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A State-of-the-Art Discussion on the Solvent Extraction Reagents Used for the Recovery of Copper from Dilute Sulfuric Acid Leach Solutions

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ABSTRACT

The recovery of copper from dilute sulfuric acid leach solutions has been a commercial reality since 1968 (1), and since then the technology has gained worldwide acceptance. Only one chelating functionality, the hydroxy oxime group, has been used commercially for this task. There are, however, two distinct classes of extractants based on the hydroxy oxime group: the salicylaldoximes, which are very strong copper extractants and the ketoximes, which are moderate copper extractants. A third class of extractants combines a ketoxime with a salicylaldoxime in about a 1/1 mole ratio and results in some surprising advantages. This paper will discuss each reagent class, showing their advantages and disadvantages and will also introduce two new reagents, LIX® 84 and LIX 984, showing their behavior with respect to copper extraction, and discussing where they may be used to advantage.

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INTRODUCTION

Copper recovery from dilute sulfuric acid leach solutions using solvent extraction-electrowinning technology (SX-EW) was first practiced commercially in 1968 at the Bluebird Mine of Ranchers Exploration and Development Company (1). Since that time, the technology has gained wide acceptance in the metallurgical community as a way to produce very high quality copper (2) at attractive costs (3) from appropriate leach solutions. Over the years a large number of molecules with a variety of extractive functionalities have been suggested as possible copper extractants to be used in this technology. Some have been tested in the laboratory and others in pilot plants but the hydroxy oximes are the only reagents which have been used in commercial plants for this task.

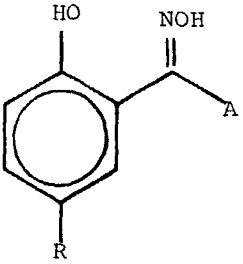
A state-of-the-art discussion of hydroxy oxime reagents is very appropriate at this time since reagents can now be evaluated not only on laboratory data collected under controlled and at times contrived conditions (4), but, also on the respective reagents performance in commercial circuits over a reasonable length of time. This is very important because it has been our experience that not all laboratory generated data translates well to commercial operations. In addition, hydroxy oxime reagent development has matured and major advances are not expected.

HYDROXY OXIMES

The general chemical structure for the hydroxy oxime reagents is shown in Figure 1. These reagents can be subdivided by structure (Figure 1) and properties into two distinct classes : the salicylaldoximes, which are very strong copper extractants, and the ketoximes, which are moderately strong copper extractants. The strength of a copper extractant is based on the degree to which the copper extraction-stripping equilibrium, shown below, is driven toward extraction by the reagent.

$$2RH_{(org)} + [Cu^{++}SO_4^{=}]_{(aq)} \rightleftharpoons R_2Cu_{(org)} + [2H^{+}\ SO_4^{=}]_{(aq)}$$

Another class of extractant combines a ketoxime with a salicylaldoxime in an approximate 1/1 mole ratio. This "third" class of extractant is based on the distinct properties the mixtures possess (5), especially as they relate to copper transfer, reagent strength and crud formation (6).



For R	A is
C_9H_{19}	H, CH_3, C_6H_5
$C_{12}H_{25}$	H, C_6H_5

For A	Reagent Class is
H	Salicylaldoxime
CH_3, C_6H_5	Ketoxime

Fig. 1 General structural formula for hydroxy oximes which have been used commercially as copper extractants.

General Reagent Properties

In order for a copper extractant to be successful it must meet certain requirements.

Requirements for Successful Copper Extractants

1. Extract copper selectively from the leach solution
2. Strip copper consistent with final metal recovery
3. Be stable to circuit conditions
4. Have acceptable extraction and stripping kinetics
5. Be soluble in an inexpensive diluent
6. Should not promote stable emulsions
7. Should not promote crud formation
8. Should not transfer excess acid from strip to extraction
9. Be safe to use
10. Have an acceptable cost

No one reagent or reagent class is the most outstanding with respect to every reagent requirement. Rather, the successful reagents possess a good balance of the required properties and unsuccessful reagents are such because they fail miserably on one or more of the requirements.

Salicylaldoximes

The salicylaldoximes are very strong copper extractants which exhibit rapid copper transfer kinetics and can show excellent copper over iron selectivity. The reagents and their respective copper complexes are quite soluble in normal kerosene SX diluents, display rapid phase separation and do not transfer excess acid from the strip to the extraction stage. The reagents are, however, so strong as copper extractants that they are often used in combination with an equilibrium modifier, normally tridecanol or nonylphenol, so that they can be stripped with a typical tankhouse electrolyte.

The ratio of active oxime to modifier can be altered to control the extractive strength of the mix so, theoretically, an extractant mix could be tailored to meet the specific needs of any given leach solution (7). In actual practice little if anything is gained by doing this and only a limited number of modified aldoxime products are available.

Unfortunately, the use of equilibrium modifiers adversely affects other reagent properties. For example, modifiers are known to accelerate reagent degradation (4) and nonylphenol has deleterious effects on certain materials of construction. Leach solutions containing dissolved silica frequently tend to form stable emulsions when contacted with metal extractant solutions, and this problem of the sensitivity of copper extractants to silica during aqueous continuous operation is intensified by the presence of nonylphenol (8). In addition, a short term pilot plant test (6) showed that equilibrium modifiers:

a) Can contribute significantly to the amount of crud generated in an SX circuit.
b) May increase organic entrainment in the exiting raffinate stream.
c) Tend to increase aqueous entrainment in the loaded organic stream.

The commercial plant at which this pilot study was done changed from aldoxime reagents heavily modified with tridecanol to LIX 864, an unmodified ketoxime-aldoxime mixture, shortly after the completion of the pilot study. The commercial circuit responded in the manner predicted by the pilot study: crud formation, aqueous entrainment in the loaded organic and most importantly, reagent usage per pound of copper produced, all decreased as the amount of LIX 864 in the SX circuit increased.

There are commercial circuits in operation which use modified aldoxime reagents but do not have excessive crud formation so the problem is not universal. In addition, others have studied crud formation and drawn conclusions that differ from those above (9).

As previously stated, aldoxime reagents can show excellent copper over iron selectivity. This selectivity does not result from the aldoximes lack of affinity for iron, since aldoximes will load significant amounts of iron (III) at pH~2.0, but rather because copper, as it is extracted by the aldoxime, crowds loaded iron from the aldoxime. Thus, a well operated aldoxime SX circuit will normally show good copper over iron selectivity while an SX circuit which is not operated properly can result in significantly lower copper over iron selectivity.

A final reagent property which must be discussed in more detail is stability. The cost of reagent degradation to the end user has been downplayed and tossed aside as insignificant (4,8). However, technical service work in our laboratory, with organics obtained from commercial SX circuits, has shown that degradation losses in circuits operating with modified aldoxime reagents can be greater than .001 pounds of reagent per pound of copper produced. This reagent loss is economically significant.

All commercially available oximes degrade by acid-catalyzed hydrolysis to the respective aldehyde or ketone. Increasing modifier concentration, increasing temperature and a higher acid concentration in the strip electrolyte all result in a higher reagent degradation rate. Laboratory studies show that: 1) As a class, the ketoximes are inherently more stable than the salicylaldoximes, and 2) Within the aldoxime class the dodecyl derivative is more stable than the nonyl derivative.

Even though direct side by side reagent degradation comparisons in long term pilot plant studies or in operating plants have not been done, there is a great deal of degradation data available to reagent suppliers, from both long term pilot plant studies and from operating plants, which supports the conclusions drawn from the laboratory degradation studies. A more detailed discussion of degradation is forthcoming (10).

Ketoximes

Commercially available ketoximes such as LIX 65N are moderately strong copper extractants which have reasonably fast copper extraction kinetics when used with a kinetic catalyst (11). They display good copper over iron selectivity and both the reagents and their complexes are quite soluble in normal kerosene diluents. The reagents are strippable with less acid than modified aldoximes and are used without added modifier. Because of their good stability these reagents are the most suitable for heated circuits. An outstanding property of this class of reagents is the good physical performance they display under a variety of conditions, especially with solutions that are known to be sensitive to modifiers, for example, agitation leach solutions which contain some solids or residual flocculents and leach solutions which contain colloidal silica.

The ketoximes which are available today, LIX 64N and LIX 65N, would be improved as reagents if they were a little stronger extractants, had faster copper transfer kinetics and showed better copper over iron selectivity. In spite of the above shortcomings, these reagents have served the end user very well in plants designed for their use when operating on leach liquors for which they are suited.

Mixtures of Ketoximes with Aldoximes

The properties of the ketoxime-salicylaldoxime mixtures, LIX 864 and LIX 865, reflect the most desirable characteristics of the components: the extractive strength, fast kinetics and excellent selectivity of the aldoximes combined with the proven, good physical performance of the ketoximes. In each instance the properties of the mixtures lie between the properties of the individual components but almost always well toward the most desirable property (6). One of the more interesting features of these mixtures is their greater than expected copper transfer because of the much lower than expected stripped organic that these mixtures give. It is felt this results from the ketoxime component of the mixture functioning in some fashion as a modifier for the salicylaldoxime component in the strip side of the circuit. On the extraction side the modifying ability of the ketoxime is reduced because of copper loading so the extractive strength of the salicylaldoxime is more fully realized.

Most LIX 64N plants have converted to ketoxime-salicylaldoxime mixtures with the addition of LIX 860, a solution of 5-dodecylsalicylaldoxime in kerosene, as makeup reagent. The conversion has led to enhanced metallurgical performance in all instances except one and overall reagent usage has decreased in many of these commercial plants. In several plants the optimal mixture is heavy on the ketoxime component but this is dependent upon the leach liquor and the design of the circuit.

It should be pointed out that the discussion of general reagent properties refers to the normal reagent behavior patterns. Individual leach solutions can vary greatly as can mixer design, operating temperatures and operating procedures. All of these factors along with the reagent and the diluent are important to the way an SX circuit performs, thus, there will be instances where the normal reagent behavior patterns are not followed, especially as they relate to physical behavior.

Commercially Available Copper Extractants

For reference purposes commercially available copper extractants and their respective compositions are given in Table 1.

Comparative Reagent Properties

The paper to this point has been focusing on the general properties of the different classes of commercially available copper extractants. As a way to give better definition and form to these general properties comparative metallurgical data for a typical lot of several different LIX copper extractants is given in Table 2. The data was generated using the following test procedure.

Test Procedure

A 350 ml sample of the respective reagent dissolved in Kermac 500T at 10 v/v% is added to a one-liter baffled beaker. An impellor/stirrer, 1.5 inches in diameter with six equidistant slots 0.125 inches deep and 0.125 inches wide, is positioned at the center axis of the beaker ~1.0 cm below the surface of the organic phase. Stirring at a constant speed of 1800 $\pm$ 25 rpm is initiated and then, over a period of five seconds, 350 ml of an aqueous solution containing 6 g/l Cu^{2+} and 3.0 g/l Fe^{3+} at a pH of 2.0 is smoothly added. A stopwatch is then started and at 59 seconds, 10 ml of the emulsion is removed and the organic portion filtered and saved (E_{60}). After 300 seconds, stirring is stopped and the stopwatch reset

Table I Composition of Commercially Available Copper Extractants

Extractant/Category	Composition	Comment
HS-LIX 64N/ketoxime	A mixture of 2-hydroxy-5-nonylbenzophenone oxime and 5,8-diethyl-n-hydroxydodecan-6-oxime in kerosene	Discontinued in 1987
HS LIX 65N/ketoxime	2-hydroxy-5-nonylbenzophenone oxime in kerosene	Discontinued in 1987
LIX 84/ketoxime	2-hydroxy-5-nonylacetophenone oxime in kerosene	Available in late 1986
LIX 860/ salicylaldoxime	5-dodecylsalicylaldoxime in kerosene	
LIX 864/mixture	A mixture of HS-LIX 64N with LIX 860	Discontinued in 1987
LIX 865/mixture	A mixture of HS-LIX 65N with LIX 860	Discontinued in 1987
LIX 984/mixture	A mixture of LIX 84 with LIX 860	Available in late 1986
LIX 622/ salicylaldoxime	A mixture of 5-dodecylsalicylaldoxime and tridecanol in kerosene	
Acorga P5100/ salicylaldoxime	A mixture of 5-nonylsalicylaldoxime and nonylphenol in kerosene	
Acorga PT5050/ salicylaldoxime	A mixture of 5-nonylsalicylaldoxime and tridecanol in kerosene, the relative level of tridecanol being greater than in LIX 622	

Table 2

Comparative Metallurgical Data of Selected LIX® Reagents

Reagent at 10 v/v%	LIX 64N	LIX 864	LIX 622	LIX 860
Max Load (g/l Cu)	4.30	5.03	5.73	5.80
E_{300} (g/l Cu)	3.20	4.07	4.64	4.87
E_{300} (Cu/Fe)	240	590	1500	1750
% Cu Extraction (60 sec/300 sec)	93	96	96	98
S_{300} (g/l Cu)	0.15	1.20	1.95	2.78
% Cu Stripping (60 sec/300 sec)	99	99	100	100
Cu Transfer (E_{300}-S_{300})	3.05	2.87	2.69	2.09
E_{300}/Max Load Ratio	0.74	0.81	0.81	0.84
Phase Sep'n (sec)	71	81	75	83

Metal Analysis: Single determinations by AAS

and restarted. The time required for phase separation is recorded. Complete phase separation is taken as the time at which only a monolayer of bubbles remains at the interface. About 5 ml of the organic sample is retained for analysis (E_{300}). The remainder of the organic sample is drained into a separatory funnel and separated from the aqueous. Then 325 ml of loaded organic is carefully decanted into a graduated cylinder and added to a clean one-liter mixing vessel. After the impellor height is properly adjusted, stirring is begun, and over a 5 second span 325 ml of an aqueous strip solution containing 170 g/l H_2SO_4 and 30 g/l Cu is added. The stopwatch is started, at 59 seconds the emulsion is sampled as previously described, and the organic portion retained (S_{60}). At 300 seconds, stirring is stopped and the organic phase is sampled again (S_{300}). The max load sample is generated by contacting the respective organic five successive times with fresh aqueous feed at an O/A = 1/1 for two minutes each contact. The E_{60}, S_{60}, S_{300} and max load samples are analyzed for copper while the E_{300} sample is analyzed for both copper and iron. Atomic Absorption Spectroscopy is used for all metal analysts with the reported value being the average of a 10 second aspiration.

The data presented in Table 2 highlights the difference in metallurgical properties seen over the series moderate to very strong copper extractant. The increase in the copper extractive strength of the reagents is shown by the dramatic increase in the stripped organic value as well as the small increase in the E_{300}/max load ratio. Copper extraction kinetics and the Cu/Fe selectivity both increase through the series LIX 64N to LIX 860 while phase separation remains essentially the same.

Copper transfer decreases across the series but this can be a little misleading because copper transfer is very much dependent upon the conditions under which it is determined. For example, as the pH of the aqueous feed decreases, assuming a constant copper content, the E_{300} copper value for a weaker extractant would decrease much faster than that for a stronger extractant. As the sulfuric acid concentration of the strip electrolyte decreases and/or the copper content increases, the stripped organic value for a stronger extractant will increase faster than that for a weaker extractant. The test method described above uses a strip solution representative of industry practice but the feed solution at 6 g/l Cu is considerably above the industry norm.

In actual practice the moderate copper extractants can be used to best advantage with feeds of relatively low copper content and high pH coupled with a strip electrolyte containing lower acid and/or higher copper. Strong copper extractants are better suited for leach solutions which have a low pH and/or a relatively high copper content. In this case the plant operator has less flexibility in stripping and a stripping electrolyte containing 165-180 g/l H_2SO_4 and 30-35 g/l Cu is the norm.

LIX 84 and LIX 984

This paper has been discussing the properties of copper solvent extraction reagents which are commercially available today. The focus will now be on two new reagents, LIX 84 and LIX 984, which will be available in late 1986.

Henkel Corporation, U.S.A. purchased the associated patent rights on SME 529 from Shell International Chemical Company Limited in October of 1984. The active extractant, 2-hydroxy-5-nonylacetophenone oxime, is being incorporated in the Henkel line of solvent extraction reagents as LIX 84 while a mixture of LIX 84 and LIX 860 will be known as LIX 984.

Contributions from both parties has resulted in new manufacturing process techniques from which a significantly improved reagent is produced (Table 3). Note the much faster copper transfer kinetics, the superior copper over iron selectivity, the faster phase separation and the gain in extractive strength of LIX 84 when compared to old SME 529. LIX 84 is also kinetically faster, more selective and a slightly stronger extractant than HS-LIX 64N, while retaining the good stripping properties of the ketoxime class of reagents (Table 3). An isotherm comparison of LIX 84 with HS-LIX 64N is shown (Table 4, Figure 2) and also illustrates well the differences in extractive strength and selectivity over iron between the two reagents.

LIX 984 is a kinetically faster, stronger and more selective copper extractant than LIX 864. Note the comparative isotherms (Table 5) and side by side circuit runs (Table 6). Of special interest is the significant increase in mixer efficiency for the extraction mixers in the LIX 984 circuit as compared to the LIX 864 circuit.

Table 3

Metallurgical Comparison of SME 529, LIX 84 and HS-LIX 64N in a Henkel Quality Control Test at Room Temperature (22°C)

Aqueous Feed: 6.00 g/l Cu, 2.00 g/l Fe^{3+}, pH=1.90
Organics: Maximum Copper Loading = 4.2 - 4.3 g/l Cu

Test	SME 529	LIX 84	HS-LIX 64N
E60/E300 Kinetics	70.4%	97.4%	92.9%
E300 Cu/Fe Ratio	200/1	2700/1	300/1
Phase Sep'n, Ext'n	300 Sec	64 Sec	83 Sec
Phase Sep'n, Strip	164 Sec	113 Sec	73 Sec
S60/S300 Kinetics	98%	100%	100%
E300/Max Load (%)*	68.1	77.8	74.0

*Provided copper extraction kinetics are reasonable the E300/max load (%) is a measure of the relative extractive strength of one reagent compared to another when both reagents contain equal concentrations of active extractant.

Metal Analysis: Single determinations by AAS

Table 4

Isotherm Comparison of HS-LIX 64N with LIX 84

O/A	HS-LIX 64N			LIX 84		
	Organic		Aqueous	Organic		Aqueous
	Cu	Fe	Cu	Cu	Fe	Cu
10/1	0.86	.010	0.36	0.99	.002	0.21
5/1	1.64	.016	0.56	1.82	.003	0.37
3/1	2.03	.018	0.69	2.24	.003	0.46
1/1	4.65	.025	1.59	5.09	.004	1.18
1/3	7.34	.036	3.55	7.79	.003	3.41
1/4	7.74	.041	4.09	8.05	.003	4.02
1/10	8.39	.063	5.29	8.41	.004	5.24
Stripped						
Org	0.31	N.D.		0.53	N.D.	
Max Load	8.37	.065		8.41	.005	
Feed			6.04			6.04

Metal Analysis: Single determination by AAS

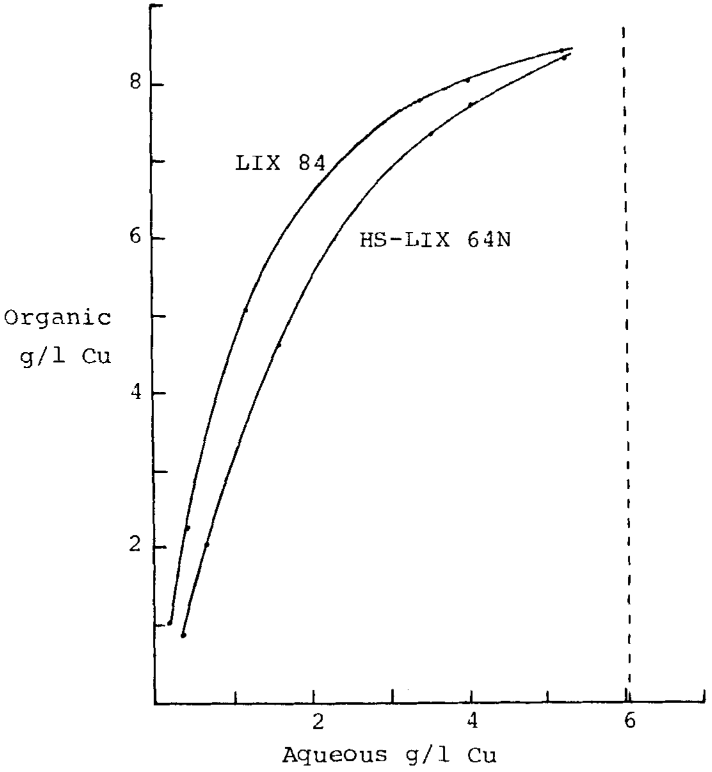


Figure 2: Isotherm Comparison of LIX 84 with HS-LIX 64N

Table 5

Isotherm Comparison of LIX 864 with LIX 984

O/A	LIX 864			LIX 984		
	Organic		Aqueous	Organic		Aqueous
	Cu	Fe	Cu	Cu	Fe	Cu
10/1	2.69	.018	0.19	3.29	.018	0.14
4/1	3.55	.022	0.26	4.15	.019	0.19
3/1	4.03	.022	0.32	4.63	.018	0.24
1/1	6.90	.017	1.24	7.60	.007	1.06
1/3	8.98	.022	3.66	9.53	.004	3.76
1/4	9.23	.027	4.13	9.62	.004	4.24
1/10	9.63	.046	5.16	9.95	.005	5.35
Stripped Org	2.12	N.D.		2.76		
Max Load	9.90	.056		10.00	.007	
Feed			6.02			6.02

Metal Analysis: Single determination by AAS

Table 6

Side by side circuit comparison of LIX 864 with LIX 984

Circuit: 2 extraction, 2 strip stages, 3 minute mixers
Feed: 2.25 g/l Cu, 1.3 g/l Fe, pH = 1.90
Strip Electrolyte: 30.5 g/l Cu, 165 g/l H_2SO_4
Advance O/A: Extraction ~1/1, Strip ~7/1

Day	Reagent	Max Load	% Cu Recovery	Pregnant Electrolyte	Cu/Fe**	Mixer Eff* E1	Mixer Eff* E2
1	984	3.11	93.8	50.5	1000/1		
1	864	3.13	85.8	48.7	225/1		
2	984		93.8	46.3	1000/1		
2	864		87.1	50.6	225/1		
3	984		94.2	44.1	800/1	92%	98%
3	864		88.0	50.7	200/1	89%	88%

* Cu/Fe selectivity taken from the iron values for strip and pregnant electrolytes.

** Average value of the mixer efficiencies obtained from aqueous and organic transfers in the circuit and transfers at equilibrium.

The good physical properties exhibited by reagents containing no added modifier extends to LIX 984. In a continuing long term pilot plant test, using an aqueous leach solution with a high silica content, the amount of crud being generated in the circuit with LIX 984 as the reagent is much less than the amount of crud which was generated when 5-nonylsalicylaldoxime, heavily modified with tridecanol, was used as the reagent (12).

The gradual trend toward reduced staging in copper SX-EW plants has been noted recently and the reasons for the trend discussed (13). A net result of this trend is that in order for a new copper SX reagent to be successful it must perform well in

1. a 2 extraction-1 strip stage circuit with feeds containing approximately 0.5 to about 3 g/l and,
2. a 2 extraction-2 strip stage circuit with feeds containing greater than about 3 g/l.

To date modified aldoximes have been the reagents of choice for commercial copper SX plants with 2 and 1 and 2 and 2 staging. The availability of LIX 84 and LIX 984 in late 1986 will change this. Circuits run in our laboratory have shown that both LIX 84 and LIX 984 are metallurgically well suited for new operations where reduced staging is the norm (Table 7). Note that under identical conditions LIX 84 performs as well as or better than LIX 622 with respect to copper recovery and copper over iron selectivity. In addition, its performance edge over LIX 622 is more pronounced when an electrolyte containing less acid is used for stripping. The performance edge for LIX 84 was with a low copper-high pH leach liquor and this may not be seen with a high copper and/or low pH leach liquor.

The sulfuric acid concentration of a typical tankhouse liquor in an SX-EW plant using a modified aldoxime extractant is normally 20-30 g/l greater than that in an SX-EW plant using a ketoxime extractant. Plant operators and others knowledgeable in copper electrowinning believe there are many benefits to having a lower concentration of sulfuric acid in the electrolyte, among them: less corrosion, less of an acid mist problem, less reagent degradation, slightly higher current efficiency and a little more consistent, smooth copper deposit. With any reagent an operator could choose to run with a lower concentration of acid in the strip electrolyte. Unfortunately, there is a penalty because of the loss in copper transfer due to an increase in the stripped organic (Table 8). The availability of a ketoxime reagent, such as LIX 84,

Table 7

Circuit Comparisons LIX 84, LIX 984, and LIX 622 at 4.4 v/v% in Kermac 500T

Circuit: 2 extraction, 1 strip staging
Mixer residence: 2.56 minutes. Temp = 22°C
Advance O/A: Extraction =1, Strip ~12/1
Pregnant Electrolyte: 45 g/l Cu

Reagent	Feed*			Barren Electrolytes		% Cu	Cu/Fe
	Cu	Fe3+	pH	Cu	H_2SO_4	Recovery	Transfer
LIX 622	1.28	1.2	1.9	31.0	165	89.0	900/1
LIX 84	1.28	1.2	1.9	31.0	165	90.0	1400/1
LIX 622	1.21	1.2	2.0	29.8	145	94.0	200/1
LIX 84	1.21	1.2	2.0	29.8	145	97.5	250/1
LIX 984	1.24	1.2	2.0	31.8	167	95.0	400/1

* The feed is a dilute sulfuric acid leach solution which was reconstituted between circuit runs. Most operations monitor and indeed try to control the pH of their pregnant leach solution rather than monitoring the acid in g/l H_2SO_4.

Metal Analysis by AAS. Values are representative of the last six hours of a 16 hour circuit run.

Table 8

Stripped Organic Values Representative for 1 Strip Stage as a Function of Acid Concentration

Final Aqueous		Stripped Organic Values for 10 v/v% Solutions in Kermac 470B		
g/l Cu	g/l H_2SO_4	LIX 84	LIX 984	LIX 622
45	149	.41	1.88	2.62
45	139	.48	2.04	2.78
45	129	.57	2.18	2.97
45	119	.67	2.37	3.20
45	109	.82	2.56	3.38

Metal Analysis: Single determination by AAS lessens the impact of reducing the strip acid concentration, and with this reagent the economic benefits of running with a less concentrated strip acid could very well be greater than the economic penalty due to the loss in copper transfer.

CONCLUSION

Today the copper industry has available more SX reagents than at any time so that the reagent with the best overall properties to fit the specific leach liquor, circuit design and operating parameters of a plant can be selected. This represents a significant advance over the time when LIX 64N was the only reagent available since the range of leach liquors which could be economically treated by SX using LIX 64N was limited by pH, copper content, ferric iron concentration and temperature. The availability of stronger, more selective modified aldoxime reagents broadened the range of leach liquors which were amenable to SX (7). The availability of LIX 84 and LIX 984 in late 1986 will allow an even better fit between the reagent and the circuit operating parameters. Since the extractive strength of LIX 984 is almost equal to that of the modified aldoximes, its selectivity is excellent and it contains no added modifier, this reagent could develop into the most universal copper reagent to date, i.e., there will be almost no situation where the reagent will not perform very well considering the typical dilute sulfuric acid leach solutions as they are known today.

The idea of selecting the reagent with the best overall properties to fit a given situation can be carried one step further. Considering the industry needs based on the typical leach liquors generated today and knowing the properties of the reagents commercially available today, or to be introduced (LIX 84 and LIX 984), it is difficult to predict where future reagent improvements will come. Not that any given class is perfect, but rather that one or more of the three classes will fit the needs of almost every situation very well. New modifiers for aldoximes could and probably will be introduced, but, whether this will result in any significant cost or performance benefit is open to question.

In spite of its commercial success the copper solvent extraction process is not completely understood. Certainly the kinetics have been studied in detail, yet a concensus on the mechanism of extraction has not been achieved (14). Several papers have addressed the relationship between the extraction ability of hydroxyoximes and the electronic and steric effects of the chelating functionality, but further work remains (15, 16). Crud generation in copper (5,9) and uranium (17) SX circuits has been discussed and a general review on crud formation written (18). The phenomenon appears to be very complex, with the following factors all playing a role: 1) Composition and concentration of solids in the leach liquor, 2) bacteria, 3) diluent, 4) reagent, 5) modifier, and 6) the phase continuity of the emulsion.

It is hoped that research work on the basic fundamentals of copper solvent extraction will continue, but both the general financial outlook for this industry and its maturity suggest that research activities will decrease.

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