Dissolved ACTP (Sigma-Aldrich) was used as a feed phase in water. The ACTP's molecular structure is shown in Fig. **1** Sodium chloride (Avon Chem. Ltd, UK) in deionized water was used to prepare the strip phase solution.

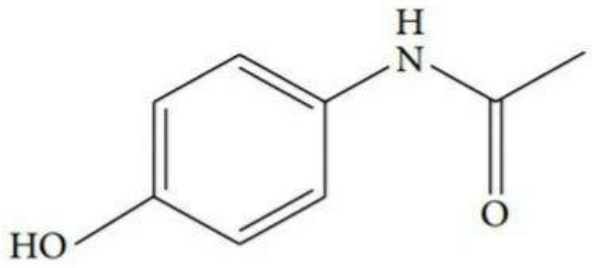

Fig. 1. Acetaminophen (ACTP) chemical structure

The experiments were performed using a borosilicate glass cell with dimensions of 12cm length, 6 cm width, and 12 cm height. The cell consists of two equal compartments; a partition wall of a thickness of 0.2 cm was located in the middle of the cell.

This wall rises from the bottom by 8 mm to permit the transfer of ACTP from one section to another.

A volume of 80 ml of carbon tetrachloride (CCl_4) was measured and transferred to the cell above the bottom clearance.

The ACTP solution of 50 ppm concentration, represents the feed phase, whilst, NaCl (0.5 M) solution represents the stripping phase. The volume of the feed phase and stripping phase was 200 ml.

Fig. **2** shows the schematic diagram of the cell used. To examine the temperature effect on the extraction efficiency of the ACTP, the experiments were carried out at 30, 40, and 50 ºC in a similar stainless steel cell.

The feed and stripping phases were agitated using mechanical stirrers (Heidloph RZR2021) with stainless steel propeller stirrer; 4-bladed of 3.5 cm diameter, whereas the membrane phase was agitated by magnetic stirrer (Labinco L-81) with a magnetic bar. A sample of (1 ml) was taken from the feed phase and stripping phase every 3 minutes.

The obtained samples were scanned by UV-VIS spectrometer (Genesys 10UV) at 287 nm to obtain the extraction efficiency of ACTP. In the case of stripping solution, the absorbency was recorded for ACTP-Na and converted to ACTP according to the balanced equations given in sec. 3.1.

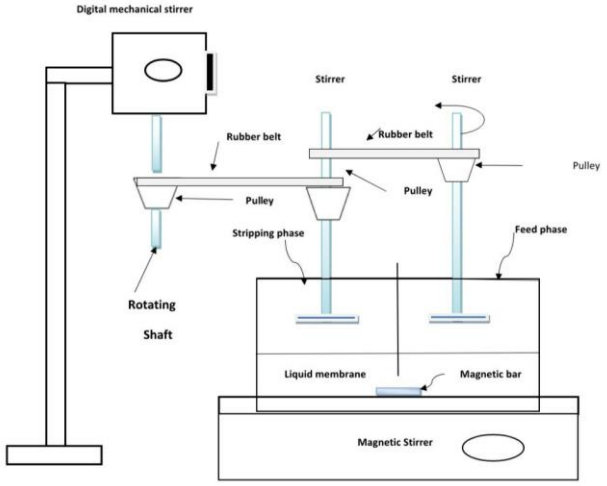

Fig. 2. Schematic diagram of the cell used for ACTP extraction

The extraction efficiency is calculated using Eq. 1 for estimating the bulk liquid membrane performance [5].

$$E\% = \frac{C_o - C_F}{C_o} \times 100 \quad (1)$$

where: E is the efficiency of extraction, C_0 is the initial feed phase concentration of ACTP (ppm), and C_F is feed samples concentration at any time of the experiment.

3- Results and Discussions

3.1. Mechanism of Transfer

ACTP's transfer mechanism from the feed phase to the strip phase, the role of Aliquat 336, and the steps of the process are illustrated in Fig. **3**. In this system, the transfer rate of Acetaminophen from the feed to stripping phase was improved by the extractant Aliquat 336, and the extractant reacted with ACTP at interface I to produce complex.

The complex then diffuses across the membrane from the interface I to interface II.

The complex breaks down and the carrier regenerates at interface II and diffuses back across the membrane. ACTP ionizes and reacts with Na^+ ions and produces a non-diffusive compound and the carrier can be recovered. The reaction between ACTP and QCl is given by Eqs. (2 and 3) [6]:

In the feed section:

$$(R_3CH_3N^+Cl^-)_{org} + (C_8H_9NO_2)_{aq} \rightleftharpoons (R_3CH_3N^+C_8H_8NO_2) + (H^+Cl^-)_{aq} \quad (2)$$

In the stripping section:

$$(R_3CH_3N^+C_8H_8NO_2)_{org} + (Na^+CL^-)_{aq} \rightleftharpoons (R_3CH_3N^+Cl^-)_{org} + (C_8H_8NO_2Na^+)_{aq} \quad (3)$$

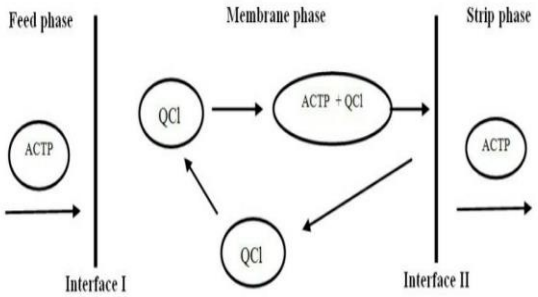

Fig. 3. ACTP transfer mechanism

3.2. Factors Affecting Bulk Liquid Membrane Performance

a. The Concentration of Carrier

The important element of BLM is the carrier which reacts with the active component from the feed phase by making a complex with it and after successive diffusion into the organic phase; the component is released into the stripping phase.

To study the carrier concentration effect on the transport of ACTP, the experiments were carried out at three different concentrations of the carrier (1, 5, and 9 wt. %) [7].

From Fig. **4**, it can be seen that there is an increase in the ACTP extraction efficiency with time which reveals that the system can extract large amounts of ACTP from dilute solutions.

It can be also observed that the transfer of ACTP was increased with an improvement in the concentration of Aliquat 336 (QCl) up to a certain concentration and then decreased. Maximum ACTP transport obtained was at carrier concentration of 5 wt percent.

This could be due to the probability of complex formation increases by increasing the concentration of QCl. Further experiments were conducted with 9% QCl and it was observed that the extraction efficiency decreased indicating that a further increase in the concentration of QCl will not have a considerable effect on the process.

This can be explained due to the slow release of QCl from the complex of ACTP-QCl. also, the resistance of mass transfer increases because of the viscosity increase in the membrane phase, which causes a reduction in the diffusivity of the ACTP-QCl complex across the membrane phase.

It is always desirable to make the BLM less expensive by using a small amount of QCl as long as there are enough carriers to extract ACTP from an aqueous solution, for which 1wt percent QCl has been chosen for all the extraction experiments. The results are consistent with that obtained by Sahoo, et.al [7].

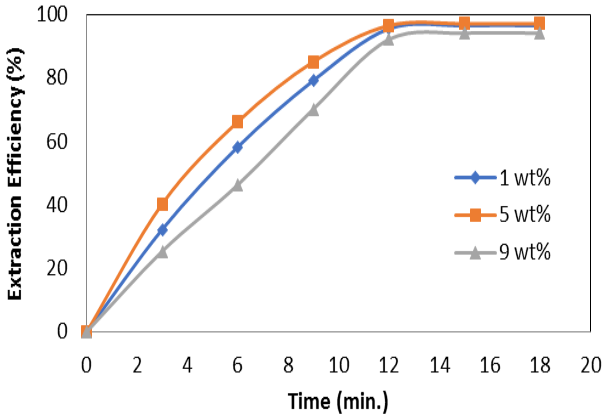

Fig. 4. Carrier concentration effect on the extraction efficiency of ACTP (Feed phase pH=6; Feed concentration=50 ppm; concentration of NaCl = 0.5 M; Agitation speed of aqueous phase = 130 rpm; Agitation speed of membrane phase =100 rpm; Temperature=22 ºC)

b. Feed Phase and Stripping Phase Agitation Speed

Fig. **5** shows that increasing the agitation rate of the feed and stripping phases from 75 to 130 rpm results in a significant increase in the efficiency of extraction.

Higher agitation speed for feed and stripping aqueous phases increases the rate of extraction by providing better mixing and thus reducing the boundary layer thickness between the membrane phase and the aqueous phase without changing its hydrodynamic stability.

It can be noticed from the figure that at further increase of agitation speed the extraction efficiency decreased to some extent, due to deformation of the interfaces between the phases, and even drops of the stripping phase were mechanically transferred to the donor phase.

The current work is in agreement with the work done by Sahoo, et. al [7].

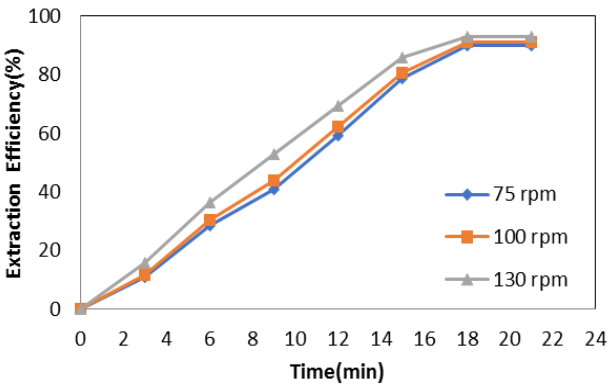

Fig. 5. Feed phase and stripping phase agitation speed effect on ACTP extraction efficiency (pH of feed phase =6; Feed concentration=50 ppm; QCl=1 wt%; Concentration of NaCl = 0.5 M; Agitation speed of membrane = 100 rpm; Temperature=22ºC)

c. The Agitation Speed of Membrane

From Fig. **6**, it can be concluded that the membrane agitation speed influenced the membrane extraction efficiency but to a lesser extent relative to the effect of increasing the aqueous phase agitation speed. Compared with the case of membrane non-agitation conditions, the performance of the bulk liquid membrane described by the extraction efficiency is considerably enhanced by the presence of membrane agitation. However, as the speed of membrane agitation increased from 100 to 150 rpm, this enhancement was lower, as the efficiency of extraction reduced due to the deformation of the interfaces between the phases. This is supported by the works of Mohammed and Hameed [8].

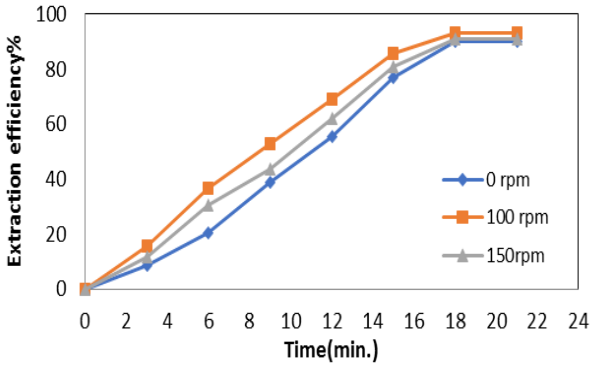

Fig. 6. Membrane agitation speed effect on ACTP extraction efficiency by bulk liquid membrane (pH of feed phase =6; Concentration of feed = 50 ppm; QCl=1 wt%; Concentration of NaCl = 0.5 M; Agitation speed of aqueous phase =130 rpm; Temperature=22ºC)

d. Feed Concentration

The effect of feed concentration on the extraction process was measured at various initial ACTP concentrations within the 10–50 ppm range. Fig. **7** shows the effect of the concentration of feed on the efficiency of extraction. The final efficiency of extraction for ACTP increases as the concentration of feed was increased from 10 to 50 ppm; this can be due to an increase in driving force.

This rapid increase may be explained by the fact that the interaction between ACTP and QCl was increased with feed concentration, and at a concentration of 50 ppm, QCl becomes saturated and reaches optimum extraction efficiency, while at a higher feed concentration, the carrier becomes fully saturated and could not efficiently transfer the ACTP from the aqueous feed phase to the organic phase. The results of the current study appear to be consistent with the work of Chaouchi and Hamdaoui [9].

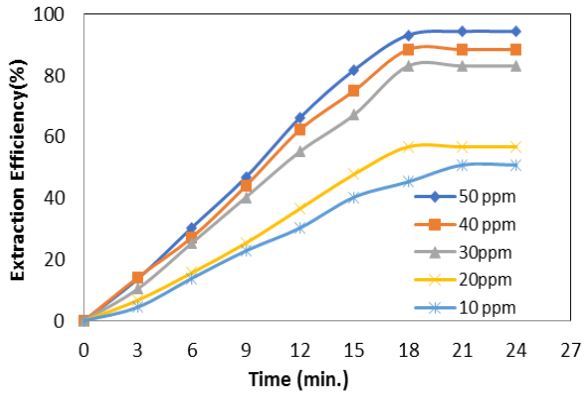

Fig. 7. Effect of feed concentration on ACTP extraction efficiency by bulk liquid membrane (pH of feed phase =6; QCl=1 wt%; Concentration of NaCl =0.5 M; Agitation speed of aqueous phase =130 rpm; Agitation speed of membrane phase =100 rpm; Temperature=22ºC)

e. Stripping Phase Concentration

The strength of the stripping phase plays a significant role as it controls the release of the ACTP- QCl complex extractant. Fig. **8** shows that the percentage of ACTP extraction improved as the sodium chloride concentration increased during the stripping process.

The complex dissociates at interface II to produce free ACTP, which combines with NaCl to give the sodium salt of ACTP. In the membrane phase, the salt is insoluble and results in the prevention of ACTP back diffusion, thereby allowing the unidirectional transfer of ACTP from feed solution to strip solution. This is supported by the works of Lakshmi, et al. [10], Ng, et al. [11], Li, et al.[12], and Husna and Sawsan [13].

An additional increase in NaCl concentration reduced the efficiency to some extent, as higher strip phase concentration provided high solution strength resulted in lower chloride ion activity coefficient to decompose the ACTP-QCl complex

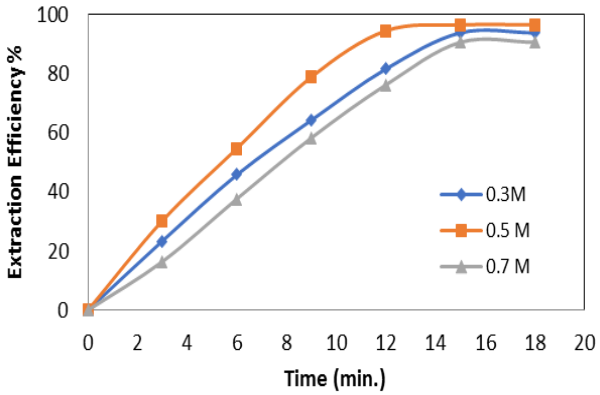

Fig. 8. Stripping concentrations effect on ACTP extraction efficiency by bulk liquid membrane (Feed phase pH =6; Feed concentration= 50 ppm; QCl=1 wt%; Agitation speed of aqueous phase =130 rpm; Agitation speed of membrane phase=100 rpm; Temperature=22 ºC)

f. Feed Phase pH

Fig. **9** demonstrates that the CCl_4 bulk liquid membrane extraction efficiency of ACTP remains almost constant when the feed phase pH is below the acid dissociation constant (pK_a) value (9.5). However, the extraction efficiency was drastically reduced when the pH of the feed solution approached the pK_a value or became greater than the pK_a value. It can be seen from Fig. 9 that the removal efficiency of ACTP remains approximately constant at about 95% when the feed phase pH is held below 6 and becomes 67 and 52 % at pH equals 8 and 10 respectively. The current research results appear to agree with that of Fan, et al.[14]. The reduction of ACTP extraction efficiency results from the fact that ACTP is a weak acid, and the molecules of QCl cannot solvate the non-charged form of Acetaminophen under high pH conditions ($\geq$ pK_a value). In the alkaline feed phase, because ACTP is an acidic substance, it converts to the ionic form, and as a result, the solubility of it in the membrane phase decreases, and therefore more ACTP remains in the feed phase.

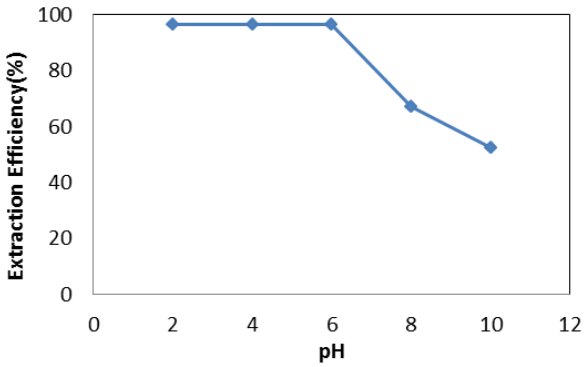

Fig. 9. Feed phase pH effect on ACTP extraction efficiency by bulk liquid membrane (Concentration of Feed = 50 ppm; QCl=1 wt%; Agitation speed of aqueous phase =130 rpm; Agitation speed of membrane phase = 100 rpm; Temperature=22ºC)

g. Feed Solution to Membrane Phase Volume Ratio

The volume ratio of the membrane-phase feed solution controls mass transfer through the interface and plays an important role in deciding the performance of BLMs.

The effect on extraction efficiency of the volume ratio of the feed solution to the membrane phase was investigated using two ranges, namely; 200 ml: 80 ml–400 ml: 80 ml, and the results obtained are given in Fig. **10**

The figure shows that as the phase volume ratio increases from 200 ml feed: 80 ml CCl_4 to 400 ml feed: 80 ml CCl_4, the extraction efficiency decreases slightly. This reduction in extraction efficiency could be attributed to the strong solvation ability of CCl_4 when used as a solvent in the liquid membrane.

A similar observation was made by Fan, et al.[14], who extracted phenol from the aqueous solution by $[C_6mim][PF_6]$ and concluded that the partitioning coefficient of phenol was changed slightly when the volume ratio of feed solution to ionic liquid membrane increased from 1:1 to 5:1.

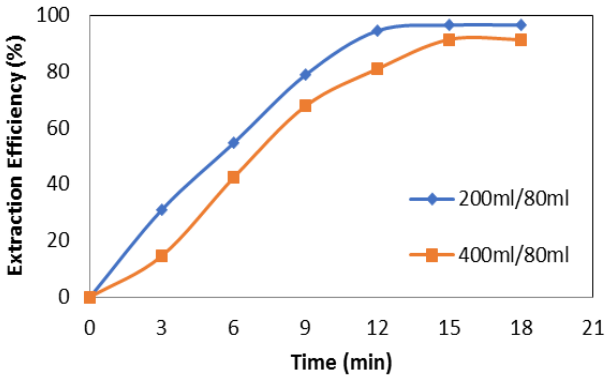

Fig. 10. Volume ratio of feed solution to membrane phase effect on ACTP extraction efficiency by bulk liquid membrane (pH of feed phase =6; Concentration of feed = 50 ppm; QCl=1 wt%; Concentration of NaCl = 0.5 M; agitation speed of aqueous phase =100 rpm; Agitation speed of membrane phase =100 rpm; Temperature=22˚C)

h. Membrane Phase Solvent Type

To select the right membrane solvent for transporting ACTP, two solvents were investigated, namely: CCl_4 and n-Heptane. Depending on the membrane solvent, the efficiency of the separation, expressed in percentage of the ACTP transported in the receiving phase is shown in Fig. **11**.

From the Figure, it is found that in the case of the CCl_4 membrane the best results are obtained. The second solvent provides a low permeability towards the transported ACTP that is reflected in the removed percentage of ACTP.

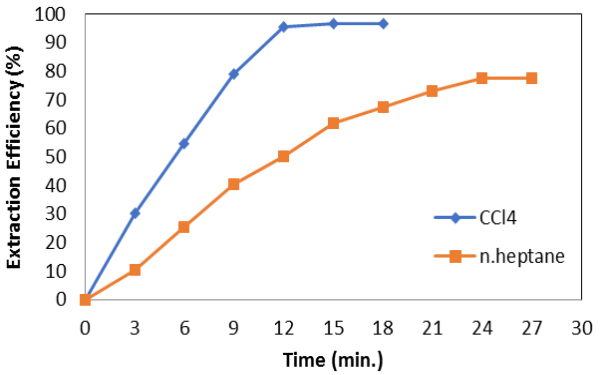

Fig. 11. The extraction efficiency of ACTP by two types of bulk liquid membrane (pH of Feed phase = 6; Concentration of feed =50 ppm; QCl=1 wt%; NaCl=0.5M; Agitation speed of aqueous phase =130 rpm; Agitation speed of membrane phase =100 rpm; Temperature=22ºC)

i. The Effect of Temperature on the Extraction

The extraction experiments were carried out at 30, 40, and 50 °C to investigate the influence of temperature on the performance of the ACTP extraction. Figure 12 shows the temperature dependence of the ACTP extraction efficiency.

It can be seen that as the temperature increased, the efficiency was also increased. This increase in efficiency can be explained by increasing the diffusion of the species that transferred through the liquid membrane of CCl_4 due to the reduction of the viscosity of the membrane. Einstein-Stokes Eq. (4), relates the diffusion coefficient (D) to viscosity μ, where it is inversely proportional to the viscosity of the liquid, and as a result, the temperature increase causes rising of extraction efficiency which is mainly controlled by diffusion [15].

$$D = \frac{kT}{c\pi\mu r} \quad (4)$$

Where: D is the diffusion coefficient (cm^2/s), k is the Boltzmann's constant (erg. K^{-1}), T is the absolute temperature (K), c is a constant (4 to 6), μ is liquid viscosity ($dyne.cm^{-2}\ s^{-1}$), and r is the Stokes radius or effective hydrodynamic in (cm).

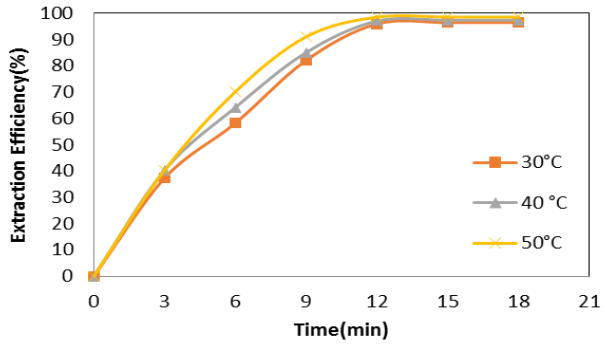

Fig. 12. Temperature effect of on ACTP extraction efficiency by a bulk liquid membrane (pH pf feed phase =6; Concentration of feed=50 ppm; Concentration of NaCl = 0.5 M; Agitating speed of aqueous and membrane =100 rpm)

3.3. Mathematical Model and Kinetic Parameters

The behavior of anti-inflammatory drugs through bulk liquid membranes demonstrated that the pertraction process from a feed phase through an organic membrane into a stripping phase takes place according to a consecutive irreversible first-order chemical reaction according to the kinetic scheme [16]:

$$C_F \xrightarrow{k_1} C_M \xrightarrow{k_2} C_S \quad (5)$$

Where: C is the solute concentration in the feed or donor phase (*F*), liquid membrane (*M*), and stripping or acceptor (*S*) phase, k_1 and k_2 are the first-order rate constants of the apparent membrane extraction and stripping.

Generally, the reduced concentrations of ACTP are used to simplify the model equations.

$$R_F = \frac{C_F}{C_0}, R_M = \frac{C_M}{C_0}, R_S = \frac{C_S}{C_0} \quad (6)$$

$$R_F \xrightarrow{k_1} R_M \xrightarrow{k_2} R_S \quad (7)$$

Then:

$$R_F + R_M + R_S = 1 \quad (8)$$

Where: R_F, R_M, and R_S are reduced mole fractions of the ACTP in the feed (F), liquid membrane (M), and stripping phase (S), respectively.

It is evident that R_F decreases mono-exponentially over time; the time variation of R_S is a monotonically increasing sigmoid type curve, whereas the time variation of R_M is the maximum, as shown in Fig. (13), at best condition [initial concentration of feed (50 ppm); stirring speed of feed phase (130 rpm); stirring speed of membrane phase (100rpm); NaCl concentration (0.5 M); carrier concentration (1wt%); volume ratio (200ml feed:80ml membrane); feed pH of ACTP is (6), temp. (50˚C)].

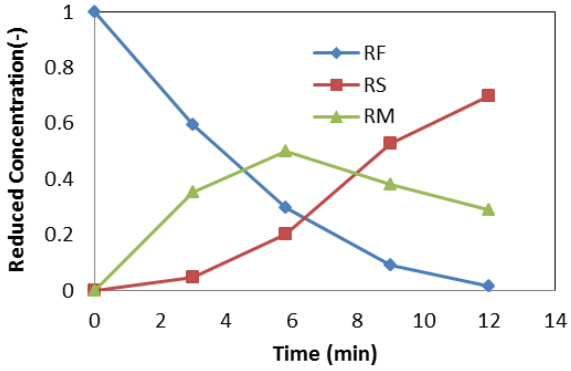

Fig. 13. ACTP pertraction experimental results in the bulk liquid membrane: R_F: feed phase; R_S stripping phase; R_M: liquid membrane calculated using the model

Maximum reduced concentration $R_M{}^{max}$ and t^{max} of membrane phase can be found from Fig. **13**. k_1 and k_2 can be calculated from the Eq. (9,10):

$$t_{max} = \frac{\ln(\frac{k_2}{k_1})}{(k_2 - k_1)} \quad (9)$$

$$k_2 = \ln\left(\frac{1}{R_m{}^{max}}\right)/t_{max} \quad (10)$$

The first-order apparent membrane extraction and stripping rate constants can be used for the determination of the maximum flux (J^{max}); the steady-state kinetics suggest that throughout the transfer process, the total permeation and exit fluxes between the two phases ${J_F}^{max}$ (Eq. 11) and ${J_S}^{max}$ (Eq.12) should be equal in value but with opposite signs, i.e. $-{J_F}^{max} = {J_S}^{max}$[16].

$$\left(\frac{dR_F}{dt}\right)|_{max} = -k_1\left(\frac{k_1}{k_2}\right)^{\frac{-k_1}{k_1-k_2}} = {J_F}^{max} \quad (11)$$

$$\left(\frac{dR_S}{dt}\right)|_{max} = k_2\left(\frac{k_1}{k_2}\right)^{\frac{-k_2}{k_1-k_2}} = {J_S}^{max} \quad (12)$$

Results of kinetic parameters of ACTP extraction by a bulk liquid membrane at best condition are illustrated in Table **1**.

For any number of reactions taking place in series, it is the slowest step that has the greatest control on the overall reaction rate. The results indicate that k_1 is larger than k_2, which means that, the rate can be determined by k_2, the slowest step in the two-step reaction [16].

Table 1. Kinetic model parameters for ACTP pertraction

Kinetic parameter	ACTP
t^{max} ,*min*	5.8
$\boldsymbol{R_M}^{\boldsymbol{max}}$	0.49876
k_1, min^{-1}	0.23798
k_2, min^{-1}	0.11994
$\boldsymbol{J_F}^{\boldsymbol{max}}$, min^{-1}	-0.05978
$\boldsymbol{J_S}^{\boldsymbol{max}}$, min^{-1}	0.0597

The activation energy (E_a) of ACTP extraction and stripping processes can be calculated from the Arrhenius equation by using k_1 and $k_2$values at various temperatures and plotting (-lnk_1 and -lnk_2) vs. T^{-1} [16]:

$$lnk_i = lnk_o - \frac{E_a}{R}\left(\frac{1}{T}\right) \quad (13)$$

The activation energy values of ACTP are 1.733 and 1.826 kJ mol^{-1} for extraction and stripping, respectively as shown in Fig. **14**.

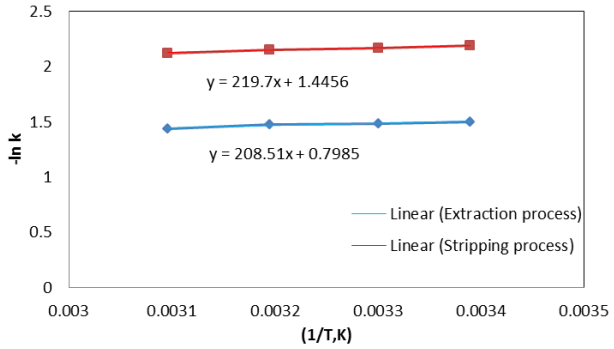

Fig. 14. Arrhenius plot for ACTP extraction and stripping processes stripping

These activation energy values indicate that the transport process for both extraction and stripping is controlled by species diffusion. Activation energy values are quite low for diffusion-controlled processes, for which the rate constants are strongly affected by temperature [16].

4- Conclusion

For extracting ACTP from acidic aqueous solutions, a BLM consisting of CCl_4 as solvent, Aliquat 336 (QCl) as carrier, and 0.5 M NaCl as stripping phase were used. An efficient ACTP transfer was accomplished for both the feed phase and the stripping phase with a stirring rate of 130 rpm and for the membrane phase 100 rpm. A transfer of almost (95 %) ACTP to stripping phase was reached after10 minutes. This process can be useful as secondary process during the wastewater treatment.

The pH of feed has no effect on the extraction efficiency of ACTP for pH values less than pK_a (9.5). However, the extraction efficiency was strongly reduced when pH of feed solution ≥ pK_a. The extraction efficiency of ACTP decreases slightly when the phase volume ratio increases from 200 ml feed: 80 ml CCl_4 to 400 ml feed: 80 ml CCl_4.

The activation energy values indicate that the transport process for both extraction and stripping is controlled by species diffusion.

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إزالة مخلفات الاستومينوفين من المياه الملوثة عن طريق الأغشية السائلة

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الخلاصة

في هذا البحث تم دراسة ازالة مخلفات الادوية المضادة للالتهابات (الاستومينوفين) من المياه الملوثة باستخدام الاغشية السائلة وبوجود مادة حاملة وهي Aliquate 336.

تم دراسة تأثير عدد من المتغيرات على عملية استخلاص (الاستومينوفين) من المحاليل المائية ,مثل ,التركيز الأبتدائي للمحلول المراد استخلاصه (10–50) جزء بالمليون للاستومينوفين, تركيز محلول كلوريد الصوديوم (0.3 , 0.5 ,0.7) مولاري ,درجة الحرارة (30,40,50) درجة سيليزية , ونسبة حجم الماء الملوث الى السائل الغشائي (200–400 مللتر /80 مللتر غشاء),سرعة خلط المحلول المستخلص (75,100,130) دورة بالدقيقه ,سرعة خلط السائل الغشائي (0,100,150) دورة بالدقيقة ,تركيز المادة الحاملة للمستخلص في السائل الغشائي (1,5,9%) وزناً, درجة الحموضة (2,4,6,8,10),نوع المذيب في السائل الغشائي (رابع كلوريد الكاربون , هيبتان).

أظهرت الدراسة نسبة استخلاص عالية للاستومينوفين وتقدر بحوالي (97%).تم حساب حركية الإنتقال بإستخدام موديل انتقال يتألف من تفاعلين متعاقبين غير إنعكاسيين من المرتبة الأولى .حيث تم التحقق من حركية الانتقال للاستومينوفين في التجارب ذات أفضل الظروف.

الوقت اللازم(t^{max}) للوصول لأعلى تركيز خلال الغشاء (R_M^{max}) و ثوابت سرعة الاستخلاص والإنتزاع (K_1 وK_2) والتدفق الانتقالي الأقصى خلال الغشاء (J_F^{max}، J_S^{max}) تم تحديد قيمها .

كذلك تم حساب طاقة التنشيط لكلا العمليتين (الاستخلاص والإنتزاع) للاستومينوفين وكانت القيم كالتالي: (1.733 , 1.826) كيلوجول\مول للاستومينوفين. إن طاقة التنشيط هذه أثبتت ان الخطوة المسيطرة للإنتقال هي عملية الإنتشار.

الكلمات الدالة: الادوية المضادة للالتهابات, الاستومينوفين, الاغشية السائلة, معالجة المياه الملوثة, مادة الكوت 336