

Analysis of the effects of changes in operating conditions on the agitated leaching of copper

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The hydrometallurgical processing of copper is a complex process due to factors such as recycles and complex chemistry. Consequently it is extremely difficult to predict the effect of changes in operating parameters on the circuit with confidence. The aim of this work is to investigate the effects of such changes in operating parameters on the economic performance of a copper circuit.

Modern hydrometallurgical processing of copper in the Central African Copperbelt involves four stages – namely, leaching, separation, solvent extraction, and electrowinning. The preferred choice for processing ores from the Democratic Republic of Congo (DRC) and Zambia is agitated leaching. Agitated leaching involves reacting copper-containing ore with acid in an agitated tank. The resultant slurry is separated in a solid/liquid separation stage, usually a countercurrent decantation (CCD) circuit. The solution is upgraded in a solvent extraction (SX) circuit, after which LME Grade A copper is recovered through electrowinning (EW). The waste streams are sent to a tailings facility where the acid is neutralized and aqueous elements are precipitated out. The liquid from tailings can be recycled as process water, while the solid content is stored in a tailings dam.

A model of the copper circuit was built in Cypad Process®. Usually when models of circuits are built, the models of operations such as leaching, SX, and EW are based on fixed conversions or extents of reaction. The novel feature of this work is that leaching kinetic rates, extraction, and stripping isotherms are used. Leaching is described by the kinetics of reaction, which depend on the concentrations of both acid and solids. In a similar manner, the extraction in the SX circuit is based on extraction isotherms that are dependent on the concentrations of both the copper and acid in solution.

The conditions that were considered are:

- The wash water ratio (the ratio of the water added to the CCD and the mass of solids in the leach slurry)
- The percentage of solids in the slurry fed to the CCD circuit
- The percentage of solids in the CCD underflow
- The number of thickeners in the CCD circuit.

These operating conditions were varied individually and the results compared to those obtained from a base case. An economic analysis was performed for each of the options.

Increasing the wash water ratio (mass of water per mass solids) from 1.5 to 3 decreased the overall copper recovery by 6.9% from 86.1%. The increase in pregnant leach solution (PLS) flow rate resulted in an increase in the reagent addition required in the circuit, which increased the production cost of copper. The production cost increased by \$1156 per ton of copper the wash water ratio was increased from 1.5 to 3. Increasing the concentration of solids in the leach slurry from 20% to 50% increased the recovery by over 3%, but increased the production cost by \$990 per ton. Increasing the concentration of solids in the CCD underflow from 40% to 60% resulted in a 14% increase in the recovery of copper and an increase in the production cost of \$190 per tonne of copper produced.

The most effective way to improve productivity and reduce the cost of producing copper is to increase the number of CCD thickeners. The recovery increased by 4.5% from 86.1% using five CCDs to 90.6% using nine CCDs, while the cost of producing copper cathode decreased by \$104 per ton. Decreasing the number of CCD units from five units to two decreased the recovery by 12% and increased the production cost by \$530 per ton.

Introduction

Agitated leaching is the preferred choice for processing ores from the Central African Copperbelt in the Democratic Republic of Congo (DRC) and Zambia. Hydrometallurgical extraction of copper consists of three main unit operations: leaching, solution purification, and metal recovery. During leaching, the valuable components of the ore are leached in an aqueous solution, known as the lixiviant. Sulphuric acid is commonly used as a lixiviant. The slurry formed is sent through a series of countercurrent decantation (CCD) units, where it is washed to separate the solid tailings from the leach liquor. The solution is purified and upgraded by solvent extraction, in which the solution is contacted with an organic with a high affinity for copper. The two stages of solvent extraction are extraction and stripping. Copper metal is recovered from the strip solution by electrowinning. Solid copper, produced at the cathode, is smooth, dense, and high in purity.

Each of the stages in a leaching circuit involve many individual pieces of equipment, and the operating conditions of each unit can greatly affect the quality and quantity of copper produced. A study was done to analyse the effect of changing certain conditions in the circuit on the annual production rate of copper and the rate of consumption of raw materials. The factors considered focused mainly on the units around the thickening section of the plant. These factors included:

- The wash water ratio - defined as the amount of water fed to the CCD circuit per unit mass of solids in the leached residue
- The fraction of solids in the leached residue – that is, the thickener feed
- The fraction of solids in the thickener underflow
- The number of CCD thickeners.

This analysis was done by designing a circuit according to initial assumptions. The circuit comprised an agitated leach circuit, a countercurrent decantation (CCD) circuit, solvent extraction (SX), electrowinning (EW), and tailings neutralization. Figure 1 shows a simplified flow sheet that summarizes the circuit used.

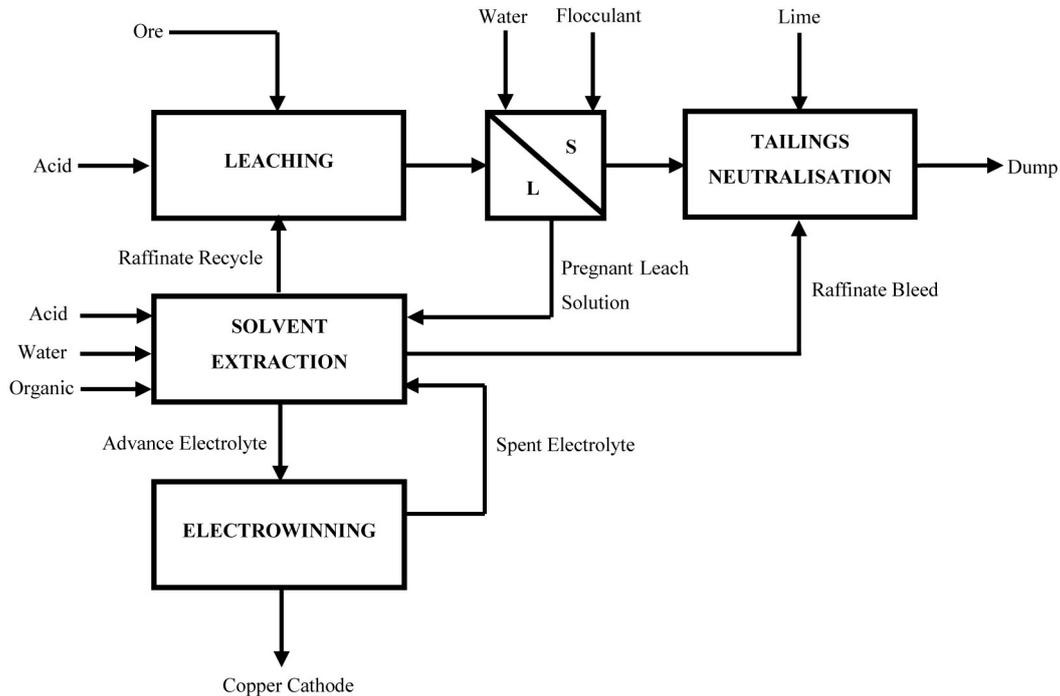


Figure 1. Simplified flow sheet of the copper hydrometallurgical process

The composition of the feed used in the study is shown in Table I and II.

Table I. Mass composition of the feed used in the study

Component	Mass composition
Silica (SiO ₂)	94.7%
Copper oxide (CuO)	3.7%
Goethite (FeO(OH))	1.6%

Table II. Elemental composition of the feed used in the study

Component	Element composition (%)
O	51.76
Si	44.27
Cu	2.95
Fe	1.00
H	0.02

Based on this model, the factors listed above were adjusted individually, with all other conditions remaining constant. For each scenario, the overall recovery of copper was calculated using Equation [1].

$$\text{Copper Recovery (\%)} = \frac{\text{Mass of copper produced}}{\text{Mass of copper in ore}} \times 100 \quad [1]$$

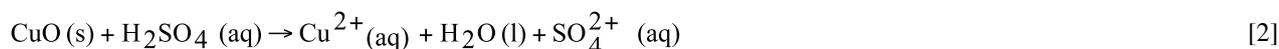
Process description and model development

The following section provides a brief theoretical background on the main processes occurring in the circuit: leaching, separation, SX, EW and tailings treatment. The costing methodology is also given, and the assumptions used to construct the model for the base case are discussed. After the construction of the base-case model, the operating conditions are then varied and effects on recovery, reagent requirements, and operating expenses are calculated. For each case, the copper recovery, reagent and water consumption, and profitability are compared.

Leaching

The ore is crushed and milled to increase the liberation of copper-containing minerals and to improve reaction kinetics. The ground ore is then mixed with the lixiviant in an agitated tank, where the copper is leached into solution. The reaction kinetics depend on the particle size, concentration of acid, residence time, and temperature.

The leaching reaction is given by Equation [2].



The base-case model of the circuit used for calculation involved four agitated leach tanks, arranged in series. Sulphuric acid, water, and ore were added to the first leach tank. The leaching of both copper and iron were modelled using rate-based equations. The rate expression used is shown as Equation [3]:

$$k[\text{H}_2\text{SO}_4][\text{CuO}_{(s)}] \quad [3]$$

where

k is the rate constant (L/mol.h) and
 $[\text{H}_2\text{SO}_4]$ and $[\text{CuO}]$ are concentrations (mol/L).

Typical leaching rates of copper oxide after four hours are 97%. Assuming a rate expression in the form shown in Equation [3], a rate constant was found that would leach 96% to 97% of the copper. The values found for the copper and iron reactions were 12 and 0.1 respectively. The leaching reactions and rate expressions of copper and iron are given by Equations [2] and [4] to [6] and are shown in Table III.

Table III. Leaching reactions and rate expressions used in the study

Component	Leaching reaction	Rate expression
Copper	$\text{CuO}_{(s)} + \text{H}_2\text{SO}_{4(aq)} \rightarrow \text{CuSO}_{4(aq)} + \text{H}_2\text{O}_{(l)}$ (2)	$12 * [\text{H}_2\text{SO}_{4(aq)}] [\text{CuO}_{(s)}]$ (4)
Iron	$\text{FeO}(\text{OH})_{(s)} + 1.5 \text{H}_2\text{SO}_{4(aq)} \rightarrow 0.5 \text{Fe}_2(\text{SO}_4)_3(aq) + 2 \text{H}_2\text{O}_{(l)}$ (5)	$0.1 * [\text{H}_2\text{SO}_{4(aq)}] [\text{FeO}(\text{OH})_{(s)}]$ (6)

A sensitivity analysis was performed to observe the effects of changes in the concentration of acid on the rate of copper leaching. The acid concentration was varied from 2 g/L to 8 g/L. The results are shown in Figure 2.

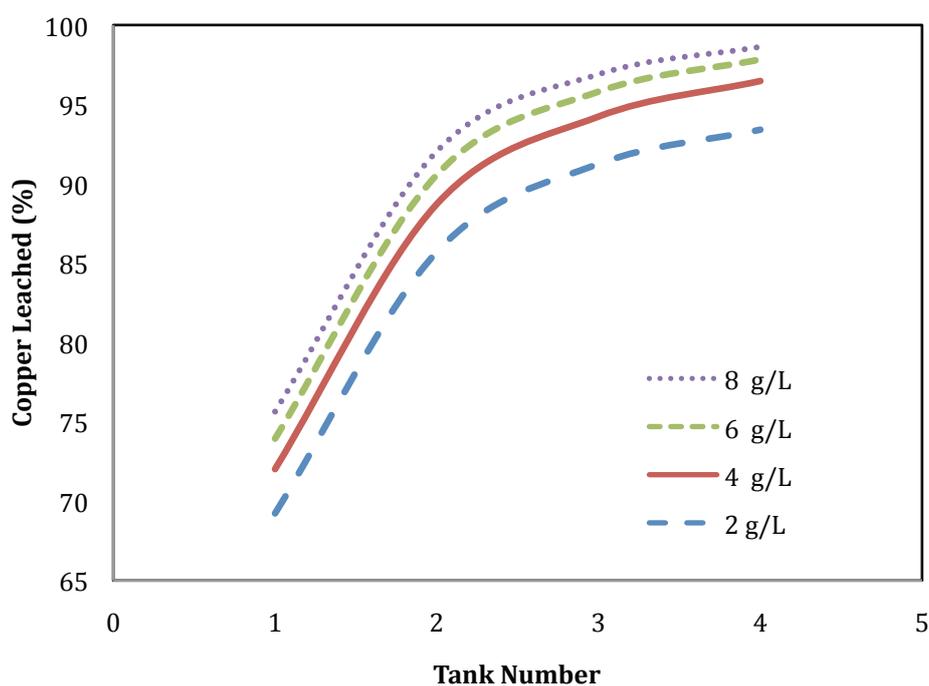


Figure 2. Effect of changes in the acid concentration of the leach slurry leaving the leach circuit on the leaching of copper

As the concentration of acid in the leach slurry was increased, the rate of leaching increased, but by a progressively smaller amount. Increasing the acid concentration from 2 g/L to 8 g/L in stages of 2 g/L increased the copper extraction from 93.4% to 96.5% (a 3.1% increase) to 97.8% (1.3% increase) to 98.6% (0.8% increase) respectively.

Solid-liquid separation

The leach slurry is transferred to a post-leach thickener (PLT) followed by a countercurrent decantation (CCD) circuit consisting of five thickeners placed in series. Wash water was added to the PLT in a ratio of 1.5 t of water to 1 t of solids in the feed to the CCD circuit. Flocculant was added to each of the thickeners at a rate of 40 g of flocculant per ton of solids. The flocculant was diluted to 0.25%. In the base model, the underflow of each thickener was set to 50% solids. The process resulted in a liquid pregnant leach solution (PLS) and underflow containing 50% solids. The underflow from the CCD circuit is sent for neutralization and then discarded as tailings.

Solvent extraction

In order to produce LME grade A copper, the PLS must be cleaned of both solids and impurities. The method used to remove impurities is solvent extraction (SX). This involves extraction stages and stripping stages, which may be organized in series or in combined series-parallel circuits. Each stage may consist of up to three units, known as mixer-settlers. In the extraction stage, the PLS is contacted with an immiscible organic phase with a high affinity for copper. The copper is transferred to the organic phase as a result of the extractant component of the organic forming a complex with the Cu^{2+} ion in the PLS (from this point onward will be referred to as the aqueous phase). At the same time, H^+ is

transferred from the organic to the aqueous phase. The organic and aqueous phases are separated by gravity settling and the aqueous phase, known as the *raffinate*, containing impurities, is returned to the leaching circuit. The acid leaving the extraction process may be used for leaching. The extraction reaction is given by Equation [7], where HX represents the barren organic and CuX_2 is the loaded organic.



The reaction between the organic and aqueous phases is sensitive to the concentration of sulphuric acid. The loading of the organic is favoured by low acid concentrations in the PLS. Increasing the concentration of acid shifts the equilibrium to the left and reverses the extraction reaction, resulting in stripping. In the stripping stage, the *loaded organic* is contacted with *spent electrolyte* from the electrowinning circuit. The copper ions are stripped from the organic phase to the electrolyte (Davenport, 2011).



The extraction achieved in the SX circuit is calculated based on extraction isotherms that are dependent on the concentrations of both the copper and acid in the PLS and the stripped solution. For each of the extraction and stripping units, solvent extraction isotherms were used to determine the equilibrium curve based on the PLS and spent electrolyte conditions respectively. The values for the isotherm used in these calculations are shown in Figure 3. These values are based on an extractant concentration of 30% and a diluent concentration of 70% at a temperature of 30°C. The actual values for each isotherm depend on the concentration of copper and the pH of the PLS.

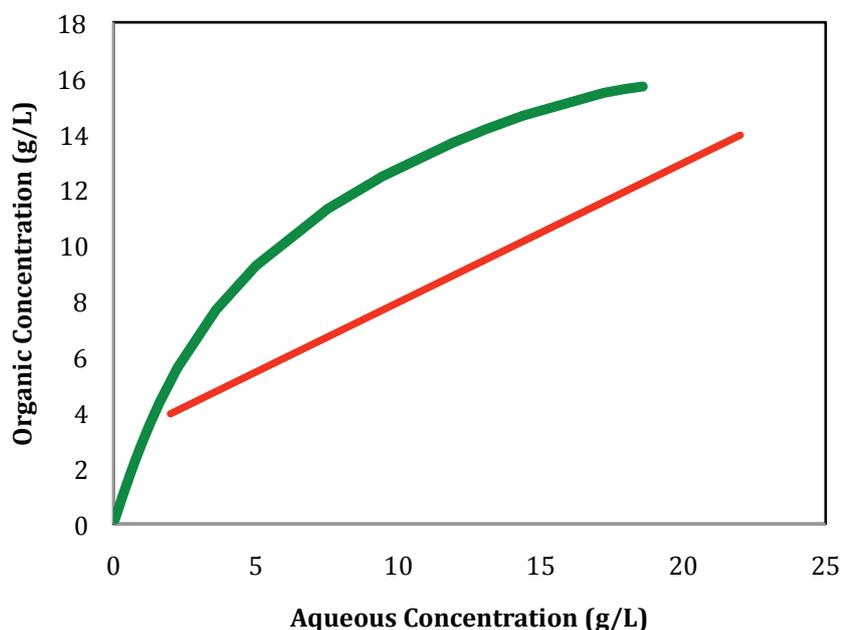


Figure 3. Solvent extraction isotherms are used to determine the extraction and stripping rates achieved in the solvent extraction circuit. Green curve is the extraction curve and red line is the operating line.

The circuit used in the model comprised three extraction stages and two stripping stages. In both the stripping and extraction stages, the aqueous entrainment was 150 ppm while organic entrainment was 50 ppm. Iron was extracted in the first extraction stage.

The extent of extraction of copper was 350 times that of iron. Of the raffinate produced in solvent extraction, 91.5% was recycled to the agitated leach section; the remainder was sent to the tailings section for neutralization and disposal.

An after-settler was placed after the stripping circuit, and it was assumed that perfect separation was achieved. This was to ensure that none of the entrained organic was passed on to electrowinning, as this would reduce the quality of copper produced. Fresh organic was added to the stripped organic stream to account for these losses.

The stripped organic phase is then recycled to the extraction unit, while the copper-rich electrolyte, known as the *advanced electrolyte*, is sent to electrowinning for copper cathode production.

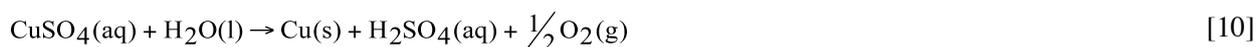
Electrowinning

During electrowinning, stainless steel cathodes and lead anodes are immersed in the advance electrolyte, which contains between 45 and 50 g/L Cu^{2+} , and a direct current is passed through the electrolyte. Pure copper metal is deposited on the cathodes as shown in Equation [9].



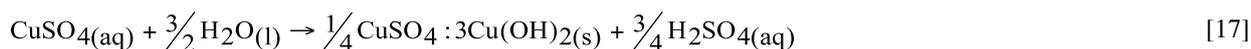
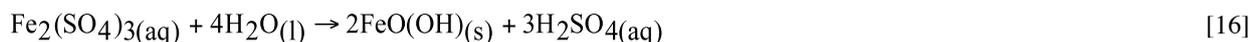
The copper is allowed to accumulate on the cathodes for a few days and is then stripped off and washed (Davenport, 2011).

Water make-up was required to bring the copper concentration of the electrolyte in the model down to 50 g/L before being sent to the electrowinning cells. The extent of the copper cathode plating reaction, given by Equation [10], was controlled to ensure a difference in the concentration of copper of 15 g/L over the tankhouse. The voltage used in the electrolytic cells was selected to result in a 2°C temperature rise across the cells. Concentrated acid was added to the spent electrolyte so that the stream recycled to solvent extraction contained 180 g/L sulphuric acid.



Tailings neutralization

Hydrated lime (90% $\text{Ca}(\text{OH})_2$ and 10% MgSiO_3) was added to the raffinate bleed and CCD underflow streams. A number of reactions, shown by Equations [16] to [19], occurred in the tank. The extent of reaction [18] was controlled to produce a solution with a calcium concentration of 0.5 g/L. The amount of lime added to the tank was adjusted to maintain a pH of 10 in the liquid stream leaving the tailings neutralization tank. At this pH, all the copper and iron precipitate out of solution.



Economic analysis

For the economic analysis, the mass balance results were used to estimate the cost of producing copper from an existing operational plant. The estimate entailed calculating the possible revenue that would be obtained from selling the pure copper cathode and deducting the monthly operating expenses. This data was used to calculate the production cost per ton of copper. The effect of changes in the operating conditions on the production costs were then calculated for each of the options studied.

Historical copper prices (\$ per ton) are shown in Figure 4. The current copper price varies, but the average value of \$7700 per ton of copper for January to March 2013 was used in this analysis.

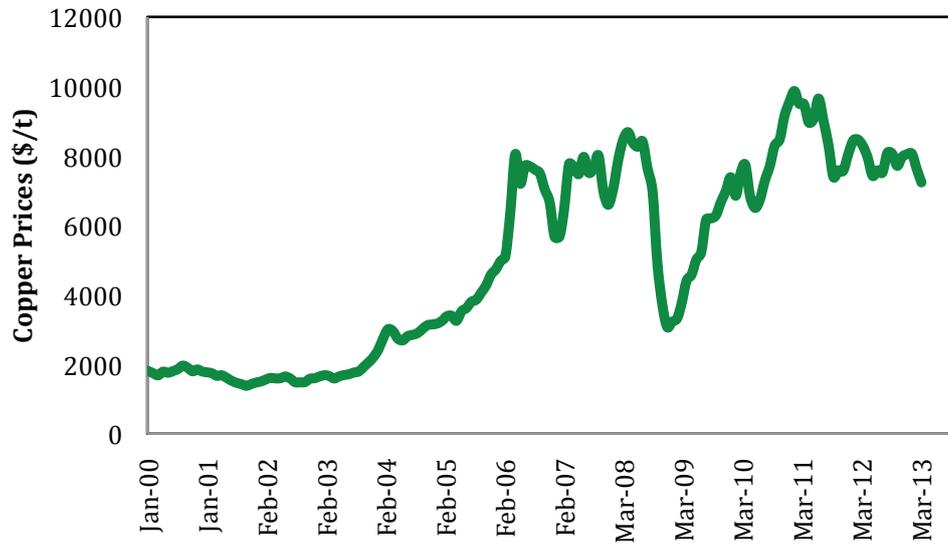


Figure 4. Historical copper prices from January 2000 to March 2013 (World Data Bank, 2013)

Methodology

The methodology used to complete the study is outlined in this section. Figure 5 summarizes the copper production circuit, reagents required per ton of ore, copper recovery, copper losses, and key concentrations for the base-case model.

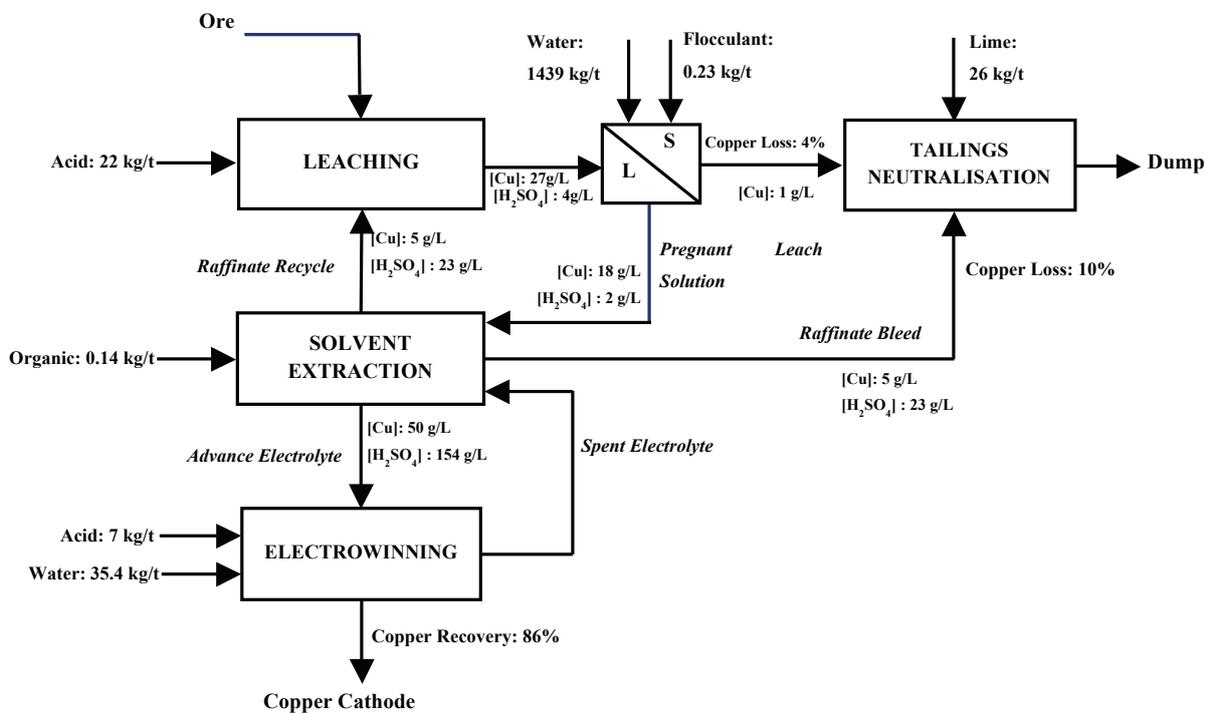


Figure 5. Summary of conditions used in the base model

Table VI is a summary of the conditions used in the base model. All other conditions were kept constant for all scenarios.

Table IV. Summary of conditions used in the base model

Conditions in the Base Model	
Wash water ratio	1.5
Percentage of solids in leach slurry	40%
Percentage of solids in underflow	50%
Number of CCD thickeners	5

The operating conditions that were varied were:

- The wash water ratio
- The percentage of solids in the leach slurry
- Percentage of solids in the CCD underflow
- The number of CCD thickeners.

At least two variations from the base case were modelled for each operating condition that was investigated. A total of thirteen options were modelled, including the base case. These are outlined in Table V.

For each variation a Cycad Process® model was run maintaining all conditions as specified. Special attention was paid to the concentration of acid and the concentration of solids in the leach slurry. These were controlled by adjusting the amount of fresh acid added to the leach tanks and the raffinate recycle fraction. The volume of the leach tanks was set to maintain a residence time of 1 hour in the base case.

Table V. Cases analysed in the study

Case	Description
Base	Base model as described above
Option 1	Wash water ratio increased to 2
Option 2	Wash water ratio increased to 3
Option 3	Solids concentration in leach slurry reduced to 20%
Option 4	Solids concentration in leach slurry reduced to 30%
Option 5	Solids concentration in leach slurry increased to 50%
Option 6	Solids concentration in CCD underflow decreased to 40%
Option 7	Solids concentration in CCD underflow increased to 60%
Option 8	Number of CCD thickeners decreased to 2
Option 9	Number of CCD thickeners decreased to 4
Option 10	Number of CCD thickeners increased to 6
Option 11	Number of CCD thickeners increased to 8
Option 12	Number of CCD thickeners increased to 9
Option 13	Number of CCD thickeners increased to 10

Results

In this section, the effect of changes in the circuit configuration on the recovery of copper, reagent, and water addition is presented.

Base model

Table VI gives the results obtained in the base model for copper recovery and copper losses, reagent consumption rates, and the economic evaluation values. These results will be considered individually for each of the options modelled. The copper feed rate in the ore was 22.7 t/h.

Table VI. Base model results

Copper recovery	%	86.1
Copper losses in CCD underflow	t/h	0.8
Copper losses in raffinate bleed	t/h	2.3
Acid addition	t/h	22.6
Lime addition	t/h	20
Organic addition	t/h	0.1
Water addition	t/h	1145
Production cost	\$/t	4450

Effect of increasing the wash water ratio on copper circuit performance

The base case, which is operated at a wash water ratio of 1.5, was found to have an overall recovery of 86.1%. As the wash water ratio is increased to 2 and 3, the recovery decreases, as shown in Figure 6.

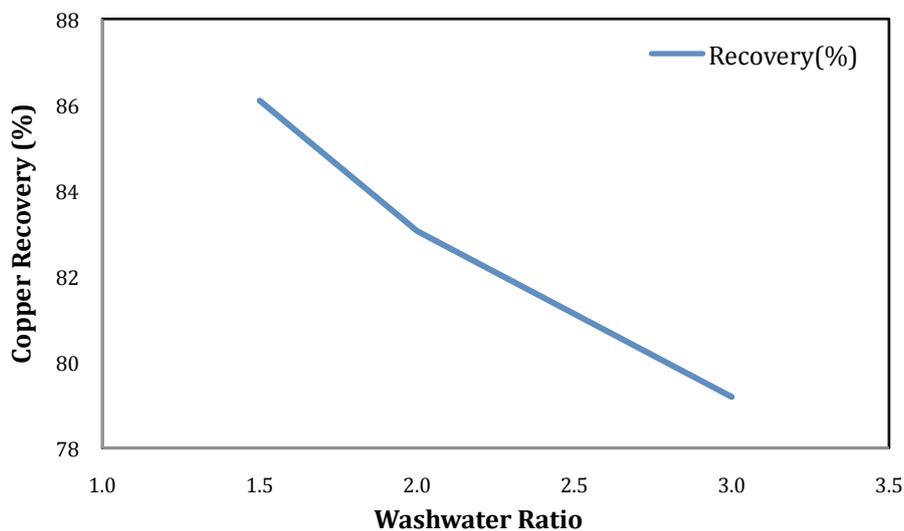


Figure 6. Effect of wash water ratio (mass water per mass solids) on overall copper recovery

The addition of water to the circuit increases the flow rate of the PLS. As the volume of PLS increases, the raffinate recycle to the leach will increase, resulting in dilution of the leach circuit and thus a decrease in recovery. In order to maintain the required solids concentration in the leach, the raffinate bleed to tailings is increased. The amount of copper lost through the raffinate bleed will thus increase, reducing the overall recovery. This is illustrated schematically in Figure 7.

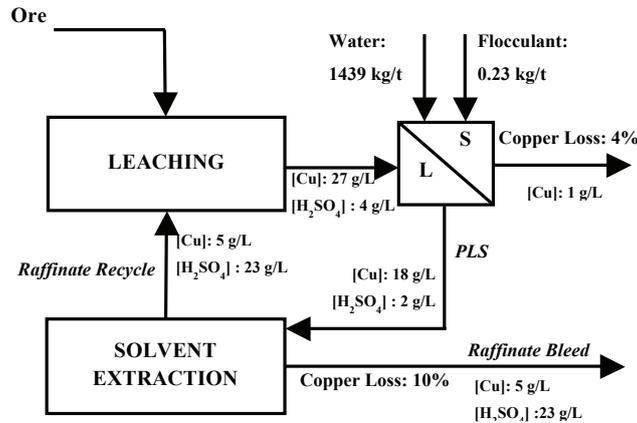


Figure 7. The effect of an increase in the PLS volume on the raffinate bleed and reagent addition to the SX circuit

Increasing the volume of the PLS also dilutes the acid present in the stream and thus the acid addition to the circuit increases. The volume of PLS also affects the organic requirements as more organic is entrained in the raffinate. The effect of wash water ratio on reagent addition is shown in Figure 8

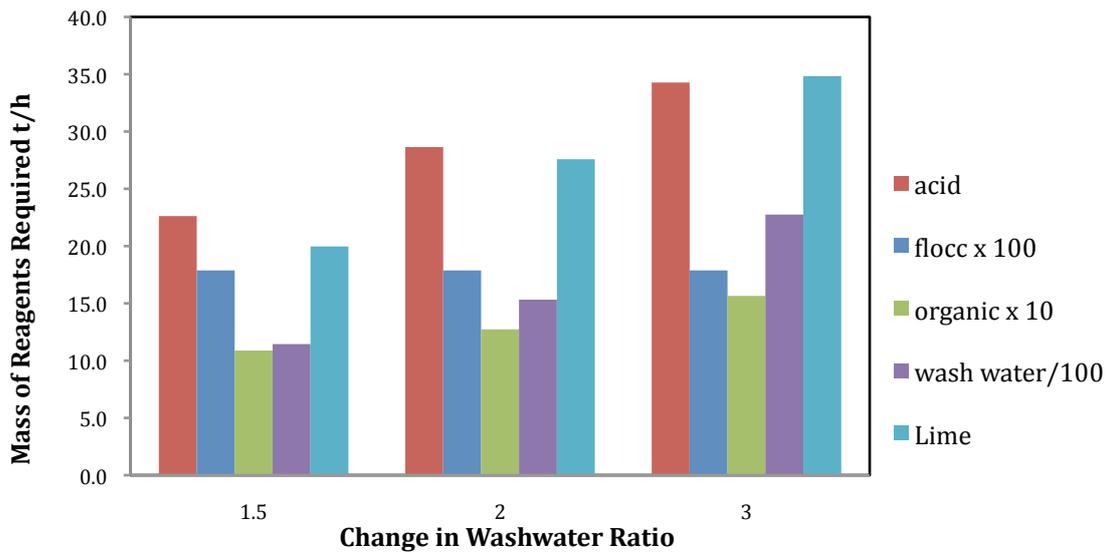


Figure 8. Effect of increasing the wash water ratio (mass water per mass solids) on reagent and water additions to the circuit

As the wash water ratio is increased, the flow of PLS increases. To maintain a constant organic/aqueous ratio, the amount of organic required increases.

The increase in the raffinate bleed results in the loss of acid from the circuit and as a result, more acid is required for leaching and stripping. The increase in acid results in an increase in the amount of lime required for neutralization.

Effect of changing solids concentration in the leach slurry on copper circuit performance

In Options 3 to 5 (Table V), calculations were done in which the concentration of solids in the leach slurry was varied from 20% to 50%. The results are shown in Figure 9.

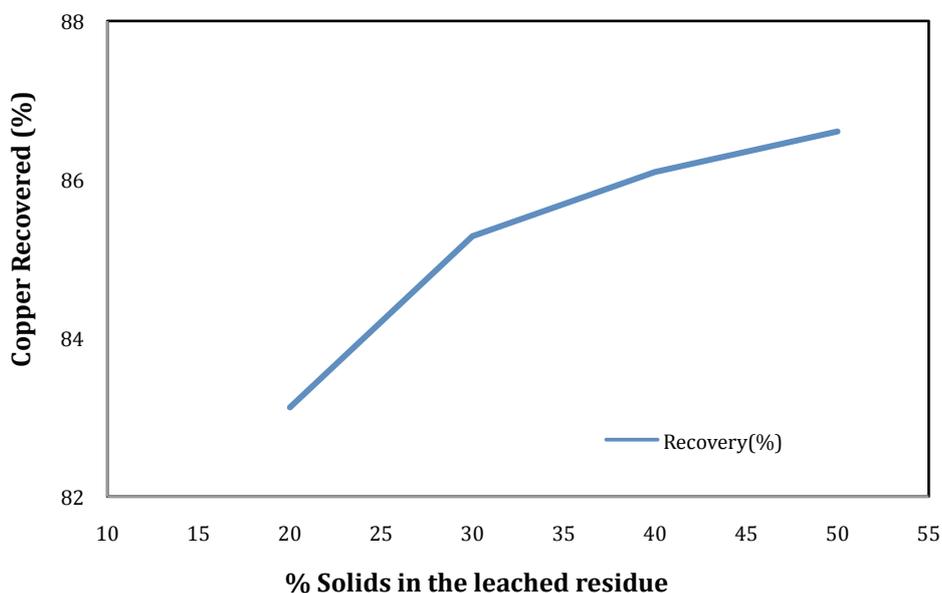


Figure 9. Effect of solids concentration in the leach slurry on copper production

Leach tank volumes and ore flow rates are kept constant while the amount of raffinate that is recycled to the agitated leach is controlled to change the concentration of solids leaving the leach tanks. In order to decrease the exit concentration of solids, more raffinate is recycled to the leach, which increases the total flow rate into the leach tanks. The volumetric flow into the leach tanks increases in order to decrease the solids concentration, which decreases the residence time, resulting in a decrease in the amount of ore that is leached. Increasing the concentration of solids decreases the volumetric flow through the leach tanks and increases the residence time in the leach tanks. This increases the copper recovery over the leach circuit and the overall copper recovery.

The effect on reagent and water requirements is shown in Figure 10.

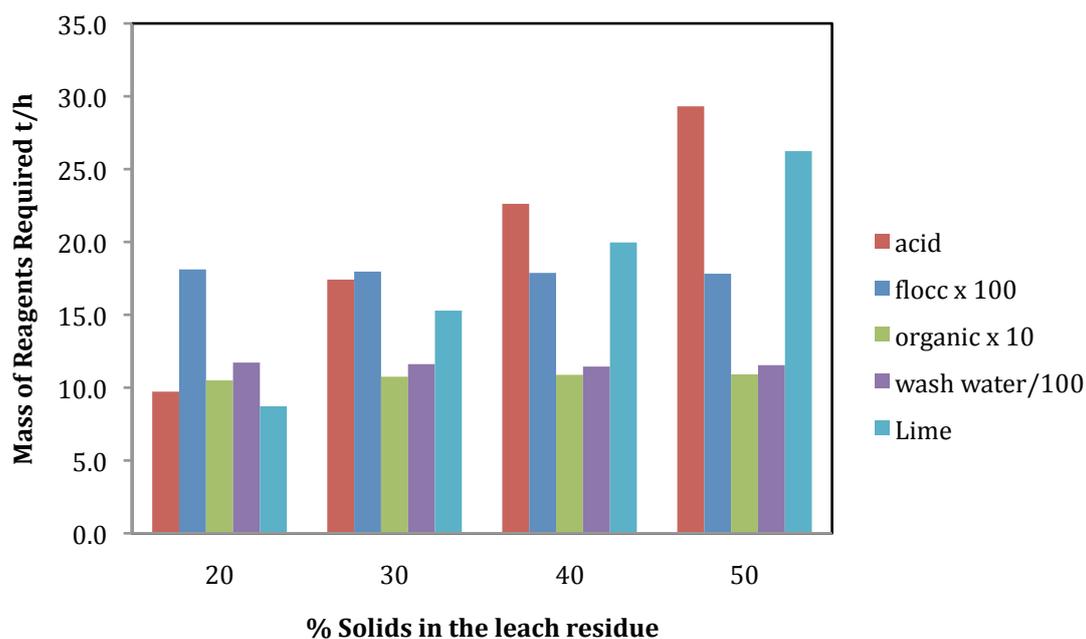


Figure 10. Effect of solids concentration in the leach slurry on acid, lime, and organic requirements

As the concentration of solids in the leach slurry decreases, the volume of liquid flowing to the thickener circuit increases. The solids concentration in the thickener underflow is maintained at 50%. As a result, the PLS volume increases. This increases the amount of organic required to maintain the desired O:A ratio as well as the organic lost through entrainment. The increase in the PLS volume and flow rates through the SX circuit increases the flow rate of the raffinate stream. In order to maintain the solids concentration in the leach, more raffinate is bled to tailings. This increases the amount of acid lost to tailings. More acid is therefore required for the leaching circuit to maintain acid concentrations in the leach slurry. Increasing the acid addition to the copper circuit results in an increase in the lime required for neutralization.

Effect of changes in solids concentration in the CCD underflow on copper circuit performance

Increasing the concentration of solids in the CCD underflow results in an increase in the recovery of copper. However, with this increase in recovery there is a concomitant increase in the consumption of all reagents.

As the fraction of solids in the underflow is increased, less soluble copper is lost to tailings. This results in an increase in the copper concentration in the PLS that flows to the stripping and electrowinning circuits. This explains the relationship between concentration of solids and copper recovery as shown in Figure 11.



Figure 11. Effect of solids concentration in the CCD underflow on copper recovery

Figure 12 shows that the consumption rate of all reagents increases as the concentration of solids in the CCD underflow increases. As the solids concentration increases, the volume of liquid in the thickener overflow (PLS) increases, which increases flow rates through the stripping and electrowinning circuits.

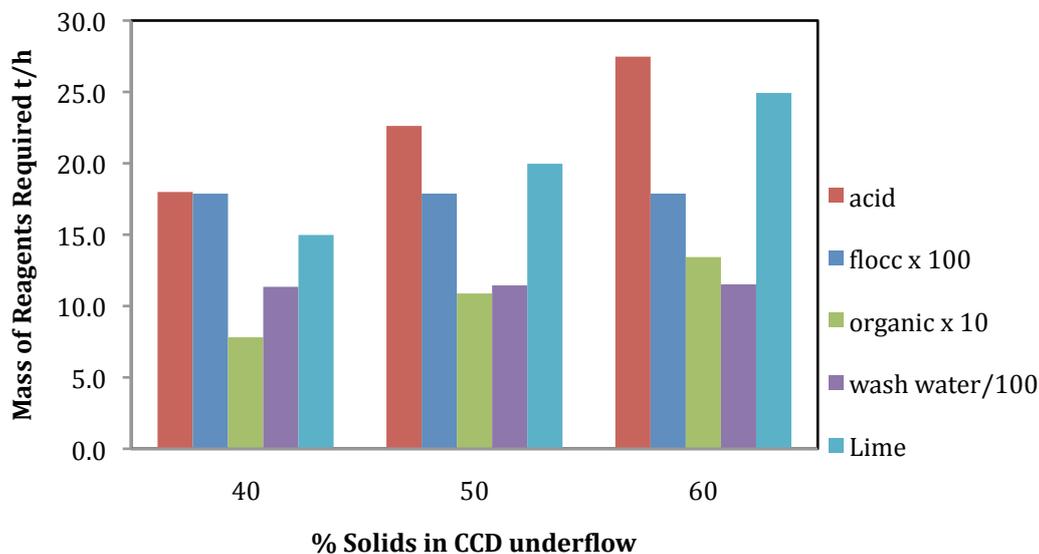


Figure 12. Relationship between the solids fraction in the CCD underflow and various reagent consumption rates

In order to effectively maintain the concentration of solids in the leach circuit, the raffinate bleed is increased, which results in more copper lost to tailings. The amount of sulphuric acid lost in the bleed stream also increases, requiring an increase in fresh acid addition to maintain the desired acid concentration in the leach slurry. Increasing the acid requirement consequently increases the lime required for neutralization.

As the volume of PLS increases, a greater amount of organic is needed to maintain the desired O:A ratio and to compensate for the increase in organic losses due to entrainment in the SX circuit. As the amount of copper fed to the SX circuit increases, more water is required to reduce the copper concentration in the advance electrolyte to 50 g/L.

Effect of changing the number of CCD thickeners on copper circuit performance

Adding more CCD thickeners to the circuit results in an increase in copper recovery. Simultaneously, the consumption rates of organic and water increase, while those of acid and lime decrease. A comparison with the base case is shown in Figure 13.

However, there is minimal further improvement after nine CCD units. This is shown in Figure 13. As the number of thickener units increases, washing efficiency increases, which results in a decrease in the copper losses in the CCD underflow. This causes more copper to be washed from the slurry into the PLS rather than being lost to tailings. More thickeners placed in the CCD circuit therefore allow for a PLS with a higher copper concentration, and as a result, more copper is available to be recovered in the electrowinning cells.

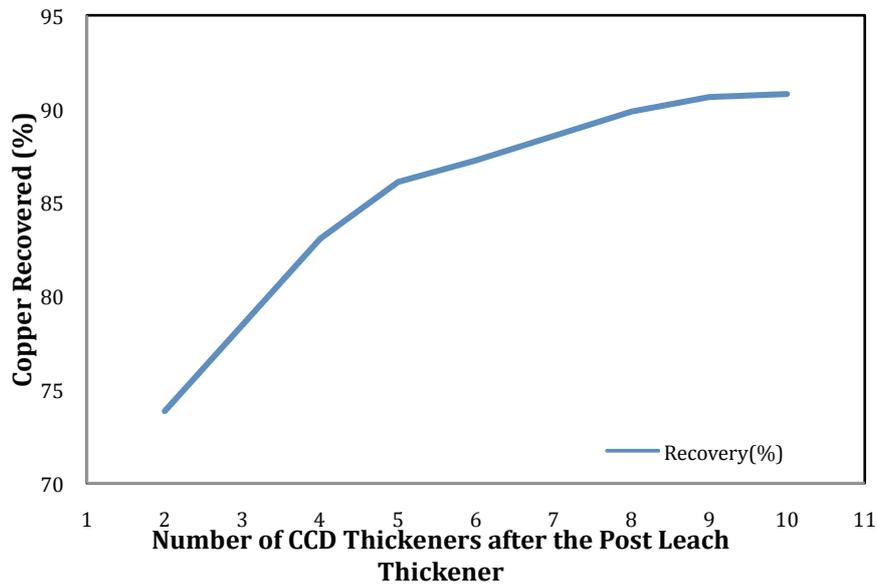


Figure 13. Effect of number of CCD thickeners on copper recovery

Figure 14 shows that as the number of CCD thickeners is increased, the rate of acid and lime consumption decreases while that of water and organic increases.

As the number of CCD thickeners increases, the acid consumption decreases. Increasing the number of thickeners while maintaining the same wash water volume results in overflow that contains a greater amount of both copper and acid. As a result, less acid is required to provide the desired concentration in the SX cells and leach slurry, which in turn decreases the amount of lime required for neutralization.

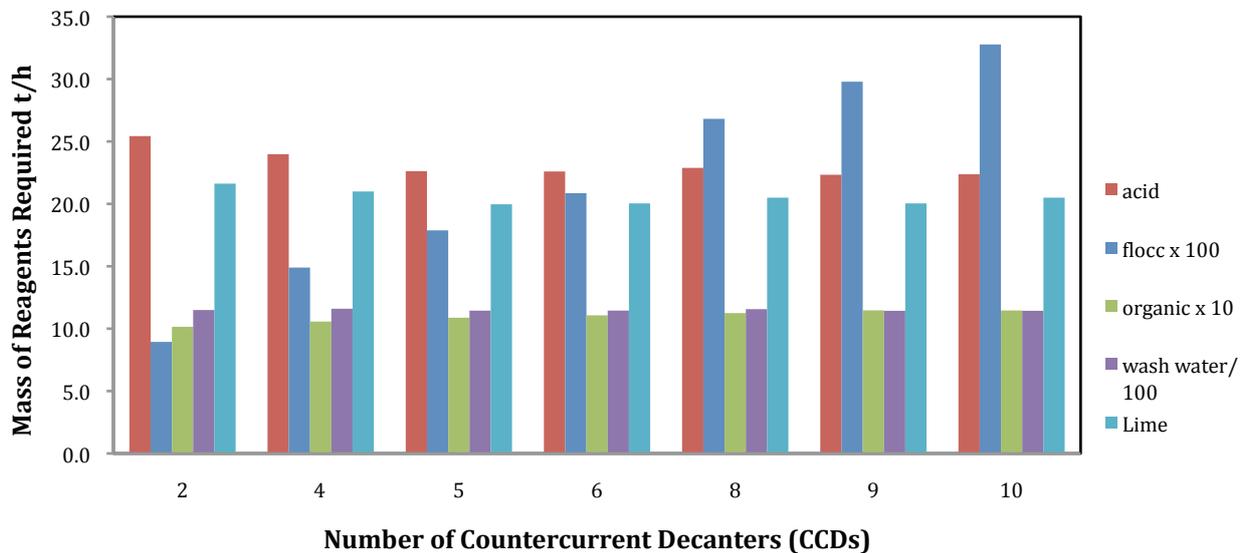


Figure 14. Effect of the number of CCD units on flocculant, water, and organic requirements and acid and lime additions

Flocculant addition increases as the number of CCD units increases, since additional flocculant is required for each thickener. Water addition to the SX circuit increases as the number of thickeners increases. More thickeners result in a better washing efficiency and an increase in the concentration of copper in the PLS and SX streams, which increases the amount of water required to dilute the copper advance electrolyte to the desired 50 g/L.

Economic effects of changes in operating conditions on copper production cost

For the economic analysis, the mass balance results were used together with costing estimates from the literature and previous projects to estimate the cost of producing copper from an existing operational plant. The estimate entailed calculating the possible revenue that would be obtained from selling the pure copper cathode and deducting the daily operating expenses. This data was used to calculate the production cost per ton of copper. The effect of changes in the operating conditions on the production costs were then observed for each of the options studied.

Effect of wash water ratio on the copper production cost

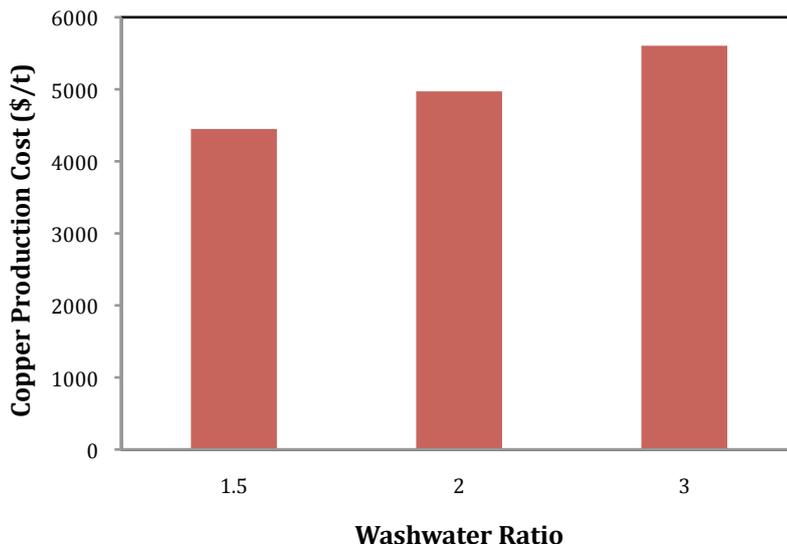


Figure 15. Increasing the wash water ratio increases the copper production cost

As discussed in the results section, increasing the wash water ratio decreases the recovery and increases reagent and water addition to the circuit. This results in an increase in the copper production cost from \$4500 per ton at a wash water ratio of 2 to \$5600 per ton at a wash water ratio of 3 (Figure 15).

Effect of leach slurry solids concentration on copper production cost



Figure 16. Increasing the leach slurry solids concentration increases the copper production cost

Although increasing the concentration of solids in the leach slurry increases the copper recovery, it also results in an increase in the addition of acid, lime, and organic to the circuit. Although the copper recovery increases, the increase in the cost of reagents required is greater than the gain in revenue. This has an overall negative effect on the production cost (Figure 16). The cost of producing one ton of copper at 20% solids is \$3800, while at 50% solids it increases to \$4800.

Effect of solids concentration in the thickener underflow on copper production cost

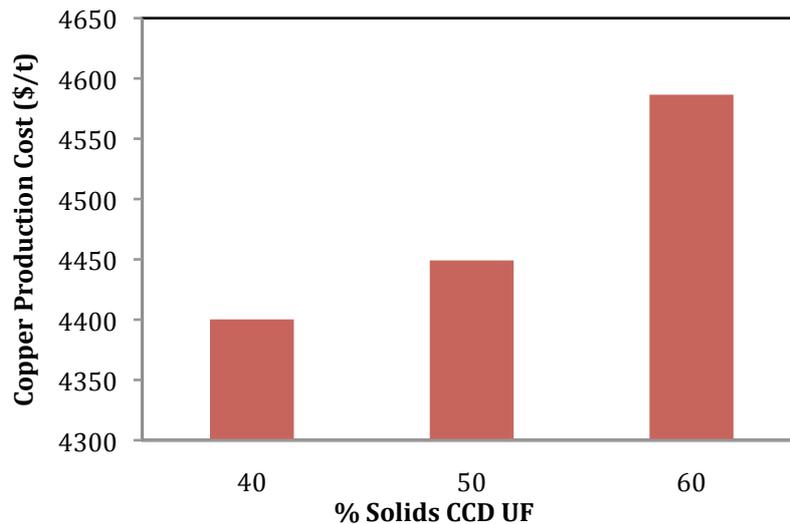


Figure 17. Increasing the solids concentration in the thickener underflow increases the copper production cost

Increasing the concentration of solids in the thickener underflow increases both copper recovery and the reagent requirements. Although the copper recovery increases, the increase in the cost of reagents is greater than the increase in revenue. This has an overall negative effect on the production cost (Figure 17). The cost of producing one ton of copper rises from \$4400 at 40% solids in the thickener underflow to \$4600 at 60% solids (Figure 17).

Effect number of CCD units after the post-leach thickener on copper production cost

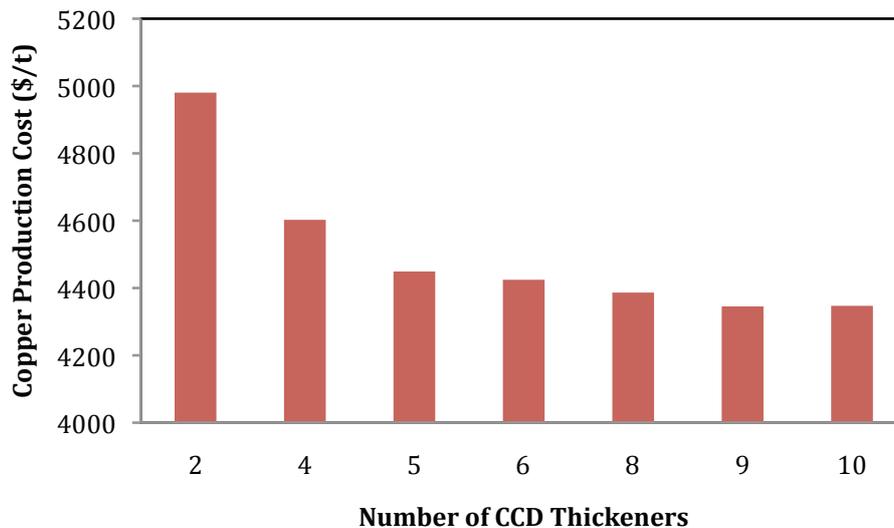


Figure 18. Increasing the number of CCD units decreases the copper production cost

Increasing the number of CCD units increases the overall copper recovery and the water, organic, and flocculant requirements, and decreases the lime and acid requirements. The decrease in acid and lime requirement, together with the increase in recovery, has a greater effect on copper production cost than the increase in water, organic, and flocculant addition. This results in a decrease in the production cost of copper per tonne as the number of CCDs increases (Figure 18). Table VII shows the decrease production costs as the numbers of CCDs increases.

Table VII. Relationship between number of CCD units and copper production cost

Number of CCD units	Copper production cost (\$/t)
2	4980
4	4603
5	4449
6	4425
8	4386
9	4345

Conclusions

Reagent consumption varied in each of the scenarios analysed. In all cases, as acid consumption increased, the lime consumption also increased.

Increasing the wash water ratio (mass water per mass solids) from 1.5 to 3 decreases the overall copper recovery by 6.9% from 86.1% to 79.2%. The decrease in recovery is due to the addition of water to the circuit, which increases the flow rate of the PLS and consequently the raffinate bleed. More copper is thus lost to tailings. The increase in PLS flow rate increases the reagent addition required by the circuit, which increases the production cost of copper from \$4450 to \$5605 per ton, which is an increase of \$1155 per ton of copper produced.

Increasing the concentration of solids in the leach slurry from 20% to 50% increased the recovery by 3%, but increased the production cost by \$990 per ton. Although the copper recovery increased, the increase in the cost of reagents required was greater than the increase in revenue.

Increasing the concentration of solids in the CCD underflow from 40% to 60% resulted in a 14% increase in recovery and an increase in the production cost of \$190 per ton of copper.

The most effective way to improve productivity and reduce the cost of producing copper is to increase the number of CCD thickeners. Of the options that were considered, the most significant increase in recovery and decrease in cost were achieved by increasing the number of CCD thickeners to 9 i.e. option 12 in Table V. The recovery increased by 4.5%, from 86.1% using 5 CCDs to 90.6% using 9 CCDs, while the production cost decreased from \$4450 per ton to \$4345 per ton of copper cathode. Decreasing the number of CCD units from 5 units to 2 units decreased the recovery by 12% and increased the production cost by \$530 per tonne of copper produced.

A summary of the results is shown in Table VIII.

Table VIII. Effect of various options on copper recovery and production cost

Option	Description	Recovery (%)	Production cost (\$/t)
Base	Base model	86.1	4449
Option 1	Wash water ratio increased to 2	83.1	4972
Option 2	Wash water ratio increased to 3	79.2	5605
Option 3	Concentration of solids in leach slurry reduced to 20%	83.1	3816
Option 4	Concentration of solids in leach slurry reduced to 30%	85.3	4184
Option 5	Concentration of solids in leach slurry increased to 50%	86.6	4809
Option 6	Concentration of solids in CCD underflow decreased to 40%	77.3	4400
Option 7	Concentration of solids in CCD underflow increased to 60%	91.2	4587
Option 8	Number of CCD thickeners decreased to 2	73.8	4980
Option 9	Number of CCD thickeners decreased to 4	83.1	4603
Option 10	Number of CCD thickeners increased to 6	87.2	4425
Option 11	Number of CCD thickeners increased to 8	89.9	4386
Option 12	Number of CCD thickeners increased to 9	90.6	4345
Option 13	Number of CCD thickeners increased to 10	90.8	4347

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