A.7.

SOLVENT EXTRACTION BOOM IN LATIN AMERICA

Arthur J. Lynch, Alan Taylor, and Carlos Avendaño Varas*

Copper production by solvent extraction and electrowinning (SX/EW) undoubtedly came of age in the '80s. Now it appears to be the key that is unlocking the enormous copper potential of Latin America. Chile in particular is seeing a veritable "explosion" of new projects.

For the uninitiated, the latter part of this article reviews the basics of SX/EX.

It is instructive to look at the factors behind this explosive growth. Perhaps the most obvious reason is the availability of suitable deposits. This is at least partially due to the coming of age of SX/EW technology, particularly in the United States where very large operations are routinely producing top-quality copper. Thus, senior executives are now looking around through "SX/EW tinted glasses", whereas they once thought strictly in terms of large sulphide deposits. The successful application of bacterial heap leaching to chalcocite ore has broadened the range of suitable deposits.

In general, greater political stability and improved government attitudes towards private and foreign ownership have undoubtedly encouraged renewed mining industry interest in Latin America. In addition, opposition to mining from environmentalists is much less in Latin America than in the United States for example. Also, the time to obtain the necessary permits is shorter. Both factors reduce project development time and costs in Latin America.

Availability of reasonably priced acid from existing copper smelters is a plus near established copper mining centers.

Finally, SX/EW presents the opportunity for small to medium size companies to produce a high purity commodity on the mine site, independent of downstream processing. This is a great incentive to both local and overseas companies, and makes it easier to obtain the necessary finance.

In Latin America, there is a growing local infrastructure of engineering, construction, and technical expertise, plus knowledgeable equipment suppliers and subcontractors. This facilitates development of smaller projects without the expense of extensive overseas support.

Current SX/EW operations are located in Mexico, Peru and Chile. Well known names include Cananea (Mexico); Cerro Verde (Peru); Lo Aguirre, El Soldado, El Teniente, Chuquicamata and Lince in Chile.

A detailed listing of some principal projects in Mexico, Peru and Chile (including some recently completed projects) is shown in Table 1. These lists indicate an additional 1.5M to 2M mt electrowon cathode will come on stream in Latin America before the year 2000.

* Lynch is with Minproc Engineers, Englewood, Colorado, Taylor with Alta Metallurgical Services, Melbourne, Australia, and Avendaño with Terral Engineering Services, Santiago, Chile. This article is based on a paper presented by the authors at the meeting, Randol at Acapulco '93—Latin American Mining Opportunities and Developments.

Technical Trends in Latin America

While Mexico, Peru and other Latin American countries will be active in SX/EW development, the focus of most of the recent activity has been in Chile. New projects there, some of them very large, tend to reflect current international SX/EW plant design trends due to the involvement of overseas mining companies and engineering firms. However, there are also technical features which reflect particular ore types and other specific conditions such as water quality. Also there are innovations and design trends evolving from the growing body of local technical and engineering expertise. Some technical trends are described briefly below.

SMP Acid-Cure Process. Following the lead of SMP, a Chilean company, a number of projects have adopted acid cure and shallow heap-leaching which has five main advantages:

- Agglomerating effect allows a fine crush size;
- Agglomeration allows high solution-application rates;
- Acid cure accelerates leach kinetics and shortens cycle time;
- The concentrated acid helps to solubilize a portion of the sulphide ore content;
- The solution pH is lowered very rapidly to a level favorable for the establishment of bioleaching for sulphides.

As with most technologies, this approach is best suited to particular ore types.

Use of High Chloride Water for Leaching. Because of the absence of fresh water, some projects have had to consider the use of highly saline water, even sea water, for leaching. The Lince project in north Chile, for example, has successfully married seawater leaching with SX/EW. In such cases, an additional mixer-settler is required to wash chloride from the loaded organic. Only low levels of chloride can be tolerated in EW, especially with permanent stainless-steel cathodes.

Countercurrent Leaching. New heap-leaching system designs tend to include provision for intermediate recirculation to facilitate the maintenance of the target solution grade in the SX feed while maximizing recovery. Raffinate from SX is recirculated over partially depleted heaps, then applied to fresher heaps thus achieving a countercurrent flow pattern. This system also allows for more effective control of acid levels.

Electrolyte Clean-up. Various innovations are being tried for the clean-up of electrolyte prior to electrowinning. This is of particular importance to Chilean projects such as Chuquicamata where there is manganese in the leach solution. New methods include flotation columns, coalescers, and alternative filters.

Crud Treatment. Chuquicamata has developed an effective method of crud treatment. Crud is mixed with organic then decanted. Most of the valuable organic in the crud is recuperated into the organic medium.

HPDE-Lined Settlers. Plants in Chile and Mexico have adopted HPDE-lined concrete for SX settler construction. This is a

Table 1

SX/EW Projects in Latin America

Company	Project	Capacity (K mt/yr)	Start-up
MEXICO			
Mexicana De Cobre	La Caridad	30	1996
PERU			
SPCC	Toquepala	50	1996
Minero Peru	Cerro Verde Expansion	30	1997
Mantos Blancos	Quellaveco	100	1997
CHILE			
Codelco El Salvador	Oxides Quebrada M	12.5	1994
	Quebrada M, Stage II	12.5	1995
	Quebrada M, Stage III	15	1996
Codelco Chuquicamata	Low-grade sulphides	12.5	1994
	Gravels, Stage II	40	1996
	Talabre tailings	36	1999
Codelco El Teniente	Quebrada Teniente	10	1996
Codelco Div. R. Tomic	Radomiro Tomic	150	1995
Codelco/Cyprus-Amax Joint Venture			
	El Abra	120	1997
Quebrada Blanca	in progress	75	1994
Cerro Colorado	in progress	45	1993
	Expansion	15	1995
BHP Escondida	Concentrates	80	1996
	Oxides	80	1998
Outokumpu/Placer	Zaldivar	120	1996
Equatorial	Leonor	30	1995
Michilla	Stage I Lince	5	1993
	Lince expansion	30	1995
Punta Del Cobre	S.P.C. in progress	7	1993
Mantos Blancos	Manto Verde	42.5	1995
	Santa Bárbara	33	1995
	Low-grade expansion	33	1997
	Old leach residues	33	1999
Minera Rayrock	Iván/Zar	12	1996
Eulogio Gordo	Caleta El Cobre	12	1995
C.M. Doña Ines	Collahuasi	225	1997
Cyprus Copper	Chimborazo	50	1998
Minera San Martin	Tuina	10	1994
Sahli Hochschild	Venado Sur	10	1996
Minera Doña Ada	Sierra Gorda	10	1996
Enami	Restructuring plants	10	1996

relatively inexpensive material and is suitable for high-chloride solutions.

Polymer-Concrete EW Cells. Traditional PVC-lined concrete EW cells are being replaced by polymer-concrete units in many new plants. These make it feasible to consider locating the cells at ground level.

Stainless-Steel Cathode Plate. Permanent stainless-steel cathode plates are increasingly replacing copper starting sheets. Local manufacturers are now competing in this field.

Leaching. Overall there appears to be a definite trend towards the treatment of sulphide ores. The most common approach is bacterial-assisted heap leaching, though one major project (Escondida) is planning ammonia leaching of sulphide concentrates, which was practiced commercially by Anaconda in Montana in the '70s.

In the past, the flow of innovations has tended to be into the region from the outside. However, as the numbers of new SX/EW operations in Latin America grows, the flow will be reversed, to some degree. In fact this has already started, and Latin American SX/EW operations are on the beaten path for those who wish to view the latest technical developments and plant design trends.

In general, future innovations will tend to improve the economics of SX/EW and make it even more attractive. Developments in leaching, especially for sulphide ores, may well turn currently undeveloped copper deposits into viable projects.

General Advantages of SX/EW

Probably the one biggest reason for the popularity of SX/EW is that, coupled with leaching, it provides an opportunity to produce a premium-grade commodity without further treatment by smelters and refineries. This is particularly attractive to small/medium size producers who do not have their own smelting/refining facilities.

Despite the power requirement for EW, operating costs for SX/EW are relatively low. The ability of SX/EW operations to keep going during low copper price periods has been noted by many mining executives. The relatively low labor requirements especially when partnered by heap leaching are particularly attractive, and make operating in remote areas much more feasible.

Together with heap or dump leaching, SX/EW can make it possible to economically process very low-grade ores.

Relatively small operations can be viable, depending of course on mining costs and infrastructure requirements.

SX/EW is historically regarded as a "clean" process route. Air emissions and waste products are generally minimal.

The environmental aspects of the leaching step are also relatively favorable, though it varies depending on the particular process employed. The currently favored heap-leaching process is generally regarded as having a low environmental impact, provided that the heap pads and ponds are equipped with impervious plastic or clay linings. However, reclamation plans, not required for older leaching operations, can involve considerable cost. This is especially true for sulphide ores which will tend to continue to bioleach over a long period of time.

There are relatively few disadvantages.

There is a significant power requirement for EW, which can increase the cost of local infrastructure.

The availability and cost of acid can have a major impact on economics. This is particularly true for oxide ores, while sulphide ores frequently generate their own acid.

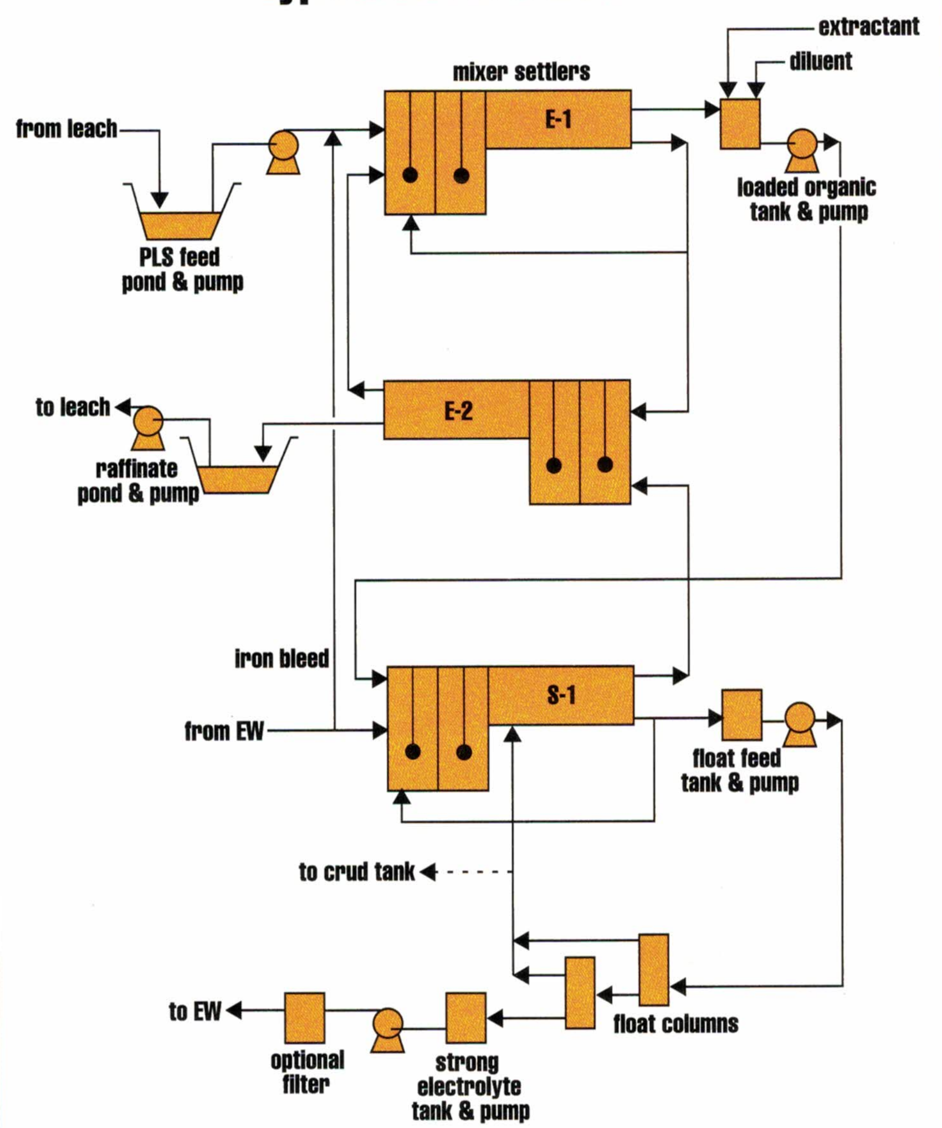
For many situations, the numerous advantages, and relatively few disadvantages are making the SX/EW approach a very popular option.

COPPER SX/EW—The Basics

Copper SX has its root in the '50s and '60s when SX was developed on a large scale for uranium extraction. Seeing the potential for copper, the General Mills Co. (now Henkel) set out to develop an organic extractant for copper. This resulted in the introduction of LIX 63 followed by LIX 64 which was widely used in early plants. Other manufacturers followed suit and developed similar extractants.

Figure 1

Typical SX Flowsheet



Key historical milestones are as follows:

- Development of LIX 63 and LIX 64 in early '60S by General Mills, United States;
- First small commercial plants at Ranchers Bluebird (1968) and Bagdad (1970), in Arizona;
- First large scale plant at Chingola, Zambia, 1973 (100K mt/yr);
- First plant in Chile, Lo Aguirre, 1980 (16K mt/yr);
- First EW plant to use ISA Process with stainless-steel cathode plates, BHAS, Port Pirie, Australia, (4,000 mt/yr).

The SX/EW process is always preceded by some kind of leaching step. The combined process consists of three closed solution loops.

In the first loop, the copper-bearing pregnant leach solution produced by leaching flows to the extraction section of the SX plant. Here it is contacted with a synthetic organic solution which selectively extracts the copper. The barren leach solution (raffinate) completes the loop back to leach more copper.

The second loop is within the SX plant proper. The loaded organic solution from extraction goes round to the stripping section. Highly acidic spent electrolyte solution from electrowinning strips the copper from the organic, which flows back around the loop to the extraction section.

Finally, in the third loop, the strong electrolyte is sent to electrowinning. High-purity cathode copper is deposited by electrolysis, and the spent electrolyte completes its loop back to the SX stripping section.

The main points to note are:

- The acid needed to leach copper is generated by the SX/EW process, and the net acid required for leaching is only that consumed by the gangue materials. In assessing reported acid consumptions, it is therefore important to know whether the figures refer to the gross consumption including the leaching of the copper, or the net amount after making allowance for the acid contribution from SX/EW. More than one has been caught unawares in the past.
- The function of the organic is to selectively transfer copper into the EW circuit and thus achieve the purification and concentration required to produce high purity copper by EW. This is the key to the entire SX/EW process and is only possible because of the development of special synthetic organic liquids.
- The EW step involves the electrolysis of water, which is the origin of the acid generated by SX/EW. Two implications of this are the emission of oxygen at the anodes which causes an acid-misting problem, and the requirement for a continuous (though small) make-up of potable-grade water. When using permanent stainless-steel cathode plates, the current trend, this water must contain less than 30 ppm chloride, which must be taken into account when assessing the need for water-treatment facilities.

Typical Modern Flowsheets

Typical flowsheets for SX and EW are shown in Figures 1 and 2. The SX process is carried out in mixer-settlers, usually comprising two or more mix boxes in series followed by a settling tank to separate the organic and aqueous phases. The case shown is typical for a heap-leaching operation, with two stages in extraction and one stripping stage. There are many variations around the industry but this serves to illustrate the main features of the process.

Traces of the residual organic must be removed from the strong electrolyte prior to electrowinning. The flowsheet shows this carried out by flotation columns, which is a current trend. Many plants use filters for added safety.

Typically, there is a build-up of solids/organic crud which must be removed for treatment by decantation, centrifuging, or filtration to recover the valuable organic. Small quantities of organic extractant and diluent (high-flash-point kerosene) are lost from the circuit by entrainment in the raffinate. Diluent is also lost by evaporation. Many plants have covers over the mixer/settlers which reduces evaporation of diluent and keeps dust out.

Electrowinning is carried out in a number of cells through which the electrolyte is circulated. In the arrangement shown, the incoming strong electrolyte passes first through a small portion of the cells (scavengers) which act sacrificially as a last line of defense against contamination of the entire tankhouse with residual organic. Traditionally, the construction of the cells has been concrete with a flexible PVC liner. More recently, polymer concrete cells have been introduced, which are less likely to develop leaks. This is leading designers to locate the cells closer to ground level resulting in smaller buildings.

The cells contain lead-based anodes and stainless-steel cathode plates on which the copper is deposited. This arrangement is tending to replace the use of copper starting-sheets, commonly seen in older plants. The stainless-steel cathode plate approach is less labor intensive and allows closer spacing of the anodes and cathode plates. At about seven-day intervals, cathode plates loaded with copper are transferred by crane to a washing and stripping facility. The degree of automation increases with the plant capacity.

A small amount of cobalt sulphate is added to the circulating electrolyte to minimize corrosion of the anodes. It lengthens anode life and keeps the lead in the cathode product down to very low levels. (Some plants are adding guar as a cathode smoothing agent.)

The acid mist generated by electrowinning is suppressed by a thin layer of plastic beads floating on top of the cells.

For high efficiency and good product quality, the temperature of the electrowinning process should be maintained between 35° and 45°C. This is simply achieved by including a heat exchanger for the strong and spent electrolyte streams. About 5-10% of the EW power input generates heat, which is kept in the EW circuit by the heat exchanger (depending on climate, some plants also include a small steam or hot-water heater for the strong electrolyte during winter).

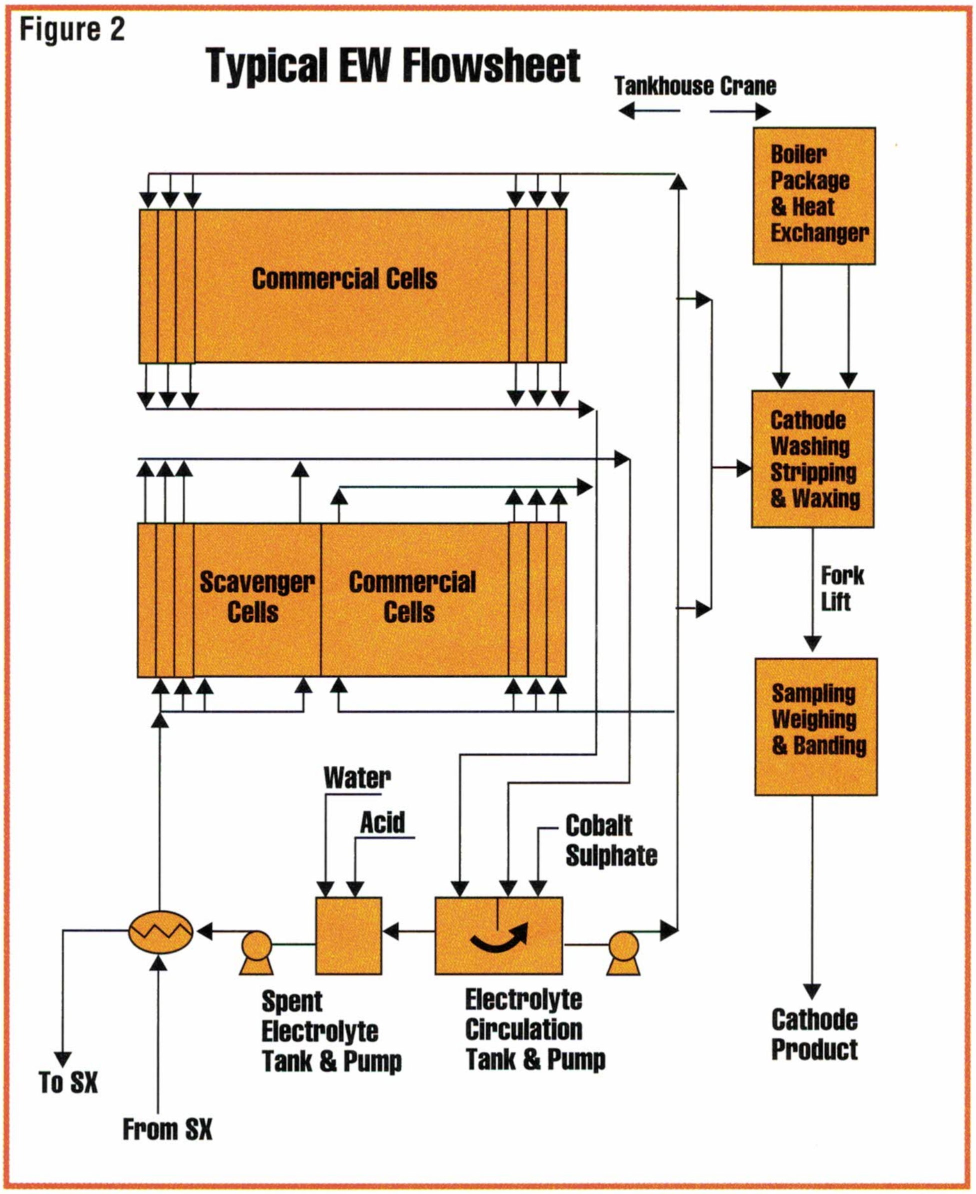


Figure 2
Typical EW Flowsheet

There is normally a small net transfer of iron through SX, which accumulates in the EW circuit. This is frequently controlled by sending a small bleed of spent electrolyte to the extraction circuit. The copper content is recuperated by SX and the acid becomes part of the acid make-up to leach.

Applicability of SX/EW

Copper SX/EW has been successfully applied to two main types of solution, namely dilute sulphuric-acid solutions and ammoniacal solutions. Copper contents can range from 0.5 to 35 g/l. The available organics are very tolerant to a wide range of impurities, especially for acid solutions. The relatively few impurities which have to be watched can usually be catered for by proper design.

A good grasp of the potential leachability of copper minerals is essential for planning exploration programs with SX/EW in view.

Sulphuric-acid leach candidates include azurite, malachite, tenorite, chrysocolla, brochantite, and atacamite. These are all readily leachable at ambient temperature with dilute sulphuric acid. The kinetics are suitable for dump, heap, and agitated leaching.

Chalcocite is only partially leachable. Leachability can be increased by using strong-acid cure.

Native copper is leachable when agitated with aerated, hot, strong acid.

Candidates for combined sulphuric acid/bioleach include chalcocite, covellite, and bornite. These copper minerals are leachable by acid/ferric-iron solutions under bioleaching conditions. The kinetics are suitable for heap or dump leaching.

Cuprite and native copper are readily leached when mixed with above minerals in bioleaching system.

Chalcopyrite undergoes very slow leaching under bioleaching conditions. The kinetics are suitable only for low-grade dump leaching.

Gangue mineralogy can have a decisive affect on suitability for leaching. High contents of acid-consumers such as carbonates may render acid leaching uneconomic. In such cases alternative approaches such as ammonia leaching may be appropriate.

Gangue mineralogy may also have a major impact on the feasibility of heap leaching. For example, a high clay content may produce permeability problems.

In assessing sulphide ores, the precious-metals content is all important, as they are not recovered by acid leaching. It may be possible to consider cyanidation after acid leaching, though the neutralization of the residual acid could be problematical, and the time delay may be unacceptable ■