Journal of Industrial and Engineering Chemistry 22 (2015) 217–228

Contents lists available at ScienceDirect

Journal of Industrial and Engineering Chemistry

journal homepage: www.elsevier.com/locate/jiec

Purification of Sn(IV) and recovery of Pd(II) from flexible printed circuit board industry wastewater via HFSLM: Temperature effect investigation

Krirkratthawit Wongkaew [a], Niti Sunsandee [b], Ura Pancharoen [a], Kasidit Nootong [a,*], Prakorn Ramakul [c,**]

[a] Department of Chemical Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok 10330, Thailand
[b] Government Pharmaceutical Organization, Ratchathevi, Bangkok 10400, Thailand
[c] Department of Chemical Engineering, Faculty of Engineering and Industrial Technology, Silpakorn University, Nakhon Pathom 73000, Thailand

ARTICLE INFO

Article history:
Received 27 January 2014
Received in revised form 10 July 2014
Accepted 12 July 2014
Available online 18 July 2014

Keywords:
Liquid membrane
Hollow fiber
Recovery
Stannous
Palladium

ABSTRACT

Purification of Sn(IV) and recovery of Pd(II) from flexible printed circuit board (FPCB) industry wastewater via HFSLM has been presented. This work examined the influence of extractant concentration in the liquid membrane, HCl concentration, and flow rates of feed and stripping solutions. The thermodynamic properties were also investigated. The results showed that percentage of recovery of Pd(II) was 100% and purify 84% of Sn(IV) remaining in the feed solution. The Sn(IV) and Pd(II) kinetic reaction orders approached 1.0 and the reaction rate constants were read at 0.00301 and 0.08509 min^{-1}, respectively. The experimental results were agreed with the mathematical model.

Introduction

Flexible printed circuit board (FPCB) technology is an enabling technology for several important applications in various industries, e.g., automobiles, computers, digital cameras, telecommunications, etc. The advantage of this electronic technology is in its effect on performance in the design of flexible circuits, allowing a reduction in their size, weight, assembly time and cost, while continuously enhancing their functionality. The demand for flexible circuits has grown rapidly, at an average annual growth rate (AAGR) of 13.5%, to reach US$11.2 billion in 2010 and a projected US$16 billion in 2015 [1]. Nowadays, in most fields the economic situation is highly competitive, particularly in regard to matters such as time of delivery, quality and, perhaps most importantly, product price. As indicated above, this is interrelated with a reduction of production costs go together. However, the specific process flow for producing FPCB must be considered [2]. The five main processes are: computer numerical control process (CNC), direct plating process (DPP), plated through-hole process (PTH) [3], circuit-forming process (CIR), and the final process (FIN). For all five of the processes, since the cause of waste is the DPP process, the activating solution and precious metals (palladium and stannous) are included in the waste. Both of these precious metals have many versatile uses, such as in the jewelry industry [4], in printed circuit boards in the electronics industry [5], in catalytic converters in the automobile industry [6], as dental alloys [7], for plating and coating processes in the steel industry [8], and as catalysts in the petrochemical industry [9], etc.

In practice, multidisciplinary research and technology was used for separation of palladium ions from aqueous solution such as precipitation [10], and solvent extraction [11] .On the other hand, these conventional methods are ineffective at a very dilute concentration of metal ions [12]. Recently, liquid–liquid extraction has been reported as a suitable method for extraction and stripping of palladium and platinum ions from various aqueous solutions by using many extractants [13,14]. The results proved that this system can be recovered palladium ions successfully. However, this system suffers from many disadvantages, i.e., the large inventory, loss of high purity solvents and extractant, as well as the disposal of solvents [15]. In recent years, the separation of metal

* Corresponding author. Tel.: +66 2 218 6864; fax: +66 2 218 6877.
** Corresponding author. Tel.: +66 3421 9368; fax: +66 3421 9368.
E-mail addresses: kasidit.n@chula.ac.th (K. Nootong), prakorn@su.ac.th (P. Ramakul).

http://dx.doi.org/10.1016/j.jiec.2014.07.014
1226-086X/

Nomenclature

A	effective area of the membrane (cm^2)
A_c	cross-sectional area of a hollow fiber (cm^2)
A_p	area of micropores of a hollow fiber (cm^2)
C	concentration (mg/L) or (gmol/L)
D	distribution ratio
G	Gibbs free energy (kJ/mol)
H	enthalpy (kJ/mol)
k	mass transfer coefficient [cm/s] or reaction rate constant (min^{-1})
K	equilibrium constant
L	length of a fiber (cm)
m	reaction order
n	stoichiometric coefficient
N	number of hollow fibers in the module
P	permeability (cm/s)
Q	volumetric flow rate (cm^3/min)
r	rate of the reaction (mol/L min), or radius (cm)
R	gas constant (8.314 J/mol K)
S	entropy (J/mol K)
t	time (min)
T	temperature (°C)
V	volume (cm^3)
x	direction of fiber axis

Greek letters

τ_0	constant in Eq. (15c)
ε	porosity of hollow fiber

Subscripts

ex	extraction
feed	feed phase
i	internal or aqueous phase
m	membrane
o	external
lm	log-mean
Pd	palladium ions
Sn	stannous ions
strip	stripping phase

ions at a very low concentration has been focused on the liquid membrane system. In particular, a hollow fiber supported liquid membrane (HFSLM) is an excellent system for the separation of metal ions at very low concentration (in ppm and ppt) from several solutions. This technique has demonstrated feasibility of application on an industrial scale for separating and increasing the concentration of several metal ions [16,17]. The advantages of a hollow fiber membrane over traditional separation techniques are its high efficiency, high contact area, high selectivity, low operating costs and energy consumption [18,19]. A summary of previous works on the separation of stannous and palladium by several methods is shown in Table 1.

The extraction and stripping reactions of metal ions across HFSLM take place on two interfaces of the feed – membrane and membrane –stripping. Both reactions are in the power of the controlled temperature in the system [24,25]. A little previous work reported the influence of temperature on the efficiency of extraction and stripping of the target of metal ions across HFSLM. Bautista-Flores et al. [26] reported that an increase in operating temperature ranging 15–35 °C results in the increasing extraction efficiency for lead (II) separation across HFSLM. Sunsandee et al. [27] reported the efficiency of temperature ranging investigated the effects of temperature ranging from 25 °C to 35 °C on extractability of enantioseparation of (R,S)-amlodipine. Usapein et al. [24] reported the influence of operating temperature on extraction and stripping of Cr(VI). Results noted that the extraction of Cr(VI) increased when the temperature was increased from 20 °C to 50 °C. However, when operating temperature was higher than 40 °C, the lifetime of liquid membrane are short. Liu and Shi [25] reported that the influence of operating temperature ranging from 15 °C to 35 °C on ethylbenzene and nitrobenzene extraction across HFSLM. Results revealed that separation percentage increased when the temperature was increased. It was found that the separation efficiency increased when the operating temperature was raised. Nonetheless, no literature information with respect to influence of temperature on efficiency of palladium ions via a single module HFSLM operation was addressed.

The main objectives of this paper are to present the effect of operating parameters, in particular operating temperature, on efficiency of extraction and stripping of palladium ions from FPCB industrial wastewater across HFSLM. FPCB industrial wastewater containing stannous as an impurity was used as the feed solution. HFSLM was impregnated with LIX84-I which was selected as the extractant as results of its efficiency in separation of palladium ions from various aqueous solution [14].

Theory

Extraction equilibrium (K_{ex})

In HFSLM, the carrier LIX 84-I was dissolved in kerosene to generate an organic solution which was embedded in the hydrophobic micropores of the hollow fiber module. The feed phase was FPCB industrial wastewater that contained Pd(II) and Sn(IV) ions. The properties of the flexible printed circuit board industry wastewater are shown in Table 2. The stripping solution was a hydrochloric acid solution.

In the HFSLM system, the feed solution was pumped into the inner side while the stripping solution was simultaneously

Table 1
Literature reviews on the separation extraction of palladium and stannous.

Author	Method	Feed solution	Extractant	Diluent
Bandekar et al. [13]	SE	Sn(IV), Sb(III), etc.	PC-88A	Toluene
Rane et al. [14]	SE	Pt(IV), Pd(II)	LIX 84-I	Dodecane
Zaghbani et al. [15]	FSSLM	Au(III), Pd(II)	Thiacalix 4 arene	NPOE
Zou et al. [20]	SE	Rh(III), Sn(II),	TBP	No use
Rovira et al. [21]	FSSLM	Pt(IV), Rh(III), Pd(II)	DEHTPA	Kerosene
Patthaweekongka et al. [22]	HFSLM	Pt(IV), Pd(II), etc.	TRHCl-OA	Chloroform
Uheida et al. [23]	HFSLM	Pd(II)	NTH	Hexane
This work	HFSLM	Pd(II), Sn(IV)	LIX 84-I	Kerosene

Note: SE, solvent extraction; FSSLM, flat-sheet supported liquid membrane; and HFSLM, hollow fiber supported liquid membrane.