

**LIX<sup>®</sup> REAGENT**  
**SOLVENT EXTRACTION PLANT**  
**OPERATING MANUAL**

**for**

**SMALL AND MEDIUM SIZE**  
**LEACH - SOLVENT EXTRACTION - ELECTROWINNING**  
**COPPER RECOVERY OPERATIONS**

**by**

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## INTRODUCTION

Solvent extraction of copper has been used in the mining industry for more than 25 years. It has proven to be the most economic technical process for recovering copper from:

- ❖ Low grade and high grade **oxide ores** by leaching with dilute sulphuric acid,
- ❖ Low grade sulphide ores while leaching with bacteria,
- ❖ Low grade oxide copper in discarded tailings,
- ❖ Metal wastes containing copper and,
- ❖ Ammoniacal etch solutions.

At this moment more than 1 million tonnes of high purity copper cathode (up to 99.999% Cu) and copper sulphate are produced annually worldwide by solvent extraction, a process invented by Henkel Corporation as a commercial process for recovering metals from mining solutions.

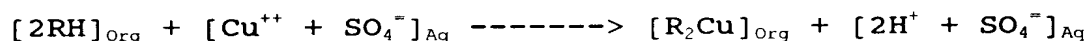
A general flowsheet of the closed cycle leach - solvent extraction -electrowinning process is shown in Figure 1.

## BASIC PROPERTIES OF LIX® REAGENTS

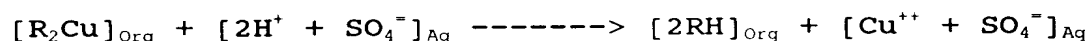
Solvent Extraction (SX) is a chemical process in which a chemical extractant can exchange hydrogen ions for specific metal ions across an organic-aqueous interface. The liquid organic phase is composed of the chemical extractant (LIX® Reagent) and a solvent, which is usually a good quality hydrocarbon diluent having a flash point greater than 105°F (66°C). The aqueous phase is generally composed of dissolved metals from a leaching process, including a weak concentration of sulfuric acid (H<sub>2</sub>SO<sub>4</sub>).

The rate of exchange, the direction of exchange (either "extraction" or "stripping"), and the amount of exchange is dependent on the concentration of the extractant in the organic phase, the concentration of the metals in the solutions, and their acidities. As an example, if a leach solution is at pH 1.5 or greater (higher), the extractant releases hydrogen ions in exchange for metal ions, such as copper. This exchange is called "extraction". If the aqueous solution is relatively stronger in acid concentration, at 180 grams/liter for example, the exchange of copper is in the other direction: the extractant releases the copper ions in exchange for hydrogen ions. This exchange is called "stripping".

### EXTRACTION:



### STRIPPING:



Some of the important chemical properties that distinguish a good chemical extractant are as follows:

- 1) High selectivity of copper over other unwanted metals and acids during the extraction process.
- 2) High "transfer capacity" of the copper on the extractant. The definition of "transfer capacity", and other technical terms are explained in the Glossary at the end of this report.
- 3) Good chemical stability. Henkel's LIX Reagents have proven time after time to be the most stable reagents on the market.
- 4) Fast "kinetics".
- 5) Good phase separation after mixing, with low losses, or low transfer, of the minor phase with the major phase (entrainment).
- 6) Non-toxic properties. Some commercial extractants require "modifiers" to improve either extraction properties or stripping properties in the solvent extraction process. Some of the modifiers used in some extractants are toxic. They can be either toxic to humans, or they can be toxic to the bacteria used in the

## CONCEPTUAL LEACH - SX-EW FLOWSHEET

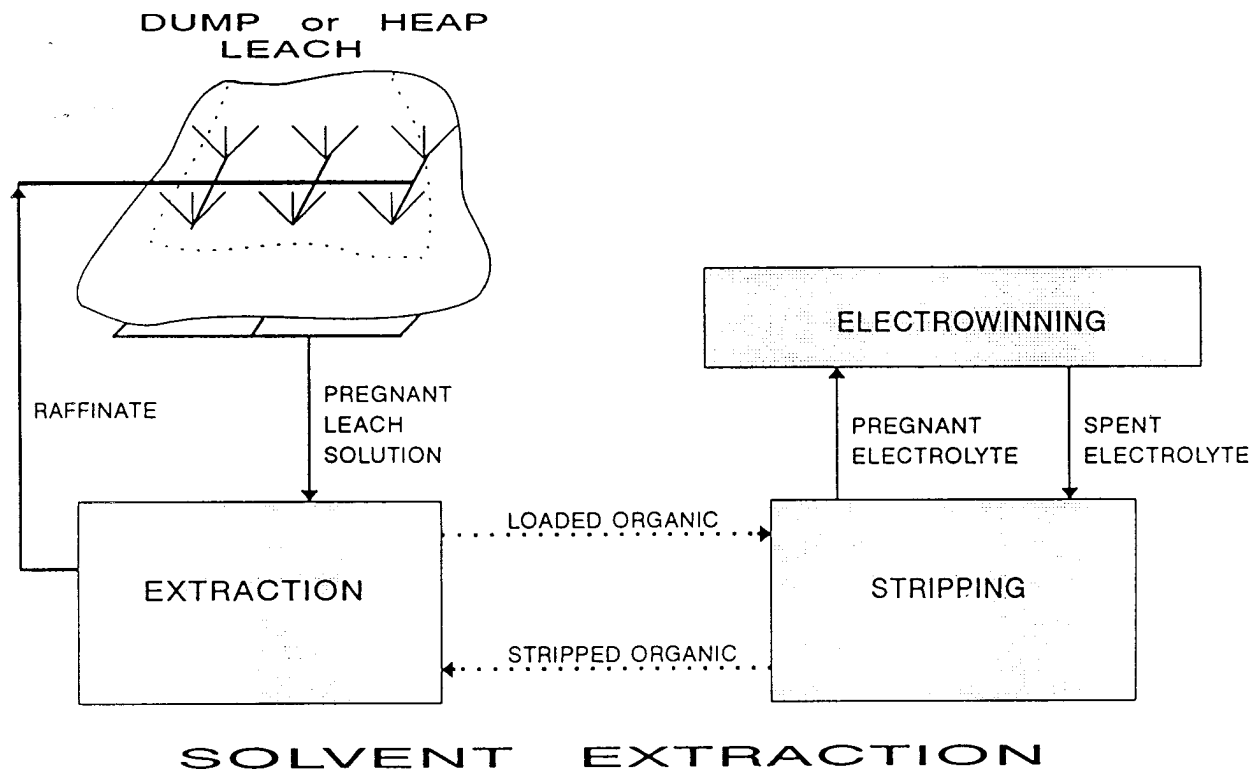


Figure 1

bacterial leaching of sulphide copper ores. The excellent quality of Henkel's LIX Reagents, and their superior physical and chemical properties, do not require modifiers in most of their extractants for best technical and economic results.

Note: Henkel Corporation manufactures three tridecyl alcohol modified reagents: LIX 622, LIX 622N, and LIX 625N. These products are sometimes used with leach solutions at very low pH. Most copper leaching -SX plants do not require such strong extractants but they are available for those who need them.

- 7) High recovery of copper from leach solutions at low capital and low operating costs to the user.
- 8) Low organic losses due to crud generation. "Crud" is the word meaning unwanted solid materials that enter and accumulate in SX plants. The solid materials originate from unclarified leach solutions, or airborne dust from windblown air, entering the solvent extraction plant. Every solvent extraction plant contains some crud. Often the solid materials can pass through the solvent extraction circuit with the incoming leach solution (PLS) and the outgoing leach solution after the copper has been extracted (raffinate) with relatively low accumulation. The presence of modifiers in some extractants increases the accumulation of crud in the solvent extraction circuit. The removal and treatment of the crud for organic recovery is one of the major sources of organic losses and high organic loss costs in most solvent extraction systems.

There are several LIX Reagents to choose from. In this report we will discuss only those extractants used for the recovery of copper from acid leaching of oxide copper ores, wastes and tailings, and sulphide copper ores and tailings leached by bacterial action. The choices of extractants include:

LIX® 84	
LIX® 984	LIX® 984N
LIX® 622	LIX® 622N
LIX® 973	LIX® 973N

The "N" products have different chemical structures than the others. As a result, the "N" products have slightly faster kinetics (rate of reaction) The faster kinetic rate can offer slightly better selectivity of copper over iron in the extraction circuit, if the circuit is designed to optimize this advantage. However, the "N" products have slightly lower stability factors due to their difference in chemical composition. In general, most solvent extraction plants will not show any significant difference in copper recovery between the "N" products and the others.

LIX 973 and LIX 973N are also strong (un-modified) extractants. As strong extractants they do not strip as easily, so two stripping stages are recommended in the solvent extraction circuit. All the other LIX Reagents work well with one stripping stage and two extraction stages. An example of a conventional 2 extraction and 1 strip stage circuit is shown in Figure 2.

CONVENTIONAL SOLVENT EXTRACTION  
CIRCUIT WITH 2 EXTRACTION  
AND 1 STRIP STAGE

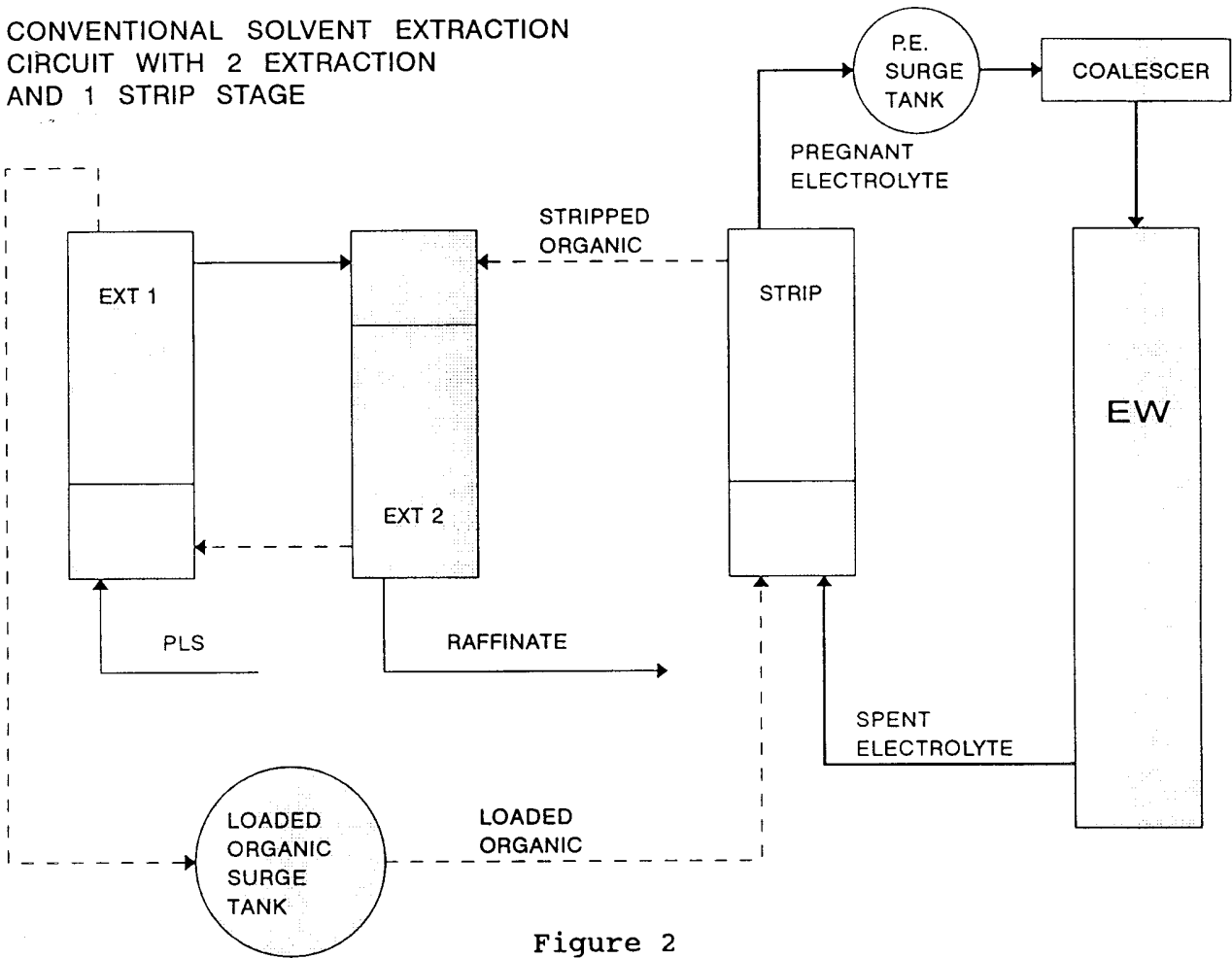


Figure 2

LIX 84 is usually recommended in plants where the leach solution contains about 1.0 gram/liter (g/l) Cu (or less) at pH 1.8 (or greater). To obtain maximum recovery with leach solutions that are more acidic, LIX 984 or LIX 984N are recommended. LIX 984 or LIX 984N would be the recommended extractants in more than 80% of the solvent extraction plants in China.

## REAGENT SELECTION AND PREPARATION

Once the average composition of the leach solution has been defined by the leaching test results, in reference to copper concentration and pH, it is then possible to determine the concentration of LIX reagent that is required in the solvent extraction circuit. The basic data for making the determination can be obtained from Henkel's "RED LINE" TECHNICAL BULLETINS, in section B, Performance specifications. The first important information to find is the Net Copper Transfer number. Let's take an example:

We will assume that we have a leach solution containing 1.2 g/l Cu and a pH of 1.7. For best recovery of copper from this leach solution we should choose LIX 984 or LIX 984N. The data in the LIX Technical Bulletin indicates that under standard test conditions we should expect a net copper transfer of approximately 2.70 grams per liter while using 10 volume percent LIX 984N in a kerosene diluent. Our leach solution is a little less than half that figure, so we will probably want about 5 volume percent LIX 984N. At 5 volume % LIX 984N the stripped organic value should be about 0.9 g/l Cu. The stripped organic value is the concentration of copper remaining on the organic after a single stage of stripping in the solvent extraction circuit. So, we want to achieve a net transfer of nearly 1.2 g/l Cu (the concentration of copper in the leach solution) and we expect a stripped organic value of approximately 0.9 g/l Cu. Adding the net copper transfer of 1.2 g/l Cu to the estimated stripped organic value of 0.9 g/l Cu, we have a total of 2.1 g/l Cu. We can see from Figure 3 that while using LIX 984N we should try to load the organic in the solvent extraction circuit to approximately 80 - 85% of the maximum

### LIX REAGENT LOADING WITH 10 VOLUME PERCENT REAGENT

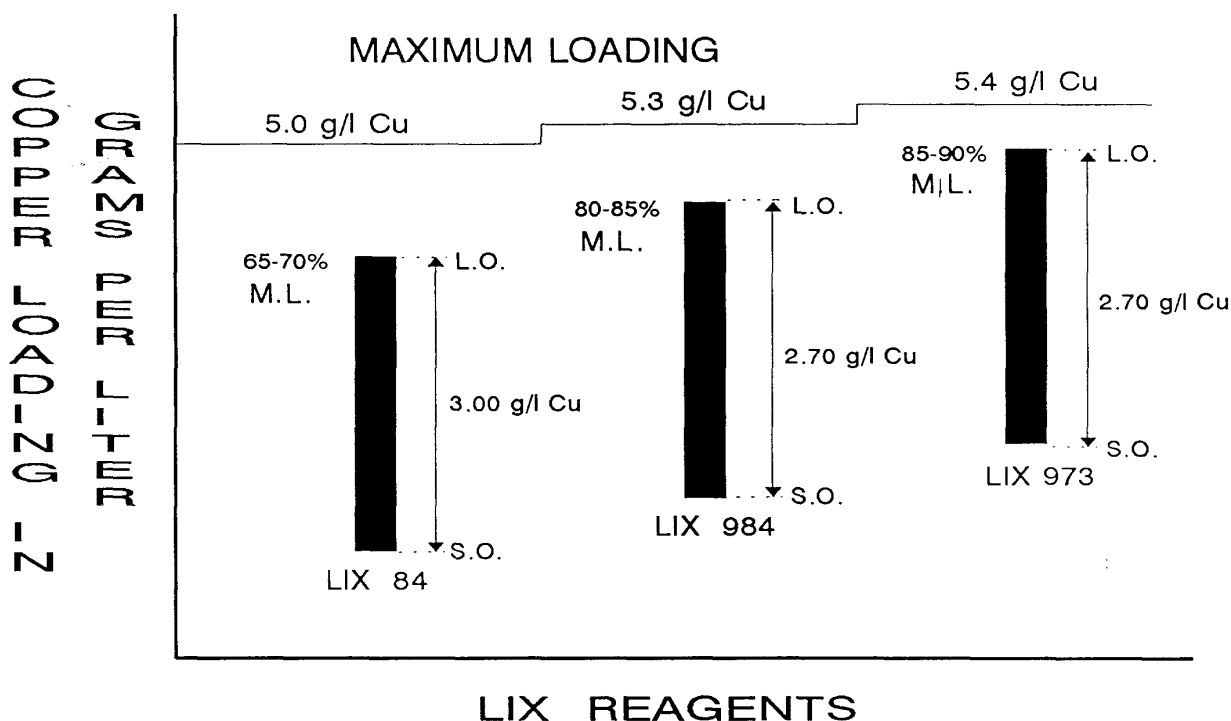


Figure 3

loading capacity, (based on our leach solution, not on the Standard). The Maximum Copper Loading data in the Technical Bulletin is the data obtained while using a "Standard Leach Solution" at 6.0 g/l Cu and pH 1.8. However, our leach solution is 1.2 g/l Cu at pH 1.8, plus various sulfate buffers such as iron and other metal salts. So the Maximum Copper Loading value should be determined by testing the reagent with the actual leach solution. For purposes of this example, let's assume that our leach solution gave a maximum loading value of 5.1 g/l Cu, or 0.51 g/l Cu per volume percent reagent in the organic phase.

So if our calculated value of 2.1 g/l Cu (Stripped Organic g/l Cu plus desired net copper transfer) is to be 85% of maximum, we will want enough reagent to give us a circuit maximum loading capacity of 2.47 g/l Cu. We had found that our measured maximum loading capacity was 0.51 g/l Cu per volume percent. By dividing the desired circuit maximum loading capacity (2.47 g/l Cu) by the actual loading capacity on one volume percent LIX 984N (0.51 g/l Cu), we find that we need to prepare our organic solution to contain 4.84 volume % LIX 984N. In summary, we can express the preparation mathematically:

- (a) 
$$\frac{(\text{Net Cu Transfer} + \text{Strip Point}) / \text{Percent of Maximum Loading in the SX circuit}}{\text{Loaded Organic}}$$
- (b) 
$$\frac{(\text{Loaded Organic}) / \text{Maximum Loading per Volume \% LIX 984N}}{\text{Volume \% reagent required in our solvent extraction circuit}}$$

The result of 4.84 volume % LIX 984N is not necessarily an exact figure. However it is a starting point. If the plant metallurgist decides to use more or less acid in the strip stage, this could change the value of the stripped organic to be obtained. Also, if the Fe:Cu ratio in the leach solution is higher than average, he might wish to operate the plant at a slightly greater percentage of maximum loading to help "crowd" some iron off the organic in the extraction stages. Or if percent recovery of copper is critical, he might want to operate at a lower percentage of maximum, which would indicate a greater concentration of reagent in the organic. So it can be seen that a reagent concentration prepared to contain between 4.75 and 5.0 volume % LIX 984N would be quite suitable for the plant start-up, and after the SX circuit has reached equilibrium additional LIX Reagent or diluent can be added as required to obtain the desired metallurgical conditions in the SX plant. Prior to adding the LIX Reagent and diluent to the SX plant the calculated data can be verified or corrected by doing some simple separatory funnel shake-out tests in the laboratory to establish the desired extraction McCabe-Thiele Isotherms.

Figure 3 also illustrates some of the important differences in the operating parameters for the different LIX Reagents. Comparing the three reagents, LIX 84, LIX 984, and LIX 973, it can be seen that the weaker extractant LIX 84 can achieve a lower stripped organic (S.O.) than the stronger extractants LIX 984 and LIX 973. However, for optimum recovery of copper from the leach solution the weaker extractant must also operate at a lower percentage of Maximum Loading. In the case of LIX 84 it is recommended to load the organic in the SX circuit to approximately 65 to 70% of its maximum loading capacity. The net copper transfer (the difference between the L.O. and the S.O.) is approximately 3.0 g/l Cu in this example. One can also see the relative maximum loadings for the various extractants-. The stronger extractants show greater maximum loading capacities under similar operating conditions, but maximum loading capacity is not an important criteria in the circuit design. The important criteria is net copper transfer. In other words, the greatest quantity of copper that can be transferred on the least amount of reagent is the best condition in terms of it's economic value. So if we have a leach solution which is relatively low in copper and high in pH, LIX 84 would be the best choice of extractant because of its better copper transfer capacity. This is true even though the LIX 84 has the lowest maximum loading capacity.

## SELECTION OF CHEMICALS AND MATERIALS OF CONSTRUCTION

It is important to use the best quality hydrocarbon diluent obtainable in solvent extraction technology. Although the best quality diluent is the most expensive to buy, it is usually the least expensive to use. Poor quality diluent evaporates faster, it gives slower phase disengagement rates, and it usually has the greatest entrainment loss rates. These disadvantages make cheap diluent more expensive to use. Poor quality diluents are usually high in impurities so quite often SX plant operators try to wash out the impurities with strong acid solution before using them in solvent extraction circuit. If the concentration of acid is not correct, however, a strong acid solution can "burn" the diluent and can result in very poor physical properties although it might look "cleaner".

Sulphuric acid used for leaching and stripping in the solvent extraction circuit should be good quality. "Black" acid, or used acid, should never be used in solvent extraction systems. These products can cause the formation of stable emulsions during mixing in the solvent extraction circuit and make the system inoperable.

The water used in leaching should be low in Cl<sup>-</sup>. Normally it should be less than 100 parts per million (ppm) in the aqueous strip solution if electrowinning is done on stainless steel blanks. At high chloride concentration the

acidic chloride can etch the stainless steel blanks such that the copper plated onto the stainless steel cannot be removed. And at low current densities the presence of chloride will result in a very soft and brittle deposit which will be very low in quality and probably unsuitable for selling as Number 1 copper cathodes.

Most of the small solvent extraction plants built in China are constructed of PVC (Poly Vinyl Chloride). Some gray PVC is made from recycled scrap and is not recommended. Good quality PVC is an acceptable material of construction with LIX Reagents, but it is not recommended for use with modified extractants or with diluents that are high in aromatic content. Some modifiers will dissolve the stabilizers in the PVC (which are fatty acid soaps), or the material which is used to bond the PVC sheets together during mixer-settler construction. The dissolution of PVC by some modifiers and/or aromatic kerosenes might be slow, but as the plasticizer dissolves from the PVC it will accumulate in the organic phase and cause very serious problems with kinetics, loading capacity and phase separation. Once an organic is contaminated with dissolved plasticizer it cannot be corrected for re-use. The same results can be found with some other types of plastics, rubbers, and tar type coatings that have been used in some storage tanks in Chinese SX plants. If there is any question about the use of any material, it should be tested before using, or the customer can contact a Henkel representative for advice.

Most of the large solvent extraction plants are constructed of stainless steel. The best grade is 316 stainless steel. The 304 grade is not recommended since it has poor resistance to corrosion by both acid and chloride ions.

## MIXER - SETTLER DESIGN CONSIDERATIONS

In most cases, the SX circuit will be constructed with 2 extraction stages and one stripping stage. If the leach solution is normally high in chloride, manganese and/or nitrates, a wash stage should be used after extraction and before stripping. The wash stage will help to prevent entrained contaminants from reaching the strip circuit.

Most small mixer-settlers use a single mixing chamber, as shown in Figure 4. This is considered a Conventional Mixer-Settler. Also illustrated is the placement of the picket fence, the organic overflow weir, and the adjustable

aqueous overflow weir. The aqueous weir is designed to adjust in height (elevation). This is convenient for changing the height of the organic:aqueous interface in the settler, and can even be useful in a normal decrudding operation. Also notice the aqueous recycle in the settler. This is used to provide an organic:aqueous mixer input ratio when the originating organic and aqueous streams are not flowing at a 1:1 ratio. The recycle is normally used in the strip mixer-settler stages, but it is often convenient in the extraction stages as well when the mixer continuity needs to be changed from one dispersed phase to another.

## CONVENTIONAL MIXER / SETTLER

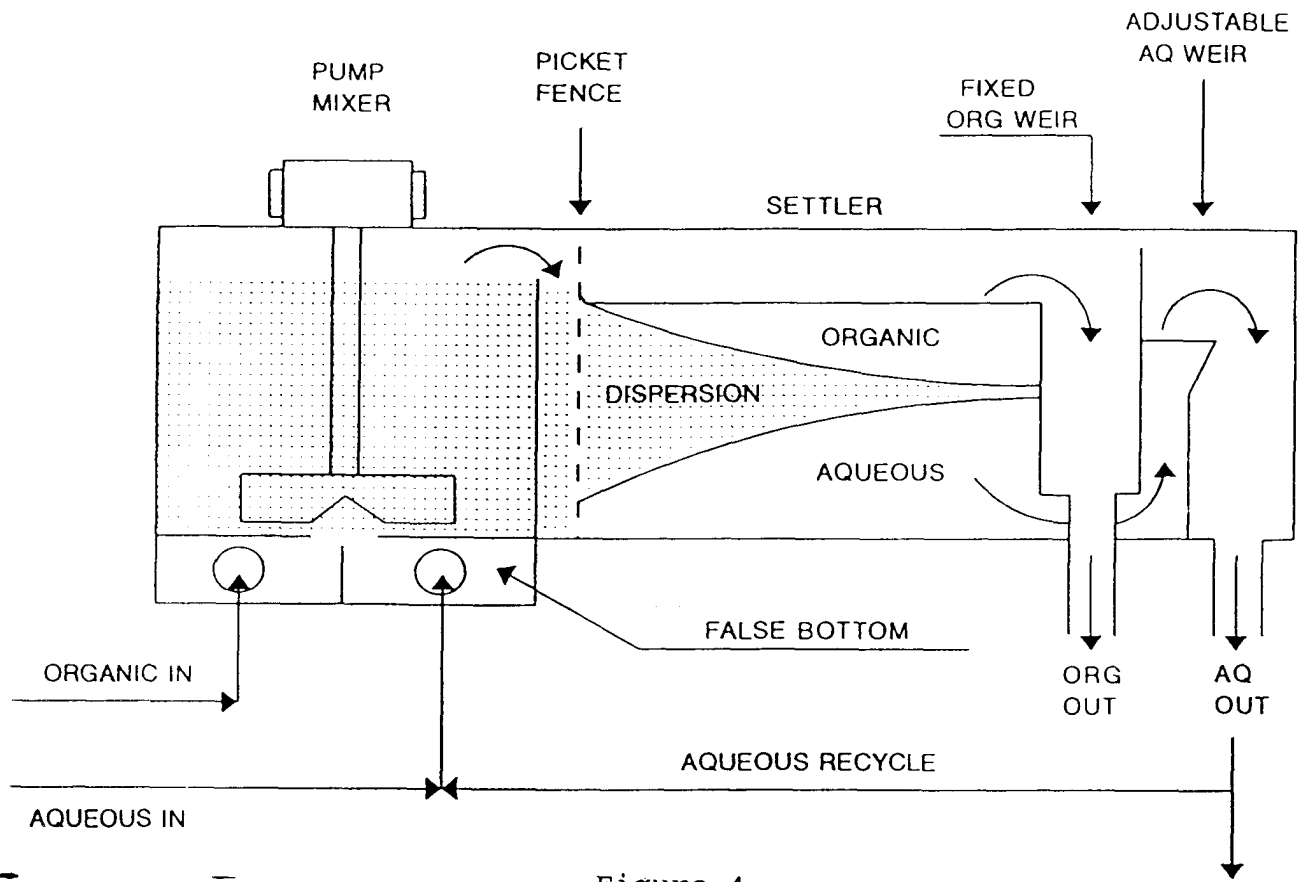


Figure 4

Figure 5 is a mixer-settler design with two mixing chambers. The first mixing chamber uses the conventional pumping/mixing type impeller while the second "down-stream" mixing chamber uses a simple propeller type impeller. This second impeller does not need to have any pumping ability, and is used only to maintain an emulsion throughout the mixing chamber. The dual mixer design results in better mixing efficiency than a single mixer, thus reaching a greater degree of equilibrium, and the second mixer design also allows both the mixers and settlers to be constructed on or near ground level. The recommended mixing time in most solvent extraction systems is three minutes per stage. So in a single mixer we need 3 minutes of mixing, and in a dual mixing system we need 1.5 minutes per mixing chamber.

## CONVENTIONAL-DUAL MIXER/SETTLER UNIT

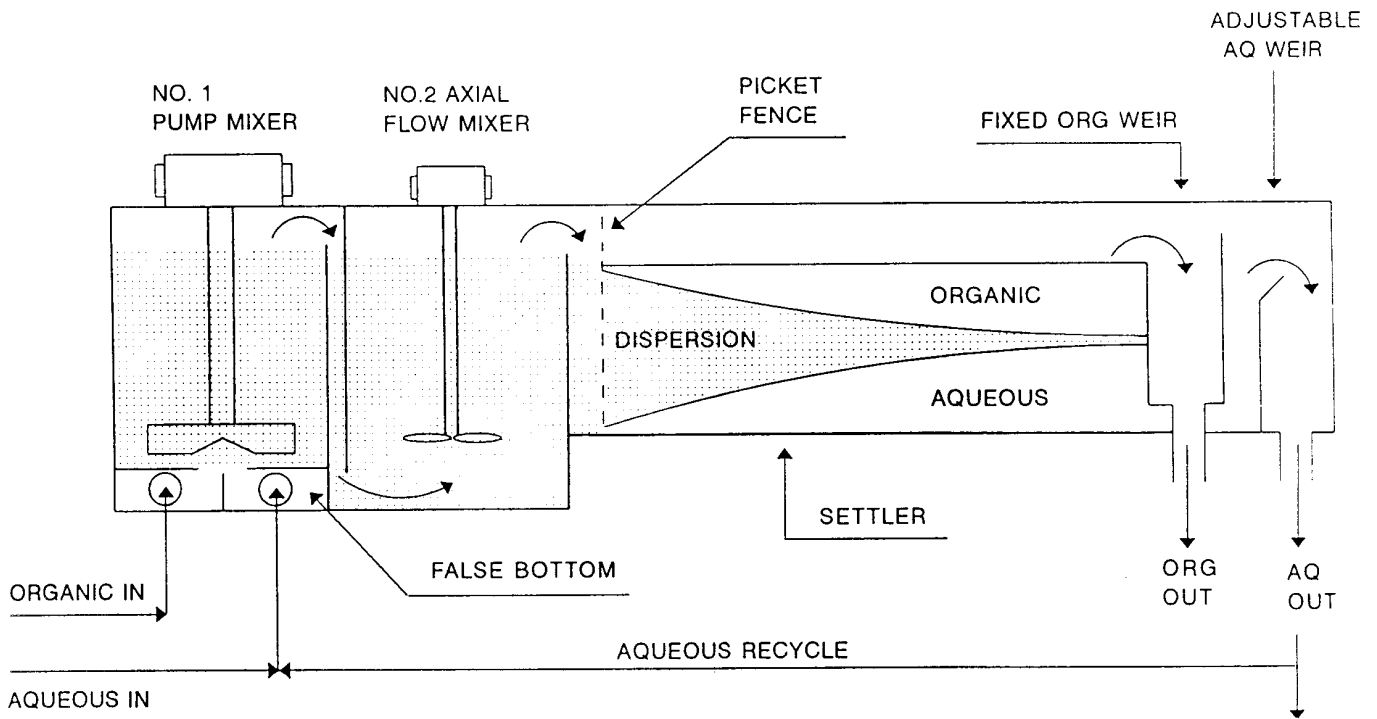


Figure 5

Figures 6 and 7 illustrate the correct designs for mixing boxes containing false bottoms. Both of these designs achieve the desired -flat surface on the entire mixer floor.

# CORRECT FALSE BOTTOM DESIGN 1

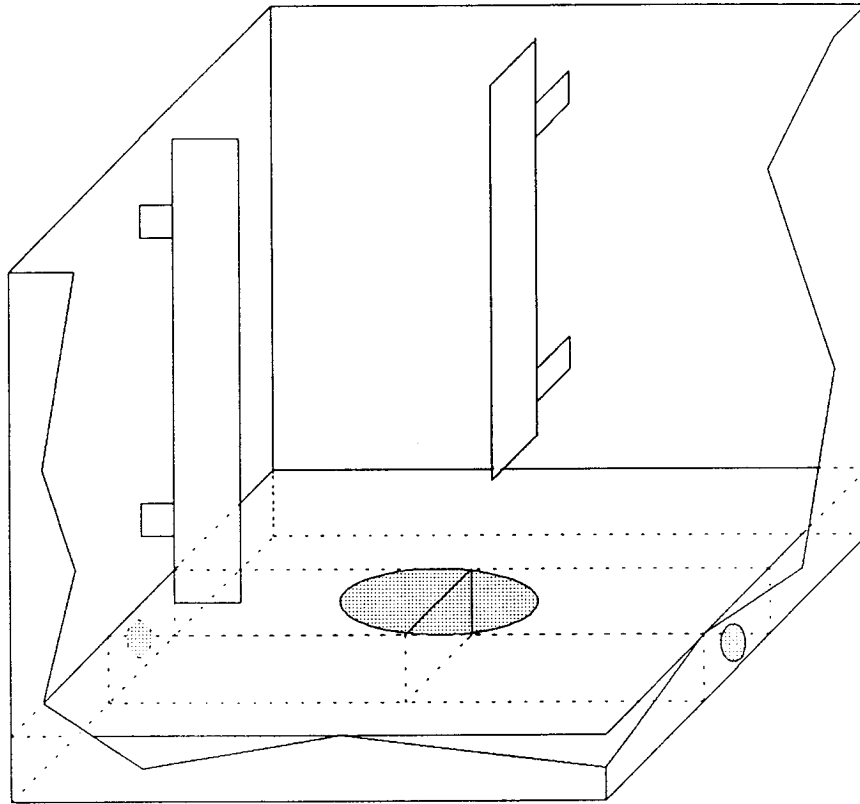
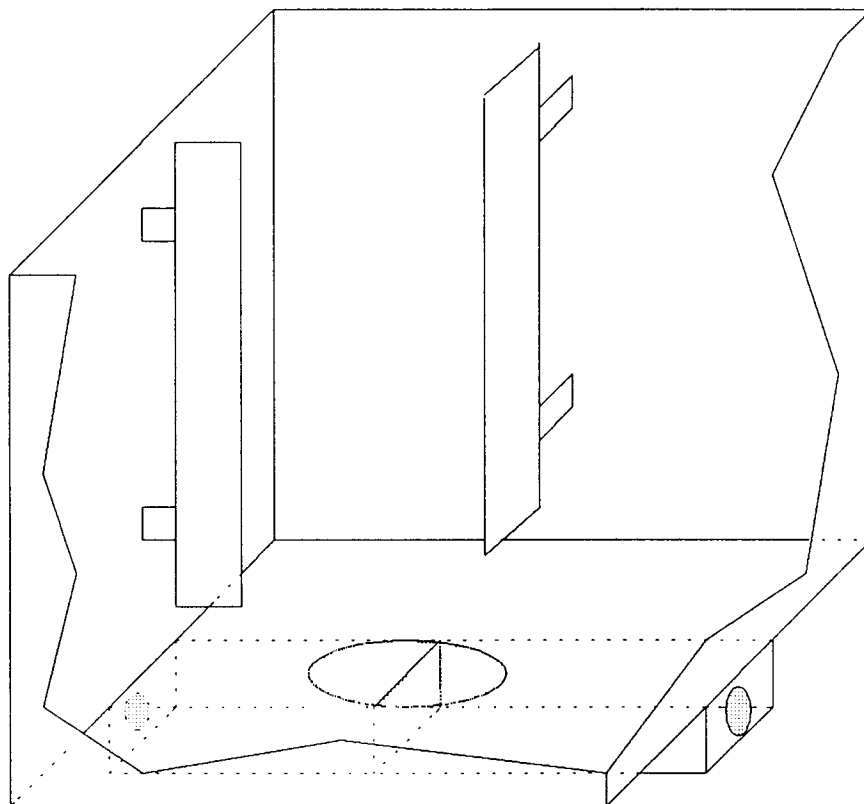


Figure 6

Also notice the wall baffles mounted on the sides of the mixing chambers with the baffles positioned away from the walls by a few centimeters. These baffles help to reduce the tendency toward the centrifugal separation of the organic and aqueous phases during the mixing process.

Settlers should be designed to have cross-sectional areas designed at  $3.6 - 4.8 \text{ m}^3 / \text{hour} / \text{m}^2$  ( $1.5 - 2.0 \text{ GPM} / \text{ft}^2$ ) based on total settler flow. The recommended geometry of the settlers is a length:width ratio of 3: 1 to 1: 1. Most large, modern SX plant settlers are designed closer to the 1:1 length:width ratio to obtain the minimum axial flowrate within the settler. The organic depth in the settlers should be at least 24 centimeters. The ideal organic and aqueous depth ratio in the settler is equal to the 1:1 flow ratio

## CORRECT FALSE BOTTOM DESIGN - 2



**Figure 7**

interfacial shear at the settler organic:aqueous interface. Major differences in flow rates between phases in the settler can create a secondary haze (entrainment emulsion) which then must recombine, or it will exit the settler as entrainment. Rapid exiting flows can also create "eddy" currents that can ultimately result as entrainment losses. Settler overflows should be designed at full settler width, again, to prevent undesired "eddy" currents in the settler.

Interstage and intrastage piping should be designed with large enough diameters to avoid vortexing of solutions in the pipes. Most solvent extraction circuits include pipe diameters that allow low-resistance flow from one stage to the next, but very few are -designed to-avoid vortexing that includes air sucking and turbulent flow. It is necessary to have pumping equipment and- piping designed so that the advancing liquid solutions contain no air, or as little air as possible.

## ANCILLARY EQUIPMENT CONSIDERATIONS AND START - UP PROCEDURES

Returning to the general plant flowsheet in Figure 2, we can see that the solvent extraction circuit should also include a "surge tank" for storing loaded organic, as shown in Figure 2. A solvent extraction circuit should never be operated without a surge tank. The surge tank has several purposes. Some of them are listed here:

- 1) To perform as an "after settler", which can help prevent entrained leach aqueous from contaminating the strip circuit.
- 2) The surge tank should be built large enough to contain all of the liquid volume from just one mixer-settler stage. It is recommended in this way so that the surge tank can contain the organic from a single stage in case the mixer-settler has to be evacuated for repair or modification.
- 3) The organic is pumped from the surge tank through a flowmeter or a flow control device so that the flowrate and the organic:aqueous flow ratio can be monitored.

After the solvent extraction circuit has been constructed it should be tested with water or slightly acidified water for detecting leaks. All leaks should be corrected before the SX circuit receives leach solution and the extractant.

After water testing, the SX circuit should be tested in the same way with diluent. Sometimes small cracks or voids in the construction of the mixer-settlers or pipes will not leak water but they will leak organic liquid. So the SX circuit should be leak tested with both organic and aqueous solutions should be checked. The diameter of the impeller should be designed to be between two-thirds and three-quarters the cross sectional dimension of the mixing chamber. Smaller impellers require greater mixing speed, and high mixing speed causes greater shear of the emulsion (slower phase separation and higher entrainment losses). Higher mixing speeds can also result in the mixing of air in the mixing chamber. If air is sucked into the organic-aqueous mixture we then have a three phase emulsion instead of a two phase emulsion, and this leads to poor phase separation, greater crud control problems, and greater entrainment losses.

During the design of the solvent extraction circuit the engineer should be sure of the sizing of the piping between mixer-settler stages. Sometimes the pipes used in the design are not too small for the normal transfer of the liquids through them, but they are too small to prevent air from being sucked intermittently into the mixers. The air results in the three phase mix as mentioned above, but it also effects the overflow of emulsion from the mixer to the settler. Uneven flow results in "surging", and surging results in very poor settling of the organic and aqueous phases in the settler. Quite often the surging will produce a significant wave motion in the settler, although it might not be so visible at the surface, and it can even result in the generation of a fine haze which contributes to higher entrainment loss rates. Pipe connections should also be made to avoid air locking, and to avoid water locking in the organic lines.

One method of reducing the problems caused by surging is by putting a "picket fence" in the settler about a quarter meter to a half meter from the mixer overflow discharge. A picket fence is illustrated in Figure 9. Many picket fences in China are designed incorrectly with their 'IV' shape. The 'IV' shape is not necessary in small settlers! and in fact it directs the flows down the sides of the settlers with a small "backflow" in the center of the settler.

Picket fences can also reduce minor interfacial wave motion caused by surging, but they do not eliminate excessive wave motion. In small settlers the picket fence should be straight, and placed perpendicular to the direction of the flow. The open spaces in the picket fence should be designed to provide about a 2 or 3 centimeter head behind the fence. The head ensures that even flow distribution is being achieved with a correctly positioned picket fence. Usually a closed:open ratio of approximately 10:1 will provide the head that is required for good flow distribution.

If the impeller is sucking air from the previous stage, the speed of the impeller should be checked. Perhaps it is rotating too fast and can be slowed down to a correct speed. If the speed is correct, but still sucking air, it is sometimes possible to raise

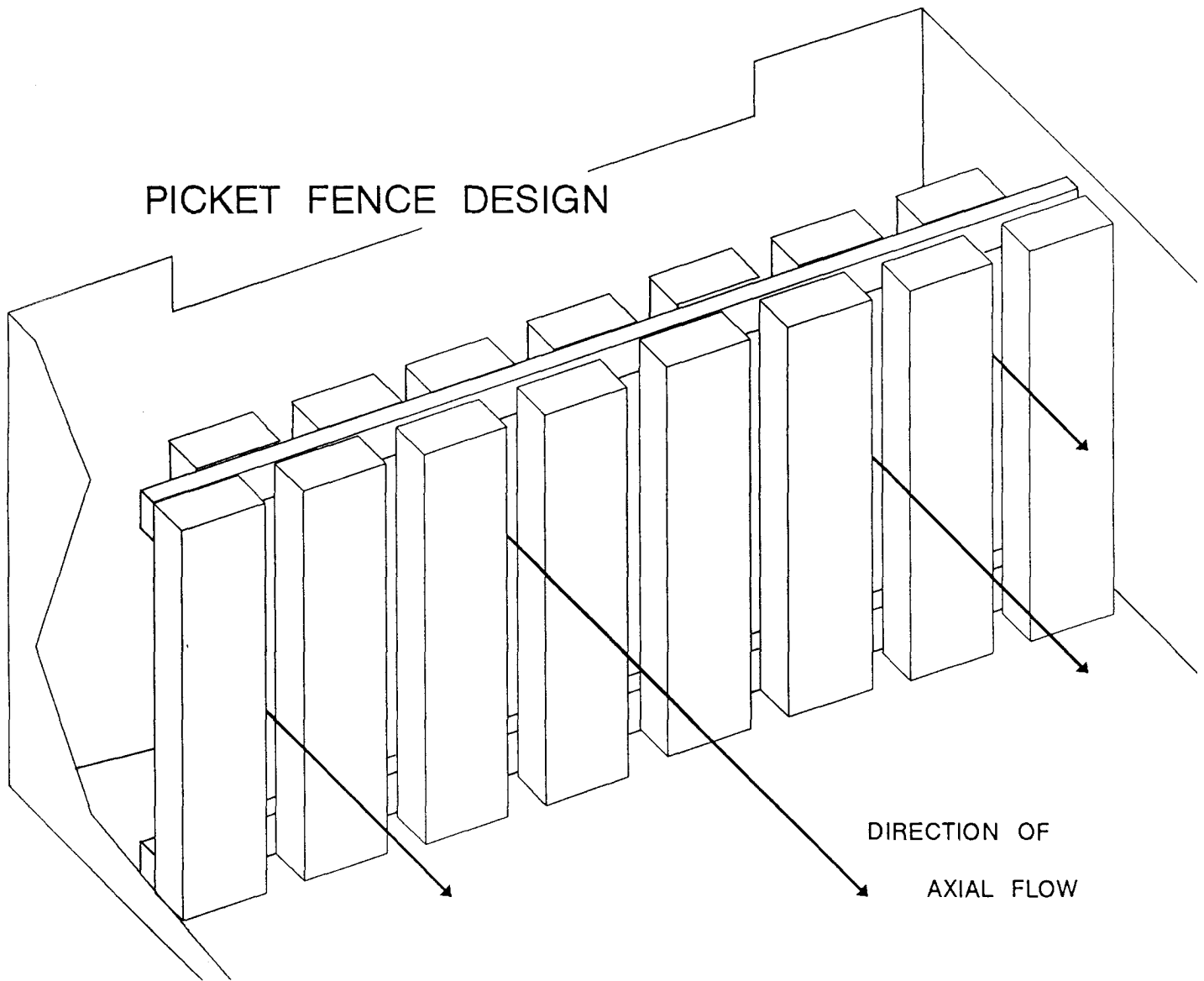


Figure 8

the impeller a few centimeters off the floor of the mixer. This might reduce the pumping efficiency enough to prevent air from being sucked into the mixer (although surging of liquid could still occur if the pipes are incorrectly sized and positioned).

Impeller speeds should be controlled within certain performance values. An equation which is often used is  $N^3D^2 < 20$ . If this formula is used correctly for the impeller design, the plant should obtain the lowest possible entrainment rates:

N = Rotational speed of the impeller, in Revolutions/Second

D = Impeller diameter in feet

Further, the impeller should be constructed similar to the design in Figure 10. This impeller features a flat top plate with straight bottom vanes only. The impeller should not have vanes on the top of the plate, it should not have vanes extending beyond the diameter of the top plate, and the vanes should be straight. Some newer solvent extraction plants are using curved vanes on the pumping impellers. This design is believed to produce less shear, thus reducing entrainment transfer. Some of the commercial curved vane impellers do provide this advantage. others do not, and some can even broaden the size distribution of the emulsion droplets in the mixers, which can have an affect on the equilibrium capability in the mixers, while also increasing entrainment. If curved vane impellers are your first choice, be sure that you select them according to plant experience and not from the sales brochures.

Some impellers used in solvent extraction also include an "O" shaped bottom plate below the vanes. The bottom plate is not necessary, and the increased pumping capacity that is achieved can result in too much pumping ability and cause the undesired sucking of air in the mixture from the previous mixer-settler. Also, this type of impeller can make it very difficult to change phase continuities in the mixer. It should be remembered that the specific gravity difference between the organic and aqueous phases is very small, so the impeller does not need to be a highly efficient pumping device. In solvent extraction systems the impeller should be considered an efficient mixer and an inefficient pumper.

It is not possible to eliminate entrainment completely. The average loss of extractant in the organic phase is approximately 2 to 3 kg of extractant per tonne of copper produced. Some plants have two or three times this

## MIXER IMPELLER

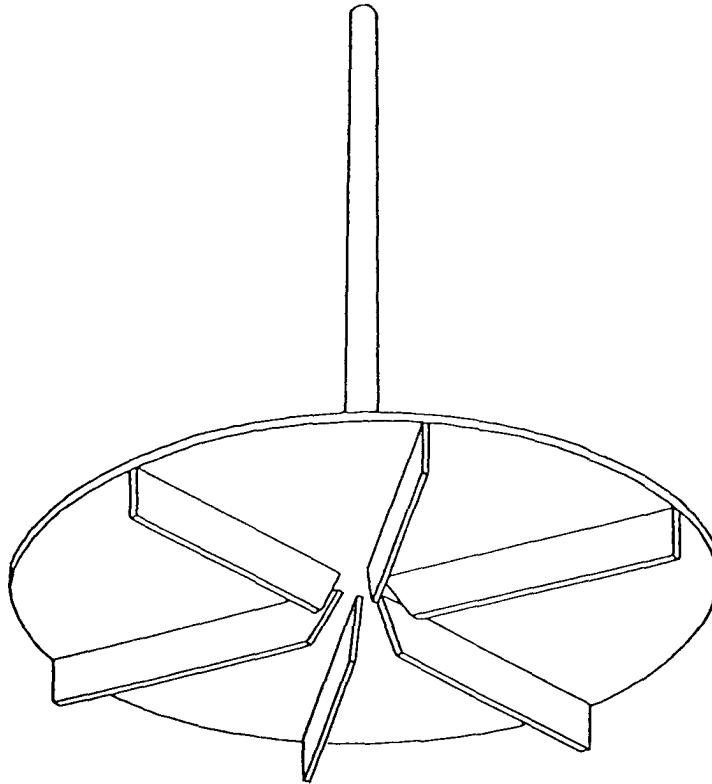


Figure 9

loss rate. The higher loss rates can be due to using a "Series-Parallel" flow design (not discussed in this report), poor quality diluent and/or acid, high solids in the leach solution, contamination of the aqueous or organic phases, operating the SX circuit above design capacity (which is the most common reason for higher organic loss rates), improper mixer and impeller design and/or operation, and inferior quality extractants. Some mention has been made of phase continuity in this report. So we will now try to describe this in detail, and explain the importance of maintaining the correct phase continuity in the mixing process.

In the mixing process where there are two immiscible liquids being mixed together, there is a tendency for one of the liquid phases to be the continuous phase while the other is the dispersed phase. If the organic phase is the continuous phase while the aqueous phase is the dispersed phase, this is called organic continuous mixing. If the aqueous phase is the continuous phase while the organic is the dispersed phase, this is called aqueous continuous mixing. Figure 11 illustrates more clearly the meaning of phase continuity and the difference between aqueous continuous and organic continuous mixing. Why is phase continuity important? When working with liquid-liquid systems, as we have in solvent extraction, it is important and desirable to achieve the separation of the liquids after mixing such that each phase has as little of the other phase entrained in it as

possible. In the extraction circuit, for example, we do not want any of the PLS to remain in the organic phase as the organic phase proceeds to the stripping section of the circuit. Any "entrained" PLS in the organic will mix with the pure copper aqueous electrolyte, thus increasing the concentration of contaminants from the PLS in the strip solution. The accumulation of contaminants from the PLS, such as iron, aluminum, manganese, chloride, and any other contaminant, can possibly have serious consequences in the electrowinning operation or in the

## MIXER PHASE CONTINUITY

### AQUEOUS CONTINUOUS versus ORGANIC CONTINUOUS

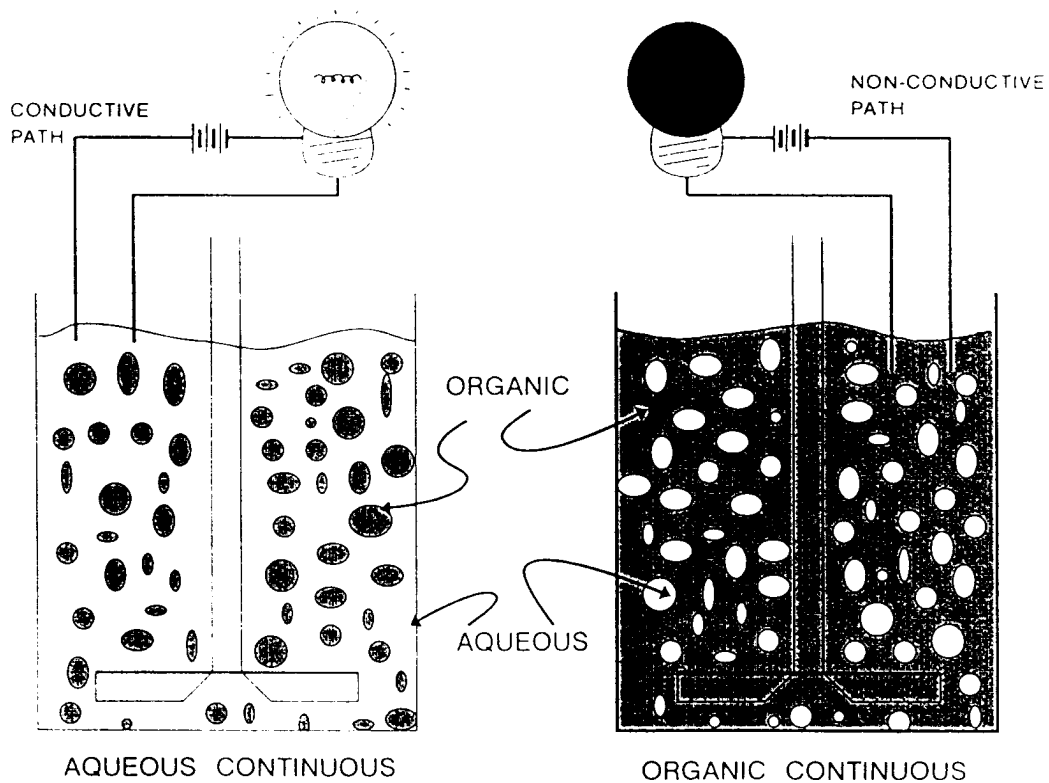


Figure 10

quality of the copper cathode. So we wish to keep the entrainment transfer at a minimum. Plant experience has demonstrated that entrainment of aqueous in the organic is at a minimum when the mixer is operated aqueous continuous. So we try to maintain an aqueous continuous emulsion in Extraction Stage 1 (the loaded organic stage) . On the other hand, we also want to minimize the loss of entrained organic from the circuit as the raffinate is returned to the leaching area. So to obtain the lowest organic entrainment we operate Extraction Stage 2 organic continuous. To put it in another way, we say:

- ❖ Clean aqueous: operate organic continuous.
- ❖ clean organic: operate aqueous continuous.

If we have only one stripping stage, what phase continuity should we use? of course we want to minimize organic loss from the SX circuit. And it is not so important to minimize the entrainment transfer of electrolyte from the strip section to the extraction section because the PLS already has both copper and acid in it. In this case the entrained electrolyte wouldn't be contaminating the extraction circuit. So it is easy to choose organic

continuous mixing to obtain a "clean aqueous" electrolyte to reduce organic entrainment to the electrowinning plant.

Determining the phase continuity in the mixer is easily done by using a conductivity meter. Another simple method, as shown in Figure 11, is to construct a probe using 2 stiff wires, a small 9 volt battery, and a miniature light bulb. If the emulsion in the mixer is aqueous continuous, the acidic aqueous provides a conductive path for the electricity and the light bulb is turned on. If the mixer emulsion is organic continuous, there is no conductive path to close the electrical circuit so the light will not turn on.

Some solvent extraction plants use a coalescer to recover entrained organic from the raffinate and/or from the pregnant electrolyte. It is not always economical to use a coalescer with the raffinate because of the relatively greater volume of solution. So instead of a coalescer, a large holding tank or holding "pond" is used. These are actually just large after-settlers to allow fine entrained organic haze to settle to the surface of the aqueous phase. It must be remembered in this recovery method to skim off the recovered organic frequently on a regular basis. In addition, before the organic is returned to the SX circuit it should be tested for phase separation time. If phase separation is slow, the organic should be treated with activated clay, and re-tested; and if that is necessary, kinetics of the recovered organic should also be tested. If the organic is not recovered from the raffinate pond on a regular basis it can degrade slightly, and adding degraded organic back into the SX circuit can adversely effect the good quality organic being used in the plant operation. So recovered organic should always be tested before returning it to the main circuit. This is even more true for organic recovered from the electrowinning (EW) section of the plant. Organic that remains in the electrowinning cells is much more likely to be degraded by oxidation from the electrolysis operation, so organic found in these cells should be recovered daily and tested. If recovered organic cannot be treated, returning it to its correct specifications, it should be discarded. A small quantity of contaminated organic added back into the circuit that contains good quality organic will result in poor performance in the SX circuit.

A coalescer is usually used to remove entrained organic from the pregnant electrolyte before it enters the EW plant. This can be done by several methods. One is to use some coalescing media such as PVC mesh (organic "wets" plastic type materials, aqueous "wets" metals surfaces). Another method to recover entrained organic is by using flotation type aeration. Small air bubbles tend to be surface wetted by small organic drops. The air raises these organic coated air bubbles to the surface of the aqueous where the air bubbles burst and the organic droplets coalesce. This system is used in several plants worldwide. A third method is by using a "sand filter". But it should be remembered that "sand filters" do not contain silica "sand". Strong acid solutions which are typically used in solvent extraction stripping circuits and electrowinning plants can slowly dissolve silica sand. The dissolved silica is present as a complex polymer and, in the combination with a flocculant, as is often used as a cathode smoothing agent, silica can cause serious phase separation problems in the SX circuit. So in reality, a "sand filter" should not use "sand", it should use a combination of garnet and charcoal. This combination will usually remove most of the entrained organic before it reaches the EW plant, and it can be easily "backwashed" (cleaned) for re-use.

## **ELECTROWINNING CONSIDERATIONS**

In most electrowinning operations the copper transfer in the electrolytic cells is normally between 5 and 10 g/l copper. The incoming electrolyte from the final solvent extraction strip stage is called the "Pregnant Electrolyte" (P.E.). The exiting electrolyte from the tankhouse back to the SX circuit is called the "Spent Electrolyte" (S.E.). If the PLS leach solution contains only a fraction of the electrolytic requirement for copper transfer, it is necessary to operate the flow ratio in the SX strip circuit at an organic:aqueous (O:A) ratio greater than one. For

example, let us assume that our leach solution to extraction in SX results in a net copper transfer of 1.25 g/l copper. But we want to have a net copper transfer of 5 g/l copper across the tankhouse. To achieve the 5 g/l net transfer we must operate the SX strip circuit at an organic:aqueous phase ratio of 4:1. That is to say, the flow rate of spent electrolyte will be one-fourth the flow rate of the leach solution flowrate. This will give us the 5 g/l transfer that we want in the electrowinning tankhouse. However, it is not desirable to operate the mixers in an SX circuit at a volume ratio of 4:1, organic:aqueous. The reason is this: At a 4:1 organic:aqueous flow ratio we get relatively poorer stripping, due to the inefficient interfacial contact at this high ratio. Also, when the O:A ratios between organic and aqueous deviate very far beyond the desired 1:1, the average size of the droplets in the emulsion gets much smaller. When the emulsion has smaller droplets it is much more difficult to achieve clean phase separation in the settler, and poor phase separation results in greater entrainment transfer and organic losses. Sometimes solvent extraction circuits are operated at organic:aqueous phase ratios of 1.2:1 or 1:1.2. This deviation is normal, and often required, to maintain the desired phase continuity in the mixer. But greater phase ratios such as described in our example are not desired. So, in our example we use the aqueous recycle to achieve a 1:1 phase ratio in the mixing chamber. So it can be seen that the originating flow ratio is 4:1, organic:aqueous, and the aqueous recycle is opened to achieve an organic:aqueous flow ratio of 4:3. The combined aqueous streams entering the mixer then have a flow rate equal to the organic flowrate, or a mixer input flow ratio of 1:1. Many solvent extraction plants in China have aqueous recycles but few are ever used as they should be.

Other electrowinning operating parameters include:

- 1) Anode spacing (the distance between the centers of the anodes)
- 2) is usually 10.2 centimeters.
- 3) Often copper electrolytes are heated to help produce better quality cathodes. An ideal electrolyte temperature is about 115 degrees F (46 degrees C).
- 4) The flowrate in each electrowinning cell should be controlled to obtain sufficient circulation to avoid copper depletion at the aqueous - cathode interface during the electrowinning process. Several electrowinning plants use a standard minimum cell flow rate of about  $0.12 \text{ m}^3 / \text{hour} / \text{m}^2$  of plating area. It might be necessary to install a recycle pump to achieve this internal flow rate if the flow of the SX electrolyte is too low.
- 5) Current density in the electrowinning process varies widely at different copper plants around the world. However, the average is generally within the range of 190 to 240 amperes/meter<sup>2</sup>.
- 6) While using Henkel's LIX Reagents, the spent electrolyte from electrowinning should contain 30 - 35 g/l Cu and 180 g/l H<sub>2</sub>SO<sub>4</sub>.

Most solvent extraction plants in the world today use anodes made of Pb, Ca, and perhaps Sn. Few plants use just Pb - Sb anymore. However, the life of any anode can be extended by adding cobalt sulfate to the electrowinning electrolyte. Normal electrowinning plant usage is approximately 100 to 150 ppm (parts per million) Co in the electrolyte. The presence of cobalt changes the surface chemistry of the anodes and helps prevent the flaking of small particles of PbO which can become trapped in the cathode. This use of Co, a proper smoothing agent in the electrolyte, and the other operating parameters mentioned in this report, should allow solvent extraction produced copper to be made at the 99.999% purity, better than the quality produced at most electrorefineries.

The preferred smoothing agents used at most SX-EW plants worldwide are products supplied by Henkel Corporation. Examples include Guarfloc 66 and Galactasol® 40H4FDS1. A smoother cathode surface helps prevent small particles of PbO flaking off the anode from being trapped on the cathode surface during the plating operation. Guarfloc and Galactasol can also reduce dendrite growth of copper metal crystals which often can cause short-circuiting between the cathodes and anodes. Smooth cathodes are easier to wash after plating has been completed, thus reducing the physical entrapment of small drops of electrolyte on the cathode surface. When the drops of electrolyte dry they report in the cathode analyses as high sulfur and oxygen assays. So these polymers have many positive benefits at very low cost. Galactasol 40H4CD (previously called Guartec® EW-C) was developed by Henkel Corporation specifically for electrowinning applications. More information about the use of guar-based polymers is found in the attached Appendix I.

Guarfloc or Galactasol are added to the electrolyte storage tank where moderate agitation is found. They should be added continuously on the basis of 150 to 300 grams per tonne of copper plated in the electrowinning plant. The Galactasol should be sifted slowly into the agitated electrolyte to allow proper dissolution during mixing.

Every electrowinning operation should include a small "bleed stream" to prevent the build-up of contaminants

### SX - EW ELECTROLYTE FLOWSHEET WITH STARTER SHEET SECTION

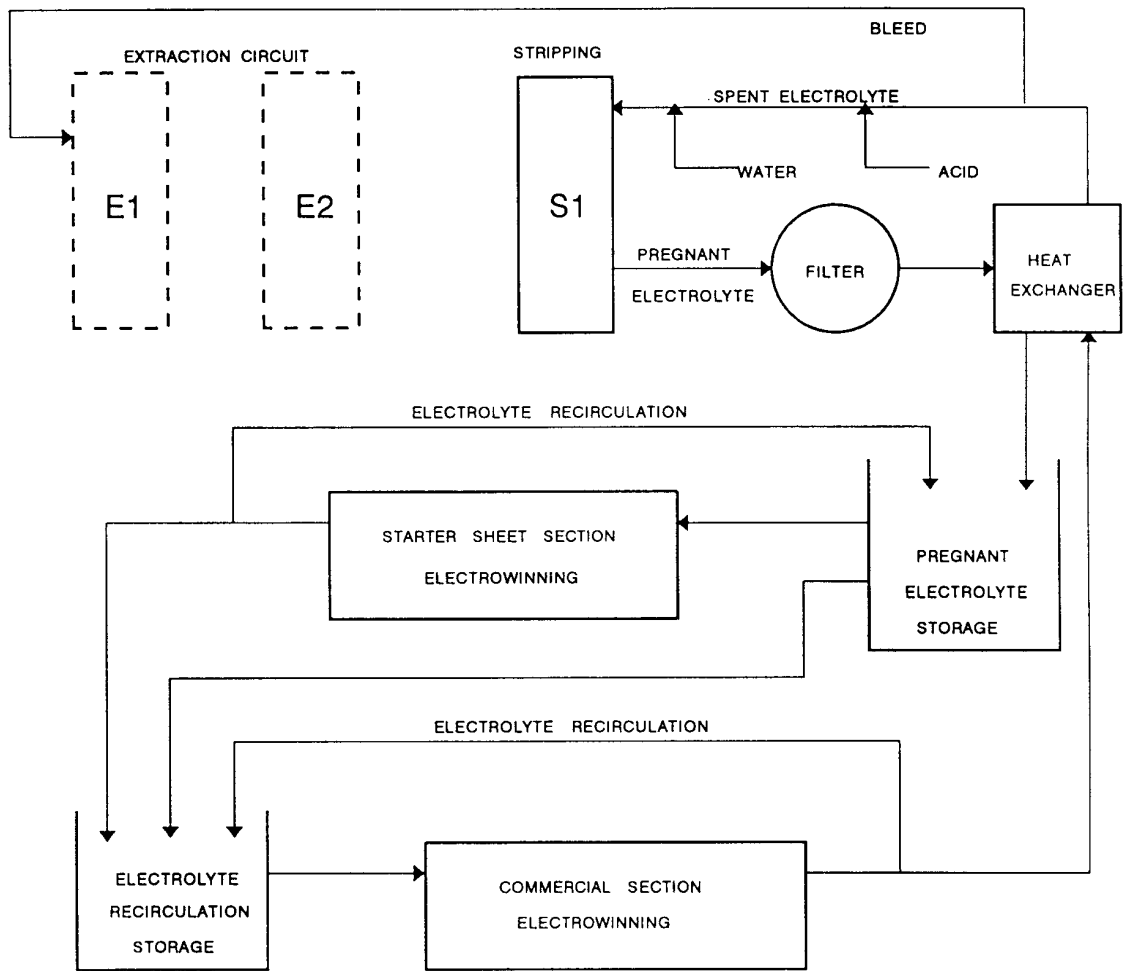


Figure 11

in the recycling electrolyte. Normally the bleed stream is controlled at a flow rate which is sufficient to maintain the Fe (iron) bleed in the electrolyte at or below 3 g/l Fe. A flowsheet for the electrowinning circuit, including the recommended bleed stream, is shown in Figure 12. Since Fe is the only contaminating metal to be extracted by most LIX Reagents (and other commercially available copper extractants), the bleed rate is usually calibrated to iron. However, even if there is no iron in the PLS, we still need to maintain the small bleed to control the accumulation of other metal contaminants in the electrolyte. For example, we want to maintain the chloride at less than 100 ppm, alumina at less than 15 g/l, and it is very important to maintain Mn at low levels due to the potential hazard of forming a permanganate compound that potentially can degrade solvent extraction reagents very quickly. In the case of Mn, it is usually desirable to maintain the Fe content below the 3 g/l concentration as previously mentioned, but also above approximately 1.5 g/l to prevent the formation of the permanganate compound. Most electrolyte bleeds are controlled at 1 to 3% of the electrolyte flowrate.

## COMMON PROBLEMS AND PROBLEM SOLVING

❖ Power loss: Intermittent power losses can always be expected at some mining operations. A short power loss period is of no concern to the solvent extraction circuit. However, extended power loss in the electrowinning plant can be a problem. When power is lost in the electrowinning cells, the cells with their anodes and cathodes, become a "battery" with current reversal. When this happens copper will plate onto the anodes until plant power is restored, and then the copper plated onto the anodes will redissolve into solution and subsequently be redeposited on the starter sheets or the cathodes. This battery action sharply reduces the life of the anodes, and/or results in a lot of Pb particles flaking onto the cathodes. To avoid this problem during extended power losses, either all of the cathodes should be pulled from the cells, or the plants should be designed with an auxiliary DC (Direct Current) generator with a "trickle" current to oppose and neutralize the battery effect in the cells. Removal of cathodes should be done if the power in the tankhouse cells is expected to be off for more than one hour.

❖ When leaching areas are designed and constructed, the leach pads where the ore will be placed should be carefully considered. If there is a great deal of vegetation on the ground where the leach dumps will be constructed, the vegetation should be removed, or covered with "plastic" sheet (HDPE is a good choice: High Density Poly Ethylene). Many kinds of plant vegetation consist of long-chain organic compounds that can have serious adverse effects on the SX organic if they enter into the leach solution. A plastic liner is not always required if the ground surface is prepared with a layer of clay, or if the geology of the ground under the leach dumps is tight to prevent loss of leach solution into the ground water below. Also, history has shown us that leach "dumps" can occasionally become waste "dumps" for other foreign materials, such as used motor oil from heavy mining equipment, or waste garbage or sewage. All of these foreign materials can dissolve in the leach solution and when the leach solution reaches the solvent extraction circuit the contaminants will contaminate the SX organic and potentially cause a number of possible problems, all of which can be expensive to remedy while production is also probably reduced. In some cases the organic can be cleaned of some contaminants, but in other cases they can't. So the best precaution is to prepare the leach areas correctly, and to keep foreign materials away from the leaching areas.

❖ Mentioned earlier in this report was the fact that all solvent extraction plants experience crud in their mixer-settlers. Removal of crud from the settlers can be one of the greater causes of organic losses. There are several methods for treating this problem, including large settling tanks and centrifuges. Both methods can be expensive. A new method has been tried in some plants with excellent recovery rates. This method can be described directly to each LIX Reagent customer.

It is not advisable to put the crud onto screens placed over the settlers if the crud is going to be pressed through the screens. Crud is composed of aqueous, organic, solid materials, and sometimes air. The solids are usually very fine particles and can pass through most screens quite easily, so "raking" the crud on a screen over the settler just allows the crud to re-enter the settler again. It is better to remove the crud from the circuit before organic recovery is attempted.

If any LIX Reagent customers have any technical problems with their SX recovery plants, they are welcome to contact Henkel Corporation directly, or one of their appointed representatives. The best advice that we can give is this: seek technical assistance from qualified engineers and chemists who have the proper training and experience. Henkel corporation, and their appointed representatives, do not require payment for technical service. Avoid any-unskilled technicians who do ask for payment; they do not represent Henkel Corporation or Henkel Corporation's products.

Finally, we wish to state that Henkel Corporation makes all of their own LIX Reagents in their factory in Ireland, using patented technology. No other company makes any LIX Reagents.

## APPENDIX I

### **THE APPLICATION OF GUAR-BASED SMOOTHING AGENTS FOR IMPROVING CATHODE QUALITY IN COPPER SOLVENT EXTRACTION - ELECTROWINNING PLANTS**

Introduction. Several years ago, Galactasol® Products were introduced to the copper mining industry as smoothing agents in copper electrowinning applications. Today, these products are used in a number of solvent extraction - electrowinning plants worldwide. The advantages of these products include:

- Increased tensile strength and elongations in the copper product.
- Improved power efficiency due to reduced dendritic short circuiting between the cathodes.
- Smoother cathodes which results in improved copper cathode quality and purity.
- The ability to electrowin at higher current densities without sacrificing copper quality.

The use of Galactasol guar-based polymers have proven to be instrumental toward the production of copper cathodes with 99.999% copper purity in several solvent extraction - electrowinning plants.

*Caution: Only Galactasol and Guarfloc® have been proven to be compatible with copper solvent extraction plants when used at recommended concentrations in the electrolyte solutions. Other smoothing agents can inhibit correct phase separation properties, influence-crud formation in solvent extraction circuits, and some can even result in the promotion of extractant degradation in solvent extraction systems. Therefore, the use of other products promoted as smoothing agents in solvent extraction - electrowinning applications is not recommended.*

Applications. There are two common methods for using Galactasol polymers in electrowinning operations. One is a simplified method where the polymer is added directly to the electrolyte storage or recirculation tank prior to electrowinning. The second common method is to use a specific preparation procedure to allow the water-polymer solution to thoroughly mix and reach the desired viscosity before adding the solution to the copper electrolyte. Both methods are used in commercial practice, and both will be described in this paper.

In a new electrowinning plant application, it is recommended to start the plant using a Galactasol concentration of 15 to 25 ppm (parts per million) in the bulk electrolyte solution. After the initial charge, Galactasol should be added to the electrolyte according to the production rate of the copper being plated in the electrowinning tankhouse. The addition rate can vary between different operations, depending on current density, application method (simple or common), and other variables unique to each electrowinning operation.

Most copper plants will test different concentrations until they find the best choice in terms of their specific results and economics. The range of concentrations in commercial practice varies between 150 and 300 grams per tonne of copper produced. Average usage in the United States and Chile is about 150 to 200 grams of Galactasol or Guarfloc per tonne of copper produced. (Guarfloc is available from Trohall (Pty) Ltd., a Henkel/Chemserve company located in the Republic of South Africa).

The chemistry of guar-based polymer smoothing agents, such as Galactasol, in electrowinning plants is not precisely known. It is generally believed that the acid in the electrolyte degrades the guar into its basic components, and it is these decomposition products that influence the surface chemistry on the cathode during copper electrodeposition. For this reason, it has been often demonstrated that testing guar usage in isolated electrowinning cells in a larger tankhouse using a common electrolyte throughout will not result in the desired effect. only full plant testing will provide successful results.

Preparation. Galactasol should be added very slowly to the aqueous solution in a tank that is well agitated to obtain proper dispersion and uniform mixing. Adding the polymer too quickly or in "handfull" quantities can result in the formation of lumps or "gumballs" which are very difficult to dissolve. The mixing speed in the tank should be sufficient to produce a pronounced vortex in the aqueous phase without including an excess of aeration in the mix. The Galactasol concentration in the mix tank should not exceed a concentration of 0.5%. Higher concentrations can result in a gelatinous lump in the mixing tank that cannot be poured or pumped. In small and mid-size electrowinning plants, Galactasol is usually added according to a schedule of 3 times per day, or once per operating shift. This will achieve uniformity in the electrolyte mixture for best results. In large electrowinning operations, continuous Galactasol addition is recommended to maintain a uniform equilibrium condition.

Simple Method. The simple method is to slowly add the Galactasol directly to the copper electrolyte recirculation tank, as illustrated in Figure 1. This can be done by hand with a simple sifter, with a mechanically vibrating sifter, (as shown in the Figure 1), or by using a feeder system in conjunction with a venturi type dispenser. The volume of the tank and the flowrate of the electrolyte from the tank should be determined in order to prevent the addition of Galactasol greater than 0.5% in the mixture. Since the application of Galactasol in electrowinning systems is based on the degradation products of the polymer rather than any inherent physical property normally associated with the use of guar-based products, (such as high viscosity), it is not necessary to pre-mix the Guarfloc in a separate preparation tank prior to use. So the Simple Method is a quite adequate procedure for Galactasol preparation in most electrowinning applications.

Common Method. Some large copper recovery plants like to use the Common Method for electrowinning applications as well, in order to supply a constant flow of Galactasol solution in an automatic feeding system. The equipment used is illustrated in Figure 2. The Galactasol is added into a bin or "feeder" which slowly feeds the Galactasol into a venturi type disperser (see Figure 3). The polymer is added to the mixing tank, after solution agitation is well established, while not exceeding a concentration of 0.5%. Cold water, or electrolyte, can be used as the aqueous media. The mixture should reach maximum viscosity within two hours. If hot water, or hot electrolyte, is used, up to 380 Centigrade, the mixture can be ready to use within one hour; or within 15 minutes at 600 Centigrade. Temperatures greater than 600 are not recommended. After the mixture has reached maximum viscosity, it is pumped to the electrolyte storage tank which is used to recirculate electrolyte in the electrowinning section of the plant.

The Common Method is usually preferred for applications in flocculation, flotation, thickening or filtration. Typical examples include solution clarification after vat or agitation leaching, as a filtration aid in rotary or horizontal belt filters, and talc depression in sulphide flotation plants. In these examples it is necessary to obtain a "sol" mixture with high viscosity before use. Further information on these specific applications is available on request. It is not recommended to store the sol mixture for more than 48 hours before usage.

Storage. Galactasol can be stored in a dry location for up to 12 months before use.

Recommended Products.

- Guarfloc 66.
- Galactasol 40H4FDS1.
- Galactasol 40H4CD (available in limited supply, by special request only).

Guarfloc is the registered trademark of Trohall (Pty) Ltd [a Henkel/Chemsolve company].

Galactasol is the registered trademark of Aqualon Company.

SIMPLIFIED  
GUAR MIXING, STORAGE,  
AND METERING SYSTEM,

WITH

VIBRATOR FEEDER

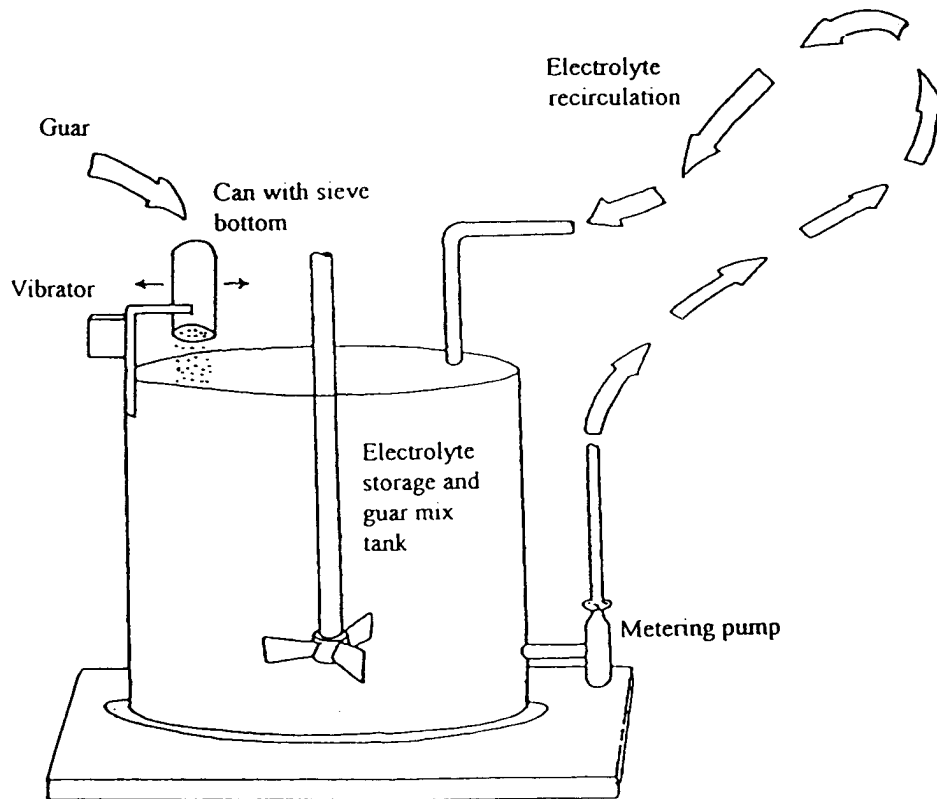


FIGURE 1

# GUAR MIXING, STORAGE, AND METERING SYSTEM

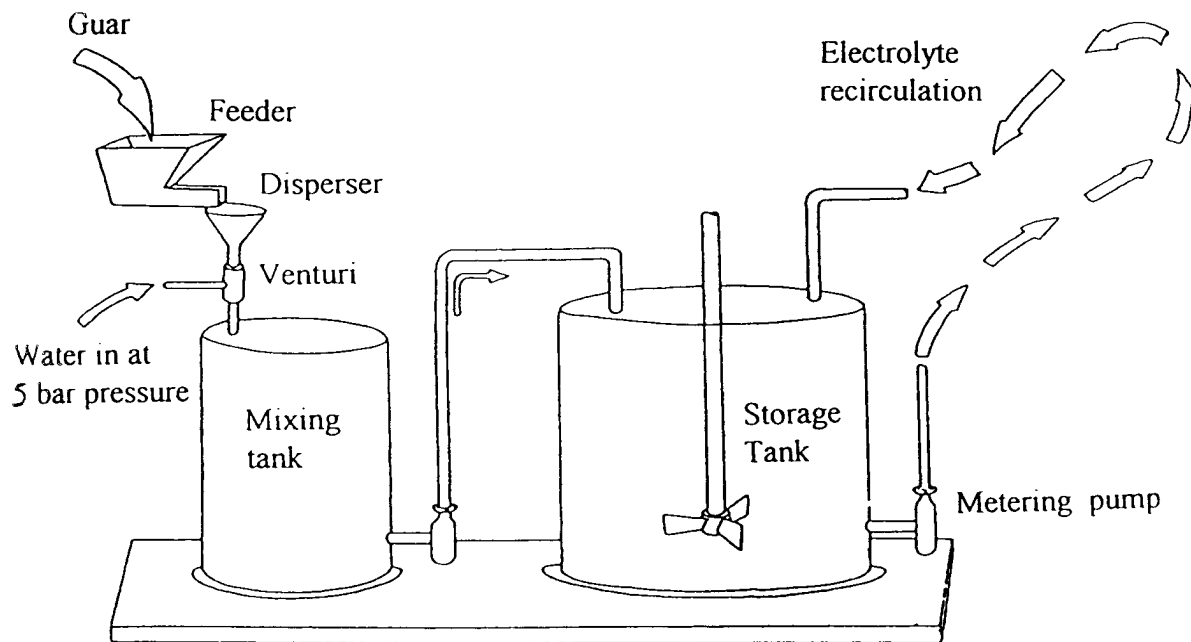
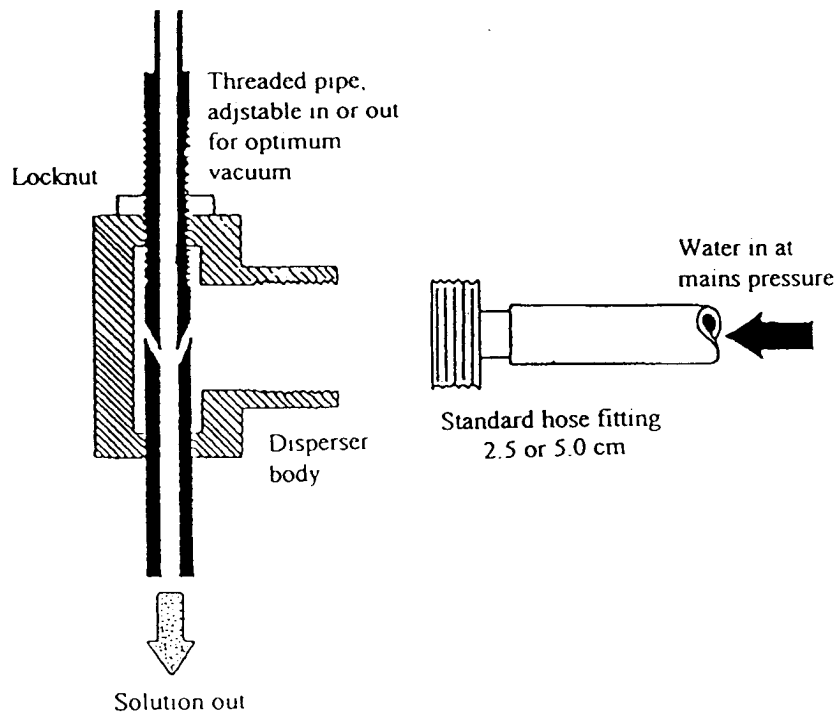


FIGURE 2

## GUAR DISPERSER VENTURI TYPE



1. The disperser requires mains water pressure to operate satisfactorily.
2. The suction is controlled by screwing the top pipe in or out. The suction is tested by holding a finger over the inlet hole. When maximum suction is obtained tighten the locknut.
3. Avoid getting moisture in the top threaded pipe as this will cause guar to block the tube.
4. Do not add Guarfloc to an empty mixing tank. Have the mixing tank containing solution, and agitating, before any Guarfloc is added.

FIGURE 3

## APPENDIX 11

### MAGMA SAN MANUEL\* LEACHING SOLVENT EXTRACTION ELECTROWINNING OPERATION

LECTURE NOTES FROM THE CIECC/HENKEL  
CORPORATION TECHNICAL CONFERENCE AT JXCC  
IN JIANGXI PROVINCE  
P.R. CHINA

Presented by

Jackson G. Jenkins  
SX-EW Superintendent  
San Manuel Mining Division  
Oxide Operations

\* Magma Copper Company is now BHP Copper Company

Ore type:             $\text{CuSiO}_3$  (Chrysocolla) at 0.45% Cu  
                       $\text{CuFeS}_2$  (Chalcopyrite) at 0.70% Cu

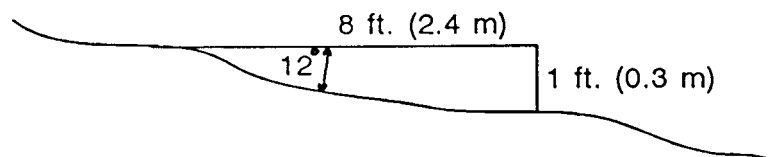
Current strip:ore ratio = 1:1.

Cut-off grade of oxide for leaching = 0.1%.

A simple drawing of the total orebody is shown in the attached illustration, including some detail of the open pit - in-situ leaching operation.

Leach pads are covered with HDPE (High Density Polyethylene) sheet over a total ground area of 10 million square feet (930,000 square meters).

**The maximum slope angle of the leach pads is 12%:**

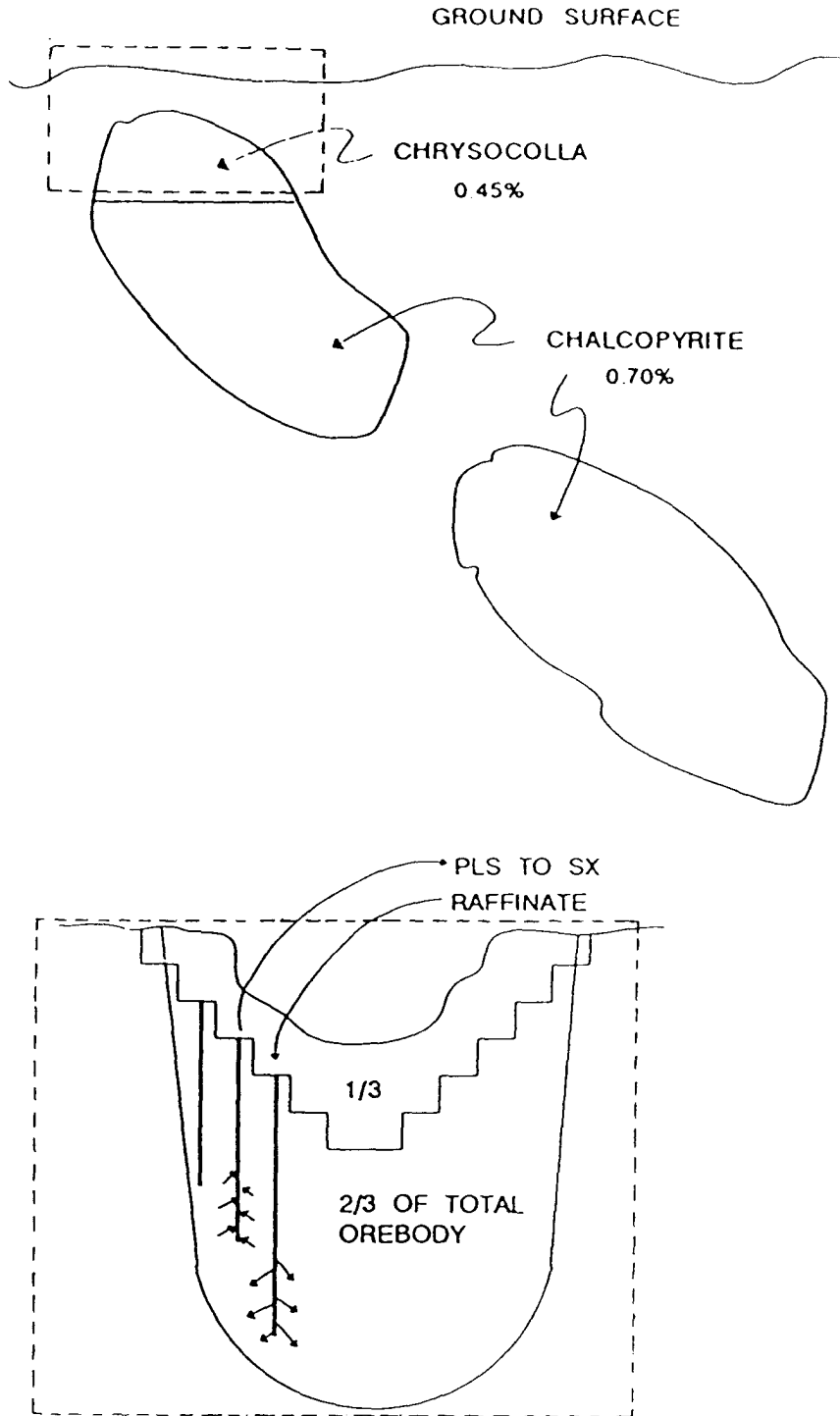


This angle is considered maximum while using a liner, to prevent a wash slide from occurring in event that the dump might get too saturated and become physically unstable. (In January and February of 1993 there was 12 inches (30.5 centimeters) of rainfall, creating an excess of 30 million gallons (113,550 M3) of water, most of which was retained in the leach dumps].

After the HDPE liner was layed down on the prepared ground surface, an 18 inch (46 centimeter) layer of sand was placed on top to protect the liner. Next, 10 inch (25.4 centimeter) diameter perforated HDPE pipe was layed on the sand where the leach solution would migrate and exit to the foot of the dump. (HDPE lasts longer than PVC) . The perforated pipe was protected by 3 inch (7.6 centimeter) diameter rock. The rock also helped prevent fine solids material from plugging the pipe perforations when covered with ore.

**HEAP LEACHING:** Two years ago (1992), when Magma San Manuel constructed 15 foot (4.6 meters) heaps, they began acid-curing pretreatment of the leach dumps. Concentrated acid was added to a portion of the raffinate to produce a solution containing about 250 grams/liter of  $\text{H}_2\text{SO}_4$ , and this was distributed on the leach pads at 15 pounds (6.8 kilograms) of acid per ton of ore. After distribution on the heaps for a period of 8 hours, the heap was allowed to "rest" for 4 days. Then more of this solution was added for another 8 hours and allowed to rest again for 3 days. This wetting allowed the heap to get saturated, but not enough to allow any solution to pass through the heap. Then raffinate was used for leaching, without any additional acid to the raffinate or on the heaps, for a leach cycle period of 45 to 60 days.

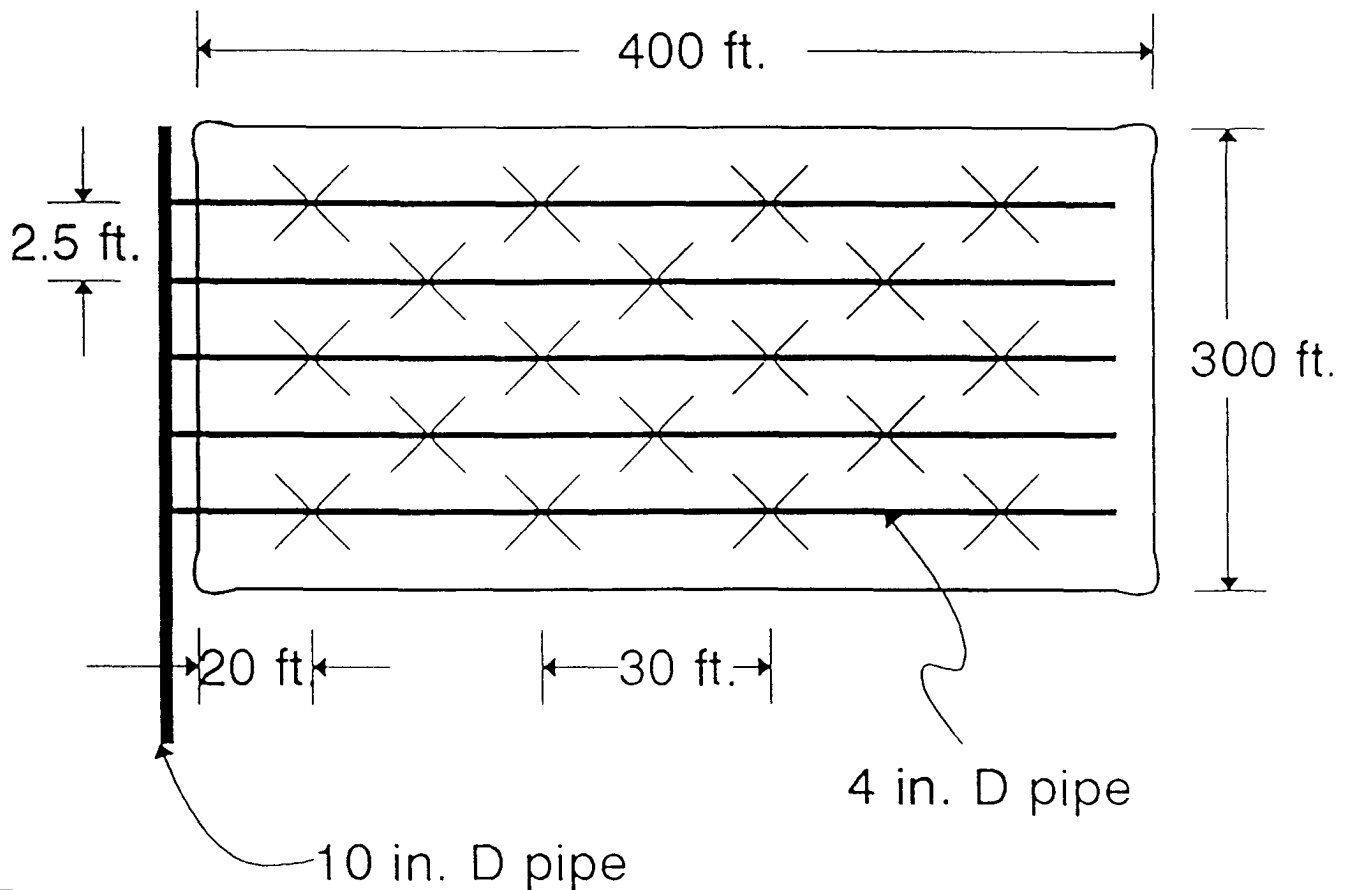
# MAGMA SAN MANUEL OREBODY



Now Magma constructs 10 foot (3.0 meter) heaps, ripping to a depth of 6 feet (1.8 meters) between the distribution pipes after the acid-cure cycles, because the strong acid-cure and the surface fines tend to create a "crust" on the surface which inhibits effective distribution and penetration of the raffinate during the leach cycle. Acid-curing, ripping, decreasing the depth of the heaps from 15 feet (4.6 meters) to 10 feet (3.0 meters), and reducing the leach cycles from 45 - 60 days to 30 - 45 days have together resulted in a 5% increase in copper recovery from the dumps.

More recently, Magma San Manuel began using a special surfactant (wetting agent) with the leach solution. This changes the surface tension of the raffinate from 73 dynes/centimeter to 15 dynes/centimeter. This allows the raffinate to flow into the heaps easier, the raffinate penetrates the cracks and pores of the ore better, and results in another 5% increase in copper recovery from the heaps. The fluorochemical surfactant, Fluorad

## MAGMA SAN MANUEL HEAP LEACH PIPING DISTRIBUTION



FC-1129 of 3M Specialty Chemicals Company, is added to the raffinate pretreatment tank. This is a cationic surfactant (Magma would prefer nonionic). Also, the acid in the acid-cure system has been increased to 300 grams/liter  $H_2SO_4$  and added to the heaps at 30 lbs (13.6 kilograms) per ton of ore. The greater acid

concentration with the wetting agent has resulted in another 5% increase in copper recovery from the heaps, for a total copper recovery from heap leaching reported at 85% (EM&J, Dec., '93, pg 31).

Distribution rate of the leach solution on the heaps at Magma is 0.008 GPM/ft<sup>2</sup> (0.020 m<sup>3</sup> /hour /m<sup>2</sup>), which is greater than the industry average of 0.003 GPM/ ft<sup>2</sup> (0.007 m<sup>3</sup> /hour/m<sup>2</sup>). San Manuel finds their heaps to be very permeable, but the higher flow rate does not result in a relatively lower copper tenor in the PLS as some people might speculate. The distribution pipes are laid out according to the illustration. Final solution distribution on the heaps is with "Wobblers" with 20 millimeter diameter orifices. (Smaller orifices would reduce the solution distribution rate but would still maintain the same coverage on the heaps.).

**IN-SITU LEACHING:** At the present time (1993 - 1994) about 80% of the copper production comes from heap leaching and 20% comes from in-situ leaching. Open pit mining and hauling of ore will cease in 1995, and the remaining oxide copper will all be leached by in-situ leaching.

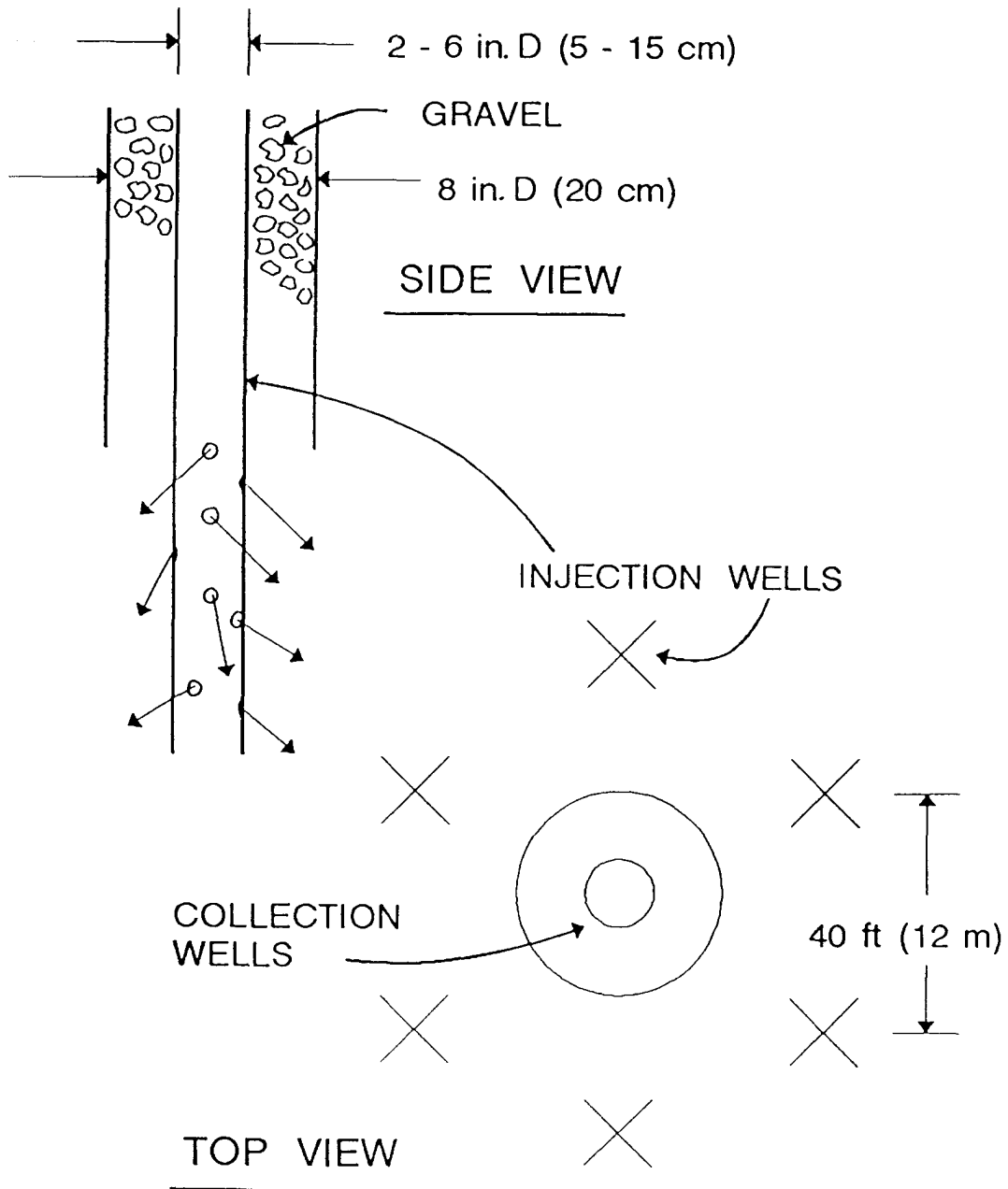
Injection wells 8 inches (20.3 centimeters) in diameter are drilled into the open pit mine. The piping into the wells are PVC pipe inside a steel casing. Some of the wells penetrate down as much as 1,500 feet (457 meters). The PVC pipe is perforated where they want the raffinate to be injected into the caved-in orebody. For every 6 injection wells Magma has one collection well, as shown in the illustration. Injection is done by gravity only, no pressure. Each collection well contains a submersible pump which brings the PLS up to the site elevation and onward to the PLS collection pond. Some of the in-situ PLS is collected in the old underground areas and pumped to the surface elevation.

Monitor wells are placed around the perimeter of the in-situ leach area, using a "piezometer" to detect wetness for flow away from the leach area. Piezometers are also used to detect solution elevations in the injection wells.

**SOLVENT EXTRACTION:** In 1986 Magma San Manuel had only two SX trains, while all the copper was recovered from the heap leach operations. It took about 2 years for the in-situ area to be saturated in order for the leach solution to be returned to the surface. Then in 1988 two more SX trains were added to the plant, for a total of four circuits in parallel. They also increased the size of the "tank farm" and the EW tankhouse. The new circuits did not have settler covers in the beginning. But later covers were added due to concerns about high evaporation losses of the kerosene diluent, loss of organic by high winds blowing across the settlers, accumulation of windblown dust in the circuits, and crud "runaways" caused by heavy monsoon rains which can affect the elevation of the organic-aqueous interface.

The total PLS flowrate to SX is 18,000 GPM (4088 m<sup>3</sup> /hour/ m<sup>2</sup> ) at a temperature of about 70 degrees F (21 degrees C). The PLS contains about 2 g/l Cu and 10 - 15 ppm solids at pH of about 1.8. The extractant used at Magma is 7 vol% LIX® 984.

# MAGMA IN-SITU INJECTION AND COLLECTION SYSTEM



Most SX plants have routine analytical testing to be sure that the chemistry and the plant operation is in equilibrium and operating correctly. In addition, Magma has two additional tests that they do to be certain that the organic performs within plant specifications. These two tests include surface tension measurements (with an interfacial tensionometer [dynamometer]). Typically the organic has an interfacial tension reading of 25 dynes/cm.

The second test is a phase separation test using 350 ml of plant PLS and 350 ml of maximum loaded plant organic. They mix the two phases organic continuous for 3 minutes. Normal phase separation is about 45 seconds. To be certain that the organic does stay within operating specifications they bleed a fraction of the organic from the SX circuit daily and treat it with activated clay to remove the polar organic compounds that might be present. These compounds can accumulate in the organic, coming from vegetation that might get leached, from the degradation products of the extractant and/or the diluent, and other possible minor sources. The clay which is used is an acid washed and hydrogen activated montmorillonite clay  $[\text{Si}_8(\text{Al}_{3.34}\text{Mg}_{0.66})\text{O}_2 \cdot (\text{OH}_4) \cdot 0.66\text{Na}]$ . The circuit organic is treated batchwise in a 300 gallon (1,136 liter) tank into which is added 400 pounds (181 kilograms) of clay. The slurry is mixed for 15 minutes. After mixing the slurry is pumped to the filter press to coat the filters. After the filter is coated the organic from the SX circuit is pumped into the filter. The organic flowrate into the filter is 50 GPM ( $11.4 \text{ m}^3/\text{hour}$ ). Each precoat is used for about 15 hours, or when the flowrate gets down to about 5 GPM ( $1.14 \text{ m}^3/\text{hour}$ ), which represents about 50,000 gallons ( $190 \text{ m}^3$ ) of circuit organic treated per precoat.

After 4 years of operation at San Manuel, prior to clay treatment, the organic had accumulated enough contaminants to slow down the phase separation to about 2 minutes. After the clay treatment campaign was initiated, and all of the plant organic was treated (taking about 2 weeks), the phase separation returned to 45 seconds. Total solvent losses at San Manuel are about 40 ppm (parts per million), measured by inventory make-up to the circuit. About 70% of that loss is lost in the raffinate, and 30% is lost to the electrolyte, due to the small specific gravity difference between the organic and the aqueous phases.

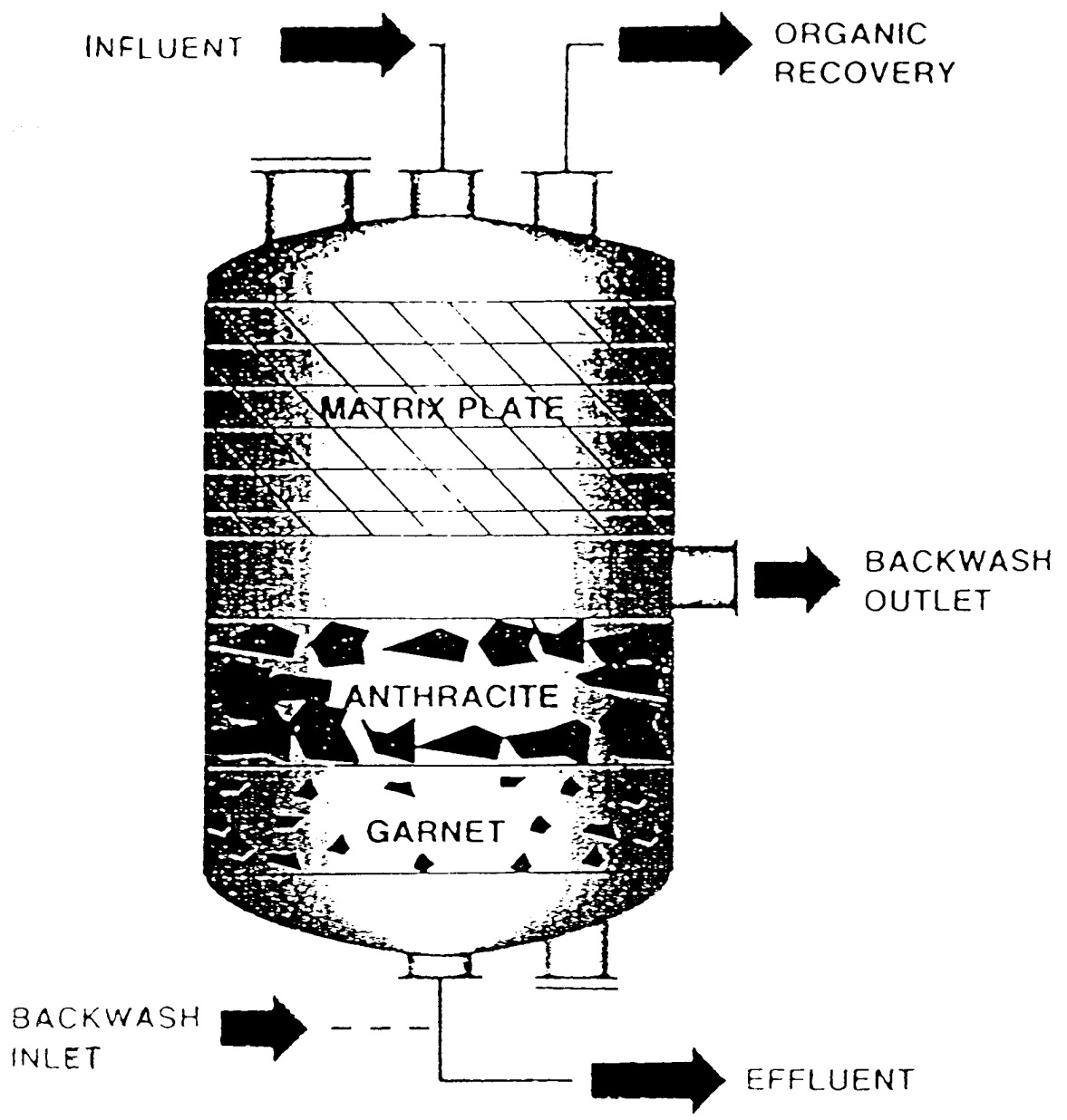
The organic from the SX circuit gets the clay treatment with an equivalent of about 2 grams of clay per liter of organic. Organic recovered from the raffinate pond and the organic from the crud treatment equipment requires about 50 grams of clay per liter of organic.

Magma has two centrifuges at the site for crud treatment for recovering organic. They are seldom used however due to the high frequency of breakdown and high maintenance cost and poor recovery (about 60% organic recovery). Magma has developed cheaper and more efficient methods of organic recovery from SX crud.

After solvent extraction at Magma San Manuel the pregnant electrolyte is sent to two Air Scrubbers of their own design, as illustrated, at a total flowrate of 2500 GPM ( $568 \text{ m}^3/\text{hour}$ ). The P.E. flows to the scrubbers by gravity to avoid further shearing of the entrained organic from the SX circuit. As the P.E. is put into the top of the scrubber, air is injected into a coil at the bottom of the scrubber using a sprinkler type perforated garden hose. The air collects the entrained organic and flows it to the surface where it is collected and returned to the SX circuit. It employs a level sensor and automatic valve for automatic discharge of the organic at the top on a 20 minute cycle. These scrubbers remove about 50 to 60% of the entrained organic from the electrolyte.

From the Magma Air Scrubbers the P.E. next goes to some "sand filters" similar to those in the illustration. Silica sand is not actually used because it can be dissolved by the acidic electrolyte and the dissolved silica can form long chain polymers which will have seriously adverse effects in the solvent extraction circuit, particularly if a polyacrylamide type product is used for smoothing in the electrowinning tankhouse. To avoid this problem the filters use two types of media: garnet and charcoal. The surface behavior of the garnet allows the coalescence of the fine organic droplets to occur while also trapping most of the solids (crud) that enter the filter

from SX. The charcoal can also absorb entrained and/or dissolved organic until it reaches saturation. The filters have a backwash feature so that crud entering the filters from the SX circuit can be removed daily. Many SX plants have automated filter systems for programmed cyclic backwashing. Magma uses filters supplied by Disep. The filter in the illustration is made by SpinTek.



Each column and filter receives approximately 600 GPM (136 m<sup>3</sup> /hour) flowrate of electrolyte. Magma has four air scrubbers in service at San Manuel.

**ELECTROWINNING:** The flowsheet of electrolyte from the filters to the tankhouse is shown in the attached illustration.

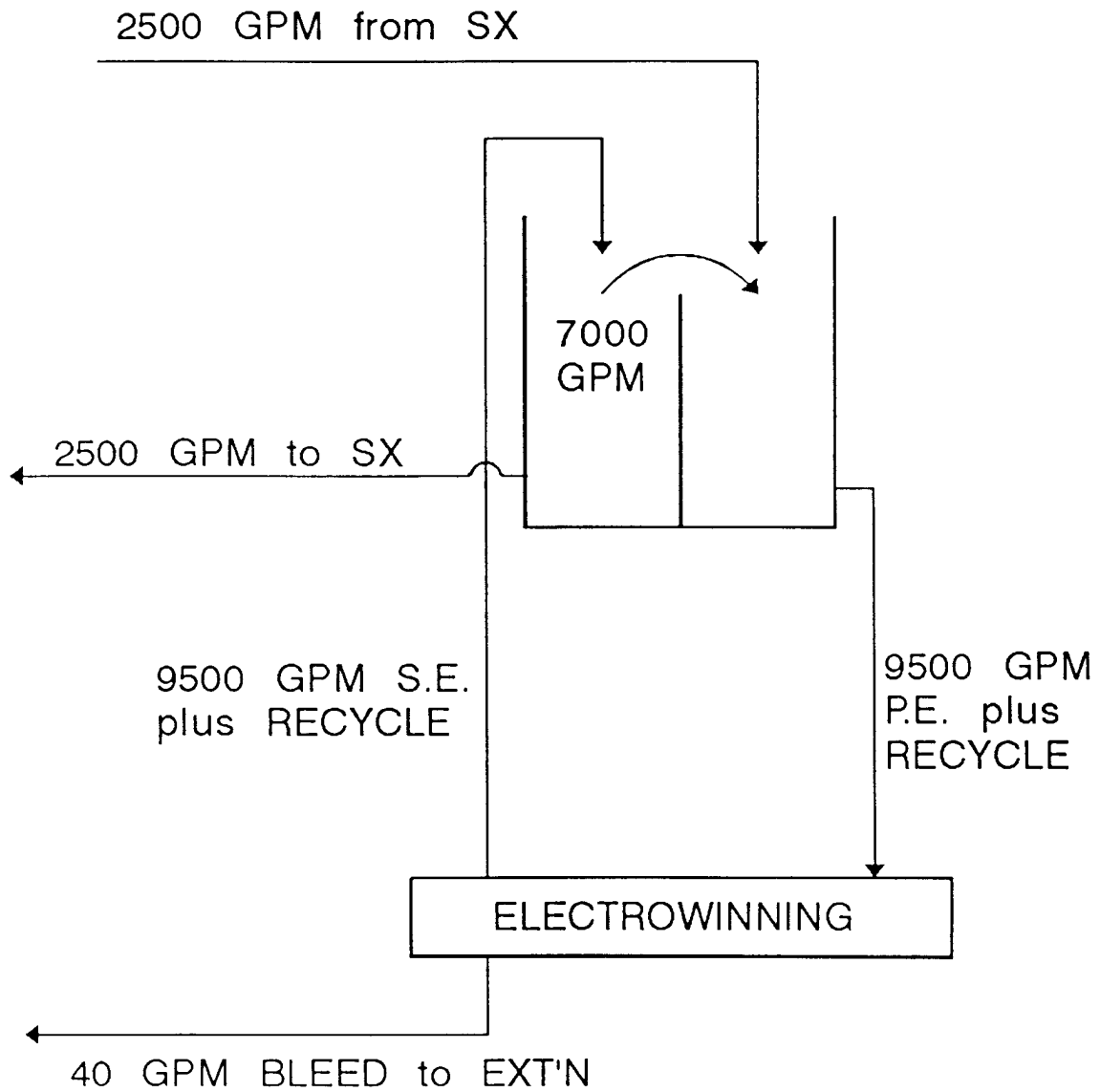
The Magma San Manuel EW tankhouse has 188 cells, each containing 60 stainless steel plates and 61 anodes. Magma uses MIM licensed technology in their tankhouse so no equipment is needed to produce and handle starter sheets and starter sheet production. The plating cycle is 7 days and they pull one-third of the cell on each "pull". Current density is about 25 amps/ ft<sup>2</sup> (269 amperes/meter<sup>2</sup>) although they did operate for about one year at 32 amps/ ft<sup>2</sup> (344 amps /m<sup>2</sup>). Current efficiency is about 93%.

The starter plates have CPVC (high temperature PVC) strips on the side edges. The anodes are made of Pb-Ca-Sn, with anode to anode spacing of 3.75 inches (9.5 centimeters) . Originally they used CPVC "hairpins" on the anodes to prevent electrode short-circuiting, but now use "buttons" on the corners instead.

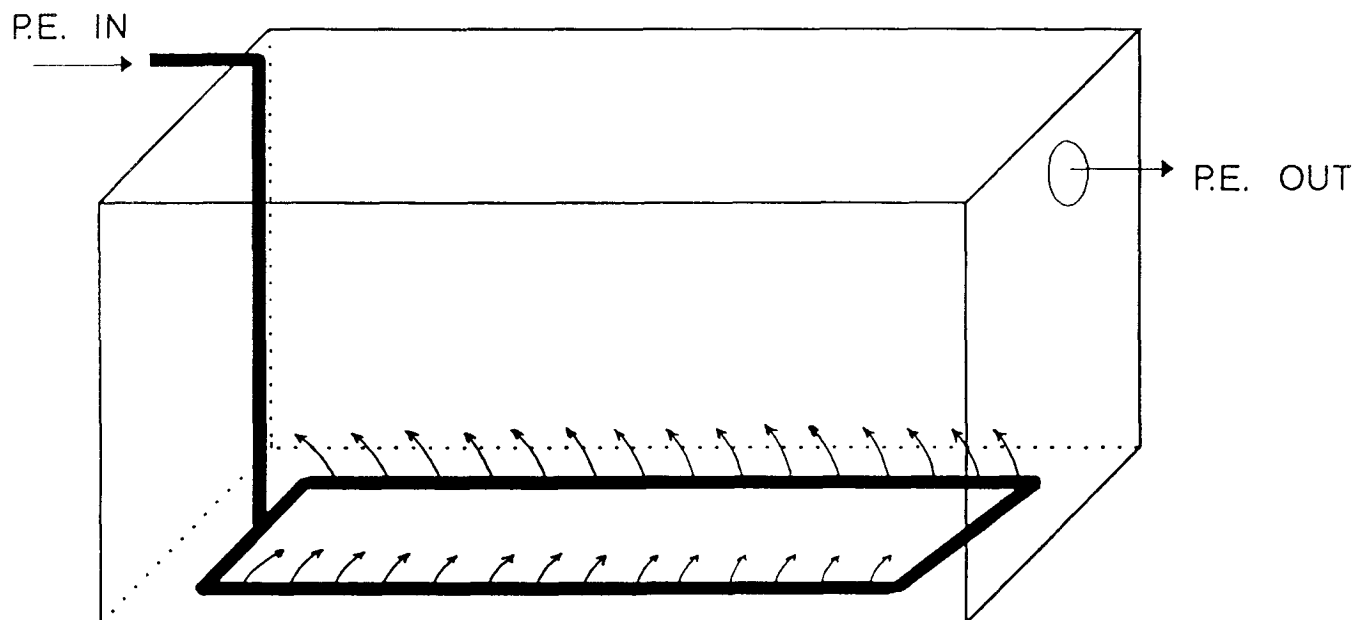
Each EW cell has a Magma designed manifold, as shown in the illustration, for improved solution distribution. The manifolds are made of 2 inch (5.1 centimeter) PVC pipe, and each manifold has 60 distribution holes (30 on each side) placed at 45 degrees from vertical, as shown in the illustration. The distance between the bottom of the plates and the bottom of the cell is 6 inches (15.2 cm). Each cell is cleaned every two months, at which time an average of 25 kg of wet sludge is removed.

In the MIM copper harvesting section of the tankhouse, the finished cathodes are washed with hot water to wash off the copper sulfate solution and to melt the wax from the bottom edge of the plate. The cathodes proceed on a conveyer to the stripper section where the sheets are flexed about 2 inches (5.1 cm) in two directions to break the copper from the steel plate. A knife edge is then inserted and the copper plates drop into a stacking pile and conveyer Below. The clean steel plates are then redipped in hot wax and conveyed to the waiting area for replacement back into the EW cells.

# MAGMA ELECTROLYTE RECIRCULATION FLOWSHEET



## MAGMA P.E. SOLUTION DISTRIBUTION SYSTEM



The electrolyte is heated to a temperature of 115 degrees F (46 degrees C). Cobalt as a sulfate is added to the electrolyte to achieve a concentration of 100 ppm (most plants now use up to 150 ppm), to reduce Pb flaking and cathode contamination. The pregnant electrolyte also contains about 50 g/l Cu, 160 g/l H<sub>2</sub>SO<sub>4</sub>, 1.5 g/l Fe or less, and less than 50 ppm Mn. Galactasol guar is added to the electrolyte as a smoothing agent at about 50 pounds per 110 tons of copper plated (23 kg/100 tonnes). At higher current densities they add Galactasol at a rate of 100 pounds per 150 tons (33 kg/100 tonnes).

Electrolyte flow into each cell is 50 GPM (11.4 m<sup>3</sup> /hour) resulting in a flow distribution in each cell at 0.047 gallons/minute/ ft<sup>2</sup> (0.115 m<sup>3</sup> /hour / m<sup>2</sup>). They would prefer a higher rate, if possible. The tankhouse bleed is 40 GPM (9.1 m<sup>3</sup> /hour /m<sup>2</sup>) , which is about 0.2% of the PLS flowrate.

The Spent Electrolyte returning to SX contains about 40 g/l Cu.

**COSTS:** Magma Copper Company has both L-SX-EW recovery of copper from their oxide ore, and flotation-smelting-refining of their sulphide ore. A comparison of their operating costs are as follows:

Hydrometallurgy

Mining.....\$0.30/lb Cu  
Leaching..... 0.04  
SX..... 0.03  
EW.....0.07  
TOTAL.....\$0.44/lb Cu

TOTAL.....\$0.97/kg Cu

Pyrometallurgy

Mining.....\$0.30/lb Cu  
Milling..... 0.22  
Smelting..... 0.15  
Refining.....0.03  
TOTAL.....\$0.70

Optional

Crushing.....0.03  
TOTAL.....\$0.73/lb Cu

TOTAL.....\$1.61/kg Cu

## GLOSSARY OF TERMS

Aq - Aqueous

Aqueous Organic Weir - Similar to the above, usually including the capability of being adjusted in elevation for purposes of changing the elevation of the aqueous organic interface in the settler.

Double Phasing - A condition of an emulsion in an SX mixer where a droplet of one phase is enclosed in a droplet of the other phase, which is suspended in a continuous phase. An example is where an aqueous droplet is enclosed in an organic droplet, which exists in an aqueous continuous phase. In another example, one might find an air bubble inside an organic droplet which exists in an aqueous continuous phase. Both cases are evident by the appearance of large white droplets, that look something like fish eyes, found at the discharge of the mixer. In both cases, phase separation is very slow relative to the design capacity of the settler, and double phasing can be a major source of entrainment transfer.

Eddy Current - A current of liquid which flows contrary to the main current. Eddy currents can be a source of entrainment transfer when the depth of the organic phase in the settler is too thin, or when the ratio of the organic depth to the aqueous depth in the settler differs significantly while mixing at a 1:1 phase ratio. The eddy currents discourage coalescence of secondary emulsion, and in extreme cases can cause the formation of a secondary emulsion (haze) in the settler, resulting in entrainment loss.

Entrainment - The presence and transfer of a secondary emulsion of one (minor) immiscible liquid phase (which tends to defy coalescence) in another (major) liquid phase, as they exit an SX mixer-settler.

Equilibrium - The point where ion exchange is complete according to the chemical conditions that prevail in the organic and aqueous phases after contact (mixing).

Extraction Stage - An extraction mixer-settler.

Impeller - The turbine used for pumping the liquid phases into the mixer and, by controlled mixing conditions, maintaining the correct qualities of an emulsion in the mixer.

Kinetics - The rate of reaction in which to reach equilibrium.

L.O. - Loaded organic: The organic phase loaded with copper, proceeding to the stripping section of the SX circuit from E1 (Extraction stage number 1).

M.L. - Maximum Loading.

Mixer-settlers - The equipment used in the solvent extraction process, comprising a mixing section (one or more mixers in series) and a settling section where the two immiscible phases are allowed to separate after mixing.

Net Copper Transfer - The arithmetic difference between the L.O. and the S.O.

Org - Organic

Organic Overflow Weir - The section of the settler where the organic overflows into a trough and is allowed to exit the mixer-settler.

P.E. - Pregnant Electrolyte: The acid stripping aqueous, rich in copper, leaving the SX strip circuit and proceeding to the electrowinning section of the recovery process.

PLS - Pregnant Leach Solution.

PLS Maximum Loading - The maximum amount of copper that can be extracted by a determined quantity of LIX Reagent, in a kerosene diluent, when contacted with PLS solution.

Ppm - Parts Per Million. In SX plants, this term usually refers to liters per 1000 liters, and often refers to entrainment losses.

Primary Emulsion - The relatively coarse aqueous organic droplets that are produced in the mixer, and which readily coalesce in the settler after mixing.

Raffinate - The leach solution leaving the SX circuit after the copper has been extracted.

S.E. - Spent Electrolyte: The acid stripping aqueous, relatively lean in copper concentration, leaving the Electrowinning plant and returning to the stripping section of the SX circuit.

S.O. - Stripped organic: The organic phase, lean in copper values, proceeding to the extraction section (E<sub>2</sub> in a two stage extraction circuit) from the stripping section of the SX circuit.

SX - Short form for "Solvent Extraction".

Secondary Emulsion, or Haze - The relatively fine droplets of organic or aqueous, nearly colloidal in suspension, that resist coalescence and exit the mixer-settlers as entrainment.

Stage - Another term for mixer-settler.

Standard Maximum Loading - The maximum amount of copper that can be extracted by a determined quantity of LIX Reagent, in a kerosene diluent, when contacted with a "Standard Aqueous Solution" prepared in the laboratory.

Starter Blank - A cathode made of stainless steel or titanium on which copper starter sheets are produced in an electrowinning operation.

Starter Sheet - The thin copper sheet that is plated onto the starter blank, which is then returned to the electrowinning cell for further copper electrolysis.

Strip Stage or Stripping Stage - A stripping mixer-settler.

Surge Tank - A storage tank placed between mixer-settler stages to contain inventory of a liquid and from which to pump liquid back into the circuit. The term usually refers to the storage of organic in an SX circuit, and most commonly used to contain loaded organic.

Surging - The non-uniform flow rate of liquids in an SX circuit, usually caused by improper design, improper operation, and/or water locks or air locks in the piping system between SX stages. One major result of surging is an extreme wave motion occurring at the organic -aqueous interface in a settler. The wave motion can inhibit the efficient coalescence of the phases in the settler, and in extreme cases can cause the formation of secondary emulsion (haze) in the settler.

Tankhouse - A term meaning an electrowinning plant and all equipment involved in the electrowinning process.

Transfer Capacity - The maximum quantity of copper that can be transferred between the stripped organic and the loaded organic in the SX circuit.