Introduction

Copper at the Ruashi II plant is leached into solution in stirred tanks and is then recovered in a counter-current-decantation (CCD) circuit. The pregnant liquor solution (copper-rich solution) from the CCD circuit goes to a solvent extraction plant, followed by an electrowinning plant where the final copper product is produced. The washing efficiency in the CCD circuit is important to the overall copper production. The basis of CCD operation is to concentrate suspended solids thereby minimizing liquor content in underflow slurry. The underflow slurry liquor is diluted with wash liquor and the suspended solids are concentrated again.

The amount of liquor in the thickener underflow is a parameter in determining the number of CCD stages required to recover the desired amount of soluble metal. Minimizing liquor in the underflow leads to a higher recovery of soluble metal. This paper reviews the process used to select high density thickeners (HDT) versus high rate thickeners (HRT) for the Ruashi II copper-cobalt hydrometallurgical process in the Democratic Republic of Congo (DRC), from lab HDT simulations, to CCD simulations and thickener design details.

Soluble metal recovery improvement using high density thickeners in a CCD circuit: Ruashi II a case study

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Counter current decantation (CCD) thickener circuits are used to recover soluble metal as pregnant liquor solution from ore leach residue. The basis of CCD operation is to concentrate suspended solids thereby minimizing liquor content in underflow slurry that flows in one direction. Then the underflow slurry liquor is diluted with wash liquor, that flows in the opposite direction, and the suspended solids are concentrated again and again.

The amount of liquor in the thickener underflow contributes to determining the number of CCD stages required to recover the desired amount of soluble metal. High density thickeners (HDT) are designed to use gravity and compression, and minimize the amount of liquor in the underflow, thus minimizing the number of CCD stages. This paper reviews the process used to select HDTs versus high rate thickeners (HRT) for the Ruashi II copper-cobalt hydrometallurgical process in the Democratic Republic of Congo (DRC), from lab HDT simulations, to CCD simulations and thickener design details.
process used to select the best thickener technology for the Ruashi II copper-cobalt hydrometallurgical process in the Democratic Republic of Congo (DRC), starting with lab simulations, then to CCD simulations, and finally thickener design details.

**Lab simulations**

The process simulations of milling and leaching the ore was performed by Mintek. Various leached samples were supplied to FLSmidth Minerals for thickening testwork. All post-leach thickening testwork was done straight after the leach was done in order to prevent ‘ageing’ of the sample.

**Thickening testwork**

The thickener simulations used a combination of bench-scale batch tests and continuous fill tests to measure the physical characteristics to be used in the size selection and design of the thickeners.

**Settling and flocculant flux curves**

Figure 1 exhibits a summary of the measured suspended solids settling flux (kg/h/m²) versus feed slurry suspended solids concentrations at different flocculant doses. A maximum settling flux is identified at a suspended solids concentration of between 7 and 8 wt%. The thickener feed slurry must be diluted to this concentration to optimize flocculation and suspended solids settling flux.

Figure 2 exhibits a summary of the measured suspended solids settling versus flocculant dose at different feed slurry suspended solids concentrations. The optimal flocculant dosage is identified by a small change in settling flux at between 50 g/t and 60 g/t.

**Batch and continuous thickener simulations**

Various batch simulations were done at the optimal feed solids percent and optimal flocculant dosage conditions. The average underflow density achieved in the batch tests was 55% solids (by mass).

Various continuous simulations with rakes were done to check the effect of residence time on underflow suspended solids concentration. Figure 3 exhibits the residence time required to
concentrate the slurry. These simulations are used to determine the suitability of using a high density thickener rather than a high rate thickener. As one can see in Figure 3, the continuous simulation achieved an underflow suspended solids concentration of 59 wt% when the mud residence time is between 4 and 6 hours. This residence time is normally associated with high density thickeners.

**Rheology for thickener**

Rheology measurements were taken using a Haake VT550 vane viscometer using FLSmidth Minerals procedures. The slurry yield stress, the force required to produce movement from a stationary bed, is measured at various underflow suspended solids concentrations. The yield stress is a function of physical properties of the suspended solids (including chemical composition, particle size distribution and concentration), flocculant type, flocculant dose, and temperature.

The yield stress results are used to:

- Define the limit to underflow density each thickener type can achieve based on ability to discharge
- Define the torque required to rotate the rakes during normal and abnormal operation. The thickener rakes must be able to restart in unsheared slurry after an unscheduled shutdown. FLSmidth Minerals thickener rake design and drive torque are designed to overcome this most severe condition.

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**Figure 2. Optimal flocculant dosage**

**Figure 3. Continuous test showing mud residence time vs. solids %**
Figure 4 identifies a general relationship of thickener type to yield stress or underflow suspended solids concentration. Typically conventional thickeners (CT) and HRT are designed to consistently discharge underflow slurries exhibiting a yield stress of ~<25 Pa. FLSmidth Minerals HDT is designed to consistently create and discharge underflow slurries exhibiting a yield stress ~<100 Pa. FLSmidth Minerals deep cone paste thickeners (DCPT) are designed to consistently create and discharge underflow slurries exhibiting ~<500 Pa.

The yield stresses measured at various slurry suspended solids concentrations for the Ruashi post-leach sample is shown in Figure 5. As one can see on the graph, at an underflow density of 55% the yield stress is 20 Pa, and at an underflow density of 59% the yield stress is 60 Pa.

At 60 Pa yield stress a FLSmidth Mineral HDT should be used. As was seen above, the residence time to achieve 59 wt% underflow suspended solids was between 4 and 6 hours.

Counter current decantation (CCD) simulations

Once the laboratory thickener simulations were completed, measured data were used to simulate various counter current decantation (CCD) design options. These CCD simulations calculate soluble metal recoveries for changes in all the main variables affecting CCD wash recovery, which are:

- Suspended solids concentration in underflow slurry
- Soluble metal content in wash liquor
• Suspended solids concentration in leach residue of CCD feed
• Wash ratio (mass wash liquor/mass suspended solids)
• Interstage mixing efficiency.

These different soluble metal recoveries form the basis for a sensitivity analysis of the CCD circuit. (Figure 6.)

**CCD wash recovery**

Metorex Ltd’s feasibility study used a high rate thickener performance scenario for the CCD soluble metal recovery. The underflow suspended solids concentration was 55 wt%. Metorex’s requirement was to achieve 99% soluble copper recovery in the CCD circuit. The initial CCD Circuit design variables are shown in Table I below.

As shown in Figure 7, a minimum of 6 stages would have been required to obtain the wash recovery of >99% at the HRT operating conditions.

**Variables influencing wash recovery**

The five variables shown in Table I are the variables that have an influence on the overall CCD wash recovery. The wash ratio and underflow suspended solids concentration, however, are the two variables that have the greatest influence on wash recovery.

<table>
<thead>
<tr>
<th>Wash ratio</th>
<th>U/F suspended solids concentration (wt%)</th>
<th>Interstage mixing efficiency (%)</th>
<th>Soluble Cu in wash liquor (g/l)</th>
<th>Feed suspended solids concentration (wt%)</th>
<th>Soluble Cu recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6</td>
<td>55</td>
<td>95</td>
<td>0.0</td>
<td>30</td>
<td>99</td>
</tr>
</tbody>
</table>

**Figure 6. High density thickeners**

**Table I**

Variables used in CCD wash recovery calculations

**Figure 7. CCD high rate thickeners wash recovery**
Figure 8 below shows that a greater difference in wash ratio, from 1.1 to 2.1, has a significant effect on CCD wash efficiency (% soluble metal recovery). Increasing the wash ratio from 1.6 to 2.1 does not offer significant benefits at 5 stages of CCD and more. It can also be seen from Figure 8 that 5 stages at a higher wash ratio of 2.1 can achieve the 99% wash recovery rather than the 6 stages at a wash ratio of 1.6. The recommended wash ratio will be between 1.6 and 2.1.

Figure 9 shows that a greater difference in underflow suspended solids concentration, from 55 wt% to 59 wt% has a significant effect on the number of stages required. An underflow suspended solids concentration of 59 wt% can be produced by a high density thickener, 5 stages are able to achieve the 99% wash recovery rather than the 6 stages at underflow densities of 55 wt%.

It is evident from Figures 8 and 9 that both wash ratio and underflow suspended solids concentration have a big influence on the wash recovery (efficiency):

- Increasing both the underflow (from 55 to 59 wt%) and wash ratio leads to an increase in wash efficiencies
- By increasing the underflow solids concentration from 55 to 59 wt% five stages are required to achieve similar wash efficiencies as six stages at 55% as shown Figure 9
- Keeping the number of stages and underflow solids concentration the same, a 0.51% increase in wash efficiency can be realized by increasing the wash ratio from 1.6 to 2.1.

Figure 8. Sensitivity to wash ratio

Figure 9. Sensitivity to underflow suspended solids concentration
The above is based on ± 95% interstage mixing efficiencies between CCD stages.

It can be seen in the above analysis, selecting high density thickeners rather than high rate thickeners, means that 5 stages can be used instead of 6 stages to achieve the required wash recovery. This means that the wash ratio of 1.6 can be used. By keeping the wash ratio at 1.6, the soluble copper concentration reporting downstream to the solvent extraction plant is greater and the plant does not need to be increased in size (i.e. if the wash ratio was 2.1 the solvent extraction plant would need to increase in size to handle the additional solution volume).

**High-rate vs. high-density thickeners**

**CCD wash recovery**

In the previous section one can see the impact of underflow suspend solids concentration on the CCD wash recovery. The higher underflow suspended solids concentration means a greater wash recovery of soluble copper. This thus means that with all other variables the same, high density thickeners will always produce greater underflow suspended solids concentration because of a combination of gravity, compression and altering of permeability of the solids in the thickener. For Ruashi II this also means that with high density thickeners, the required wash recovery can be achieved with one fewer stage.

**Cost and payback implications**

In general there is a perception that high rate thickeners have a lower cost than high density thickeners. This is perhaps another reason for the preference for high rate thickeners in CCD circuits. However, high density thickeners are always smaller in diameter than high rate thickeners, allowing for a significant savings in installed cost. The use of high density thickeners at Ruashi has, however, meant one stage fewer in the CCD circuit. The high density thickener had an installed cost about the same as a high rate thickener, and with one fewer thickener in the CCD circuit offered a significant capital and operating cost saving.

Even if the same number of stages were to be used with a high rate CCD circuit or high density CCD circuit, the increase in wash recovery has a good payback. Table II is an indicative increase in income due to a 0.61% increase in wash recovery. The extra copper recovery leads to an extra 1.5 million dollars per annum. This increase in income leads to a quick payback for the additional cost of the high density thickeners.

**Differences in thickener design**

There are some differences in the design between the high rate and high density thickeners. The following list gives an overview of the main design differences between the two types of thickeners.

- **Tank side wall depth**—high density thickeners use a combination of gravity and compression to consolidate suspended solids. The mud residence time required to increase the underflow suspended solids concentration is achieved by increasing the sidewall height.
- **Tank floor slope**—due to the greater rheology as a consequence of higher underflow suspended solids concentration, a steeper floor slope is used to assists the slurry movement to the centre of the thickener for discharge.
- **Rake drive**—since high density thickeners are always smaller than high rate thickener, the unit torque of ‘K factor’ must be greater. Typically the same rake drive required for a high rate can be used for a high density thickener and achieve a significantly greater unit torque input.
- **Rake mechanism**—the rakes are designed to minimize the cross-sectional area of the mechanical members to minimize resistance or torque production and allow the most dense underflow suspended solids to discharge from the thickener. High density
thickeners also have pickets attached to the rake arms to alter the permeability of the compacted solids. Pickets create paths for the liquor in the compacted solids to escape, allowing solids concentration to continue.

- **Thickener discharge**—high density thickeners are designed with discharge cylinders with much more volume than cones to facilitate discharge and to minimize or prevent rat-holing or underflow dilution.

**Conclusions**

The use of extensive laboratory thickening simulations to measure solid-liquid separation properties and CCD simulations enabled good information to be gathered for the design of the Ruashi II CCD circuit. The use of the CCD simulations showed that higher underflow densities in the thickeners means 5 stages rather than 6 stages in the CCD circuit can be used to achieve the same wash recovery of soluble copper. This thus led to the decision to use high density thickeners in the CCD circuit rather than High Rate thickeners. The use of high density thickeners allows Capex and Opex cost savings to be made due to the reduced number of stages.

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Had a bursary from Sappi whilst studying BSc Chemical Engineering. Worked in the Pulp and Paper industry for 6 years in Process and Projects Engineering roles. Spent these years working on optimization projects and large Capital projects in the Pulp, Liquor recovery, Leach and Chlorine dioxide plants. Then spent a year working at Process Projects in a Process Engineering position, primarily working on projects in the Phosphoric acid and Fertiliser industries.

Have been with FLSmidth Minerals for 3 years in the Solid Liquid separation part of the business, getting involved in all process related issues on all the projects relating to these technologies.