

Copper Extraction Using Liquid Ion Exchanger

Khyati Shah, Bina Sengupta, R. Sengupta

*Chemical Engineering Department, Faculty of Technology and Engineering,
The Maharaja Sayajirao University of Baroda, Vadodara, 390 001, Gujarat, India*

Abstract-Solvent extraction separation of copper from synthetic sulphate liquors media using oxime based extractant 2-hydroxy-5-nonylaceto phenona oxime (LIX 84-IC) in kerosene was studied. Parameters such as equilibrium pH, feed concentration, phase ratio, extraction kinetics, stripping kinetics were analysed. The effect of electrolyte was also optimized. At pH 2, LIX[®]84-IC shows a linear relationship having a slope of 2, indicating that the extracted species binds to two extractant molecule. Effect of feed concentration gives a linear relationship with a slope 0.85 (nearly 1) indicating that the extracted species is CuR₂. Experiments shows maximum loading capacity for copper is 3.7gm/dm³ using 10% LIX[®]84-IC. At the maximum loading capacity the stripping is less favorable while at half the maximum loading capacity, upto 2.12 g/lit there is almost complete amount of copper is stripped.

Keywords- LIX[®]84-IC, copper, leach liquor, solvent extraction, Stripping,

I. INTRODUCTION

The global demand for refined copper is approximately 13MTPA. Almost 40% of this demand is met by recycling. International Copper Study Group estimates that 13% of the refined copper production from ores is by solvent extraction electrowinning technology. This technology is accounts for an even larger market share of refined copper production from scraps and tailings.

An increasing demand for metals in general, and higher purity metals in particular, coupled with decline in ore grades and more stringent environmental regulations have driven, and will continue to drive, research into finding more effective and efficient methods for processing the ores available to us, and recycling previously used metals. Hydrometallurgy has provided many of the new processes and solvent extraction technology will certainly play an important role in developing new processes. [55]

Mechanism of solvent extraction:

The mechanism of solvent extraction usually proceeds in three stages: [34]

- The formation of uncharged complex
- The distribution of the extractable complex
- Interaction, if any, of the complex in the organic phase

The formation of uncharged complex is the most important step in extraction. Such uncharged complex can be formed by the process of chelation, salivation or ion pair formation. Hence to generate such uncharged metal complexes different types of reagents are used to bind with metal ions, such reagents are called extractant. In absence of the extractant in the organic solvent the metal ions would never get extracted in the organic phase. The solvent extraction of metals differs from conventional solvent extraction in this aspect that for metal extraction the solvent contains both the extractant and the diluent (organic phase).

Solvent extraction involves essentially two operations: Extraction and Stripping. Metals in ionic form have a strong affinity for the aqueous phase whereas they are energetically less favorable to the organic solvent. Metal ions are energetically inefficient to combine with organic phase, so for extracting metal ions to the organic phase, metal ions must be neutralized by forming organic soluble neutral metal complexes. The reaction of this complex formation must be reversible because of the necessity of back extraction to another aqueous phase for further processes of metal purification.

II MATERIALS AND REAGENTS

LIX[®]84-IC supplied by Cognis (Ireland) was used as the extractant. The physical properties and performance specifications of the extractant was reported in Table 1. Kerosene (Indian Oil Corp. Ltd.) having boiling range 152–271 °C containing n-paraffins (27.08%), naphthenes (55.92%), aromatics (16%) and olefins (1%) having density (15) of 821.3 kg/m³ was used as the diluent. The extractant and kerosene were used directly as received from the manufacturers. copper salts (AR grade), were supplied from Merck Specialties Limited. All other reagents used were also of AR grade.

Table 1 Properties of LIX[®]84-IC

Properties	Appearance	Specific Gravity (25°/25°C)	Flash Point	Copper Complex Solubility	Maximum Copper Loading	Extraction Kinetics	Strip Kinetics	Extraction Isotherm Point	Strip Isotherm Point
LIX [®] 84-IC	Amber Liquid	0.930-0.950	>170°F	>30 g/l	> 4.7 g/l	> 90% (60 sec.)	> 90% (30 sec.)	> 3.65 g/l Cu	< 0.50 g/l Cu

III. EXPERIMENTAL METHODS AND TECHNIQUES

Copper solutions were prepared by dissolving the requisite amount of sulfate salt in deionised water and the pH was adjusted with sulphuric acid or sodium hydroxide to the desired value and measured with pH meter Systronics make – 335. The commercial extractant LIX[®]84-IC (10% V/V) was used for extraction. Equilibrium studies were carried out by contacting equal volume of aqueous and organic phase for different time in shaker flasks at 30±2^oC. Preliminary experiments on the kinetics of metal extraction showed that equilibrium was achieved in 20 minute contact.. After phase disengagement, the aqueous phase was separated and analyzed for metal concentration using Atomic Absorption Spectrophotometer ‘Chemito’ make, model AA–203 (AAS). The concentration of the metal in the organic phase was calculated from mole balance. Loaded organic phase was stripped using 1.5M and 2M sulfuric acid in 2 stages and the stripped phase was analyzed for copper using AAS.

Experiments were performed to study the loading of copper from aqueous media with a variation equilibrium pH, initial copper concentration in aqueous phase and oil/aqueous phase ratio. Further the maximum loading capacities of the solvent extractant system was determined and the effect of electrolyte on copper loading was investigated. The results are reported in subsequent sections.

A. Influence of equilibrium pH

Extraction studies were carried out using aqueous solution containing 0.0157 M (1g/dm³) copper. The extraction of Cu with 10% (v/v) LIX[®]84-IC as a function of pH was studied in the pH range 0.9 to 3.33. The results shows for 10% LIX[®]84-IC extraction of copper starts at 0.9 pH and quantitative extraction takes place at 2 pH.

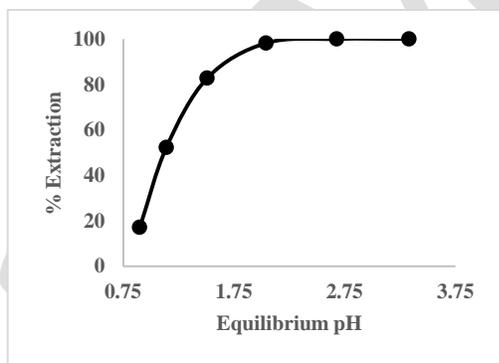


Fig.1 Effect of Equilibrium pH

B. Effect of equilibrium pH on distribution coefficient

A linear increase in the extraction of copper, expressed by the Distribution ratio D [$D = \frac{(Cu)_{org}}{(Cu)_{Aq}}$], with the increase in equilibrium pH. The lines shows a slope 2 indicating that the extracted species binds to two extractant molecule, which agrees with the equation,

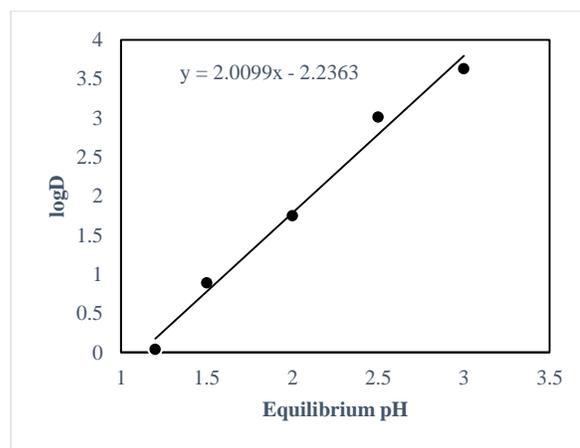


Fig.2: Log D v/s. Equilibrium pH for Copper Extraction

Ramachandra Reddy and Neela Priya [53] also reported that the log D v/s Equilibrium pH plot gave a slope of 2 for LIX 84. However, Agrawal and Kumari [1] reported that the log D v/s Equilibrium pH plot gave a slope of 1.72 at oil to aqueous ratio of 2:1 using LIX 84 for the treatment of copper bleed electrolyte. Reddy and Rajesh Kumar [52] reported that the plot of log D v/s LIX[®]84-IC (M) for Hafnium gave a straight line with slope 2. Ali Aman et. al. [4] reported log – log plot of D versus extractant concentration for LIX[®]84 which gave a linear relationship of slope 2. Nearly identical results are obtained from the plot of Log D v/s Log Extractant (LIX[®]84-IC), M (Molar) concentration as tabulated in Table 2 and Fig.2.

Table 2 Effect of Log D v/s. Log extractant Concentration

Log Extractant, M	Log D				
	1.2pH	1.5 pH	2 pH	2.5pH	3pH
-0.60	0.04	0.89	1.75	3.01	3.63
Slope	y = 1.87x + 1.17	y = 1.91x + 2.03	y = 1.99x + 2.9	y = 2.0x + 4.1	y = 2.04x + 5.0

Table 2 shows that for LIX[®]84-IC at an equilibrium pH above 2 the value of slope is almost 2, indicating that, 2 moles of the extractant are involved in the extracted species, but for low equilibrium pH slope is much less than 2. Within the range of experimental variables it is observed that at pH 2 and above the concentration of the carrier does not play a significant role in the extraction behavior, The effectiveness of the carrier for copper transfer is substantially reduced at pH below 2 comparison with pH greater than 2.

C. Effect of initial copper concentration in the aqueous feed

Copper loading with 10% LIX[®]84-IC in kerosene was studied for aqueous feed solution having equilibrium pH about 2 and copper concentration of 500-4500 mg/dm³. The oil to aqueous phase ratio was 1:1.

Table 3 Effect of initial copper concentration on extraction

Copper Concentration (mg/dm ³)	%Extraction
569	99.99
1100	97.96
1650	96.19
2121	96
4500	95

It can be seen from Fig. 3 that almost quantitative extraction is obtained in all cases in the experimental range. Even at 4500 mg/dm³ copper concentration 95% copper was extracted at equilibrium pH 2.

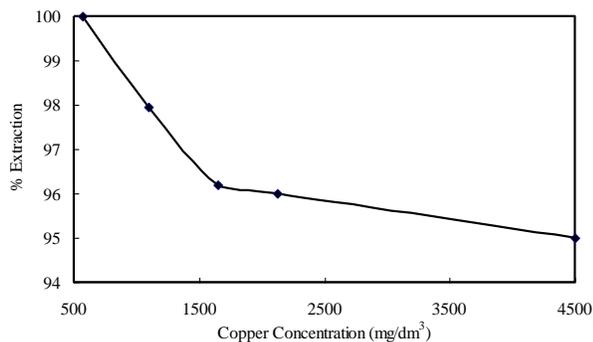


Fig. 3: Effect of Initial Copper Concentration on %Extraction

D. Maximum Loading Capacity

As can be seen from Fig.3 even at 4500 mg/dm³ copper concentration 95% copper was extracted at equilibrium pH 2, experiments were carried out for maximum loading capacity of LIX[®]84-IC. The loading capacity of LIX[®]84-IC was determined by two methods. In the first method, 10% LIX[®]84-IC was contacted for 20 minute with fresh volume of the aqueous phase containing 0.958 gm/dm³ Copper. The phase ratio of Organic : Aqueous phase was 1:1. In this case, a maximum loading of 7.2gm/dm³ was reached after 16 extraction stages as shown in Fig. 4 and thereafter it remains constant.

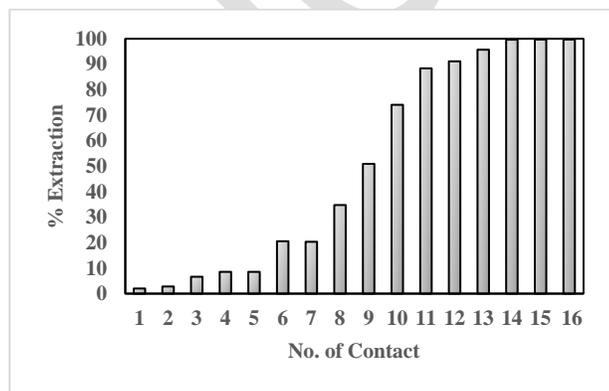


Fig. 4: Maximum Copper loading

E. Effect of change in O:A phase ratio on Copper extraction

The second procedure to evaluate the loading capacity, used the organic solution of 10% LIX[®]84-IC at the same organic phase at equilibrium pH 2 and conditions described as above except that various O:A phase ratio (1:0.33 to 1:4) were employed the results are shown in Fig. 4.8. It shows that a maximum loading of 3.763 gm/dm³ was obtained at phase ratio of 1:4. Ali Amal et. al. [4] reported the maximum loading of 3.125 gm/dm³ of copper in LIX[®]84.

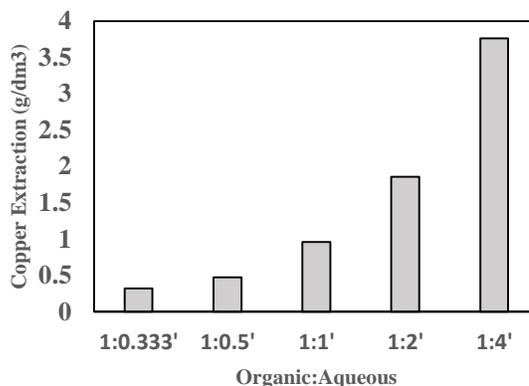


Fig: 5 Effect of change in Oil:Aqueous phase ratio on Copper extraction

F. Effect of Copper concentration and equilibrium pH on percentage extraction:

Experiments were carried out to study the effect of change in copper concentration change at equilibrium pH 2 as discussed earlier; however in contrast to earlier case where equilibrium pH was constant in this case the equilibrium pH was varied. It can be seen in the Fig.6 that even at 0.96 pH, for 0.5 gm/dm³ copper concentration, LIX[®]84-IC extracts almost 95% copper. Increasing pH leads to quantitative loading. However, below 0.9 pH with initial copper concentrations of 1 gm/dm³ and also 2 gm/dm³ only 17% copper could be extracted. As the pH is increased it is found that beyond pH 2 in all cases there is a quantitative loading.

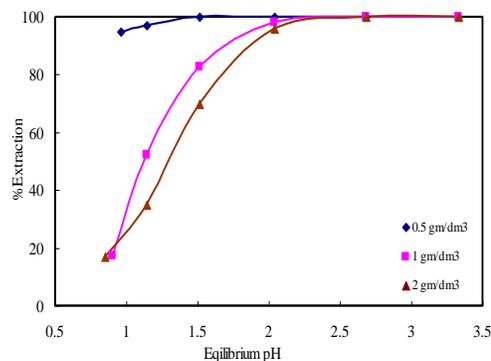


Fig. 6: Effect of Copper concentration and Equilibrium pH on the %Extraction

G. Effect of Electrolytes

The effect of Electrolytes salts, such as NaOH, was studied for initial copper concentration of 1 gm/dm³. The experimental data is presented in Fig.7. It was observed that at lower pH there was a decrease in the percentage extraction of.

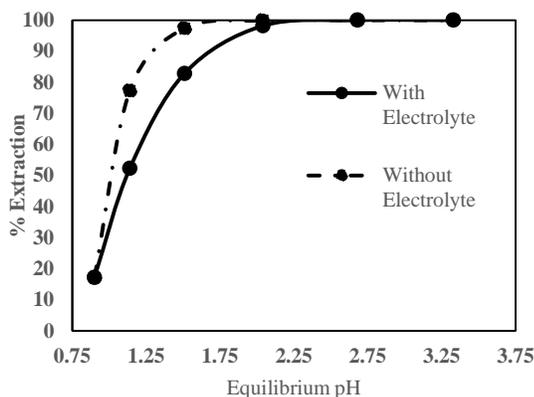


Fig.7: Effect of Electrolyte

copper by using NaOH, but at relatively higher pH that is above 2 pH there is a quantitative loading and the effect of NaOH was marginal.

H. Stripping of Copper from Loaded Organic Phase

Stripping of the copper loaded organic phase, was carried out using 1.5M H₂SO₄ and 2M H₂SO₄. As single stage stripping was not sufficient to strip the totally loaded aqueous phase so a two-stage counter-current stripping was carried out at oil to aqueous phase ratio of 1. Results of these experiments are tabulated in Table 4. After stripping, the organic phase was found to contain up to 262 mg/dm³ copper when 2M H₂SO₄ was used. there was a definitive increase in the extent of stripping when 1.5M H₂SO₄ was used as strippant in comparison with 2M H₂SO₄ as evident from Table 4.

Table 4 Effect of Equilibrium pH on copper stripping

Eq. pH	Loading (g/dm ³)	% Extraction	% Stripping			
			1.5M H ₂ SO ₄		2M H ₂ SO ₄	
			I Stage	II Stage	I Stage	II Stage
3.3	0.967	100	90.93	95.00	66.73	72.94

I. McCabe and Thiele plot for copper stripping by varying Oil:Aqueous phase ratios with 10% LIX[®]84-IC

The isotherms for stripping depend on the acid concentration of the strip liquor. A properly generated stripping isotherm represents the best stripping.

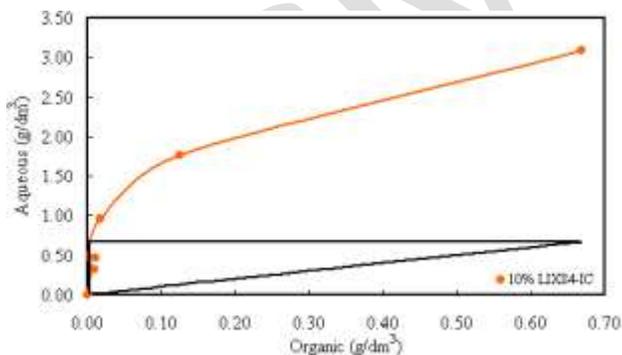


Fig.8: McCabe and Thiele plot by varying O:A phase ratios

As shown in Fig.8 at different acid concentration different isotherms are generated. Copper from the loaded organic was stripped with 1.5 M and 2 M H₂SO₄ in 2 stages at phase ratio from 1:0.33 to 1:4. Stripping of metal increases with rise in acid concentration. Only one stripping stage is required for the complete stripping of loaded organic of 3.1 gm/dm³ at 1:4 phase ratio. Alguacil [3] observed that it was possible to

obtain upto 3g/l copper in the aqueous stripped phase in two stages at an O:A ratio of 1 using LIX[®]973 N was extractant.

IV. CONCLUSION

The extraction and stripping of copper from aqueous sulphate media into kerosene phase containing LIX[®]84-IC as extractant was investigated. Effects of variation in LIX, equilibrium pH, change in aqueous phase concentration, phase ratio, effect of electrolyte were investigated. Maximum loading capacities were determined at extractant concentrations of 10% LIX[®]84-IC. The significant findings of this study are the following:

- The effectiveness of the carrier for copper transfer is substantially reduced at pH below 2 in comparison with pH above 2. At pH 2, LIX[®]84-IC shows a linear relationship having a slope of 2, indicating that the extracted species binds to two extractant molecule.
- Effect of feed concentration gives a linear relationship with a slope 0.85 (nearly 1) indicating that the extracted species is CuR₂.
- Experiments shows maximum loading capacity for copper is 3.7gm/dm³ using 10% LIX[®]84-IC.

- At the maximum loading capacity the stripping is less favorable while at half the maximum loading capacity, upto 2.12 g/lit there is almost complete amount of copper is stripped.

It is anticipated that these results will contribute significantly to the understanding of the extraction of copper using the new generation of LIX reagents and also help to identify the optimal condition for such extraction and stripping operation.

REFERANCES

- [1]. Agrawal A., "Separation and recovery of copper and nickel from Copper bleed stream by solvent extraction route", National Metallurgical Laboratory, Jamshedpur.
- [2]. Alguacil Francisco José and Antonio Cobo, "Solvent extraction with LIX 973N for the selective separation of copper and nickel", *Journal of Chemical Technology & Biotechnology*, 74, 467, 1999
- [3]. Alguacil F.J. "Recovery of copper from ammoniacal/ammonium carbonate medium by LIX 973N", *Hydrometallurgy* 52, 55, (1999)
- [4]. Ali, A. I., J. A. Daoud, and H. F. Aly, "Recovery of Copper from Sulphate media by LIX[®] 84 in Kerosene," *Journal of Chemical Technology and Biotechnology*, 67, 137 (1996).
- [5]. Aminian H. and Bazin C. "Technical Note Solvent Extraction Equilibria in Copper(II) – Iron(III)-LIX 984 System", *Minerals Engineering* 13, 667, (2000)
- [6]. Arpad Torma E., "Influence of Organic Solvents on Chalcopryrite Oxidation Ability of Thiobacillus ferrooxidans", *Applied and Environmental Microbiology*, 32, 102, (1976).
- [7]. Ashbrook A.W., "Commercial Chelating Solvent extraction reagents III. Oximes: Spectra, Structure and Properties", *Hydrometallurgy*, 1, 5, (1975)
- [8]. Aurora Molinari and Alfonso Oliva. "Studies on the extraction of copper(II) with 4-alkyldithiocarboxylate derivatives of 1-phenyl-3,5-dioxopyrazolidine", *Talanta* 43, 545, (1996)
- [9]. Borowiak-Resterna A. and Szymanowski J. "Effect of hydroxyoxime structure upon metal-complexing properties" *Journal of Radioanalytical and Nuclear Chemistry*, 150, 235, 1991
- [10]. Brown, G. R., J. R. Camn, L. O. Case, E. C. Dunlop, U. S. Horton, A. L. Jones, F. D. Leipziger, H. C. Matraw, I. May, L. B. Rogers, A. Rose, C. L. Rulfs, L. Schubert, H. H. Willard, "Reactive Group as Reagents: Inorganic applications," *Treatise on analytical chemistry*, Eds. Kolthoff, I. M., and P. J. Elving, Vol. 2, Part I, Wiley – Interscience, New York, pp. 863 – 900 (1968).
- [11]. Charles R. Merigold, "LIX Reagent Solvent extraction plant Operating manual", laboratory work 2004.
- [12]. Chakraborty M., "Extraction of Copper (II) and Nickel (II) from Wastewater by Emulsion Liquid Membranes"
- [13]. Christie, P.G., Lakshmanan V.I and Lawson G.J. "The behavior of LIX 63 in the extraction of Cu(II) and Fe(III) from chloride media" *Hydrometallurgy*, 2, 105, 1976
- [14]. Chung-hsu wang and Ying-chu hoh, "The Effect of pH on cadmium Extraction by LIX 34", *Hydrometallurgy*, 8, 161, (1982)
- [15]. Columbia University Press, "The Columbia Electronic Encyclopedia", 6th Edition.
- [16]. Dallas B. Warren , "Kinetics and the effect of electrostatic surface potential on nickel(II) extraction by 2-hydroxy-5-nonylaceto-phenone oxime (LIX 84) in a micellar phase", *Colloids and Surfaces A: Physicochem. Eng. Aspects* 243, 127, (2004)
- [17]. Debasis Senapati., "Purification of nickel sulphate solutions containing iron, copper, cobalt, zinc and manganese" *Journal of Chemical Technology & Biotechnology*, 59, 335, (2004)
- [18]. Dounggeethanveeraatana D. and Sohn H.Y. "Solvent Extraction Equilibria in the CuSO₄ – H₂SO₄ – H₂O – LIX 860 – kerosene system", *Minerals Engineering*, 11, 821, 1998.
- [19]. Eccles, H. "The extraction of Copper(II) and Fe(III) from chloride and sulphate solutions with LIX 64N in kerosene" , *Hydrometallurgy*, 1, 349, 1976.
- [20]. Eric Jackson, "Hydrometallurgical Extraction and Reclamation"
- [21]. Flett D S "Review New reagents or new ways with old reagents" *Journal of Chemical Technology and Biotechnology*, 74, 99, (1999)
- [22]. Flett D.S. and Melling J., "Extraction of Ammonia by commercial Copper chelating extractants", *Hydrometallurgy*, 4, 135, (1979)
- [23]. Flett D.S., Okuhara D.N. and Spink., "Solvent Extraction of Copper by Hydroxyoxime", *Journal of Inorganic and nuclear Chemistry*, 35, 2471, (1973)
- [24]. Francisco Jose Alguacil and Manuel Alonso , "Recovery of copper from ammoniacal/ammonium sulfate medium by LIX 54", *Journal of Chemical Technology and Biotechnology*, 74, 1171, (1999)
- [25]. Harada, M., and Y. Miyake, "Solvent Extraction with Chelating Agents," *Handbook of heat and mass transfer: catalysis, kinetics and reactor engineering*, Vol. 3, Ed., Nicholas P. Chermisnoff, Gulf Publications pp. 769 – 881 (1989).
- [26]. Holzbecher, Z., L. Davis, M. Kral, L. Sucha, and F. Vlácil, "Application of organic reagents in inorganic analysis," *Handbook of organic reagents in inorganic analysis*, Ed. Dr. R. A. Chalmers, Ellis Horwood Ltd., Chichester, England, pp. 213–231 (1976).
- [27]. Huebra M., Elizalde M.P and Almela A., "Hg(II) extraction by LIX 34. Mercury removal from sludge", *Hydrometallurgy* 68, 33, (2003).
- [28]. Hughes M.A., "The Kinetics of the solvent extraction of Copper(II) with LIX 64B reagents-II", *Journal of inorganic nuclear chemistry*, 38, 2067, (1976)
- [29]. Jaaskelainen E., and Paatero E and Nyman B., "Adsorption of hydroxyoxime-based extractants on silica and mica particles in copper extraction processes", *Hydrometallurgy*, 49, 151, (1998)
- [30]. Jena K.N., Sarma, Das and Misra., "Extraction of Copper From sulphate Solution Using LIX 84I", *Regional Research Laboratory, Bhubaneswar*.
- [31]. Jong Sung Kim, Jongheop Yi, "Selective removal of copper ions from multi-component aqueous solutions using modified silica impregnated with LIX 84" *Journal of chemical Technology and Biotechnology*, 75, 359, (2000)
- [32]. Kazuharu Yoshizuka, Hiroshi Arita and Katsutoshi., "Equilibria of Solvent Extractio of Copper(II) with 5-Dodecylsilyl-dioxime", *Hydrometallurgy*, 3, 247, 1990
- [33]. KGP002, "Solvent Extraction of Cu⁺² using LIX 984", *Hydrometallurgy*.
- [34]. Khopkar, S.M., "Solvent Extraction Separations," *Basic concepts of analytical chemistry*, IInd ed., New age international (P) Ltd., New Delhi, India, pp. 91–121 (1998).
- [35]. Kongolo K., Mwema M.D. and Gock E., "Cobalt and zinc recovery from copper sulphate solution by solvent extraction", *Minerals Engineering* 16, 1371, (2003).
- [36]. Kordosky G. A.' "Copper solvent extraction for Concentrate Leach Sloutions", *Cognis Corporation*.
- [37]. Kordosky, G. A., "Solvent Extraction-Reagents And Selectivity Control,"
- [38]. Kordosky, G. A., "Copper Solvent Extraction Reagents, Past, Present and Future," in *Expomin*, Cognis Corporation (2000).
- [39]. Kyuchoukov G. and Szymanowski J., "Extraction of Copper(II) and Zinc(II) from Chloride Media with Mixed Extractants, " *Journal of Radioanalytical and Nuclear Chemistry*, 246, 675 (2000)
- [40]. Lakshmanan, V.I. and Lawson, G.J., "The Extraction of Copper from aqueous chloride solution with LIX70 in kerosene", *Journal of inorganic nuclear chemistry*, 37, 207, (1975)
- [41]. Lazarova Zdravka and rova Madlen "Solvent Extraction of Copper from Nitrate Media with Chelating LIX-Reagents: Comparative Equilibrium Study", *Solvent Extraction and Ion Exchange*, 23, 695, (2005)
- [42]. Mellah A., Benachour D., "Solvent extraction of heavy metals contained in phosphoric acid solutions by 7-(4-ethyl-1-methyloctyl)-8-hydroxyquinoline in kerosene diluent", *Hydrometallurgy*, 81, 100, (2006)
- [43]. Miller J. D. and Atwood R. L., "Discussion of the kinetics of Copper solvent extraction with Hydroxyoximes ", *Journal of inorganic and nuclear Chemistry*, 37, 2539, (1975).

- [44]. Mishonov I. and Kyuchoukov G., "Separation of copper and zinc during their transfer from hydrochloric acid to sulphuric acid medium using a mixed extractant", *Hydrometallurgy* 41, 89, (1996)
- [45]. Osman Nuri Ata "Modelling of copper ion transport through supported liquid membrane containing LIX 984", *Hydrometallurgy*, 77, 269, (2005)
- [46]. Parija Chinmay, and Bhaskara Sarm P.V.R. "Separation of Nickel and Copper from ammonical solutions through Co-extraction and selective stripping using LIX 84 as the extractant", 54.195, 2000.
- [47]. Pingwei Zhang Katsutoshi Inoue and Hiromi Tsuyama., "Extraction and selective stripping of molybdenum(VI) and vanadium(IV) from sulfuric acid solution containing aluminum(III), cobalt(II), nickel(II) and iron(III) by LIX 63 in Exxsol D80", *Hydrometallurgy*, 41, 45, (1996).
- [48]. Pratl, J. M., and R. I. Tilly, "The Reaction of Cu(II) with LIX[®] 65N in Homogenous Solution," *Hydrometallurgy*, 5(1), 29 (1979).
- [49]. Rajiv K. Singh and Purshottam M. Dhadke, "Extraction and separation stueids of Zinc and Copper with D2EHPA and PC-88A from perchlorate media", *J.Serb. Chem.Soc.* 67, 41, (2002)
- [50]. Ramachandra Reddy B., Rajeshkumar and Varada Reddy., "Solvent extraction of zirconium(IV) from acid chloride solutions using LIX 84-IC", *Hydrometallurgy* 74, 173, (2004).
- [51]. Ramachandra Reddy B., Rajeshkumar and Neelapriya., "Solvent extraction of zirconium(IV) from acidic chloride solutions using 2-ethyl hexyl phosphonic acid mono-2-ethyl hexyl ester (PC-88A)", *Hydrometallurgy* 72, 303, (2004)
- [52]. Ramachandra Reddy B. and Rajesh Kumar J., "Studies on liquid-liquid extraction of tetravalent hafnium from weakly hydrochloric acid solutions by LIX 84-IC", *Separation and Purification Technology* 42, 169, (2005)
- [53]. Ramachandra Reddy B. and Neela Priya D. "Process development for the separation of copper (II), nickel(II) and zinc (II) from sulphate solutions by solvent extraction using LIX 84F", 45, 163, (2005).
- [54]. Rare Metals Division Materials Processing Department, "Interpretation of Extraction Isotherm in The Metal Solvent Extraction with Chelating Reagents", (1997)
- [55]. Redbook, "The chemistry of metal recovery using LIX[®] reagents, Cognis Corporation, Mining Chemical Division (1997).
- [56]. Sastre, A. M., and Alguacil, F. J. "Co-extraction and selective stripping of copper(II) and molybdenum (VI) using LIX622, " *Chemical Engineering Journal*, 81, 109 (2001)
- [57]. Sengupta B, Tamboli CA, Sengupta R. Synthesis of nickel oxalate particles in the confined internal droplets of W/O emulsions and in systems without space confinement, *Chemical Engineering Journal.*; 169 (1-3): 379-389, (2011)
- [58]. Uhlig E., "Liquid-liquid Extraction of Metal ion by Chelating ligands," *Coordination Chemistry Reviews*, 43,299, (1982).
- [59]. Van de Vorde, I, Pinoy and Verpoort. "Influence of acetate ions and the rele of the diluents on the extraction of copper(II), nickel(II), cobalt(II), magnesium(II) and iron (II,III) with different types of extractants.", *Hydrometallurgy*, 78, 92, 2005
- [60]. Venkatachalam, S., "Solvent Extraction," *Hydrometallurgy*, Narosa Publishing House, New Delhi, India, pp.153-161 (1998).
- [61]. Whewell R.J. and Hanson C., "Metal extraction with hydroxyoxime", University of Bradford.