The implications of ore hardness variability on comminution circuit energy efficiency (and some other thoughts)

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Thursday 6 December 2012
NPV optimization subject to constraints
- Scarcity of capital, water, human resources, land, energy, and others

It’s a competition
- It’s not about reducing the carbon footprint, it’s about cost and risk optimization
- Social and ecologic sustainability are evaluated in this context.

Project Economics and Project Risk define the limits of corporate citizenship.
- This is where geometallurgy is useful
Topics

- What is being done with geomet?
  - Some examples

- What could be done with geomet?
  - Some examples
What is being done with geomet?

Example 1 – HPGR Trade-off Study
HPGR Tradeoff Studies

- Usually grinding circuits are sized for a homogenous ore
  - Constant $A^*b$, SPI, Wi, etc.,
- Usually evaluated for a fixed tonnage
  - No variability is incorporated
- Problems:
  - *SAG mill circuits are directly coupled to ball mill circuits, so changing ore properties (feed size, hardness, etc.) lead to changing process bottlenecks (SAG-limited vs. ball mill-limited)*
  - *For any given unit operation, an upstream or downstream bottleneck creates a loss of efficiency*
  - *Sizing a SAG-based circuit for a single ore hardness ignores this important concept.*
Global Distribution of Bond Ball Mill Work Index

- **Hard Ore**, BWI = 18.5 kWh/tonne
- **Medium Ore**, BWI = 14.4 kWh/tonne
- **Soft Ore**, BWI = 11.8 kWh/tonne

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### Work Index (Metric) Cumulative Distribution

Variability: Effects on HPGR Economics

- Simple Trade-off study
  - 96K TPD
  - Perfectly homogenous ore body
  - Equipment sized for average hardness

- Incorporate revenue stream using annual mine plans
  - Yearly SPI & Bond Wi
  - P80 vs. Recovery

- Incorporate revenue stream using daily hardness variability
  - Simulated values
Case 1 – Perfectly Homogenous

- Both circuits sized for the median ore hardness
  - SPI = 104 minutes, BWI = 14.0 kWh/t
- $158 Million additional CAPEX for HPGR circuit
- $0.49/t lower operating cost

...SAG circuit wins by $33 million NPV
Comparison

Case 1 (median ore hardness)

Hardness (SPI, min)

Trade-off NPV (thousands)
Case 2: Annual Variability

- **Yearly Throughput Assumptions**
  - T80 limit = 5mm
  - P80 limit = 225 microns
  - Upstream limit = 125K TPD
  - Downstream limit = 1.15*Nominal
  - Ramp up limit (9 months)
Economics Including Mine Plan

**TPH & P80 - SABC-A 96K TPD**
- 40' x 26' inside shell x EGL SAG Mill, 26' x 40' Ball Mills

- Higher tonnage most years

**TPH & P80 - HPGR 96K TPD**
- 3 x 2.4m x 1.65m HPGRs, 2 x 26' x 41' Ball Mills

- Small difference in recovery due to coarser P80

...HPGR circuit wins by $50 million NPV
Comparison

Case 2 (Annual Variability)
Case 3: Daily Variability

SPI & Wi - First 5 Years

Mill performance simulated for each day and results summed over the entire mine plan

...HPGR circuit wins by $84 million NPV
Comparison

Case 3 (Daily Variability)

Trade-off NPV (thousands) vs. Hardness (SPI, min)

HPGR
Cone Crusher

Daily Variability

Comparison

($200,000)
($150,000)
($100,000)
($50,000)
$0
$50,000
$100,000
$150,000
$200,000
0 20 40 60 80 100 120 140 160 180 200

Trade-off NPV (thousands) 
Hardness (SPI, min) 
HPGR 
Cone Crusher
Conclusions – Case 1

- Variability should be an integral part of any HPGR/SAG tradeoff study
  - Particularly those near the equilibrium ore hardness point
- Study highlights the importance of geometallurgical profiling, mine plan, and production forecasts early in the development cycle
What is being done with geomet?

Example 2 – Feasibility Level engineering study for a Chilean SAG mill concentrator (recently constructed)
Design & Engineering

- Performed by a well-known international engineering firm
- Grinding circuit designed for the hardest of several ore types
  - About 100 – 150 SPI tests performed but were not used.
  - JK DWT on composites representing each ore type
  - Some McPherson tests, some pilot plant tests
- Scale-up was performed principally from pilot plant
Plant started up and reached significantly less than design capacity
- Ore was significantly harder than the composite samples
- SAG mill was the bottleneck

The good news?
- Recovery was a bit higher because of the higher retention time and finer grind

Expansion project implemented to increase the tonnage to design levels

Total Cost: $1 billion in losses ($3.00 copper, approximate)
- $850 million lost revenue
- $150 million approx. for the expansion
- $150 thousand for the SPI tests that weren’t used
The problem?

- Risk is fuzzy, costs are not
  - What is risk?
    - Is SPI risky?
    - Is JK DWT or JK SimMet risky?
    - Is a pilot plant risky?
    - Is geology or metallurgy risky?
- What’s a fatal flaw?
  - Torremolinos diamond mine?
  - Escondida moly plant?
Summary of Current Practice

- Good design approach
  - Cost of geometallurgy: $100K – 300K
  - Benefit: $117 million

- “Challenged” design approach
  - Cost of geometallurgy: 0, (not including unused SPI tests)
  - Losses: approx. $1.0 billion (we’ll never know for sure)

Question: Why is the downside (in these examples) so much greater than the upside?
What else could we do?

- Grind size vs. recovery optimization
  - What if higher head grade ore is softer?
  - What if harder ore is deeper?

NPV vs Grind
What else could we do?

- Tailings Impoundment and Water Balance

For HDTT, % solids, % fines, clay content affect deposition angle

Seepage losses are affected clays, % fines

Underflow density affects evaporation losses

**HD/P Thickener Design**

- P80 = 220 um
- P80 = 180 um
- P80 = 140 um

**Diagram**

- Mill
- Evaporation
- Underflow density
- Seepage losses
Grind – Recovery – Tailings Optimization

This was from cost-benefit around grinding & flotation, using geometallurgical methods

Incorporate the cost of tailings and water handling in the NPV calculation, using geometallurgical methods

NPV vs Grind

US$, thousands

P80 (microns)
What else can we do?

- Desalination
- Pumping
- Everything Else

Percent of Opex

Percent of Capex

Grind-recovery-tailings-water-power optimization?
Components

- Block model with distributed geometallurgical parameters
- Mine plan
- Integrated process models (validated)
- Capital cost models
- Operating cost models
- Fast computers
Summary (my opinions)

- The positive economic impacts of geometallurgy are significantly understated in our field
- The scope of geometallurgical programs are driven by risk avoidance rather than economics
- Adoption rate for geometallurgical methods is increasing
Current Cu/Mo Mill Design (a green perspective)

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- It’s a competition
  - It’s not about reducing the carbon footprint, it’s about cost and risk optimization
  - Social and ecologic sustainability are evaluated in this context.

- Project Economics and Project Risk define the limits of corporate citizenship.
  - Geometallurgy is part of good corporate citizenship
Thanks

- Co-authors
  - M.A. Mular, J. Vanderbeek, L. Hill, and E. Herrera (Freeport-McMoRan Copper & Gold)
  - D. Meadows (FLSmidth)

- Organizing Committees for Geomet, Gecamine

- CEEC (Coalition for Eco-Efficient Comminution)

- You the audience, for your patience