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Study on the Performance of Polymer Inclusion Membrane for Gold Extraction

Nor Zafirah Nor'Azmi, Noor Fazliani Shoparwe*, Abdul Hafidz Yusoff

Gold Rare Earth and Material Technopreneurship Centre (GREAT), Faculty of Bioengineering and Technology, University Malaysia Kelantan, Kelantan, Jeli 17600, Kelantan, Malaysia

**Corresponding author: fazliani.s@umk.edu.my*

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ABSTRACT

The efficiency of polymer inclusion membranes (PIMs) for gold extraction, particularly using Aliquat-336 as a carrier, has been extensively studied. The membrane was fabricated by combining poly(vinylidene fluoride-co-hexafluoropropylene) (PVDF-co-HFP) with dioctyl phthalate (DOP) and varying concentrations of Aliquat-336 (5, 10, 15, 20, and 25 wt.%). The optimal formulation, incorporating 20 wt.% Aliquat-336 (M5), demonstrated significant improvements in ion exchange capacity (IEC) extraction rates, achieving an impressing 1.697 meq/g and 95.96% extraction efficiency, respectively.

Keywords: polymer inclusion membrane (PIMs); gold extraction; poly(vinylidene fluoride-co-hexafluoropropylene) (PVDF-co-HFP); dioctyl phthalate (DOP); aliquat-336

1. Introduction

Polymer inclusion membranes (PIMs) have emerged as a viable alternative, particularly with the use of Aliquat-336 as a carrier. PIMs are environmentally friendly, offering high stability and mechanical properties, making them suitable for selective metal ion transport [1]. They simplify the extraction process while minimalizing hazardous chemical use, contrasting with traditional methods that often involve toxic substances such as cyanide [2]. The study emphasizes varying concentrations of Aliquat-336 to enhance ion exchange capacity and extraction efficiency, aligning with findings that highlight the importance of optimizing membrane formulations [3].

2. Materials and Methods

2.1 Materials

DOP and PVDF-co-HFP pellets were purchased from the company Sigma-A (USA). Alfa Aesar, Thermo Fisher Scientific (Shanghai, China), was the supplier of Aliquat-336 TG. The supplier of THF was R&M Chemicals (UK). The analytical-grade phenolphthalein, NaOH, and HCl utilized in the tests were purchased from Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China). Without any additional purification, thiourea was used. The proper amount was diluted in 1.0 mol/L HNO3 to prepare a gold standard solution of 1000 ppm. Every experiment utilized deionized water.

2.2 Membrane Preparation

Table 1 provides a list of the composition of the prepared PIMs. Each membrane composition was kept consistent in terms of THF (30 wt.%), PVDF-co-HFP (60 wt.%), and DOP (10 wt.%), while the concentration of Aliquat-336 systematically varied based on the list in Table 1. PVDF-co-HFP, Aliquat-336, and DOP were dissolved in THF while being stirred magnetically for 24 hours at room temperature. The THF was then allowed to gently evaporate over 24 hours at room temperature in a fume hood after the solution had been put into a flat glass that had been positioned horizontally. The resultant membrane was meticulously sliced into a circle once the solvent had completely evaporated.

Table 1: Formulation of PIMs in this research.

Membrane	THF (wt.%)	PVDF-co-HFP (wt.%)	DOP (wt.%)	Aliquat-336 (wt.%)
M1	30	60	10	0
M2	30	60	10	5
M3	30	60	10	10
M4	30	60	10	15
M5	30	60	10	20
M6	30	60	10	25

2.3 Materials

2.3.1 Ion Exchange Capacity

Assuring that all charge sites were converted to the Cl− form, the dry membrane was submerged in 1.0 M HCl for a full day. The membrane was soaked in 1.0 M NaCl for 24 hours to promote ion exchange after rising with deionized water. Using phenolphthalein as an indicator, 0.01 M NaOH was used to titrate the displaced ions. The following formula was used to determine the IEC [4]:

$$IEC = \frac{ab}{wd} \tag{1}$$

Where a represents the concentration of the NaOH solution used for titration (mol/dm^3), b is the volume of the NaOH solution (dm^3), and wd represents the dry weight of PIMs (g).

2.4 Transport Experiment

In the transport experiment shown in Fig. 1, the mechanically stirred feed and stripping solution (150 ml each) were separated in an H-cell glass setup with an exposed membrane area of 16.61 cm^2. The feed solution contained a gold standard solution diluting into 50 ppm, while the receiving solution consisted of a thiourea solution. Every experiment was carried out at room temperature. Inductively coupled plasma optical emission spectroscopy (ICP-OES) was used to analyse samples from the feed and stripping solution every four hours for 24 hours [5].

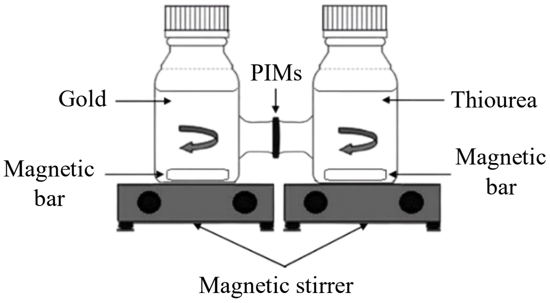

Fig. 1: H-cell device set-up

2.5 Kinetic studies

Equations (2) and (3) demonstrate how pseudo-first- and pseudo-second-order models were used to build the kinetic model. Using Polymath software version 6.0, a nonlinear least-square regression analysis was performed to ascertain the k^1 and k^2 values for the anticipated gold extraction profile. To compare the accuracy of the examined model, the coefficient of determination and variance were computed for each model using equations (4) and (5), as shown below [6]:

$$C = Ce - \exp(-k^1 t)(Ce - Co) \tag{1}$$

Where

Co = amounts of gold removed (mg/g)
Ce = equilibrium removal capacity
t = time (min)
k^1 = rate constant of removal (g/mgmin)

$$C = Ce - \frac{1}{k^2 t + \frac{1}{Ce - Co}} \tag{2}$$

Co = amounts gold removed (mg/g)
Ce = equilibrium removal capacity
t = time (min).
k^2 = rate constant of removal (g/mgmin)

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{n\left[\sum x2 - (\sum x)^2\right]\left[n[\sum y2 - \sum y]^2\right]}} \tag{3}$$

r = the correlation coefficient
n = number in the given dataset
x = the first variable in the context
y = second variable

$$\sigma = \frac{\sum x^2}{N} - \mu^2 \tag{4}$$

μ = average of the mean of the individual data point
N = number of individual data points in the distribution
x = value of individual data point

3. Results and Discussion

3.1 Ion Exchange Capacity

3.1.1 Figure Captions

The IEC is defined as the density of charged functional groups within the membrane, which facilitates ion transport [7]. Fig. 2 indicates that the incorporation of Aliquat-336 significantly enhances IEC, with values increasing from 0.612 to 1.697 meq/g as the concentration of Aliquat-336 increases from 0 to 25 wt.%. New methodologies for measuring IEC, such as redox titration, provide more accurate assessments compared to traditional methods [8].

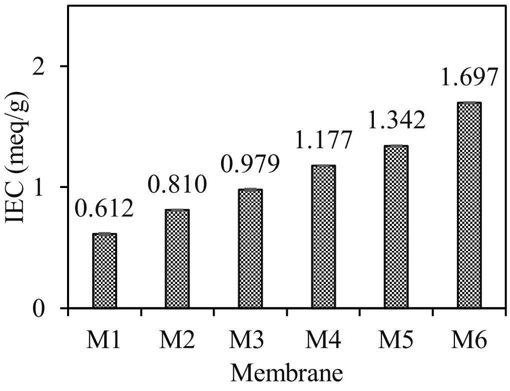

Fig. 2: IEC of the PIMs.

3.2 Kinetics Studies

3.1.2 Tables

The data plotted in Fig. 3 indicate that the experimental values align with the predicted values. This shows that both the experimental and anticipated values' linear plots pass through together. The values obtained for gold extraction using the PVDF-co-HFP, Aliquat-336, and DOP are listed in Table 2 below.

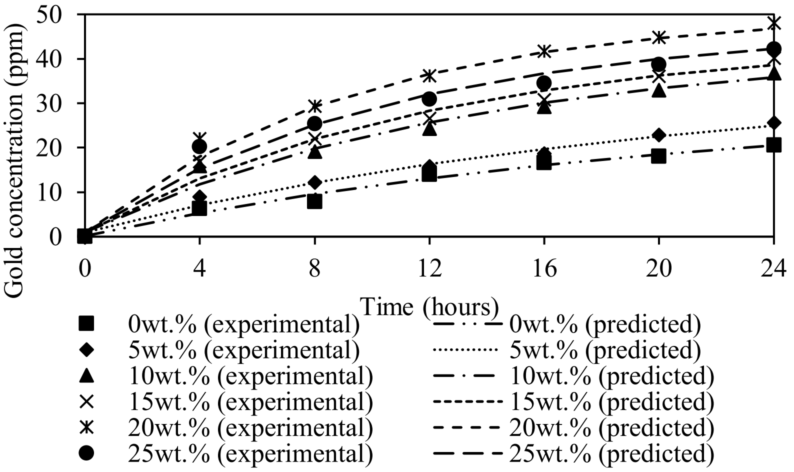

Fig. 3: Predicted and experimental values of gold concentration under the different effect of Aliquat-336.

Table 2: Parameters values for the first-order kinetic for the different of the carrier.

Membranes	**Ce**	**k^1**	**Co**	**R^2**	**Variance**
M1	30.48579	0.0463817	0.1582338	0.9846604	1.259633
M2	36.23995	0.0475493	0.9493835	0.9866462	1.522378
M3	42.83608	0.0744874	0.999983	0.9756721	5.591972
M4	44.88633	0.0809674	0.999978	0.9775664	6.071184
M5	50.79119	0.1047918	0.9999555	0.989222	4.470271
M6	47.28272	0.0925513	0.9999963	0.9722988	8.395184

Based on Table 2, the pattern shows the Aliquat-336 concentration increases, and the reaction rate also increases. The value is higher at M5. This indicates that when the concentration of Aliquat-336 rises to 20 wt.%, the reaction is more efficient and occurs more quickly. The gold extraction efficiency was highest at M5, which is 95.960%. The extraction of gold by the PIMs is more efficient at 20 wt.% Aliquat-336 due to the increase in the number of active sites for gold interaction [9].

The data plotted in Fig. 4 indicate that the experimental values align with the predicted values. This shows that both the experimental and anticipated values' linear plots pass through together. The values obtained for gold extraction using the PVDF-co-HFP, Aliquat-336, and DOP are listed in Table 3.

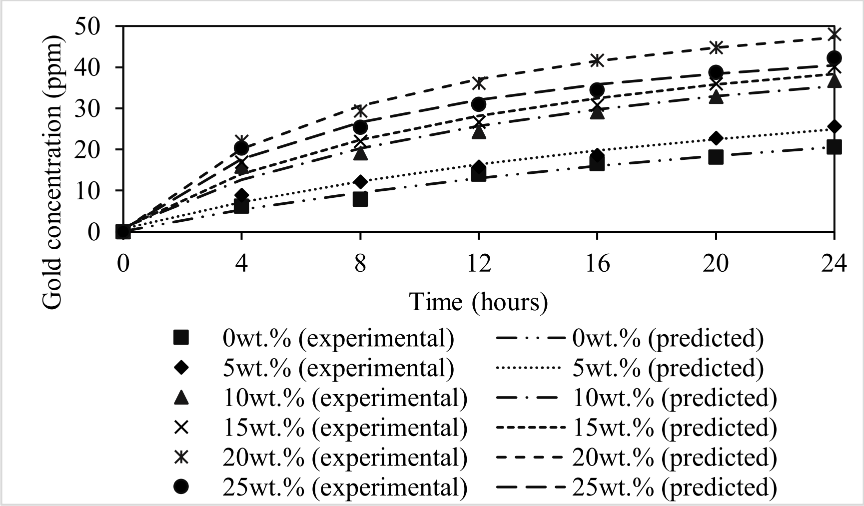

Fig. 4: Predicted and experimental values of gold concentration under the different effect of Aliquat-336.

Table 3: Parameters values for the second-order kinetics for the different of the carrier.

Membrane	Ce	k^2	Co	R^2	Variance
M1	49.01252	0.0006138	0.1236908	0.9844581	1.276245
M2	54.40949	0.0006368	0.7453858	0.9882604	1.338359
M3	57.30333	0.0011621	0.9999745	0.9812561	4.308443
M4	60.56882	0.001177	0.9583149	0.9836661	4.420445
M5	64.94805	0.0017036	0.4084376	0.9960222	1.649823
M6	54.88957	0.00212	0.5937658	0.9881406	3.594153

Table 3 indicates that the highest value, 0.00212, was observed for M6 with 20 wt.% Aliquat-336. However, as the carrier concentration increased, the intercept values (Ce) decreased, suggesting a reduction in ion exchange during the extraction process.

4. Conclusion

This research demonstrated the effectiveness of PIMs in gold extraction, particularly using Aliquat-336 as a carrier. The optimal formulation, containing 20 wt.% Aliquat-336, achieved the highest extraction efficiency of 95.96%, which is attributed to the chemisorption process as indicated by the pseudo-second-order kinetics, which suggests the extraction was primarily driven by the chemical interaction within the gold ions and the PIMs [1]. Increasing the Aliquat-336 concentrations correlates with enhanced ion exchange capacity and faster reaction rates, although efficiency declines beyond the optimal concentration [10].

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References

[1] Keskin B, Zeytuncu B, Koyuncu I. Efficient separation and recovery of precious metal ions by polymer inclusion membranes (PIMs): A mini review. Solvent Extr Ion Exch, 2024;1(23):1-23.

[2] Wang R, Fan G, Zhang C. Process and systematic study of gold recovery from flexible printed circuit boards (FPCBs) using a choline chloride–ethylene glycol system. Waste Manag, 2024;178(1):351-361.

[3] Li J, Zhang J, Du Y, Liu X, Liu R, Yang Y. Efficient extraction of Au (III) by a piperidine-based ionic liquid and exploration of the mechanism driving force. Sep Purif Technol, 2024;345(1):127353.

[4] Lu X, You W, Peltier CR, Coates GW, Abruña HD. Influence of ion-exchange capacity on the solubility, mechanical properties, and mass transport of anion-exchange ionomers for alkaline fuel cells. ACS Appl Energy Mater, 2023;6(2):876-884.

[5] Husna SM, Yusoff AH, Mohan M, Azmi NA, Ter TP, Shoparwe NF, Sulaiman AZ. Effect of graphene oxide on the properties of polymer inclusion membranes for gold extraction from acidic solution. Membranes, 2022;12(10):996.

[6] Gunasegaran M, Shoparwe NF, Mohamad M, Ahmad AL, Abdullah AZ, Zainuddin N. Effect of aliquat 336 in PVDF-Co-HFP polymer inclusion membrane for silver ion removal. AIP Conf Proc, 2022;2454(1):1-1.

[7] D'Alessandro A, Moranda A, Campione M, Riva A, Paladino O. A novel method for Ion Exchange Capacity characterization applied to Anion Exchange Membranes for Water Electrolysers. E3S Web Conf, 2023;414(1):01001.

[8] Wang L, Rojas-Carbonell S, Hu K, Setzler BP, Motz AR, Ueckermann ME, Yan Y. Standard operating protocol for ion-exchange capacity of anion exchange membranes. Front Energy Res, 2022;10(1):887893.

[9] Suhaimi SMH, Shoparwe NF, Yusoff AH. Influence of extractant concentration in poly (vinylidenefluoride-co-hexafluoropropylene)/aliquat 336 polymer inclusion membranes for gold extraction from aurocyanide solution. AIP Conf Proc, 2024;3014(1):1-1.

[10] Salmana LI, Zanguina Adamou MC, Ibrahim NP. Extraction par Solvant de L'or par l'Aliquat 336 Et par le TOPO Dans des Solvants Apolaires. 2024;1(1):1-1.