

1 *Type of the Paper (Article, Review, Communication, etc.)*

2 **Non-dispersive extraction of Ge(IV) from aqueous** 3 **solutions by Cyanex 923: Transport and modeling** 4 **studies**

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13 **Abstract:** A transport process was studied from an aqueous solution containing oxalic acid and
14 100 mg/L Ge using a flat sheet supported liquid membrane (FSSLM) system. Cyanex 923
15 immobilized in a polytetrafluoroethylene membrane was employed as a carrier. The solution
16 chemistry and related diagrams were applied to study the transport of germanium. The effectual
17 parameters such as oxalic acid, carrier concentration, and strip reagent composition were
18 evaluated in this study. Based on the results, the oxalic acid concentration of 0.075 mol/L and the
19 carrier concentration of 20 %v/v were the condition in which the efficient germanium transport
20 occurred. Among strip reagents, NaOH (0.04-0.1 mol/L) had the best efficiency to transport
21 germanium through the SLM system. Furthermore, the permeation model was obtained to
22 calculate the mass transfer resistances of the membrane (Δ_m) and feed (Δ_f) phases. According to the
23 results, the values of 1 and 1345 s/cm were evaluated for Δ_m and Δ_f , respectively.

24 **Keywords:** Germanium; Supported liquid membrane; Transport; Cyanex 923; Modeling
25

26 **1. Introduction**

27 Germanium is a strategic metalloid mainly used in a wide range of high-technology devices
28 Liu, *et al.* [1]. Germanium is found in lead-zinc ores [1] and coal fly ashes [2]. In the view of
29 hydrometallurgy, the leach solutions obtained from zinc plant residues and coal fly ashes contain
30 germanium along with the other metals. The most important elements that can be found in these
31 solutions are heavy metals such as zinc, nickel, cobalt, etc. [3,4]. The germanium separation from
32 these solutions is a vital objective to obtain a purified germanium product.

33 Gasification coal fly ashes (GCFAs) containing germanium can be leached with water to
34 dissolve germanium as water-soluble species [5]. Several processes have been developed to recover
35 and separate germanium from impurities such as precipitation [6], flotation [7], ion-exchange [8],
36 distillation [2], adsorption [9], liquid-liquid extraction (LLX) [10], and supported liquid membrane
37 (SLM) [11-13]. Among these techniques, the LLX processes have been extensively applied to
38 separate germanium from aqueous solutions [14,15]. However, some disadvantages such as high
39 loss of extractant, high capital cost, difficult operation, etc. make this method inappropriate for
40 treating low concentrations of ions. The supported liquid membrane techniques have been
41 introduced as alternative methods to overcome these disadvantages [16]. High selectivity, easy
42 operation, low consumption of carrier, and the one-step process are some advantages of SLMs [17-
43 20].

44 Liu, *et al.* [1] reported oxalic acid as an efficient reagent to dissolve germanium from zinc
45 residues. Therefore, one of the important leachates containing germanium is oxalate solution. In

46 order to separate germanium from this type of solution, a few studies have been carried out.
47 Liquid-liquid extraction of germanium from zinc leachates containing oxalic acid solutions has been
48 carried out using tertiary amines in the literature [21,22]. Since the species of germanium oxalates
49 are in the neutral form ($\text{H}_2\text{Ge}(\text{C}_2\text{O}_4)_3$) [15], it was anticipated that a neutral extractant could be used
50 to extract germanium. In this regard, Cyanex 923 (four trialkyl phosphine oxides) with solvation
51 extraction behavior was selected. Solvent extraction experiments using Cyanex 923 showed good
52 efficiency for the extraction of germanium from oxalate solutions [15]. On the other hand, in order
53 to overcome the challenges mentioned for an LLX system, an SLM system containing Cyanex 923
54 was firstly developed to transport germanium from an oxalate solution.

55 Cyanex 923 has been widely used in SLM systems. The permeation of cadmium ($\text{H}_{(n-2)}\text{CdCl}_n$)
56 from wastewater containing chloride anions has been investigated through SLM processes using
57 Cyanex 923 [23]. Chromium(VI) neutral species (H_2CrO_4) were transported across an FSSLM system
58 using Cyanex 923 from chloride solutions [24]. Zinc(II) species in the form of $\text{H}_n\text{ZnCl}_{(2+n)}$ were
59 permeated by a solid-SLM from chloride medium using Cyanex 923 [25]. In addition, an FSSLM
60 system has been used to transport HFeCl_4 species through a PVDF membrane with the carrier of
61 Cyanex 923 from a solution containing chloride ions [26]. Alguacil, *et al.* [27] investigated the
62 transport of Au(III) in the form HAuCl_4 through a PVDF membrane film impregnated in Cyanex
63 923 from an HCl solution. Results showed good transport efficiency for gold species. Neutral
64 complexes of uranium(VI) ($\text{UO}_2(\text{H}_2\text{PO}_4)_2$) were separated through an SLM system from phosphoric
65 acid solutions using the mobile carriers containing 2-ethyl hexyl phosphoric acid mono-2-ethyl
66 hexyl ester (PC88A) and Cyanex 923 [28].

67 The presented research describes a flat-sheet supported liquid membrane (FSSLM) process
68 with a Cyanex 923 carrier, in which the facilitated transport of germanium species is carried out
69 from a solution containing oxalic acid. Significant parameters affecting the transport of germanium
70 such as germanium concentration in the feed phase, carrier composition, oxalic acid concentration,
71 membrane type, and NaOH concentration in the strip phase have been investigated in detail.
72 Finally, a mass transfer model was developed to find Δ_{aq} and Δ_{org} values which are the resistances
73 corresponding to the species diffusion through the feed-membrane interfacial layer and membrane
74 phase, respectively.

75 2. Experimental

76 2.1. Materials

77 Cyanex 923 consisting of four trialkyl phosphine oxides (93%) was supplied by CYTEC Inc.,
78 NJ, USA. Various concentrations of Cyanex 923 (5-30 %v/v) as a carrier were prepared by dissolving
79 it in kerosene (Sigma-Aldrich, MO, USA). In all experiments, purified water used was supplied
80 through a water purifier (Siemens, Germany). Solutions used in this study contained 100 mg/L of
81 germanium which were prepared by dissolving GeO_2 (99.99%) from Sigma-Aldrich. Desired
82 amounts of oxalic acid powder from Panreac, Barcelona, Spain were added to the aforementioned
83 solutions to prepare various oxalate concentrations in the range of 0.05-0.2 mol/L. Sodium
84 hydroxide (NaOH) was used to prepare stripping phases.

85 Poly tetra fluoro ethylene (PTFE) and polyvinylidene difluoride (PVDF) flat sheet hydrophobic
86 membranes with the characteristics being porosity of about 85%, 47 mm diameter, pore size of 0.45
87 μm , and diameter of 47 mm from Millipore, KGaA, Darmstadt, Germany were used in the present
88 study.

89 2.2. Membrane experiments

90 FSSLM experiments were carried out in a system including two cells attached together with a
91 flanged chamber between the cells in which a membrane filter could be placed. The effective
92 membrane area was calculated to be 11 cm^2 . The configuration of this system was introduced
93 elsewhere [23]. In order to prepare membranes for experiments, PTFE membranes were put in
94 Cyanex 923 solutions for 30 min. The carrier molecules fill membrane pores by capillarity in this

95 time. Afterward, each membrane was taken out from a Cyanex 923 solution and washed with water
 96 to remove additional carriers. Finally, each membrane was placed between two cells. The samples
 97 with volumes of 0.5 mL from both phases were taken to evaluate the concentration of ions during
 98 the experiments. The composition of solutions was determined using an inductively coupled
 99 plasma atomic emission spectroscopy (ICP-AES Agilent, USA). The reproducibility of experimental
 100 values was calculated in the range of $\pm 5\%$ and illustrated as error bars in figures.
 101

102 2.3. Transport equations

103 Transport phenomena in SLM processes principally occur in three steps including the reaction
 104 of species with the carrier at the feed-membrane interface, diffusion across the membrane and
 105 stripping at the membrane-strip interface. According to the literature, the flux of species (J) can be
 106 found by disregarding the concentration of germanium in the strip phase with respect to Eq. (1)
 107 [17]:

$$108 \quad J = P_f C_f \quad (1)$$

109 In this equation, P_f and C_f represent the permeability coefficient at the feed-membrane
 110 interface and the ions concentration in the feed phase, respectively. Furthermore, the flux can be
 111 written according to Fick's first law in a differential form as Eq. (2):

$$112 \quad J = -\frac{V}{A} \left(\frac{dC_f}{dt} \right) \quad (2)$$

113 Where V and A are the volume of the feed phase and the membrane efficient area, respectively.
 114 With respect to Eqs. (1), the integration form of Eq. (2) can be written as Eq. (3):

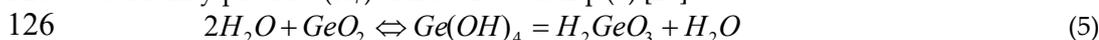
$$115 \quad \ln(C_{f,0} / C_{f,t}) = -\frac{AP_f t}{V} \quad (3)$$

116 Where $C_{f,0}$ and $C_{f,t}$ depict the concentration of ions in the feed phase at the initial time and time
 117 of ' t ', respectively. Hence, the permeability coefficient can be evaluated from the slope
 118 corresponding to the plot of $\ln(C_{f,0} / C_{f,t})$ against t . Furthermore, the transport efficiency (%T) of
 119 germanium is calculated as Eq. (4):
 120

$$121 \quad \%T = \frac{C_{f,t}}{C_{f,0}} \times 100 \quad (4)$$

122 3. Solution chemistry

123 Germanium dioxide can be dissolved in water. However, this dissolution is slowly carried out
 124 as an intermediate tetra-hydroxide. These species can be converted to germanic acid with the
 125 solubility product (K_{sp}) of $2.39 \times 10^{-4.5}$ as Eq. (5) [29]:



127 Germanium can form various complexes with organic acids such as tartaric acid, citric acid,
 128 oxalic acid, etc. Oxalic acid is a possible complexant which forms various complexes with
 129 germanium. According to the literature and observations, the solubility of germanium increases in
 130 the presence of oxalic acid in aqueous solutions (Liu et al., 2017b). The formation of germanium
 131 anionic and neutral species has been reported. For instance, Pokrovski et al. (2000) described that
 132 germanium (0.02 mol/L) and oxalic acid (0.1 mol/L) form anionic species of $Ge(OH)_2(ox)_2^{2-}$ ("ox"
 133 depicts oxalate) at pHs below 7. Furthermore, Liu et al. (2017a) introduced $Ge(ox)_3^{2-}$ as an anionic
 134 complex of germanium and oxalic acid. The concentrations of germanium and oxalic acid in the
 135 latter study were reported to be 0.013 and 0.67 mol/L, respectively. However, others [15,29]
 136 reported the formation of neutral species of trisoxalato germinates as Eq. (6):

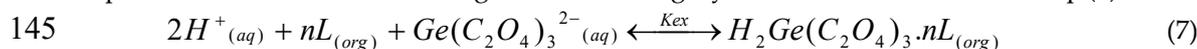


138 In the current study, germanium neutral soluble species in the form of trisoxalatogermanate
 139 have been considered as predominant species participated in the reactions.

140

141 **4. Results and discussions**142 *4.1. Determination of the extraction mechanism by slope analysis*

143 With respect to the “solution chemistry” section and the literature review [23,30,31], the
 144 probable extraction reaction of germanium using Cyanex 923 can be written as Eq. (7):



146 Where L and K_{ex} depict the organic extractant (Cyanex 923) and the equilibrium constant,
 147 respectively. In order to find the number of extractant molecules that participated in the reaction, a
 148 series of liquid-liquid extraction experiments were conducted and the results were reported
 149 elsewhere [15]. According to Eq. (7), K_{ex} can be written as Eq. (8):

$$150 \quad K_{ex} = \frac{[H_2Ge(C_2O_4)_3 \cdot nL]_{(org)}}{[H^+]^2_{(aq)} [L]^n_{(org)} [Ge(C_2O_4)_3^{2-}]_{(aq)}} \quad (8)$$

151 Since $\frac{[H_2Ge(C_2O_4)_3 \cdot nL]_{(org)}}{[Ge(C_2O_4)_3^{2-}]_{(aq)}}$ is equal to the distribution coefficient (D) at an equilibrium state, Eq.

152 (8) can be written as Eq. (9):

$$153 \quad K_{ex} = \frac{D}{[H^+]^2 [L]^n} \quad (9)$$

154 By taking the logarithm of Eq. (9), Eq. (10) was rearranged:

$$155 \quad \log(D) = \log K_{ex} + 2 \log[H^+] + n \log[L] \quad (10)$$

156 According to solvent extraction experiments [15], $n=4$ was proposed for the number of Cyanex
 157 923 molecules reacted with transported germanium species at the condition similar to the present
 158 study.

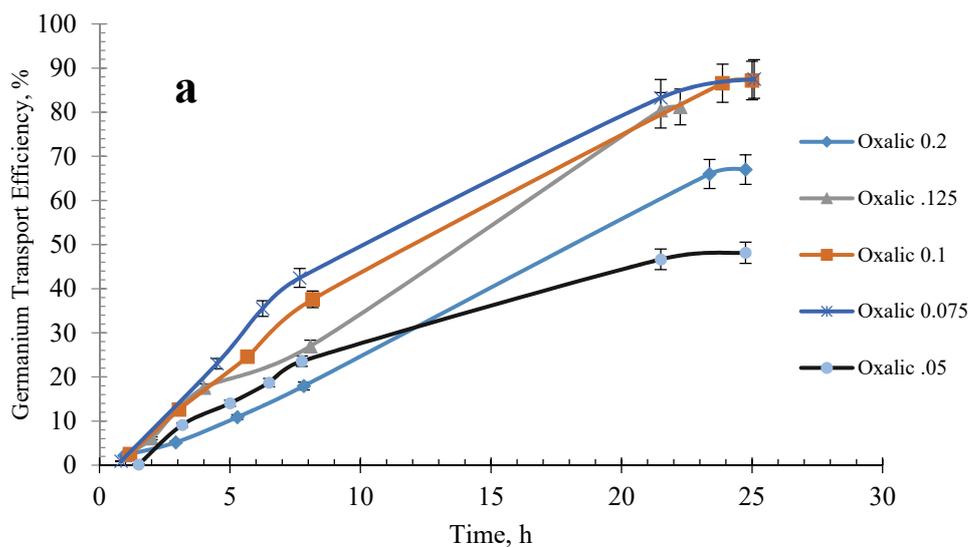
160 *4.2. Determination of appropriate oxalic acid concentrations in the feed phase*

161 With respect to the “solution chemistry” section, germanium was transported across FSSLM as
 162 a neutral complex (trisoalato germanate) using Cyanex 923. The transport efficiency depends on
 163 the complexation of germanium and oxalate. Therefore, the concentration of oxalic acid is a
 164 significant parameter for transport. In this regard, a series of experiments were conducted at the
 165 oxalic acid concentration in the range of 0.05-0.2 mol/L with the carrier concentration of 20 %v/v.
 166 Figures 1a and b illustrate the obtained results. As seen in these figures, the transport efficiency and
 167 permeation coefficients decrease at lower and higher values of this range. Moreover, at the oxalic
 168 concentration of 0.075 mol/L, the maximum permeation coefficient and transport efficiency were
 169 found to be 9.97×10^{-4} cm/s and 88%, respectively. The species of germanium at various oxalic acid
 170 concentrations have been illustrated in Figure 2. As seen in this figure, at lower oxalic acid
 171 concentrations, the dissociation of oxalic acid (H_2ox) is not complete and the germanium is in the
 172 form of $Ge(OH)_4$. However, by increasing the oxalic acid concentration (up to 0.1 mol/L), the
 173 concentration of ox^{2-} enhances results in increasing $H_2Ge(C_2O_4)_3$ and consequently the germanium
 174 transport. On the other hand, with more enhancement of oxalic acid concentration, the
 175 concentration of germanium oxalates decreases resulting in the decrease in the germanium
 176 transport at a higher oxalic acid concentration (>0.1 mol/L).

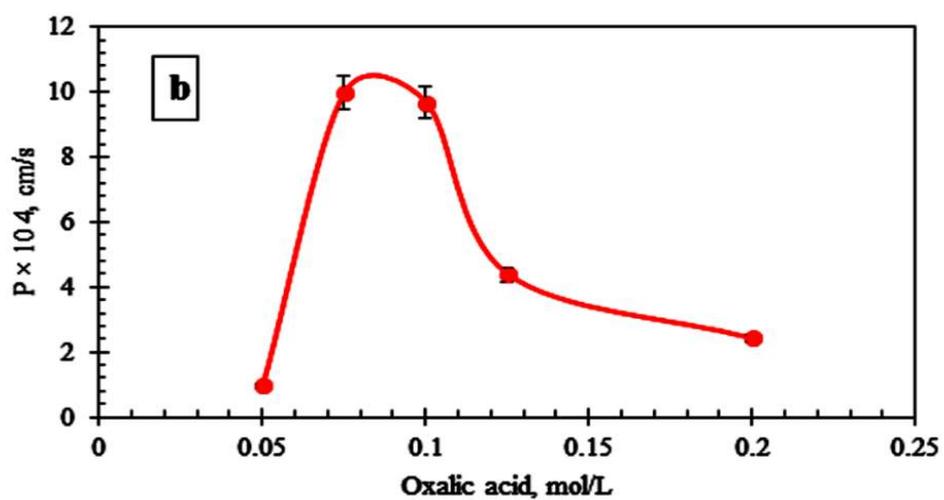
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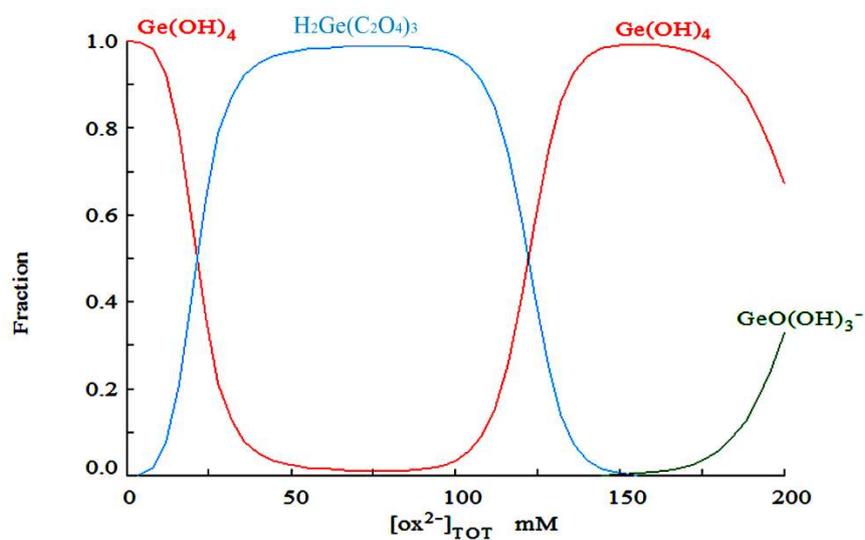


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181

182 **Figure 1.** The effect of oxalic acid concentration on (a) transport and (b) permeability coefficient of
 183 germanium in the FSSLM system ([Cyanex 923] = 20 %v/v, temperature of 22°C, and [NaOH]= 0.1
 184 mol/L).



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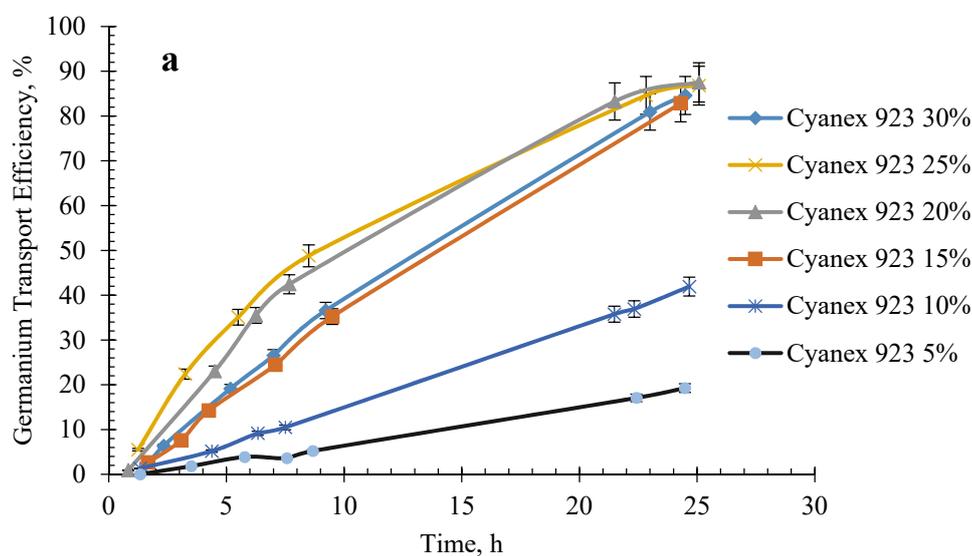
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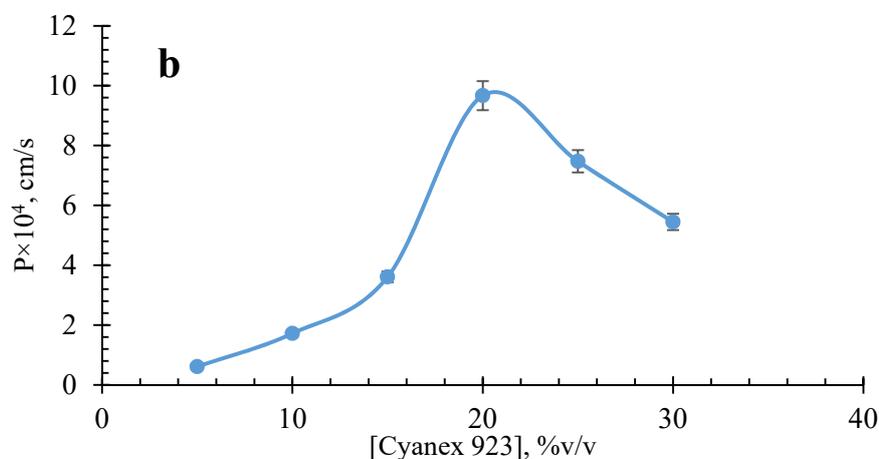
Figure 2. Species of germanium in various oxalic acid concentrations and 100 mg/L Ge (calculated by Medusa software).

188 4.3. Evaluation of appropriate carrier concentration

189 The presence of mobile carriers in a membrane phase is necessary for the transport
 190 phenomena; however, an excess amount enhances the viscosity and decreases transport [32].
 191 Therefore, in order to obtain efficient transport, determining an optimum concentration of the
 192 carrier is important. In the present study, the range of 0-30 %v/v for the Cyanex 923 concentration
 193 was selected with respect to the liquid-liquid extraction experiments. All FSSLM experiments were
 194 conducted at the oxalic acid concentration of 0.075 mol/L, the temperature of 22°C, and the NaOH
 195 concentration of 0.1 mol/L. The result has been plotted in Figures 3a and b. As seen in this figure,
 196 the complete reaction between species and the carrier does not occur at lower concentrations of the
 197 carrier. The germanium transport efficiency rises to about 88% when the carrier concentration
 198 increases from 10 %v/v to 20 %v/v. Moreover, with increasing the carrier concentration, the curves
 199 corresponding to Cyanex 923 of 30 and 25 %v/v are shifted down, showing the decrease in
 200 germanium transport. In Figure 3b, this behavior can be observed in the reduction of the
 201 permeability coefficient. The mentioned reduction may occur due to the enhancement of Cyanex
 202 923 viscosity and its precipitation in pores of the membrane [33]. According to the aforementioned
 203 discussion, the concentration of 20 %v/v was selected as an optimum concentration.
 204



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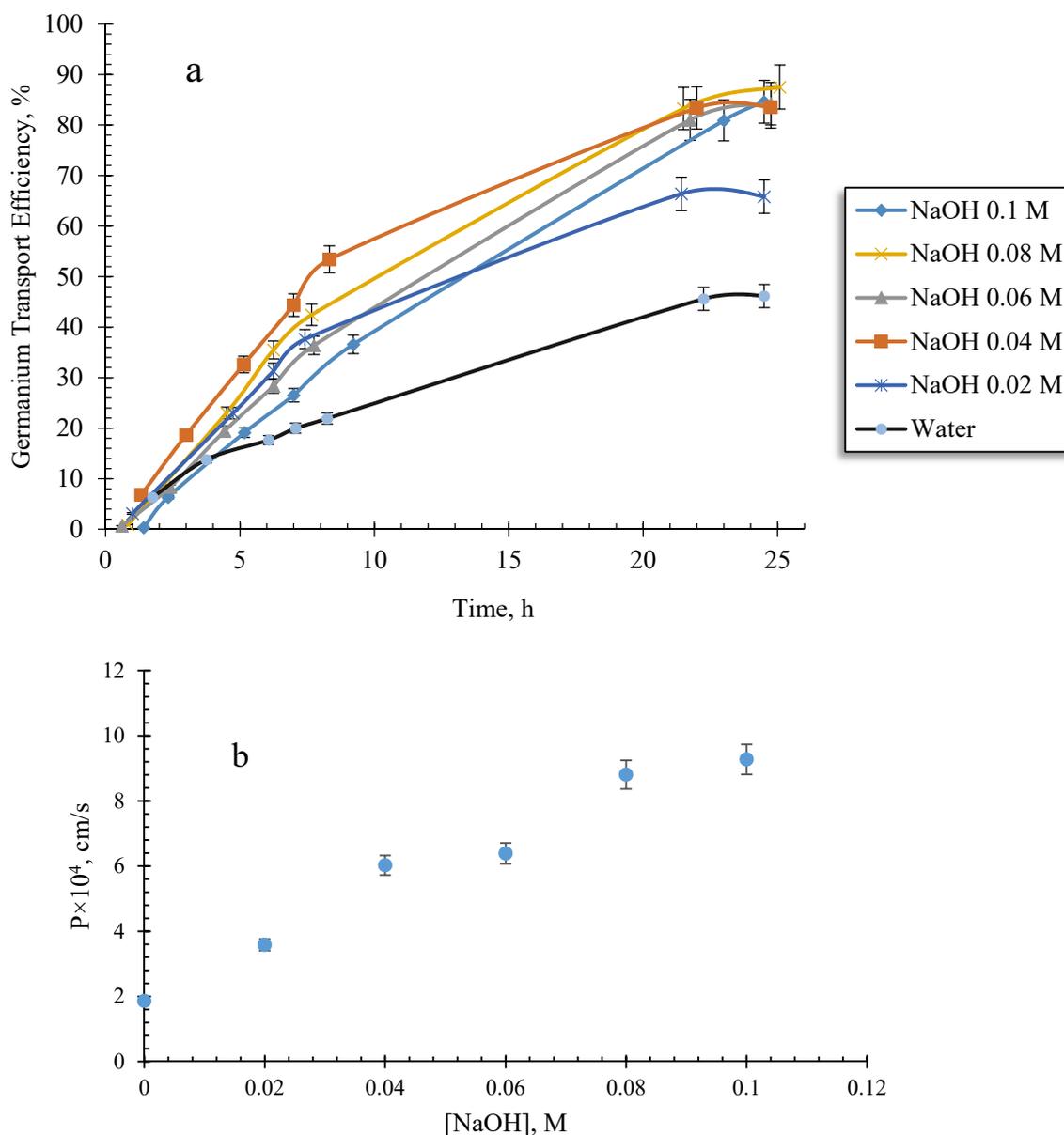
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208 **Figure 3.** Effect of the carrier concentration on (a) transport and (b) permeability coefficient of
 209 germanium in the FSSLM system ([Oxalic acid] = 0.075 mol/L, temperature of 22°C, and [NaOH] =
 210 0.1 mol/L).

211 4.4. Investigation on appropriate strip reagent

212 In order to select efficient reagent/reagents for stripping germanium from the loaded organic
 213 carrier, a series of liquid-liquid extraction experiments were conducted and the results have been
 214 published elsewhere [15]. Among several reagents such as ammonium chloride (NH_4Cl), sodium
 215 hydroxide (NaOH), catechol ($\text{C}_6\text{H}_6\text{O}_2$), citric acid ($\text{C}_6\text{H}_8\text{O}_7$), ammonia (NH_3), sodium sulfate
 216 (Na_2SO_4), and sulfuric acid (H_2SO_4), NaOH was selected as an efficient reagent for stripping
 217 germanium from 20 %v/v Cyanex 923. Thus, FSSLM experiments were conducted to evaluate the
 218 effect of the NaOH concentration on the transport of germanium with the carrier concentration of
 219 20 %v/v Cyanex 923 and an oxalic acid concentration of 0.075 mol/L in the feed phase. The results
 220 can be seen in Figures 4a and b.



221

222

223

224 **Figure 4.** Effect of NaOH concentration on (a) transport and (b) permeability coefficient of
 225 germanium in the FSSLM system ($[\text{Oxalic acid}] = 0.075 \text{ mol/L}$, the temperature of 22°C , and $[\text{Cyanex}$
 226 $923] = 20 \text{ \%v/v}$).

227 As seen in these figures, the transport efficiency and the permeability coefficient increase with
 228 an enhancement of NaOH concentration. About 87% of germanium was transferred to the strip

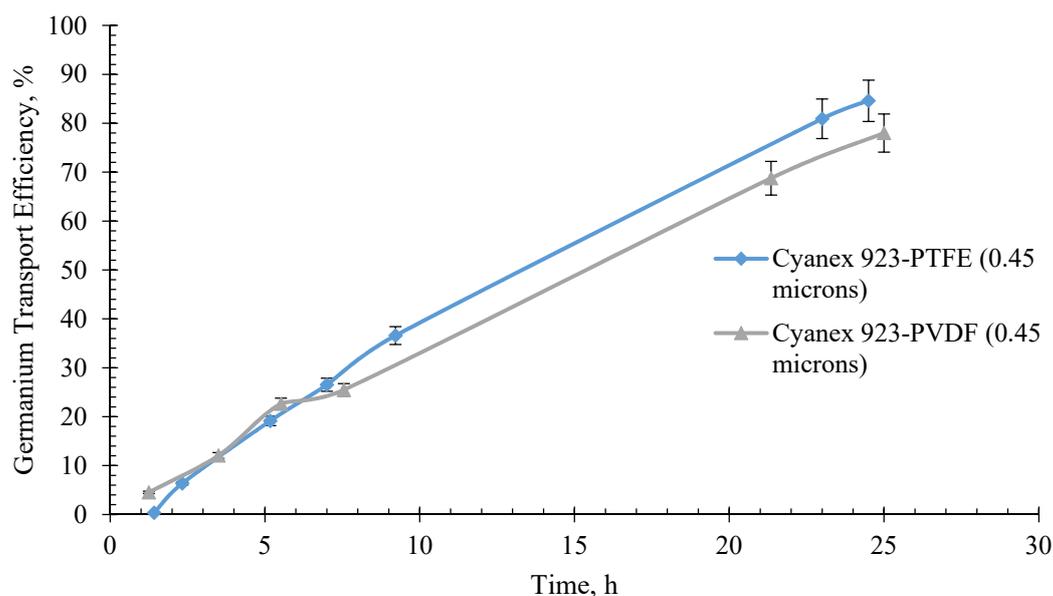
229 phase at concentrations in the range of 0.04-0.1 mol/L. The transport efficiency corresponding to the
 230 NaOH concentration of 0.02 mol/L is approximately 66%. Furthermore, according to Figure 4b, the
 231 permeability coefficient rises to 9.28×10^{-4} cm/s at the NaOH concentration of 0.1 mol/L. This is due
 232 to the increase in the amount of OH⁻ anions which enhances the de-complexation rate at the
 233 interface of the strip side [30]. The probable reaction for stripping species from the loaded carrier
 234 can be written as Eq. (11) [15]:



236 4.5. Effect of membrane type on transport

237 In order to know the effect of membrane type on the transport of germanium, an experiment
 238 was conducted at the condition of 100 mg/L Ge and oxalic acid of 0.075 mol/L, and the NaOH
 239 concentration of 0.1 mol/L with a polyvinylidene difluoride (PVDF) membrane.

240 As seen in Figure 5, there is not a significant difference between the transport efficiencies
 241 corresponding to the PTFE and PVDF membranes obtained from the experiments conducted under
 242 a similar condition. However, the overall transport efficiency of the PTFE membrane is somewhat
 243 greater than that of PVDF. The germanium permeability coefficients of the PVDF and PTFE
 244 membranes were obtained to be 3.14×10^{-4} and 9.28×10^{-4} cm/s, respectively. Therefore, the
 245 germanium permeability through the PTFE membrane is approximately 3 times the PVDF
 246 permeability. Similar results have been reported by Adnan, *et al.* [34]. Various parameters such as
 247 higher tortuosity of PVDF membranes result in reducing their permeability [35].



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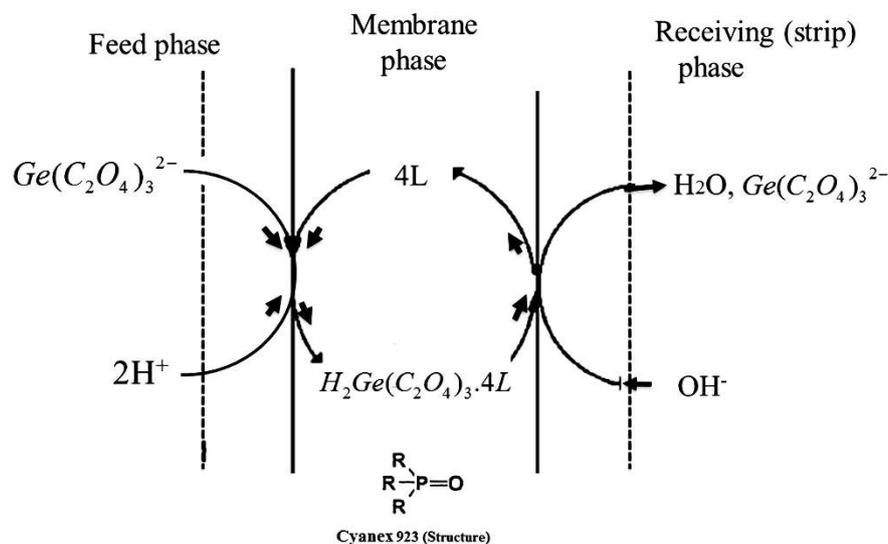
249 **Figure 5.** Transport efficiency of germanium versus time across PTFE and PVDF ([Oxalic acid] =
 250 0.075 mol/L, the temperature of 22°C, [Cyanex 923] = 20 %v/v, and [NaOH] = 0.1 mol/L).

251 4.6. Permeability model

252 The permeation of germanium through the FSSLM (with PTFE membrane) was modeled to
 253 find the mass transfer resistances. To model the mentioned system, it was assumed that species
 254 transported through SLM were performed by diffusing and the chemical reactions took place
 255 instantly [36]. Figure 6 illustrates how germanium oxalates permeate through a PTFE membrane
 256 containing Cyanex 923 based on the following steps:

- 257 (i) In the feed phase, germanium oxalates and protons diffuse to the interface layer.
- 258 (ii) Diffused species and Cyanex 923 molecules react together in the mentioned layer.
- 259 (iii) The produced complexes permeate across the membrane toward the membrane-strip
 260 interface layer.

- 261 (iv) NaOH detaches germanium-Cyanex 923 complexes at the membrane-strip phase interface.
 262 Thus, germanium species are stripped from the organic carrier.
 263 (v) The unloaded carrier molecules permeate inversely toward the feed phase.



264

265

Figure 6. A schematic transport of germanium through FSSLM-Cyanex923.

266 The extraction reaction of germanium by Cyanex 923 has been described in Eq. (7) with $n=4$.
 267 According to an LLX model developed by Kamran Haghighi, *et al.* [37], the extraction equilibrium
 268 constant of the aforementioned reaction was calculated to be 2056. The germanium flux can be
 269 obtained using Fick's first diffusion law. Hence, the fluxes at the feed-membrane boundary layer
 270 and the membrane phase (J_f and J_m , respectively) can be presented as Eqs. (12) and (13):

$$271 \quad J_f = \frac{1}{\Delta_f} ([Ge(IV)]_f - [Ge(IV)]_{bl,f}) \quad (12)$$

$$272 \quad J_m = \frac{1}{\Delta_m} ([H_2Ge(ox)_3 \cdot 4R]_{bl,f} - [H_2Ge(ox)_3 \cdot 4R]_{bl,s}) \quad (13)$$

273 Where Δ_m and Δ_f depict the resistances corresponding to the membrane phase and the feed
 274 phase boundary layer, respectively. Subscripts of f , bl , and s show feed, boundary layer, and strip,
 275 respectively. Moreover, $[Ge(IV)]_f$, $[H_2Ge(ox)_3 \cdot 4R]_{bl,f}$, and $[H_2Ge(ox)_3 \cdot 4R]_{bl,s}$ represent the
 276 germanium concentration in the feed phase, the feed-membrane, and the strip-membrane boundary
 277 layers, respectively. It is noted that since the germanium concentration in the strip-membrane
 278 boundary layer is lower than that in the feed-membrane boundary layer, $[H_2Ge(ox)_3 \cdot 4R]_{bl,s}$ has
 279 been neglected. Hence, Eq. (13) can be rewritten as Eq. (14):

$$280 \quad J_m = \frac{1}{\Delta_m} ([H_2Ge(ox)_3 \cdot 4R]_{bl,f}) \quad (14)$$

281 Since the chemical reactions instantly took place, the flux values in the feed-membrane layer
 282 and the membrane phase are equal ($J_f = J_m = J$). Therefore, overall J can be found as Eq. (15):

$$283 \quad J = \frac{K[H^+]^2[R]_{org}^4[Ge(IV)]_f}{\Delta_m + \Delta_f(K[H^+]_{aq}^2[R]_{org}^4)} \quad (15)$$

284

285 Regarding Eq. (1), the permeability coefficient is also written as Eq. (16):

$$286 \quad P = \frac{K[H^+]^2[R]_{org}^4}{\Delta_m + \Delta_f(K[H^+]_{aq}^2[R]_{org}^4)} \quad (16)$$

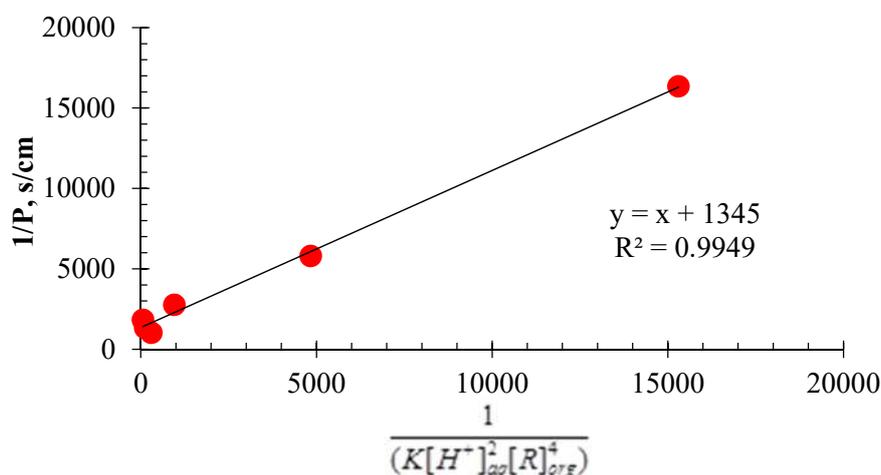
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288 By arranging Eq. (16), Eq. (17) was found to obtain the mass transfer resistances:

289

$$\frac{1}{P} = \Delta_f + \frac{\Delta_m}{(K[H^+]_{aq}^2[R]_{org}^4)} \quad (17)$$

By plotting $\frac{1}{(K[H^+]_{aq}^2[R]_{org}^4)}$ versus $1/P$ and the corresponding trend line, the intercept and slope values (Δ_f and Δ_m , respectively) can be found. The mentioned plot was shown in Figure 7. According to this plot, the values of 1 and 1345 s/cm were found for Δ_m and Δ_f , respectively.



295

Figure 7. The plot of $1/P$ vs. $\frac{[H^+]^4}{(K[R]_{org}^4)}$ (100 mg/L of Ge, [Oxalic acid] = 0.075 mol/L, the temperature of 22°C, [Cyanex 923] = 20 %v/v, and [NaOH] = 0.1 mol/L).

298 5. Conclusion

299 This paper focused on studying the transport of germanium across an FSSLM system from
 300 aqueous solutions using Cyanex 923. The main achievement of this study was that germanium and
 301 oxalate can form neutral species which can be extracted and transported by Cyanex 923 through an
 302 FSSLM system. Results showed that the oxalic acid concentration is vital for the transport of
 303 germanium because extractable germanium oxalate species are not formed in out range of the
 304 optimum values. An optimum concentration of oxalic acid for the complete transport of germanium
 305 was found in a concentration range of 0.075-0.1 mol/L. The investigation on the effect of the Cyanex
 306 923 concentration in the membrane phase showed that the concentration of 20 %v/v was
 307 appropriate for the complete germanium transport. Due to the inverse effect of viscosity in the
 308 higher concentrations of Cyanex 923 on germanium transport, Cyanex 923 concentrations more
 309 than 20 %v/v were not proposed as optimum conditions. Several stripping reagents were classified
 310 based on liquid-liquid extraction experiments to select appropriate reagents used in the FSSLM
 311 system. Accordingly, NaOH was chosen as an efficient stripping reagent for the FSSLM system. The
 312 NaOH concentrations of 0.04-0.1 mol/L were the range in which the maximum germanium
 313 transport achieved. Finally, a permeation model was developed to find the mass transfer
 314 resistances. As a result, the values of 1 and 1345 s/cm were found for Δ_m and Δ_f , respectively.

315

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