THE UNIVERSITY OF ZAMBIA

SCHOOL OF MINES

DEPARTMENT OF METALLURGY AND MINERAL PROCESSING

PROJECT REPORT 2008

SUBMITTED IN PARTIAL Fulfilment FOR THE BACHELOR OF

MINERAL SCIENCE

(B.MIN.SC)

OPTIMIZATION OF THE SOLVENT EXTRACTION WITH THE

AID OF THE

ISOCALC SOFTWARE

AUTHOR: MASAPI JUSTIN
EXAMINERS

HEAD OF DEPARTMENT:  
MR. C. V. LUNGU

INTERNAL EXAMINER:  
MR. C. V. LUNGU

EXTERNAL EXAMINER:  
PROF. D. J. SIMBI
ACKNOWLEDGEMENTS

I would like to register my appreciation to Mr. Pyokera Kawonga who was my supervisor at Kansanshi process plant, Mr. Edward Chisunka, Mr. Frederick Wouters, Mr. Ben Daka and Mr. Reoecardo Mumba for making it possible for me to do the project at the Mine.

I would also like to extend my gratitude to Mr. Gift Chisakuta and the cognis group for providing the software to enable me to do the analysis concerning the project.

With deep indebtedness to Mr. C.V. Lungu, my supervisor, for having tirelessly read through my report word by word and assisted me with the technical aspect and presentation format of this report.
Abbreviations

SX = Solvent extraction
GPL = grams per litre
PLS = pregnant leach solution
ML = milliliter
PPM = parts per million
RAFF = raffinate
LO = loaded organic
SO = stripped organic
NT = net transfer
E1 = extraction stage 1
W1 = wash/scrubbing stage 1
S1 = strip stage 1
PDT = phase disengagement time
CCD = counter current decantation
O/A = organic to aqueous (ratio)
UV = ultra violet
AAS = Atomic Absorption Spectrometer
EW = Electrowining
ABSTRACT

Leaching of sulphide minerals has never been successful under atmospheric conditions. Process plants that attempt to treat sulphides via the hydro metallurgical route can either pre-treat the sulphides which include roasting, to decompose to leachable oxide or leach under high pressure in the Autoclaves. In this project, the high pressure leaching was utilized. As the result of that it was projected that more acid would result in the pregnant solution, higher temperature and above all the copper tenor was also expected to improve. To quickly determine the effects of changing these operating parameters, the isocalc software was used. Preliminary testworks were done to have an overview of the plant operating conditions and also make it possible to run the software.

The pH was varied to see how it affects the SX performance, organic strength, temperature and also the organic to aqueous flowrates were varied to counter the effects of improved copper grades without changing the staging. In this project it was established that, at a stabilized copper grade of 4.5gpl Cu in the pregnant solution, the optimum pH of 2 was arrived at, O/A flowrates of 1.7, and the organic strength of 27 v/v% gave the best results in that the recoveries were high. These also gave minimal copper losses in the raffinate. It was also observed that increasing the aqueous flows while keeping the organic flowrates constant resulted in high copper losses in the raffinate and the converse reduced the losses. The optimized parameters were entered into the program and gave a good result in the advance solution of 50gpl copper. This is higher than the average 43-45 gpl Cu.
CHAPTER ONE

1.0 INTRODUCTION

1.1 Brief History of the Plant
Mining operations at Kansanshi begun in 2005. Due to the difficulty of leaching the sulphide material, the process plant could only leach the oxide material, while the sulphide ore was sold as a concentrate to other mining industries that had smelters. In an effort to increase production, investigations were carried out to find out the best method of leaching the sulphide material. Due to environmental considerations and high operational costs of smelting, the investigation team recommended that the material be treated using the high pressure leaching method.

The process consists of the following stages;

i. Material reclamation from the sulphide concentrate stock pile

ii. High pressure leaching at the autoclaves

iii. Leaching at the oxide leach tanks

iv. Solid-liquid separation at the CCDs

v. Clarification at the clarifiers

vi. Solvent extraction

vii. Electrowining at the tank house.
1.2 General Arrangement of the Kansanshi Solvent Extraction (SX) Trains

1.2.1 Solvent Extraction (SX1) Train – High Grade
The SX1 train treats high grade pregnant leach solution (pls) from the high grade pregnant leach solution pond. This contains between 3.5 - 4.5 grammes per litre (gpl) copper. It has two extraction stages (in series or countercurrent connection), one wash or scrubbing stage and one strip stage.

![Diagram of SX1 profile]

Figure 1: SX 1 profile

1.2.2 Solvent Extraction (SX2) Train – Low Grade
The low grade solvent extraction treats low grade pregnant leach solution from the low grade pregnant leach solution pond. This usually contains between 2 - 3 gpl copper. It has three extraction stages (2 series and 1 parallel) and one strip stage.

![Diagram of SX2 profile]

Figure 2: SX 2 profile
1.2.3 Solvent Extraction (SX3) Train – High Grade (New)

The SX3 also called the new SX or High Grade 3 treats high grade pregnant leach solution like the one described under SX1. It has two countercurrent extraction stages and two strip stages. The profile is as shown below;

![Diagram](image)

Figure 3: SX 3 profile

The advance solution from the new SX goes for final product recovery at the new Tankhouse. The introduction of pressure leaching meant that the solution composition would change in terms of the following:

(i) The Copper tenor would improve
(ii) The temperature of the leach solution would increase
(iii) The feed capacity to the SX plant would also increase and
(iv) The acid content would equally increase

The introduction of high pressure leaching at Kansanshi invited a lot of research to determine whether the Solvent Extraction Plant would cope with the extra tonnage of solution and whether there was need to change the staging or simply make the necessary adjustments. The situation prompted management to introduce the Isocalc Software.
1.3 Overview of the Isocalc Software

The ISO-CALC is a computer simulation program which has been developed as a tool to provide researchers and plant operators with fast and accurate simulations of any copper solvent extraction process involving sulphuric acid leaching followed by extraction with a chelating type extractant. An example of a chelating type extractant is LI X 984N, which is used at the Kansanshi Solvent Extraction Plant. The software is currently the most advanced and flexible and widely available computer model of solvent extraction performance.

The program can be used in several ways such as the following indicated;

- It can be used to generate extraction isotherms for dilute sulphuric acid copper leach solutions in combination with a number of LI X reagents. These isotherms can then be used to construct the McCabe Thiele diagrams for the system under study in a range of mixer settler arrangements.

- A second way isocalc can be used is to enter isotherm data for any reagent and copper leach solutions into the programme. Strip isotherms can also be entered into the programme. This tool is important for plants that are either looking at changing the staging or looking at change in the copper content of the leach solution.

- A third way isocalc can be used is to insert actual plant operating data into the program. The program will then calculate the stage efficiency or mixer efficiency.

In the optimization of the solvent extraction, various operating parameters are considered. These are pH, temperature, organic strength, settler retention time, concentration of metal ions in the raffinate, the organic to aqueous flowrates and the concentration of the pregnant solution.

In the development of the programme laboratory experiments were done to simulate actual plant performance. All the data displayed by this program is based on the reactions
in the solvent extraction. The results are displayed in a summarized form of the McCabe Thiele diagrams and point calculations.

The programme can be used to analyse the effects of varying the operating parameters. It can also be used to design a new plant with the aid of Metcalc II programme. In the case where the plant has been designed and constructed, meaning that the number of stage is fixed, changes in the pregnant solution can be compensated by manipulating the operating parameters and the fastest way to do that is by utilizing the software. Some of the reactions that have been simulated into the programme are as follows;

i. \[2RH + Cu^{2+} \rightarrow R_2Cu + 2H^+\] ........................................... 1

As the pH is decreased, (increasing H\(^{+}\) ions ) metal extraction will decrease since the equilibrium will be shifted towards the left. Conversely, as the pH increases, metal extraction will increase. Isocalc optimizes the pH by utilizing the in built iterations.

ii. For improved solution grade, Isocalc has in built McCabe Thiele diagrams which minimize the copper losses in the raffinate.

iii. To optimise the organic strength, the following equation is utilized;

\[N.T = \frac{LO - SO}{V/V\%}\] ........................................... 2

Where \(N.T\) = net transfer, 
\(LO\) = loaded organic, 
\(SO\) = stripped organic and 
\(V/V\%\) = organic strength
The maximum copper loading capacity for LIX 984N is 0.53 gpl copper per V/V %. Therefore 0.265 gpl copper is used as reference value per molecule according to the balanced extraction equation. Net transfer gives the information about the reagent concentration.

1.4 Objective

The objective of the project was to apply isocalc software to simulate the solvent extraction of copper using plant determined data and to optimize the operating parameters namely: pH, O/A flowrates organic concentration and temperature.
CHAPTER TWO

2.0 LITERATURE SURVEY

2.1.0 Solvent Extraction
Solvent extraction is a concentrating process used to selectively remove or extract a metal species from one solution into another. This can be applied either to the removal of a valuable component from contaminants or to the removal of contaminants from a valuable component. The solution originally containing the desired species and the solution into which these species or the contaminants are to be extracted must be immiscible to effect separation.

In metal recovery operations, the valuable component is normally a metal ion contained in an aqueous solution. This aqueous solution is mixed with an immiscible organic phase containing the active extractant at which time the active extractant transfers the desired metal from an aqueous phase into the organic phase.

2.1.1 The Chemistry of Extraction
Copper extractants extract copper and other metal cations by a chelating mechanism. Chelation refers to a ‘claw’ which is a graphic description of the way the extractant chemically bonds the metal ion. The balanced chemical equation for extraction of 2+ metals is shown below:

\[ [2RH]_{org} + [M^{2+}SO_4]_{aq} \Leftrightarrow [R_2M] + [2H^+ + SO_4] \]

From the above equation, it can be noted that for the extraction of one gramme of copper 1.54 grammes of sulphuric acid is produced. This is why there is a high acid content in the raffinate which can be recycled to the leach tanks. In plant environments, the conditions that increase copper extraction are:

- Increasing the pregnant leach solution flow
- Increasing the organic flow
- Increasing the pregnant leach solution copper concentration
- Decreasing the pregnant leach solution acid concentration

2.1.2 Stripping Chemistry
The stripping stage of the solvent extraction of copper can be represented by:

$$R_2Cu + 2H^+ \rightleftharpoons 2RH + Cu^{2+} \ldots \ldots 4$$

Stripping of copper is where a strongly acidic solution (spent electrolyte at 180 gpl acid) is mixed with the loaded organic containing the LIAX-Copper complex. The copper extractant releases its copper and takes on acid so that the level of copper in the aqueous solution (electrolyte) increases and the acid level decreases as copper transfers out of the organic phase and is replaced by acid.

The stripping reaction chemistry is similar to the extraction reaction except that the stripping reaction is in the opposite direction to the extraction reaction. Because of the nature of this reaction, the amount of copper stripped increases as the amount of copper in the loaded organic and the amount of acid in the electrolyte increases. Conversely, as the amount of copper present in the spent electrolyte increases, the amount of copper stripped decreases.

The stripping section fulfills the final criteria for solvent extraction which is upgrading as it allows the copper concentration in electrolyte to be increased up to 50 gpl. As the loaded organic only contains copper then this resulting solution is very pure and ideal for electrowinning.

2.1.3 Scrubbing
Scrubbing refers to the removal of unwanted co-extracted species in the loaded solvent from the extraction stage of the process. The specificity of an extractant depends on many factors, including pH, metal and extractant concentration. No extractant is entirely specific for one metal, hence co-extraction of other metals will occur to some extent. Co-extraction may be physical or chemical in nature. For example, entrainment of
aqueous phase in the loaded organic is considered to be physical. This situation can be overcome by scrubbing with water. Purification of the loaded organic is more of a problem if the co-extraction is chemical in nature. There are two ways of approaching this situation.

Use of acidic solution at a pH which is just sufficient to strip the unwanted metal and leave the metal of interest in the organic phase or use of a solution of a salt of the metal of interest which, by contacting with the loaded organic, replaces the unwanted metal by the metal required.

2.1.4 Phase Continuity
One of two phase states will exist at any one time with the tanks. These are :-

- Aqueous Continuous
- Organic Continuous

Each will be dependent on the relative phase volume within each mixer. Under normal conditions if there is more organic than there is aqueous (ie Organic to Aqueous Ratio of 2 to 1) then the mixing will be organic continuous, and aqueous continuous will result if these ratio’s are reversed.

The term organic continuous means that there will be a ‘sea’ of organic and dispersed through it is small bubbles will be the aqueous phase.

For aqueous continuous there is a ‘sea’ of aqueous with bubbles of organic dispersed through it.

The relative volume of the phases in the mixers can be changed in one of two ways:

- Increase the actual pumped flowrate of one phase. This will result in a change in the extraction, stripping or washing chemistry as it will change the relative amounts of reactive components present (organic, acid or copper).

- Recycling one phase back into the mixer. This will not change the extraction or stripping chemistry as the components recycled have already reacted in that mixer already.
Under normal conditions the mixer continuity does not affect the overall chemistry of the extraction process. The mixer continuity is important, however as it is the major controlling factor for entrainment.

This phase continuity can be checked in three ways, these being:-

1. **Sample Collection.**  
Manually taking a sample and observing the separation of the organic and aqueous. This sample collection is performed regularly during normal operation through the designated sample points on all Secondary Mixers, and is also used to determine O/A ratio in the mixing stage.  
The phase continuity is determined by observing the separation of the two phases. If the organic is flowing upwards out of the aqueous it is considered to be aqueous continuous.

2. **Solution Conductivity**  
The ability for the solution to transfer an electrical current is referred to as its conductivity. The aqueous phase allows electrical current to flow through easily, and when the mixing stages are operated in aqueous continuous a high conductivity is measured.

An organic phase does not allow the current to flow as easily as the aqueous, and when a mixing stage is operated in organic continuous a low conductivity is measured.

3. **Observation of Settler discharge launders**  
Observing the aqueous discharge launders can assist with determining the phase that the mixers are running. For example, the presence of large droplets of organic in the aqueous indicate that the mixer emulsion is aqueous continuous.

The phase continuity is altered through the adjustment of the organic and aqueous process flowrate, which is ultimately measured by the O/A ratio. Poor management of the O/A ratio and ultimate phase continuity can lead to operational problems in the circuit including organic and aqueous entrainment.

### 2.1.5 O/A Ratio
Dependent on the function of the particular Mixer/Settler in the process, it is important to maintain the appropriate O/A ratio to achieve the required phase continuity, and ultimately aid in controlling the amount of entrainment of one solution within the other.

If one of the flow rate set points is altered, then this alters the O/A ratio. Monitoring of the phase continuity is therefore very important.
2.1.6 Phase Disengagement Times

Phase disengagement time (PDT) is the time taken for the organic and aqueous phases to separate following mixing. The settler is designed in such a way that there is sufficient time for both phases to adequately separate, with minimal entrainment, under ideal conditions. PDT is used to indicate the quality of the organic, and presence of impurities. There are many operational constraints that effect PDT, for example:-

**Temperature**
The cooler the temperature the colder the organic phase and the more viscous it becomes and therefore the longer it takes for the separation of the phases to occur in the Settler, (high pdt). Higher temperatures (>45°C) can lead to increase in the degradation of the organic.

**Organic Quality**
The organic is recycled continuously around the SX Circuit, being loaded and stripped. The presence of impurities in the PLS and often the spent electrolyte can be transferred or contained in the organic. A build-up of these undesirables leads to less extractant being available for the recovery of copper. To manage this, a set volume of circulating organic is regularly treated through the Clay Treatment Circuit with the aim to rejuvenate it to as near as new condition.

If the organic quality is poor the PDT can tend to increase. Similarly, the presence of various reagents and mixing conditions can also have detrimental effects on the PDT, and the alteration or addition of these should be investigated thoroughly. The PDT is measured via sample collection from the Primary Mixer and recording the time it takes for the organic and aqueous phases to completely separate. After the aqueous and organic phases have been mixed and the chemistry has had sufficient time to extract or strip the copper, then the mixing ceases. The two phases will then naturally separate as the organic is insoluble in the aqueous phase. The organic is lighter than the aqueous (ie PLS, electrolyte or water) and therefore floats on top. If there is insufficient time in the settler for separation to occur such that phase disengagement time is greater than the settler residence time, then excessive aqueous and organic entrainment can occur. This condition is called flooding.
New organic has a phase disengagement time of about 30-60 seconds. When the phases have been mixed under conditions of aqueous continuous, the phase disengagement time will tend to be more rapid than when the phases have been mixed in organic continuous. There are number of substances which if present during the mixing, will result in increasing phase disengagement times and some of these are listed below:

- Suspended solids
- Entrained air
- Chemical surfactants such as soap, flocculants, degreases
- Degraded organic products
- Colloidal material
- Over mixing

In extreme cases phase disengagement times in excess of 300 seconds may result and remedial action must be taken to stop the material of concern entering the circuit. In such instances, it may be necessary to operate the plant in organic continuous.

If phase disengagement problems do occur, it may be necessary to slow the flow rate through the settler (i.e. decrease the plant flow rate). This decreased flow rate allows for an increase in the settler residence time and therefore more time for the two phases to separate before exiting. In less extreme case it may only require the volume (indicated by the level) of the organic or aqueous in the settler to be changed by utilising the settler aqueous weir. In some instances it may be beneficial to ‘flip’ the mixers running organic continuous so that they run aqueous continuous thus giving improved disengagement times.

2.1.7 Laboratory Analysis

It is necessary method of quality control to ensure that regular samples are collected to determine the efficiency of the solvent extraction process. Some of these samples are analysed via quick and easy methods, eg O/A Ratio, PDT, whereas others require more detailed tests.

Two main analyses performed are to determine the Electrolyte Impurities and the Entrainment (either aqueous or organic). The importance of both in reference to the operation of the SX circuit is discussed below.
1. Electrolyte Impurity

Due to the relationship between the Solvent Extraction, Electrowinning and Leach Circuits an effect in one can lead to a decrease in the quality of the copper produced, and due to the circulation nature of the circuit this effect can continually reoccur.

In order to manage this it is necessary to analyse the impurities that are present in the electrolyte as ultimately this is an indicator that these are working their way through the system.

The simplest indicator of the organic circuit performance is the increase in electrolyte impurities. The three main electrolyte impurities monitored are:-

- Iron
- Chloride, and
- Manganese.

When the electrolyte impurity increase is recognised, further checks of the SX Circuit should be undertaken to determine the cause and minimise further effects on the process.

2. Organic & Aqueous Entrainment Analysis

Aqueous entrainment must be monitored in the loaded organic exiting the extraction settlers and also from the loaded organic pump after the coalescing tank. This will indicate,

- the extent of aqueous entrainment in the organic leaving the settlers, therefore the conditions in the Mixer/Settler, and
- the effectiveness of the coalescing media.

If there is a difference between the entrainment results and they are higher than usual, then it may be necessary to clean the coalescer media.

The product aqueous streams from the SX Plant are considered as the Strong Electrolyte to EW and the raffinate streams returning to CCD and/or leaching circuit.

The amount of organic in the electrolyte stream is an important parameter to be monitored as it indicates the condition of the organic phase and the effectiveness of the organic removal.
The raffinate organic entrainment analysis is critical in determining the amount of organic lost to the raffinate pond, and subsequent analysis of the raffinate discharge can indicate the extent of organic lost to the leaching circuit.

As with the aqueous entrainment in organic, higher levels than usual can indicate problems within the Mixer/Settler or with the organic phase in general.

2.1.8 Crud

When solids, colloidal material or chemical precipitates enter a solvent extraction circuit there is a strong likelihood that these materials, when mixed with organic and aqueous, will form a stable material called ‘CRUD’. Crud was first observed in a very early uranium SX plant at the Chalk River Mine in Canada. It formed in the organic of this plant and was described as Chalk River Unidentified Deposit (CRUD). This crud contains varying quantities of organic and aqueous solution stabilised by very small quantities of the solids mentioned (i.e. normally less than 5% by weight). The type of crud formed and where it will appear in a circuit is difficult to predict and is very ‘site specific’.

The problem with crud is that it can:-

- Retain organic material and reduce the effective amount of organic available for extraction and stripping.
- Build up in a settler and result in decreased settler capacity.
- Migrate through the circuit and transfer impurities from the extraction stage to the stripping stage.
- Lead to excessive entrainment of one phase or the other.

Generally when running Mixers in an aqueous continuity the generated crud tends to disperse throughout the organic phase. In the settler the crud stays dispersed and can then transfer over the organic weir and into the next solvent extraction stage. By changing the mixer to organic continuity the crud tends to either compact at the aqueous/organic interface in the settler or wash out with the aqueous.
Crud generated from suspended solids generally builds up in the extraction stages whilst crud generated from colloidal material or chemical precipitates tends to build up in stripping stages.

The presence of crud can be most effectively observed at the discharge end of the Settler. The most noticeable type of crud is the floating crud associated with aqueous continuous operation. The compacted organic continuous crud is more difficult to observe, unless the amount is such that it has build enough to alter the flow characteristics of the organic phase through the settler.

For the majority of crud observations, it is necessary to use a clear tube to ‘dip’ into the organic phase to the aqueous interface and remove a cross section sample for observation.

2.1.9 Organic Treatment

There are two methods of organic treatment employed in most solvent extraction plants. These being Crud Treatment and Clay Treatment, each discussed below.

1. Crud Treatment

Crud is a stable emulsion of the organic and aqueous phases and may be combined with solids and/or air. Crud can consist of up to 40-50% organic and the remainder being contaminants and aqueous, therefore recovery of this organic is a vital part of crud treatment.

The first step in crud treatment is to remove the solids content from the crud to produce clean organic and aqueous components. This is achieved by using diatomaceous earth in a plate and frame filter press or tricanter. The high operating pressure of the filter press combined with this extremely effective filter aid produces an effluent that is relatively solids free, and able to be returned to the circuit.

2. Clay Treatment

The solvent extraction process operates with an ‘internal closed loop’ on the organic circuit. Contaminated organic can effectively be ‘rejuvenated’ by the clay treatment process. An acid activated clay, ie bentonite is an effective medium to remove any contaminants that may accumulate in the organic phase. The clay has a large surface area and contains active sites whereby the contaminants adhere. This mixture is then filtered and the contaminants along with the clay are left on the filter cloth and the rejuvenated organic is returned to the circulating organic circuit.
Clay treatment also works effectively on recovered organic from the Raffinate Pond which has been affected by UV degradation.

2.2.0 **Entrainment**

Entrainment is where quantities of one phase, remain in the other phase when it leaves the settler. If the organic phase is exiting the settler with small amounts of aqueous, this is called aqueous entrainment in organic. Organic entrainment in aqueous is where small quantities of organic remain with the aqueous phase as it exits the settler.

The following relationship applies for mixer continuities:

<table>
<thead>
<tr>
<th>Mixer continuity</th>
<th>Effect on entrainment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic continuous</td>
<td>Minimises organic entrainment in aqueous</td>
</tr>
<tr>
<td></td>
<td>Maximises aqueous entrainment in organic</td>
</tr>
<tr>
<td>Aqueous continuous</td>
<td>Minimises aqueous entrainment in organic</td>
</tr>
<tr>
<td></td>
<td>Maximises organic entrainment in aqueous</td>
</tr>
</tbody>
</table>

When deciding on what continuity a mixer should be operated in then the impact of entrainment exiting the settler must be considered.

Under conditions of excessive phase disengagement times it may be necessary to run aqueous continuous, or if there is significant crud is being generated, it may be necessary to run organic continuous such that the crud compacts at the aqueous/organic interface in the settler.

To determine the entrainment a sample is taken from the settler launder (either aqueous or organic) and place in a volumetric ‘funnel’. The phases are allowed to separate and the volume of entrained organic or aqueous can easily be read off the scale on the side. It is important to ensure that entrainment is minimised during operation.

2.2.1 **Diluent**

The function of the reagent diluent is to act as a solvent for the extractant complex, Lix, and transport it through the organic circuit. It has a high viscosity and density (1.15g/l) which assists in the phase separation and reduces entrainment, and is insoluble in the aqueous phase.
The diluent used at Kansanshi is Shellsol 2046 and when the extractant is added it is then termed organic.

2.2.2 Extractant

The extractant is the key reagent to the SX process. It is responsible for collecting and carrying the copper, and then releasing it into a more pure solution.

All copper extraction solutions exhibit a maximum copper uptake that is measured in grams of copper per litre, per volume percent of extractant. (gpl / vol.%). The maximum copper uptake (max. load) is dependent upon the pH of the aqueous solution used, contact time between aqueous and organic phases, and sufficient copper to load the available extractant. As the pH decreases the maximum copper loading potential of the extractant will also decrease.

The extractant concentration or organic strength is determined through laboratory analysis of samples collected, and the results are predominately used to :-

- determine when extractant or diluent additions are required,
- calculate circuit organic copper loading.

2.2.3 Construction of the McCabe Thiele

The McCabe Thiele construction was originally developed to explain stage performance in multistage distillation. It has a major role in the explanation of multistage SX extraction and stripping and in the prediction of the SX circuit performance. The Isocalc programme has the construction of McCabe Thiele diagrams built into it.
In constructing this diagram, the extraction isotherm is first drawn using copper concentration in both aqueous and organic phases at different O/A ratios. A vertical line is then drawn from the concentration of metal in the feed solution on the abscissa. The operating line is next inserted. This is the graphical representation of the mass balance of the system. The slope of which is equal to the phase ratio aqueous to organic (A/O ratio) to be used. This line may be considered as representing the fact that in any extraction stage, the increase in metal concentration in the organic phase is equal to the decrease in metal concentration in the aqueous phase multiplied by the phase ratio. This line may is governed by the equation, for extraction;

\[ y = \frac{va}{vo} [x - raff] + s.o \]

\[ y = \text{metal concentration in organic} \]
\[ x = \text{metal concentration in aqueous} \]
\[ va = \text{aqueous flowrate} \]
\[ vo = \text{organic flowrate} \]
\[ raff = \text{raffinate copper grade} \]
\[ s.o = \text{gpl copper in stripped organic} \]

The graphical representation of this diagram is shown below;

Figure 4; Extraction McCabe Thiele diagram
For the stripping chemistry the following equation is utilized when constructing the operating line;

\[ X = \frac{v_O}{v_a} [Y - S.O] + S.E \]  

Where, S.E=metal concentration in spent electrolyte

The McCabe Thiele diagram for stripping is shown below;

![McCabe Thiele diagram](image)

*Figure 5; Strip McCabe Thiele diagram*
CHAPTER THREE

3.0 EXPERIMENTAL PROCEDURES

Laboratory test work was done on the following:
- Determination of maximum load
- Determination of equilibrium isotherm points and
- Determination of mixer efficiency

You cannot run the programme without prior determination of the above experiments.

3.1 Determination of Maximum Load

Apparatus:

- Separating funnel
- 200 ml volumetric flask and
- 1 ml pipette

Reagents:

- Synthetic copper sulphate solution
- Cupric sulphate
- Ferric sulphate and
- Shelsol 2046 (diluent)

3.2 Experimental Details

Synthetic copper sulphate solution was prepared by adding 117.870 grammes cupric sulphate and 53.705 grammes of ferric sulphate into a 5000 ml volumetric flask mixed with distilled water and filled up to the mark. The resulting solution was a standard solution of 6.7 gpl copper. The pH of this solution was controlled by the addition of sulphuric acid to get to 1.75.
Two hundred milliliters (200 ml) of this synthetic pregnant leach solution was contacted with 200 ml plant stripped organic in the separating funnel for three (3) minutes and allowed the phase to disengage or separate. The aqueous phase was drained out leaving the loaded organic phase. The loaded organic was contacted with fresh synthetic pregnant leach solution for three (3) minutes and the same procedure was repeated for five contacts.

The resulting loaded organic phase could no longer extract any more copper from aqueous solution and was therefore considered to be “max loaded”. An aliquot of 1ml was obtained and diluted with the diluent, Shellsol 2046 and filled up to the mark in a 200 ml volumetric flask. The solution was analysed for copper in ppm using the Atomic Absorption Spectrometer (AAS).

The “max load” was calculated using the formula;

\[ \text{Maxload(gpl)} = \frac{\text{ppmCu}}{1000} \times 200 \]  

The reagent used at Kansanshi SX Plant is LIIX 984N and the specification for this product from the manufacturers, Cognis Mining Technology, is that LIIX 984N has a maximum copper loading capacity of 0.53 gpl copper for each V/V %. The reagent concentration is given as;

\[ \text{organic strength} = \frac{\text{max load(gpl)Cu}}{0.53\text{gplCu}} \]

<table>
<thead>
<tr>
<th></th>
<th>ppm Cu</th>
<th>Max Load (gpl Cu)</th>
<th>Organic strength (v/v %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HG SX 1</td>
<td>55</td>
<td>11</td>
<td>20.76</td>
</tr>
<tr>
<td>LG SX 2</td>
<td>65.2</td>
<td>13.04</td>
<td>24.61</td>
</tr>
<tr>
<td>HG SX 3</td>
<td>59.65</td>
<td>11.93</td>
<td>22.52</td>
</tr>
</tbody>
</table>

Table 3.2: Determination of organic strengths
Sample calculation

\[ \text{max load} = \frac{55}{1000} \times 200 = 11 \text{gpl} \]

\[ \text{organic strength} = \frac{11}{0.53} = 20.76 \text{ v/v\%} \]
3.3 **Determination of Equilibrium Isotherm Points**

3.3.1 Extraction isotherm points

The samples of stripped organic and high grade pls were cut and contacted for 8 min in the O/A ratios of 10:1, 5:1, 2:1, 1:1, 1:2, 1:5 and 1:10. The dispersion was allowed to settle and phases separate. Both the aqueous and organic phases were analysed for g/l Cu at all the O/A ratios.

3.3.2 Strip isotherm points

The samples of loaded organic and spent electrolyte were cut and contacted for 8 min in the O/A ratios of 10:1, 5:1, 2:1, 1:1, 1:2, 1:5 and 1:10. The dispersion was allowed to settle and phases separate. Both the aqueous and the organic phase were analysed for gpl Cu at all the O/A ratios.

3.4 **Determination of Mixer Efficiency**

Samples were cut from all the SX trains and stages. These were;

- Aqueous product exiting the mixer (Ap)
- Organic product exiting the mixer (Op)
- Aqueous feed entering the mixer (Af)
- Organic feed entering the mixer (Of)

The metal transfer at equilibrium was also determined by sampling the dispersion from the mixers and further mixing it i.e at the same O/A ratio as the plant configuration, for 8 minutes.
3.5 RESULTS AND ANALYSIS

The extraction isotherms were determined and these were used in the programme to construct the McCabe Thiele diagram. The first row shows O/A ratios and the second row shows the concentration of the organic phase in ppm. The third row has the concentration of the aqueous solution in g/pl Copper. Concentration of the free acid was only determined in the aqueous solutions.

Table 3.5: SX 1 extraction isotherm

<table>
<thead>
<tr>
<th>O/A</th>
<th>10</th>
<th>5</th>
<th>2</th>
<th>1</th>
<th>0.50</th>
<th>0.2</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm Cu</td>
<td>23.9</td>
<td>26</td>
<td>32</td>
<td>41</td>
<td>49.4</td>
<td>52.5</td>
<td>53.2</td>
</tr>
<tr>
<td>g/l Cu in org</td>
<td>4.77</td>
<td>5.2</td>
<td>6.4</td>
<td>8.3</td>
<td>9.88</td>
<td>10.5</td>
<td>10.6</td>
</tr>
<tr>
<td>g/l Cu in Aq</td>
<td>0.08</td>
<td>0.1</td>
<td>0.18</td>
<td>0.5</td>
<td>1.7</td>
<td>3.12</td>
<td>3.8</td>
</tr>
<tr>
<td>g/l H2SO4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>L.O</th>
<th>S.O</th>
<th>HG PLS</th>
<th>HG Raff</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.55</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2.11</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4.45</td>
<td>0.64</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6.4</td>
<td>10.4</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Figure 6: SX 1 extraction graph
Figure 7; SX 1 strip graph
# MIXER EFFICIENCIES

## Table 3.5 b: SX1 MIXER EFFICIENCY

<table>
<thead>
<tr>
<th>PLS</th>
<th>3.84</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>S1aq</td>
<td>41.4</td>
<td>S1 mixer</td>
<td>7.6</td>
<td>8.6</td>
</tr>
<tr>
<td>S1mix</td>
<td>42.4</td>
<td>efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E1 raff</td>
<td>0.36</td>
<td>E1 mixer</td>
<td>3.48</td>
<td>3.5</td>
</tr>
<tr>
<td>E1 mix</td>
<td>0.34</td>
<td>efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E2 raff</td>
<td>0.14</td>
<td>E2 mixer</td>
<td>0.22</td>
<td>0.24</td>
</tr>
<tr>
<td>E2 mix</td>
<td>0.14</td>
<td>efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E3 raff</td>
<td>-</td>
<td>W mixer</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>E3 mix</td>
<td>-</td>
<td>efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spent</td>
<td>33.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Table 3.5 c: SX 2 MIXER EFFICIENCY

<table>
<thead>
<tr>
<th>PLS</th>
<th>2.3</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>S1aq</td>
<td>44.8</td>
<td>S1 mixer</td>
<td>11.8</td>
<td>12</td>
</tr>
<tr>
<td>S1mix</td>
<td>45</td>
<td>efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E1 raff</td>
<td>0.14</td>
<td>E1 mixer</td>
<td>2.16</td>
<td>2.18</td>
</tr>
<tr>
<td>E1 mix</td>
<td>0.12</td>
<td>efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E2 raff</td>
<td>0.06</td>
<td>E2 mixer</td>
<td>0.08</td>
<td>0.09</td>
</tr>
<tr>
<td>E2 mix</td>
<td>0.05</td>
<td>efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E3 raff</td>
<td>0.28</td>
<td>E3 mixer</td>
<td>2.02</td>
<td>2.04</td>
</tr>
<tr>
<td>E3 mix</td>
<td>0.26</td>
<td>efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spent</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

29
Table 3.5 d: SX3 MIXER EFFICIENCY

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>S1 mixer efficiency</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PLS</td>
<td>2.24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1 aq</td>
<td>59</td>
<td>12.6</td>
<td>13.4</td>
<td>94.02985</td>
</tr>
<tr>
<td>S1 mix</td>
<td>59.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E1 raff</td>
<td>0.59</td>
<td>1.65</td>
<td>1.69</td>
<td>97.63314</td>
</tr>
<tr>
<td>E1 mix</td>
<td>0.55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E2 raff</td>
<td>0.33</td>
<td>0.26</td>
<td>0.28</td>
<td>92.85714</td>
</tr>
<tr>
<td>E2 mix</td>
<td>0.31</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S2 aq</td>
<td>46.4</td>
<td>4.2</td>
<td>5.6</td>
<td>75</td>
</tr>
<tr>
<td>S2 mix</td>
<td>47.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spent</td>
<td>42.2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sample calculation for mixer efficiency

\[
\frac{(Af - Ap)}{(Af - Ae)} \times 100 = \frac{3.84 - 0.36}{3.84 - 0.34} \times 100 = 99.43\% = E1 \text{ mixer efficiency}
\]

Where:

Af = g/l Cu in pregnant solution

Ap = E1 g/l Cu

Ae = E1 mix = gpl copper at equilibrium
3.6 Results Analysis Using ISO-CALC

The isotherms were determined in the lab as earlier illustrated in the experimental. These were entered into the program and the following was the analysis.

The parameters looked at were:

- the O/A flowrates,
- organic strength,
- copper tenor (gpl Cu in the leach solution),
- pH,
- and the temperature.

Any changes in these parameters affect the SX performance.

The O/A flow rates were varied across the range 0.9, 1.0, 1.3, 1.5, and 1.7.

The performance at any particular ratio was analysed by taking note of the recovery, the copper content of the raffinate and the net transfer.

The results were tabulated as shown below:

| Table 3.6a: Results obtained from varying the O/A flowrates |
|------------------|---|---|---|---|---|
| O/A              | 0.9 | 1.1 | 1.3 | 1.5 | 1.7 |
| Recovery %       | 96  | 96.928 | 97.87 | 98.105 | 98.240 |
| Gpl Cu in raff   | 0.175 | 0.137 | 0.095 | 0.084 | 0.078 |
| Net transfer     | 0.229 | 0.208 | 0.161 | 0.140 | 0.124 |
The organic strengths were varied from 16, 20.75, 24 and 27 %v/v.

Table 3.6b: Results obtained from varying the organic strengths

<table>
<thead>
<tr>
<th>Strength</th>
<th>16</th>
<th>20.76</th>
<th>24</th>
<th>27</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery %</td>
<td>97.915</td>
<td>98.118</td>
<td>98.736</td>
<td>98.857</td>
</tr>
<tr>
<td>g/l Cu in raff</td>
<td>0.093</td>
<td>0.084</td>
<td>0.056</td>
<td>0.051</td>
</tr>
<tr>
<td>Net transfer</td>
<td>0.16</td>
<td>0.124</td>
<td>0.108</td>
<td>0.096</td>
</tr>
</tbody>
</table>

Table 3.6c: Results obtained from varying pH

<table>
<thead>
<tr>
<th>pH</th>
<th>1.3</th>
<th>1.5</th>
<th>1.8</th>
<th>2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery %</td>
<td>94.908</td>
<td>95.84</td>
<td>98.243</td>
<td>98.698</td>
</tr>
<tr>
<td>g/l Cu in raff</td>
<td>0.227</td>
<td>0.141</td>
<td>0.078</td>
<td>0.058</td>
</tr>
<tr>
<td>Net transfer in g/l Cu per v/v%</td>
<td>0.12</td>
<td>0.122</td>
<td>0.124</td>
<td>0.124</td>
</tr>
</tbody>
</table>

Table 3.6d: Effect of temperature on extraction

<table>
<thead>
<tr>
<th>Temp in °C</th>
<th>20</th>
<th>30</th>
<th>39</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery %</td>
<td>98.703</td>
<td>98.475</td>
<td>98.268</td>
</tr>
<tr>
<td>g/l Cu in raff</td>
<td>0.058</td>
<td>0.07</td>
<td>0.077</td>
</tr>
<tr>
<td>Net transfer in g/l Cu per v/v%</td>
<td>0.125</td>
<td>0.124</td>
<td>0.124</td>
</tr>
</tbody>
</table>
3.7 Optimized SX model

If we set the O/A flowrate at 1.7, organic strength at 27%, pH 1.8 and the feed pls at 4.5gpl Cu, the following would be the SX model. Note that the advance solution would improve to 50gpl Cu.

= McCabe-Thiele Calculations =

Net Transfer: 0.097 g/l Cu per 1 vol. % LIX 984N
Series Circuit Recovery: 58.824%  
Loaded Organic is 50.64\% of Max Load

PLS
4.500 g/l Cu  
ph = 1.80

Raffinate
0.053 g/l Cu

Spent Elec.
36.0g/l Cu  
190 g/l H2SO4

O/A = 1.7  
Mixer Eff 97.6%  
E1

Mixer Eff 92.9%  
E2

Striped Org.
4.479 g/l Cu

Mixer Eff 75.0%  
S2

Loaded Org.
7.095 g/l Cu

4.570 g/l Cu

5.310 g/l Cu

Preg. Elec.
50.0g/l Cu

40.44 g/l Cu
3.8 Discussion of Results

From Table 3.6 a in the above results, the maximum recovery was found to be 98.24% which corresponds to the ratio of 1.7. This ratio also gave minimal copper losses in the raff at 0.074. From Table 3.6 b, the maximum recovery was obtained to be 98.857% at the organic strength of 27%v/v. This produced a final raffinate of 0.051 g/l. From Table 3.6 c, the maximum recovery was found to be 98.698% with the lowest copper content in the raffinate of 0.054. This was at a pH 2. From the results shown in Table 3.6 d it was observed that varying the temperature did not significantly affect the SX performance. However, from literature, a rise in temperature increases the extraction while decreasing the stripping stage. This is because the extraction reaction is a reversible one. Increasing the forward reaction eliminates the stripping stage in the circuit. Therefore, a balance has to be met between optimum temperature and reasonable recovery.
CHAPTER FOUR

4.0 CONCLUSIONS AND RECOMMENDATIONS

In arriving at the conclusion, care was taken to ensure that co-extraction of species other than copper was avoided. The analysis using the software was based on the reaction kinetics of copper only. It did not give the information about other species that would be entrained into the tankhouse for electrowinning. The conclusions and recommendations were also based on the assumption that the feed pregnant solution stabilized at 4.5 gpl copper. The temperature used was the plant average of 39°C.

4.1 CONCLUSION

In this project it was established that, at a stabilized copper grade of 4.5gpl Cu in the pregnant solution, the optimum pH of 2 was arrived at, O/A flowrates of 1.7, and the organic strength of 27 v/v% gave the best results in that the recoveries were high (>97%). These also gave minimal copper losses in the raffinate (less than the target 0.1gpl Cu). It was also observed that increasing the aqueous flows while keeping the organic flowrates constant resulted in high copper losses in the raffinate and the converse reduced the losses.

The optimized parameters were entered into the program and gave a high copper grade in the advance solution of 50gpl copper. This is higher than the average 43-45 gpl Cu.

4.2 RECOMMENDATIONS

The programme gave the trend on how to get good results. In the optimization it was recommended that the organic strength of 24v/v % be used. If one refers to Table 3.2 in chapter three, one realizes that 0.1gpl Cu in raffinate was exactly at the target grade. The recommended 24 v/v % was less than the highest set of 25 v/v%.
Unnecessarily too high organic strengths result in chemical co-extraction of iron and manganese and these have an adverse effect in the electrowinning of copper. These impurities may also be transferred to the tankhouse by means of physical entrainment. To effectively address this problem, I would recommend that Extraction stage 1 for Solvent extraction 1 and 3 be run in aqueous continuous. This means that there would be less or no aqueous entrainment in the loaded organic which usually contaminates the advance electrolyte. Extraction stage 2 for SX1 and 3 produce the final raffinate and therefore, must be run in organic continuous. Organic entrained in the raffinate can be lost to the ponds. Organic continuity reduces this problem. Strip stage 1 for all the SX plants must be run in organic continuous. This reduces organic entrainment in the advance solution going for electrowinning. Organic in the electrowinning electrolyte causes organic burns which distort the quality of the cathodes. Also the organic would be chemically degraded due to acid, temperature and oxygen. Return of this organic to SX would, over time, result in unbearable crud formation and high phase disengagement time.
APPENDIX I: SX 1 strip isotherm

<table>
<thead>
<tr>
<th>O/A</th>
<th>10</th>
<th>5</th>
<th>2</th>
<th>1</th>
<th>0.50</th>
<th>0.2</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm Cu</td>
<td>20.5</td>
<td>17.9</td>
<td>17.1</td>
<td>16</td>
<td>15.35</td>
<td>14.5</td>
<td>13.6</td>
</tr>
<tr>
<td>g/l Cu in org</td>
<td>4.1</td>
<td>3.58</td>
<td>3.41</td>
<td>3.2</td>
<td>3.07</td>
<td>2.89</td>
<td>2.71</td>
</tr>
<tr>
<td>g/l Cu in Aq</td>
<td>46</td>
<td>45.2</td>
<td>43.1</td>
<td>41</td>
<td>38.96</td>
<td>36.9</td>
<td>34.8</td>
</tr>
<tr>
<td>g/l H2SO4</td>
<td>135</td>
<td>145</td>
<td>160</td>
<td>16</td>
<td>167</td>
<td>166</td>
<td>166</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>L.O</th>
<th>S.O</th>
<th>strong g/l Cu</th>
<th>spent g/l Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>38.51</td>
<td>22.65</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7.702</td>
<td>4.53</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>45.2</td>
<td>34.8</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>150</td>
<td>168</td>
</tr>
</tbody>
</table>

APPENDIX II: SX2 extraction isotherm

<table>
<thead>
<tr>
<th>O/A</th>
<th>10</th>
<th>5</th>
<th>2</th>
<th>1</th>
<th>0.50</th>
<th>0.2</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm Cu</td>
<td>26.4</td>
<td>28.7</td>
<td>35.2</td>
<td>45</td>
<td>56.78</td>
<td>62</td>
<td>63</td>
</tr>
<tr>
<td>g/l Cu in org</td>
<td>5.28</td>
<td>5.73</td>
<td>7.03</td>
<td>9</td>
<td>11.36</td>
<td>12.4</td>
<td>12.6</td>
</tr>
<tr>
<td>g/l Cu in Aq</td>
<td>0.07</td>
<td>0.09</td>
<td>0.15</td>
<td>0.3</td>
<td>1.291</td>
<td>3.04</td>
<td>3.77</td>
</tr>
<tr>
<td>g/l H2SO4</td>
<td>15.2</td>
<td>13</td>
<td>13.2</td>
<td>12</td>
<td>10.4</td>
<td>8.4</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>L.O</th>
<th>S.O</th>
<th>L.G pls</th>
<th>L.G raff</th>
</tr>
</thead>
<tbody>
<tr>
<td>48.48</td>
<td>20.57</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9.696</td>
<td>4.114</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>4.55</td>
<td>0.64</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>6.4</td>
<td>10.4</td>
</tr>
</tbody>
</table>
### APPENDIX III: SX 2 strip isotherm

<table>
<thead>
<tr>
<th></th>
<th>10</th>
<th>5</th>
<th>2</th>
<th>1</th>
<th>0.50</th>
<th>0.2</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm Cu</td>
<td>23.5</td>
<td>23.3</td>
<td>22.2</td>
<td>21</td>
<td>19.85</td>
<td>18.7</td>
<td>17.5</td>
</tr>
<tr>
<td>g/l Cu in org</td>
<td>4.7</td>
<td>4.66</td>
<td>4.43</td>
<td>4.2</td>
<td>3.97</td>
<td>3.74</td>
<td>3.5</td>
</tr>
<tr>
<td>g/l Cu in Aq</td>
<td>49.7</td>
<td>48.8</td>
<td>46.5</td>
<td>44</td>
<td>41.96</td>
<td>39.7</td>
<td>37.4</td>
</tr>
<tr>
<td>g/l H2SO4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>L.O</th>
<th>S.O</th>
<th>ADVANCE</th>
<th>SPENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>42.52</td>
<td>19.42</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8.504</td>
<td>3.884</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>48.8</td>
<td>37.4</td>
</tr>
</tbody>
</table>

### APPENDIX IV: SX 3 extraction isotherm

<table>
<thead>
<tr>
<th></th>
<th>10</th>
<th>5</th>
<th>2</th>
<th>1</th>
<th>0.50</th>
<th>0.2</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm Cu</td>
<td>18</td>
<td>19.5</td>
<td>24</td>
<td>30</td>
<td>41.6</td>
<td>52.6</td>
<td>54.7</td>
</tr>
<tr>
<td>g/l Cu in org</td>
<td>3.6</td>
<td>3.9</td>
<td>4.7</td>
<td>6</td>
<td>8.32</td>
<td>10.5</td>
<td>10.9</td>
</tr>
<tr>
<td>g/l Cu in Aq</td>
<td>0.03</td>
<td>0.04</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
<td>1.35</td>
<td>2.02</td>
</tr>
<tr>
<td>g/l H2SO4</td>
<td>11</td>
<td>10.2</td>
<td>11</td>
<td>10</td>
<td>9.8</td>
<td>8</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>L.O</th>
<th>S.O</th>
<th>HG pls</th>
<th>raff</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.6</td>
<td>11.72</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4.53</td>
<td>2.344</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>2.78</td>
<td>0.05</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>5.8</td>
<td>11.8</td>
</tr>
</tbody>
</table>
APPENDIX V: SX3 strip isotherm

<table>
<thead>
<tr>
<th>O/A</th>
<th>10</th>
<th>5</th>
<th>2</th>
<th>1</th>
<th>0.50</th>
<th>0.2</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm Cu</td>
<td>18</td>
<td>17.6</td>
<td>17</td>
<td>17</td>
<td>16.6</td>
<td>16.3</td>
<td>16</td>
</tr>
<tr>
<td>g/l Cu in org</td>
<td>3.6</td>
<td>3.52</td>
<td>3.5</td>
<td>3.4</td>
<td>3.32</td>
<td>3.26</td>
<td>3.19</td>
</tr>
<tr>
<td>g/l Cu in Aq</td>
<td>41</td>
<td>41.6</td>
<td>41</td>
<td>40</td>
<td>39.4</td>
<td>38.7</td>
<td>38</td>
</tr>
<tr>
<td>g/l H2SO4</td>
<td>126</td>
<td>139</td>
<td>152</td>
<td>154</td>
<td>160</td>
<td>162</td>
<td>160</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>L.O</th>
<th>S.O</th>
<th>ADVANCE</th>
<th>SPENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>38.7</td>
<td>21</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7.74</td>
<td>4.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>41.6</td>
<td>38</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>145</td>
<td>170</td>
</tr>
</tbody>
</table>
APPENDIX VI: SX 1 Extraction Report

Isocalc® TM Ver. 8.00 May 8, 2007
© Copyright 2006 Cognis Corporation

Isotherm Point Calculations and Graphics / McCabe-Thieles

NOTICE: Please read Cognis’ Disclaimer of Warranty and Limitation of Liability statements.

Extraction Data
Client Name: Kansanshi
Project: MM 590 SX1
Reagent Selected: LIX 984N
PLS g/l Cu: 4.45
Reagent Volume: 20.76%
PLS pH: 1.80
PLS SO4 Activity: 16.0%
Max Load, g/l Cu: 10.738
Spent Elec., g/l H2SO4: 192
Preg. Elec., g/l Cu: 45.2

Number of Strip Stages: 1
Temperature: 39 ℃
Other Parameters/Information:

<table>
<thead>
<tr>
<th>Extraction Isotherm Points</th>
<th>Org., g/l Cu</th>
<th>Aq., g/l Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>O/A=10.0</td>
<td>4.777</td>
<td>0.084</td>
</tr>
<tr>
<td>O/A= 5.0</td>
<td>5.210</td>
<td>0.102</td>
</tr>
<tr>
<td>O/A= 2.0</td>
<td>6.471</td>
<td>0.188</td>
</tr>
<tr>
<td>O/A= 1.5</td>
<td>7.130</td>
<td>0.265</td>
</tr>
<tr>
<td>O/A= 1.0</td>
<td>8.276</td>
<td>0.514</td>
</tr>
<tr>
<td>O/A= 0.5</td>
<td>9.892</td>
<td>1.674</td>
</tr>
<tr>
<td>O/A= 0.2</td>
<td>10.520</td>
<td>3.214</td>
</tr>
<tr>
<td>O/A= 0.1</td>
<td>10.644</td>
<td>3.820</td>
</tr>
</tbody>
</table>

=McCabe-Theile Calculations=================

Net Transfer: 0.124 g/l Cu per 1 vol. % LIX 984N
Series Circuit Recovery: 98.118%
Loaded Organic is 61.67% of Max Load
APPENDIX VII: SX 1 Extraction Graph

May 8, 2007

MM 590 SX1

Key Extraction Data

Feed=4.45 g/l Cu
pH=1.8
L.O.=5.622 g/l Cu
S.O.=4.053 g/l Cu
S.E.=34.8 g/l Cu
S.E. Acid =192 g/l
P.E.=45.2 g/l Cu
Recovery=38.118%

Series Extraction

E1-S=99.0%
E2-S=91.67%
O/A=1.7
Raff=0.084 g/l Cu

NOTICE: Please read Cognis' Disclaimer of Warranty and Limitation of Liability statements.
APPENDIX VIII: SX 1 Strip Report

Isocalc® TM Ver. 8.00 May 8, 2007
© Copyright 2006 Cognis Corporation

 Isotherm Point Calculations and Graphics / McCabe-Thieles
NOTICE: Please read Cognis' Disclaimer of Warranty and Limitation of Liability statements.

Strip Data
Client Name: Kansanshi
Project: MM 590 SX1
Reagent Selected: LIX 984N
Spent Elec., g/l Cu: 34.8
Desired Preg. Elec., g/l Cu: 45.2
Calc. Preg. Elec., g/l Cu: 45.20
L.O. 6.622 = 61.67% of M.L.
Stripped Organic g/l Cu: 4.053
MAX LOAD: 10.738 g/l Cu

Reagent Volume Percent: 20.76%
Spent Elec., g/l H2SO4: 192
Number of Strip Stages: 1
Temperature: 39 °C

Strip Isotherm Points

<table>
<thead>
<tr>
<th>Aq., g/l Cu</th>
<th>Org., g/l Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>34.800</td>
<td>2.710</td>
</tr>
<tr>
<td>36.880</td>
<td>2.890</td>
</tr>
<tr>
<td>38.960</td>
<td>3.070</td>
</tr>
<tr>
<td>41.040</td>
<td>3.240</td>
</tr>
<tr>
<td>43.120</td>
<td>3.410</td>
</tr>
<tr>
<td>45.200</td>
<td>3.580</td>
</tr>
</tbody>
</table>

================== McCabe-Theile Calculations =================

The net transfer of the strip circuit is 0.124 g/l Cu per 1 vol % of LIX 984N

Diagram of McCabe-Theile calculations
APPENDIX IX: SX1 Strip Graph

May 8, 2007

MM 590 SX1

Key Strip Data

L.O. = 6.622 g/l Cu
P.E. = 45.2 g/l Cu
S.E. = 34.8 g/l Cu
S.E. Acid = 192 g/l
S1-S = 88.37%
O/A = 4.048
S.O. = 4.053 g/l Cu
Temp = 39°C
NT = 0.124 g/l Vol. 9

NOTICE: Please read Cognis' Disclaimer of Warranty and Limitation of Liability statements.
APPENDIX X: SX2 Extraction Report

Isocalc® TM Ver. 8.00 May 8, 2007
© Copyright 2006 Cognis Corporation
Isotherm Point Calculations and Graphics / McCabe-Thiele
NOTICE: Please read Cognis’ Disclaimer of Warranty and Limitation of Liability statements.

Extraction Data
Client Name: Kansanshi
Project: MM 590 SX 2
Reagent Selected: LIX 984N
PLS g/l Cu: 4.55
PLS g/l SO4: 80
Stripped Organic, g/l Cu: 4.790
Number of Strip Stages: 1
Spent Elec., g/l H2SO4: 185
Temperature: 39 °C
Reagent Volume: 24.64%
PLS pH: 1.75
PLS SO4 Activity: 16.0%
Max Load, g/l Cu: 12.738
Spent Elec., g/l Cu: 37.4
Prep. Elec., g/l Cu: 48.8

Other Parameters/Information:

<table>
<thead>
<tr>
<th>Extract Isotherm</th>
<th>Org-, g/l Cu</th>
<th>Aq-, g/l Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>O/A=10.0</td>
<td>5.285</td>
<td>0.074</td>
</tr>
<tr>
<td>O/A= 5.0</td>
<td>5.730</td>
<td>0.088</td>
</tr>
<tr>
<td>O/A= 2.0</td>
<td>7.039</td>
<td>0.147</td>
</tr>
<tr>
<td>O/A= 1.5</td>
<td>7.741</td>
<td>0.195</td>
</tr>
<tr>
<td>O/A= 1.0</td>
<td>9.039</td>
<td>0.348</td>
</tr>
<tr>
<td>O/A= 0.5</td>
<td>11.356</td>
<td>1.291</td>
</tr>
<tr>
<td>O/A= 0.2</td>
<td>12.409</td>
<td>3.036</td>
</tr>
<tr>
<td>O/A= 0.1</td>
<td>12.601</td>
<td>3.774</td>
</tr>
</tbody>
</table>

=============== McCabe-Thiele Calculations ===============
Cognis Series Parallel Extraction

Net Transfer: 0.183 g/l Cu per 1 vol. %LIX 984N
Series Circuit Recovery: 96.225%
Parallel Circuit Recovery: 96.16%
Series+Parallel Circuit Recovery: 96.20%
Loaded Organic is 72.95% of Max Load

PLS 4.550 g/l Cu
pH = 1.75

Raffinate 0.175 g/l Cu
Raffinate 0.172 g/l Cu

PLS 4.550 g/l Cu
pH = 1.75

O/A= 2.27
Mixer Eff 99.0%
EP1

0.436 g/l Cu
Mixer Eff 88.9%
ES2

6.718 g/l Cu

0.873 g/l Cu
Mixer Eff 99.0%
ES1

Stripped Org. 4.790 g/l Cu

O/A= 2.532
Mixer Eff 98.0%
S1

6.929 g/l Cu

O/A= 1.7
Mixer Eff 99.0%

Spent Elec. 37.4 g/l Cu

Prep. Elec. 48.8 g/l Cu

185 g/l H2SO4
APPENDIX XI: SX 2 Extraction Graph
May 8, 2007

MM 590 SX 2

24.64 v/v% LIX 984N

Key Extraction Data
- Feed=4.55 g/l Cu
- pH=1.75
- L.O.=9.293 g/l Cu
- S.O.=4.79 g/l Cu
- S.E.=37.4 g/l Cu
- S.E. Acid =185 g/l
- P.E.=48.8 g/l Cu
- Recovery=96.198%

Parallel Extraction
- E1-P=99.0%
- O/A=2.27
- Raff=0.175 g/l Cu

Series Extraction
- E1-S=99.0%
- E2-S=88.9%
- O/A=1.7
- Raff=0.172 g/l Cu

NOTICE: Please read Copier Disclaimer of Warranty and Limitation of Liability statements.
APPENDIX XII: SX 2 Strip Report

Isocalc® TM Ver. 8.00 May 8, 2007
© Copyright 2006 Cognis Corporation
Isotherm Point Calculations and Graphics / McCabe-Thiele

NOTICE: Please read Cognis' Disclaimer of Warranty and Limitation of Liability statements.

Strip Data
Client Name: Kansanshi
Project: MM 590 SX 2
Reagent Selected: LIX 984N
Spent Elec., g/l Cu: 37.4
Desired Preg. Elec., g/l Cu: 48.8
Calc. Preg. Elec., g/l Cu: 48.80
L.O. 9.293 = 72.95% of M.L.
Stripped Organic g/l Cu: 4.790

MAX LOAD: 12.738 g/l Cu

Reagent Volume Percent: 24.64%
Spent Elec., g/l H2SO4: 185
Number of Strip Stages: 1
Temperature: 39 °C

Strip Isotherm Points

<table>
<thead>
<tr>
<th>Acq. g/l Cu</th>
<th>Org. g/l Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>37.400</td>
<td>3.500</td>
</tr>
<tr>
<td>39.680</td>
<td>3.740</td>
</tr>
<tr>
<td>41.960</td>
<td>3.970</td>
</tr>
<tr>
<td>44.240</td>
<td>4.200</td>
</tr>
<tr>
<td>46.520</td>
<td>4.430</td>
</tr>
<tr>
<td>48.800</td>
<td>4.660</td>
</tr>
</tbody>
</table>

--------------- McCabe-Thiele Calculations ---------------

The net transfer of the strip circuit is 0.183 g/l Cu per 1 vol % of LIX 984N

- Stripped Org. 4.790 g/l Cu
- Loaded Org. 9.293 g/l Cu
- Spent Elec. 37.4 g/l Cu
- Preg. Elec. 49 g/l Cu

Mix Eff. 98.0

O/A = 2.532

S-1
APPENDIX XIII: SX 2 Strip Graph

May 8, 2007

MM 590 SX 2

Key Strip Data
L.O.=9.293 g/l Cu
P.E.=48.8 g/l Cu
S.E.=37.4 g/l Cu
S.E. Acid =185 g/l
S1-S=98.0%
O/A=2.532
S.O.=4.79 g/l Cu
Temp=39°C
NT=0.183 g/l/Vol.%

NOTICE: Please read Cognis’ Disclaimer of Warranty and Limitation of Liability statements.
APPENDIX XIV: SX 3 Extraction Report

Isocalc® TM Ver. 8.00 May 9, 2007
© Copyright 2006 Cognis Corporation
Isotherm Point Calculations and Graphics / McCabe-Thiele
NOTICE: Please read Cognis' Disclaimer of Warranty and Limitation of Liability statements.

Extraction Data
Client Name: Kansanshi
Project: MM 590 SX3
Reagent Selected: LIX 984N
PLS g/l Cu: 2.78
PLS g/l SO4: 80
Stripped Organic, g/l Cu: 3.355
Number of Strip Stages: 2
Spent Elec., g/l H2SO4: 188
Temperature: 39°C
Reagent Volume: 22.52%
PLS pH: 1.50
PLS SO4 Activity: 16.0%
Max Load, g/l Cu: 11.232
Spent Elec., g/l Cu: 38.0
Preg. Elec., g/l Cu: 41.6

Other Parameters/Information:

<table>
<thead>
<tr>
<th>Extraction Isotherm Points</th>
<th>Org., g/l Cu</th>
<th>Aq., g/l Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>O/A=10.0</td>
<td>3.629</td>
<td>0.034</td>
</tr>
<tr>
<td>O/A= 5.0</td>
<td>3.903</td>
<td>0.039</td>
</tr>
<tr>
<td>O/A= 2.0</td>
<td>4.717</td>
<td>0.095</td>
</tr>
<tr>
<td>O/A= 1.5</td>
<td>5.163</td>
<td>0.067</td>
</tr>
<tr>
<td>O/A= 1.0</td>
<td>6.036</td>
<td>0.098</td>
</tr>
<tr>
<td>O/A= 0.5</td>
<td>8.317</td>
<td>0.299</td>
</tr>
<tr>
<td>O/A= 0.2</td>
<td>10.513</td>
<td>1.348</td>
</tr>
<tr>
<td>O/A= 0.1</td>
<td>10.942</td>
<td>2.021</td>
</tr>
</tbody>
</table>

============== McCabe-Thiele Calculations ===============

Net Transfer: 0.072 g/l Cu per 1 vol. % LIX 984N
Series Circuit Recovery: 90.635%
Loaded Organic is 44.22% of Max Load

PLS
2.780 g/l Cu
pH = 1.50

O/A= 1.7
Mixer Eff 97.6%

E1
0.127 g/l Cu
3.407 g/l Cu

Mixer Eff 92.9%

E2
3.355 g/l Cu
3.626 g/l Cu

Mixed Eff 75.0%

S2
38.6 g/l Cu

O/A= 2.233
Mixer Eff 94.0%

S1
4.967 g/l Cu

Loaded Org.
APPENDIX XV: SX 3 Extraction Graph

May 9, 2007

MM 590 SX3

Key Extraction Data

<table>
<thead>
<tr>
<th>Feed=2.78 g/l Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH=1.5</td>
</tr>
<tr>
<td>L.O.=4.967 g/l Cu</td>
</tr>
<tr>
<td>S.O.=3.355 g/l Cu</td>
</tr>
<tr>
<td>S.E.=38.0 g/l Cu</td>
</tr>
<tr>
<td>S.E. Acid =188 g/l</td>
</tr>
<tr>
<td>P.E.=41.6 g/l Cu</td>
</tr>
<tr>
<td>Recovery=90.635%</td>
</tr>
</tbody>
</table>

Series Extraction

| E1-S=97.63% |
| E2-S=92.86% |
| O/A=1.7     |
| Raff=0.038 g/l Cu |

NOTICE: Please read Cognos Disclaimer of Warranty and Limitation of Liability statements.
APPENDIX XVI: SX 3 Strip Report

Isotecâ® TM Ver. 8.00 May 9, 2007
© Copyright 2006 Cognis Corporation

Isotherm Point Calculations and Graphics / McCabe-Thiele
NOTICE: Please read Cognis’ Disclaimer of Warranty and Limitation of Liability statements.

Strip Data
Client Name: Kansanshi
Project: MM 590 SX3
Reagent Selected: LIX 984N
Spent Elec., g/l Cu: 38.0
Desired Preg. Elec., g/l Cu: 41.6
Calc. Preg. Elec., g/l Cu: 41.60
L.O. 4.967 = 44.22% of M.L.
Stripped Organic g/l Cu: 3.355
MAX LOAD: 11.232 g/l Cu

Reagent Volume Percent: 22.52%
Spent Elec., g/l H2SO4: 188
Number of Strip Stages: 2
Temperature: 39 °C

---

Strip Isotherm Points

<table>
<thead>
<tr>
<th>Ag, g/l Cu</th>
<th>Org, g/l Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>38.000</td>
<td>3.190</td>
</tr>
<tr>
<td>38.720</td>
<td>3.260</td>
</tr>
<tr>
<td>39.440</td>
<td>3.320</td>
</tr>
<tr>
<td>40.160</td>
<td>3.390</td>
</tr>
<tr>
<td>40.880</td>
<td>3.450</td>
</tr>
<tr>
<td>41.600</td>
<td>3.520</td>
</tr>
</tbody>
</table>

---

McCabe-Thiele Calculations

The net transfer of the strip circuit is 0.072 g/l Cu per 1 vol % of LIX 984N

---

Diagram:
- Loaded Org. 4.967 g/l Cu
- Preg. Elec. 42 g/l Cu
- Mixer Eff. 94.0%
- Q/A= 2.233
- Mixer Eff. 75.0%
- S1
- S2
- 3.626 g/l Cu
- 38.60 g/l Cu
- Spent Elec. 38.0 g/l Cu
- 188 g/l H2SO4
- Stripped Org. 3.355 g/l Cu
### Key Strip Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>L.O.</td>
<td>4.967 g/l Cu</td>
</tr>
<tr>
<td>P.E.</td>
<td>41.6 g/l Cu</td>
</tr>
<tr>
<td>S.E.</td>
<td>38.0 g/l Cu</td>
</tr>
<tr>
<td>S.E. Acid</td>
<td>188 g/l</td>
</tr>
<tr>
<td>S1-S</td>
<td>94.0%</td>
</tr>
<tr>
<td>S2-S</td>
<td>75.0%</td>
</tr>
<tr>
<td>O/A</td>
<td>2.233</td>
</tr>
<tr>
<td>S.O.</td>
<td>3.355 g/l Cu</td>
</tr>
<tr>
<td>Temp</td>
<td>39°C</td>
</tr>
<tr>
<td>NT</td>
<td>0.072 g/l/Vol.%</td>
</tr>
</tbody>
</table>

**NOTICE:** Please read Cogni's Disclaimer of Warranty and Limitation of Liability statements.
REFERENCES

1. More J.J., Chemical Metallurgy
2. Ritcey and Ashbrook, Solvent Extraction, Principles and Application to Process Metallurgy, Part 1 and Part 2
3. MCT Redbook, Solvent Extraction Reagents and Applications, Cognis Mining Chemicals
4. Operation of copper solvent Extraction Plants, A Cognis Overview, Cognis Mining Chemicals