

Evaluation of Copper Solvent-Extraction Circuit Data and Performance

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A well-performing solvent-extraction circuit is a key part of producing good quality copper cathode. To ensure consistent operation, a good understanding of the circuit's operation and an ability to rapidly troubleshoot key parameters is required. This paper briefly discusses the modeling of solvent-extraction circuits. The paper then goes on to discuss the determination of key performance parameters from plant data and comparing these with the circuit models to quantify circuit performance. The identification and troubleshooting of circuit issues is presented with a worked example.

INTRODUCTION

A well-performing solvent-extraction (SX) circuit is a key part of producing good quality copper cathode. To ensure a consistent, high-quality operation, a good understanding of the circuit performance is required. Evaluating the performance of an SX circuit is an extensive topic. The objective of this paper is to focus on the evaluation that the metallurgist should be performing on a regular basis using flow and concentration data. This paper does not cover important topics, such as crud management, phase continuity, or organic management. Some basic SX modeling concepts are first be presented. The calculation of the parameters is then presented with a brief discussion and recommended ranges (where applicable). A worked example is used to provide a basis for further discussion on the evaluation of the calculated parameters and use of data collected.

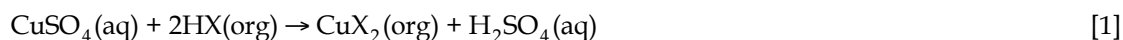
BASIC SOLVENT-EXTRACTION MODELING CONCEPTS

This section presents the basic modeling concepts used in SX simulation packages currently available. SX reagent suppliers have invested significant time and effort into collecting data on the performance of their reagents under different conditions. Based on these data, suppliers have developed packages which they normally make available to their clients for free. These are typically used for process design and plant optimization studies. For example, BASF developed ISOCALC™ and CYTEC Industries developed MINCHEM® and MEUM™.

Chemistry of Copper Solvent Extraction

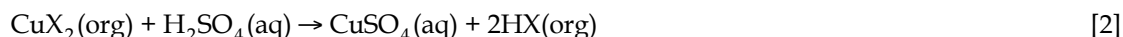
Liquid-liquid extraction involves the selective transfer of a substance between two immiscible liquid phases by controlling the relative solubility in each phase. In the case of copper SX, the exchange is typically achieved by an oxime-based chelating mechanism. In particular, mixtures of aldoxime and ketoxime are normally used in conjunction with modifiers. More detail on this extensive topic can be found in Schlesinger et al. (2011).

Under low acidic conditions (pH 1-2), copper has greater solubility in the organic phase (extraction). A simplified reaction representing the copper exchange from the aqueous to organic phase is shown in Equation 1:



where HX(org) represents the extractant and CuX₂(org) represents the copper-organic complex.

Under highly acidic conditions (180 g/L H₂SO₄), the copper has a greater solubility in the aqueous phase (strip):



Both extraction and stripping are typically assumed to achieve pseudo-equilibrium conditions. The similarities with binary distillation mean that the McCabe-Thiele method can be used to model the process. This method provides a simple but powerful visual representation of the counter-current SX process. This method is described in detail extensively in literature (Schlesinger et al., 2011; Sinnott, 2005).

Extraction and Strip Isotherms

Extraction and strip equilibrium isotherms are a key aspect of the McCabe-Thiele method. These isotherms are a graphical representation of the equilibrium copper concentrations in the aqueous and organic phases at different organic-to-aqueous (O/A) ratios. Typically these isotherms are specific to a particular operation or set of conditions. It is important to note that in copper SX these isotherms are not at constant pH.

There are two ways of determining the isotherm for a particular operation: either by theoretical prediction based on the extraction and stripping conditions or by performing laboratory-scale tests. In practice, both methods are used in conjunction with each other.

Theoretical Prediction of the Isotherm

As previously mentioned, most organic reagent suppliers develop software-modeling packages. These packages all predict the extraction and strip equilibrium isotherms for specified plant conditions.

Analytical Measurement of the Isotherm

In addition to predicting the isotherms, most packages allow the user to input their own isotherms for extraction or stripping. This allows the user to decide whether to use the theoretical isotherm or rather one specifically measured for the operation.

The following generic procedure for determining the extraction isotherm is followed:

1. Select at least 7 organic-to-aqueous (O/A) ratios at which to perform the test;
2. Measure the initial aqueous feed copper and acid concentrations (or pH);
3. For each O/A ratio:
 - a. Combine aqueous feed (process pregnant leach solution (PLS)) with previously stripped organic (plant stripped organic) at the specified O/A ratio;
 - b. Agitate mixture and allow to settle;
 - c. Once settled, sample and measure the aqueous product copper and acid concentrations;
4. For each O/A point, perform a mass balance to determine the equilibrium copper concentration in the organic phase or the organic can also be analysed to verify the mass balance points.

It is possible to perform a similar set of measurements to determine the strip isotherm. Ideally, these measurements should be performed with loaded organic (washed loaded plant organic) and spent electrolyte.

Determination of Maximum Organic Loading

An important parameter that is generally calculated by the modeling packages when predicting the isotherm is the maximum copper loading achievable for the given conditions. This maximum loading is often referred to as the *system* maximum loading. The maximum loading can be determined by the following procedure:

1. Combine process PLS and organic with an O/A ratio of 1:1;
2. Agitate for 3 minutes and allow the phases to separate;
3. Repeat steps 1 & 2 four times, each time with fresh process PLS; and,
4. The copper tenor in the organic after four iterations is the *system* maximum loading.

Determination of Extractant Concentration

When evaluating a particular operation, it is important to know the relative extractant concentration. To determine this value, the maximum loading of the organic must be determined for a standardized (or synthetic) PLS. Most reagent suppliers have a standard procedure for determining this absolute maximum load; one such method is:

1. Combine synthetic PLS (6 g/L Cu at pH = 2.0) and process organic with an O/A ratio of 1:1;
2. Agitate for 3 minutes and allow the phases to separate;
3. Repeat steps 1 & 2 four times, each time with fresh synthetic PLS; and,
4. The copper tenor in the organic after four iterations is the *absolute* maximum loading.

Given the reagent type and absolute maximum loading, reagent suppliers are able to determine the extractant concentration. This concentration should be used for any simulations performed and will be used in the calculation of some of the parameters discussed later in this paper.

Comparing Model Isotherms with Analytical Isotherms

Invariably, there will be a difference between the predicted and analytically determined isotherms. All of the modeling systems typically do not take into account the effect of all the impurities of the leach solution. However, many of the packages allow the users to modify some stream parameters so that the leach solutions are better represented, providing better correlation to the actual operation.

This is an important first step in evaluating the performance of an operation. Large variation between the laboratory and theoretical isotherms indicate unaccounted-for differences, such as an uncalibrated pH sensor or an issue with the analytical metal concentration measurement. Effort should be made to ensure that the isotherms (and maximum loadings) tie up between the model and the measured plant data.

EVALUATION OF CIRCUIT DATA AND PERFORMANCE

Several important parameters should be reviewed on a regular basis. These parameters, once determined, can be used to check the internal consistency of the mass balance data collected. They can further be compared to the theoretical predictions of circuit performance based on similar PLS, circuit configurations. By considering all of these results together, it is possible to:

1. Gain insight into the performance of the process;
2. Develop a deeper understanding of the operation;
3. Correct potential issues; and,
4. Begin process optimisation.

What Data Should Be Collected

To assess the performance of an SX circuit, the following data should be collected at a minimum:

- Mixer volumes (should be known from design).
- Settler surface areas (should be known from design).
- Flowrates for the:
 - PLS (including any parallel extraction streams);
 - Organic; and,
 - Strip electrolyte.
- Copper tenor in the:
 - PLS, raffinate (including parallel extraction streams);
 - Loaded and stripped organic streams; and,
 - Advance and spent electrolytes.

In addition, the following data should also be collected, if possible:

- Phase disengagement time.
- Copper tenor in the intermediate aqueous and organic streams.
- Acid tenor in all streams.
- Iron tenor in all streams.
- Other metal tenors (such as manganese) in:
 - PLS, raffinate and any parallel extraction streams;
 - Loaded and stripped organic; and,
 - Advance and spent electrolytes.

It is important that these data be based on a daily average at least, and preferably a weekly or monthly average. The rest of this section will present the calculations using these data.

Copper Recovery and Transfer

Copper recovery and mass transfer can be calculated across three sections of the circuit – the aqueous extraction streams, the organic streams, and the aqueous strip streams. In addition, the copper cathode actually produced can also be measured. By determining the recovery and transfer for each section, it is possible to gain insight into the quality of the mass balance data and the performance of the operation.

$$R_{Cu} = 100 \times \frac{[Cu(aq)]_{feed} - [Cu(aq)]_{product}}{[Cu(aq)]_{feed}} \quad [3]$$

$$T_{Cu} = 24 \times F_{PLS} \times \frac{[Cu(aq)]_{feed} - [Cu(aq)]_{product}}{1000} \quad [4]$$

where:

- R_{Cu} is the copper recovery, %;
- T_{Cu} is the copper transfer, t/day;
- F_{PLS} is the flow rate of PLS, organic or strip electrolyte, m³/h;
- $[Cu(aq)]_{feed}$ is copper concentration in feed stream, g/L;
- $[Cu(aq)]_{product}$ is copper concentration in product stream, g/L.

For an internally consistent set of data, the mass transfer values should all be the same. However, the recoveries will be different for each section, since the basis for the recovery over each section is different. Normally, only the recovery across the extraction is of interest to us.

When considering real data, these values will differ. Depending on the values calculated and by how much they vary from one another, it is possible to begin assessing the quality of the data. This is particularly useful when the actual cathode production is also taken into consideration.

In addition, the mass transfer calculation can be applied to the acid in the aqueous streams. This provides a double check on flows and compositions. It also provides a further check for the copper transferred because, in an ideal situation, for every gram of copper transferred, 1.54 grams of acid is produced.

Recovery vs Transfer

It is important to note that the recovery indicates the amount of copper extracted from the PLS but the transfer indicates the mass of copper transferred (ultimately the amount of cathode produced). It is possible to increase the net transfer of copper across an SX circuit while its recovery decreases. However, since the raffinate is often recycled back to the leach circuit, such process changes are often acceptable, given the increase in cathode production.

For example, consider changing a series extraction circuit configuration with a feed flow of 1000 m³/h, recovery of 95%, and copper transfer of 3.78 t/h, to a series-parallel extraction circuit. The feed flow can then be increased to 2000 m³/h and the copper transfer will increase to 4.58 t/h, however the recovery decreases to 57%. The decision on whether to implement such a change is dependent on the mine plan, the stage in the life cycle of the plant and the economic conditions (Sole & du Preez, 2012). High copper prices may encourage high copper transfers, while being near the end of mine-life may encourage high copper recoveries.

Depending on the leaching and solid-liquid separation techniques employed at a particular operation, it is possible to further explore the impact of different circuit configurations on the recovery and copper transfer. For further discussion on the Split Circuit™ and other circuit modifications, see Nisbett *et al.* (2007) and Cole & Feather (2008).

Extraction Organic-to-Aqueous Ratio

It is possible to estimate the organic-to-aqueous ratio for the circuit either directly from the flow measurements or analytically using the extraction copper concentrations. As with the recoveries and net transfers, by comparing these two values it is possible to gain further insight into the quality of the mass balance data and a better understanding of the performance.

Analytical O/A Ratio

$$\frac{O}{A_A} = \frac{[Cu(aq)]_{PLS} - [Cu(aq)]_{raffinate}}{[Cu(org)]_{LO} - [Cu(org)]_{SO}} \quad [5]$$

where:

- O/A_A is the analytical O/A ratio;
- $[Cu(aq)]_{PLS}$ is the copper concentration in PLS, g/L;
- $[Cu(aq)]_{raffinate}$ is the copper concentration in raffinate, g/L;
- $[Cu(org)]_{LO}$ is the copper concentration in the loaded organic, g/L;
- $[Cu(org)]_{SO}$ is the copper concentration in the stripped organic, g/L.

Flowmeter O/A Ratio

$$\frac{O}{A_F} = \frac{F_{organic}}{F_{PLS}} \quad [6]$$

where:

- O/A_F is the flowmeter O/A ratio;

- F is the PLS or organic flow rate, m³/h.

Every operation will have different operating circuit O/A ratios. However, it is common to see operations with ratios between 1:1 and 3:1, with the mixers typically operating at a ratio of 1.1:1.

Organic Net Transfer and Percentage of Maximum Loading

In any consideration of an operations performance, it is important to quantify the performance of the organic. Two common measures are the net transfer of copper per percent of extractant and the percentage of maximum loading. These are important parameters in assessing the performance of the organic. For example, low organic transfer rates may indicate a potential issue with the organic and targeting higher percentages of the maximum loading assists in the minimization of ferric-iron extraction.

$$NT_{organic} = 100 \times \frac{[Cu(org)]_{LO} - [Cu(org)]_{SO}}{V_{extract}} \quad [7]$$

$$\%ML = 100 \times \frac{[Cu(org)]_{LO}}{ML} \quad [8]$$

where:

- NT_{organic} is the organic net transfer, g/L/%;
- %ML is the percentage of maximum loading, %;
- V_{extract} is the extractant concentration, % vol;
- ML is the organic maximum load, g/L;

It is difficult to provide typical organic net transfer values and percentages of maximum loading because these vary drastically with organic concentration and selection, PLS composition and circuit configuration. However, as an initial rule of thumb, a net transfer of 0.25 g/L/% is often used (Schlesinger et al., 2011). Most operations target high percentages of maximum loading, above 80%, particularly when the PLS concentration of ferric iron is high. Increasing percentage of maximum loading above 80% can decrease the circuit recovery achieved. This trade-off must be considered for each operation, depending on its current performance, impurity transfer, etc.

Mixer Residence Times

The mixer residence time is an important parameter in ensuring that the copper is transferred between phases. Before determining the residence times, the recycle (normally organic) flow must be estimated. Since this recycle flow is normally not measured, it must be determined indirectly. One possible method to do this is to measure the mixer O/A ratio from a physical sample. Since the aqueous and organic feed flows are known, the recycle can be determined by difference. Equation 9 presents this calculation for an organic recycle:

$$F_{OR} = F_A \times \frac{O}{A_M} - F_O \quad [9]$$

Once the organic recycle has been determined, the residence time is determined using Equation 10:

$$RT = 60 \times \frac{F_O + F_A + F_{OR}}{V_{mixers}} \quad [10]$$

where:

- O/A_M is the mixer O/A ratio;
- RT is the mixer residence time, minutes;
- F is the aqueous (A), organic (O), or organic recycle (OR) flowrate, m³/h;
- V_{mixers} = volume of mixers, m³.

It is generally accepted that the residence time should be at least 3 minutes, although a range of 2 to 5 minutes is normally acceptable.

Phase Disengagement Time

Samples are typically taken from the first extraction stage (E1) and first strip stage (S1). It is generally accepted that the phase disengagement time should be 60–120 s. Times longer than this, or where the phase boundary is particularly dirty, may indicate:

- Running a high extractant concentration (greater than 35%) or running a high concentration of equilibrium modifiers;
- That the organic phase contains excessive contaminants, some of which can be removed by clay treatment;
- Excessively high levels of impurities are present in one of the phases; or,
- In the more extreme cases, that the organic is degraded.

Settler Flux

Settler flux is an important parameter, both in the design of settlers and for assessing the performance of operating settlers. Equation 11 shows how this parameter is determined:

$$SF = \frac{F_O + F_A + F_{OR}}{SA_{\text{settler}}} \quad [11]$$

where:

- SF is the settler flux, m³/h/m²;
- SA_{settler} is the active surface area of the settler, m².

Generally, the settlers are designed with a specific settler flux in mind. This design value is normally dependent on the equipment supplier and specific equipment used. Where possible, the design value should be used as a guide when considering this value. However, as a general rule, the settler flux is often 3–5 m³/h/m² for more traditional settler designs. Fluxes as high as 6 m³/h/m² or higher may be acceptable, depending on the equipment and conditions.

Mixer and Stage Efficiencies

SX reactions (Reactions 1 and 2) approach equilibrium, but they do not necessarily achieve it. The mixer and stage efficiencies are used to measure how close to equilibrium each stage gets. For each stage, there are two efficiency values that can be estimated – mixer-only and stage (mixer and settler combined) efficiency.

The mixer efficiency can be used to identify potential issues with the mixing and exchange of copper between phases during mixing. The stage efficiency includes the additional contact time that occurs in the settler during phase disengagement. It is also an important input parameter when modeling the circuit because it defines how close each stage as a whole gets to equilibrium.

Stage Efficiency

The stage efficiency can be determined by taking a sample of the organic and aqueous feeds to a particular stage. These samples are then mixed for 5 minutes at the same O/A ratio as is fed to the mixer and allowed to separate. The copper concentrations in the organic and aqueous are then measured. These values are compared with the actual exit streams from the stage to determine the efficiency. Using the aqueous compositions for an extraction stage as an example:

$$Eff_A = 100 \times \frac{[Cu(aq)]_{\text{MixerFeed}} - [Cu(aq)]_{\text{SettlerProduct}}}{[Cu(aq)]_{\text{MixerFeed}} - [Cu(aq)]_{\text{Equilibrium}}} \quad [12]$$

where:

- Eff_A is the extraction stage efficiency based on the aqueous phase copper concentrations, %;
- $[Cu(aq)]_{SettlerProduct}$ is the settler aqueous product stream copper concentration, g/L;
- $[Cu(aq)]_{MixerFeed}$ is the mixer feed aqueous copper concentration, g/L;
- $[Cu(aq)]_{Equilibrium}$ is the manually determined aqueous equilibrium copper concentration, g/L.

The same calculation can (and should) be performed for the organic streams around a particular stage. The two efficiencies should be comparable for each stage and are normally averaged to give the indicated stage efficiency. Stage efficiency can also be estimated using the model-predicted equilibrium point. These model-based estimates can be used until physical samples are taken and the actual efficiency determined. Once determined from physical samples these values can be compared with the model-based estimates as an additional point to check.

Mixer Efficiency

For the mixer efficiency, the feed aqueous and organic feed streams must still be sampled. However, an additional two samples must be taken from the last mixer. One of the samples must be allowed to separate and then analysed. The other sample must be mixed for 5 minutes, allowed to separate and analysed. Equation 13 shows the efficiency calculation based on the organic phases:

$$Eff_O = 100 \times \frac{[Cu(org)]_{LastMixer} - [Cu(org)]_{MixerFeed}}{[Cu(org)]_{Equilibrium} - [Cu(org)]_{MixerFeed}} \quad [13]$$

where:

- Eff_O is the extraction stage efficiency based on the organic phase copper concentrations, %;
- $[Cu(org)]_{LastMixer}$ is the last mixer organic sample copper concentration, g/L;
- $[Cu(org)]_{MixerFeed}$ is the mixer feed aqueous copper concentration, g/L;
- $[Cu(org)]_{Equilibrium}$ is the manually determined organic equilibrium copper concentration, g/L.

Typical efficiencies for extraction should be 90–100% and typical efficiencies for stripping should be 98–100%. Values outside of these ranges should be investigated further. Low efficiencies are normally indicative of issues with the following:

- Mixer residence time.
- Turbine tip speed or insufficient mixing for creating adequate interfacial area for mass transfer.
- O/A ratio and internal recycle.
- Temperature.
- Short-circuiting within the mixer or the mixer and turbine design.

WORKED EXAMPLE

To assist with explanations of the previous sections, data from a standard series extraction circuit with stripping (3E-2S) is reviewed. For the purposes of the clarity, washing stages are excluded from the example.

Flowsheet

Figure 1 shows the flowsheet for the worked example.

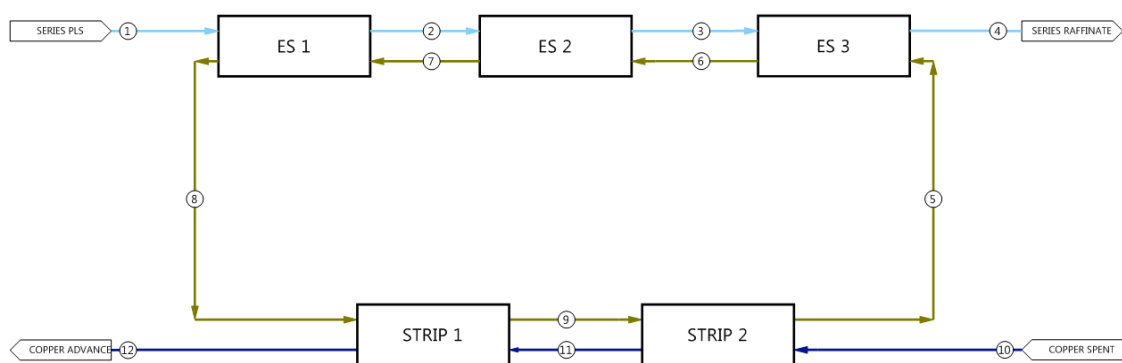


Figure 1. Flowsheet of 3E-2S worked example.

Mass Balance Data and Simulation Results

Table I shows the semi-raw data that an engineer will typically be presented with when needing to review the performance of an SX. In addition, the simulated results have been included in brackets with these data under the same conditions as the plant data.

Table I. Selected values for the 3E-2S worked example data and simulation results.

Measurement	Measured Flow (m ³ /h)	Simulated Flow (m ³ /h)	Measured Cu (g/L)	Simulated Cu (g/L)	Measured H ₂ SO ₄ (g/L)	Simulated H ₂ SO ₄ (g/L)
PLS	300	300	39.0	39.0	23.3	14.85
Organic	1100	1100	-	-	-	-
Strip electrolyte	700	633	42.0	42.0	192.5	193
Extraction						
E1 organic			12.3	14.87		
E1 aqueous			29.0	26.77		
E2 organic			10.0	11.47		
E2 aqueous			15.7	16.33		
E3 organic			7.8	8.68		
E3 aqueous			10.3	10.3	63.7	59.14
Strip						
S1 organic			6.0	8.55		
S1 aqueous			55.6	55.6	171	171
S2 organic			5.3	6.9		
S2 aqueous			43.8	44.82		

Additional information:

- Max load (synthetic PLS) = 17.60 g/L;
- Extractant concentration = 32.8%;
- Average cathode production = 210 t/day;
- The residence times, setter fluxes, and, phase disengagement times are within desired operating ranges.

Figure 2 shows the McCabe-Thiele constructions for the measured plant data and the simulated data. The isotherms for each McCabe-Thiele are predicted curves based on the PLS and organic flows and compositions and not the analytically determined isotherms.

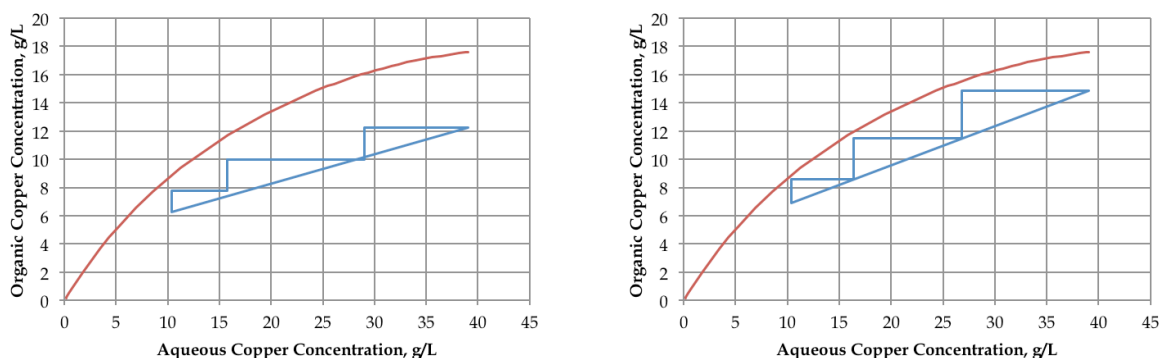


Figure 2. McCabe-Thiele construction for (a) the measured data and (b) the simulation of the worked example.

Calculating the Parameters

Tables II to IV present the calculated parameters based on the data presented. The parameters are determined for the simulation data and are also included in each table.

Table II. Worked example copper recoveries and transfers.

Section	Measured Cu recovery (%)	Simulated Cu Recovery (%)	Measured Cu transfer (kg/h)	Simulated Cu transfer (kg/h)	Measured Acid transfer (kg/h)	Simulated Acid transfer (kg/h)
Extraction	74%	74%	206.6	206.6	290.9	319
Organic	-	-	168.0	206.6	-	-
Strip electrolyte	-	-	228.6	206.6	361.2	319

Table III. Worked example copper O/A ratios.

	Measured O/A ratio	Simulation O/A ratio
Analytical	4.7	3.6
Flowmeter	3.6	3.6

Table IV. Worked example organic net transfer, percentage max load and extraction stage efficiencies.

	Measured value	Simulation value
Net transfer (g/L/%)	0.192	0.243
Percent of maximum load (%)	-	84
E1 efficiency (%)	56.2	91.0
E2 efficiency (%)	84.1	93.0
E3 efficiency (%)	82.1	95.0

Evaluating the Circuit Performance

With the model results and these calculated parameters, it is now possible to begin evaluating the circuit performance. The evaluation presented here only covers the preliminary review of the key aspects of an SX circuit. In practice, after the initial evaluation, further plant data would be collected and modifications, calibrations, etc. made where highlighted. Thereafter, new data would be collected and the review process performed again.

From the results presented in Tables II to IV, the following parameters are not consistent with the others:

1. The organic copper transfer is lower than the PLS copper transfer and the cathode production;
2. The strip electrolyte copper transfer is higher than the PLS copper and the cathode production;
3. There is a large difference (50 t/d) between PLS and strip acid transfers;
4. The analytical O/A ratio is 4.7 as opposed to the flow meter O/A that is 3.6;
5. The organic net transfer is lower than the simulated value; and,
6. The apparent stage efficiencies (see Figure 2) are very low - 56% for E1 and about 80% for E2 and E3.

There are two potential causes for the lower organic copper transfer - either the flow meter reading is incorrect or the concentrations measured in the organic stream are incorrect. If the organic flow rate is increased from 1080 m³/h to say 1500 m³/h, then the organic copper transfer will be increased to about 206 t/d, which is in line with the PLS copper transfer and cathode production. The flow meter O/A ratio increases to about 4.8, which is closer to the analytical O/A ratio (issue #4). However, changing the flow rate does not affect the stage efficiencies (issue #6) or the organic net transfer (issue #5). Thus, increasing the organic flow corrects issues #1 and #4.

Alternatively, the organic concentrations could be increased. If they are all increased by about 25%, then the analytical O/A ratio will drop to about 3.7, very close to the flow meter O/A ratio. The copper transfer increases to 204 t/d (in line with PLS and cathode production). With this change, the copper net transfer is also increased to 0.24 g/L/%, which is much closer the simulation value of 0.243 g/L/%. The stage efficiencies are also increased in this scenario to above 90%, more in line with what is expected. Unfortunately, the stage efficiencies for E2 and E3 are slightly above 100%, however this is likely just measurement error or that the concentration measurement error is not consistent over all measurements. Thus, increasing the organic copper concentrations corrects issues #1, #4, #5 and #6.

From the above analysis, it seems likely that the issue is related to the measurement of the copper concentration in the organic streams. However, this must be confirmed by checking both the flow-meter calibrations and the analytical methods associated with organic copper measurements.

Neither of the above changes corrected issues #2 and #3. As with the organic copper transfer, a possible explanation for the high copper transfer is that the flow meter is over-reading the flow rate. The simulation predicted that a flow of 633 m³/h was required to achieve the copper transfer, however the measured value is 700 m³/h. This may indicate that the flow meter is reading slightly high. Based on the expected copper transfer (about 205 t/d), we would expect the acid transfer to be about 315 t/d. By lowering the spent flow rate, the acid transfer in the measured data begins to reduce to values closer to what is expected, correcting issues #2 and #3.

From this evaluation, we now have a set of data that has better internal consistency than when initially considered. Based on this evaluation, the following actions and investigations should be implemented:

1. Check calibration of the organic and aqueous (organic in particular) flow meters;
2. Check analytical methods for possible issue in measurement of copper tenors, particularly in organic;
3. Determine the stage efficiencies from plant samples and compare these with the calculated stage efficiencies;
4. Check the various parameters that could lead to poor mixer efficiencies, particularly in the first extraction stage; and,
5. Determine the laboratory isotherm and compare it with the simulated isotherm to ensure that the simulation is a valid reference.

Once these have been reviewed, the analysis should be repeated until an internally consistent set of data that the metallurgist has confidence in is generated. Such a consistent data set provides the metallurgist with a realistic snap-shot of the SX circuit and its performance. By performing this on a regular basis (twice monthly), it is possible to observe longer-term trends in the operation.

Additionally, with such a data set it is possible to fine-tune the simulator settings to these conditions. It is then possible to begin performing what-if scenario simulations to estimate the impact of changing various circuit properties, such as PLS pH, O/A ratios, circuit configuration and flow rates.

CONCLUSIONS

This paper has focused on presenting some of the key performance parameters that should be used to evaluate an SX circuit. By combining these parameters with expected performance based on theoretical models, it is shown that it is possible to gain a deeper understanding of the operation and resolve potential plant issues that may arise.

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