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New SAG Mill Model for Better Mine-to-Plant Planning

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Contents

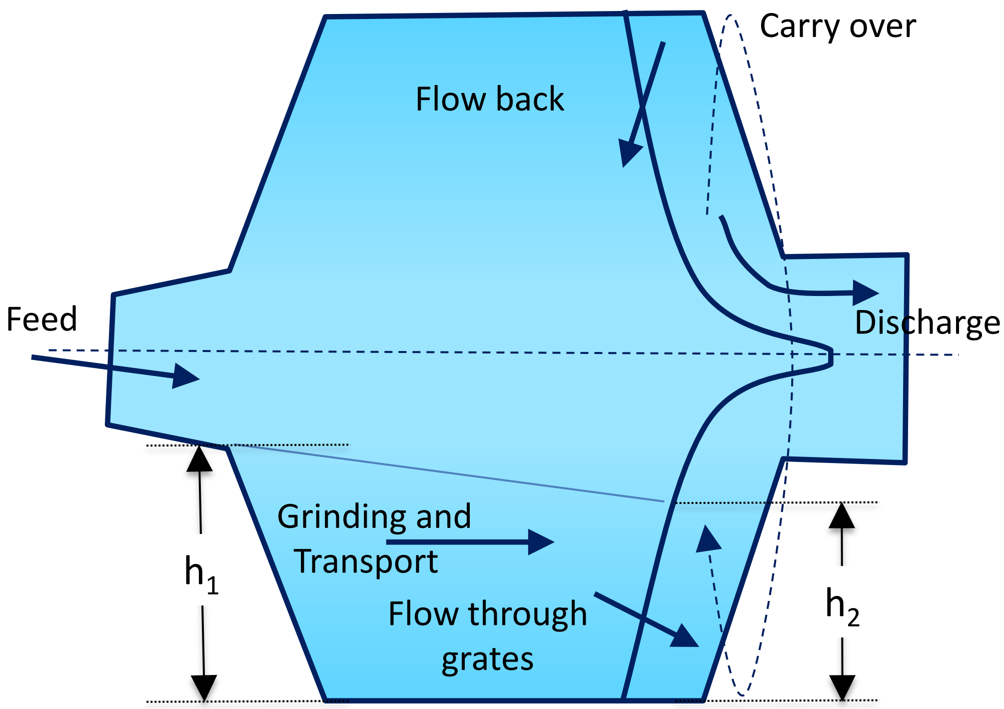
Framework

- ✓ Lack of assertiveness in production planning tasks
- ✓ Current models are low precision
- ✓ Mill mass transfer needs better understanding
- ✓ The SAG mill within a mine-to-plant frame

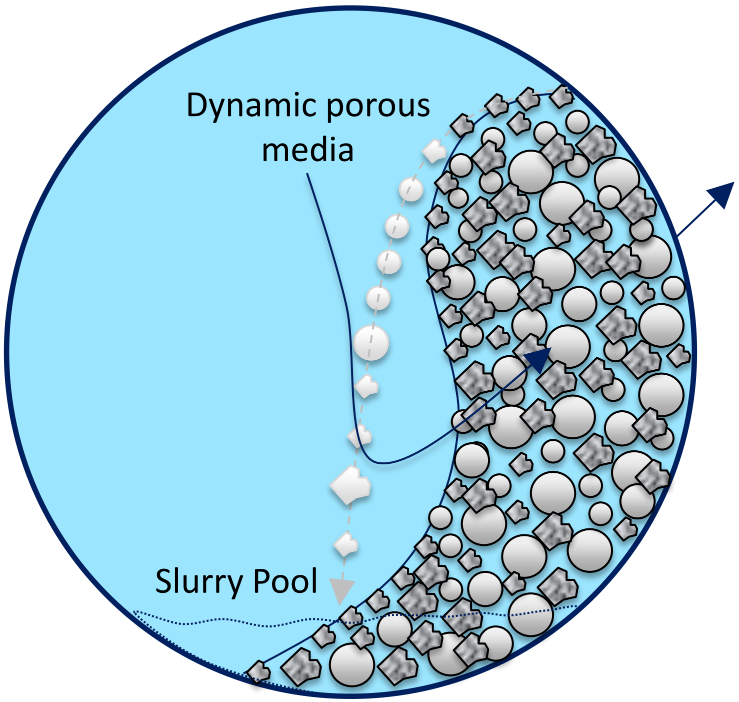
Milestones in Mill Mass Transfer

- ✓ Hogg, Shoji and Austin (1974, 1976) made the earlier contribution on axial transport models in rotary mills.
- ✓ Marchand, Hodouin and Everell (1980) proposed the empirical relationship $W=k\ F^{0.5}$. Similar expression was later used by Austin (1984), Morrison and Morrell (1999), among others.
- ✓ Moys (1986) reported a model for the effect of flowrate and viscosity of the slurry on the hold up of the slurry in a grate-discharge grinding mill.
- ✓ Powell, Morrell and Latchireddi (2001) expressed later the Marchand "k" constant as an empirical function of the open area, grate design, mill speed, charge volume and pulp lifter specifications.
- ✓ Menacho and Chávez (2008) reported a slurry transport model in SAG mills by using the porous media fluid transport theory.
- ✓ Tupper, Govender, Mainza and Neville Plint (2013) reported a mechanistic model for slurry transport , based on fluid mechanics considerations.

Breakage and Transport Modelling



Draw taken from Weerasekara y Powell, 2014.



J. Menacho, 2009.

The Slurry Hold Up

Most of the current mass transport expressions used today are empirical and do not include rheology.

The proposed mass transport model combines Bernoulli and Ergun equations to determine the slurry hold up (W_p). The mathematical solution includes rheology variables (ρ_L, τ_0, Φ), packed bed variables (ε, d_{32}), mill design variables (D_M, V_M) and operational variables (Q, N_C, J_B).

In a limiting case the expression here derived reduces to the classical Marchand equation.

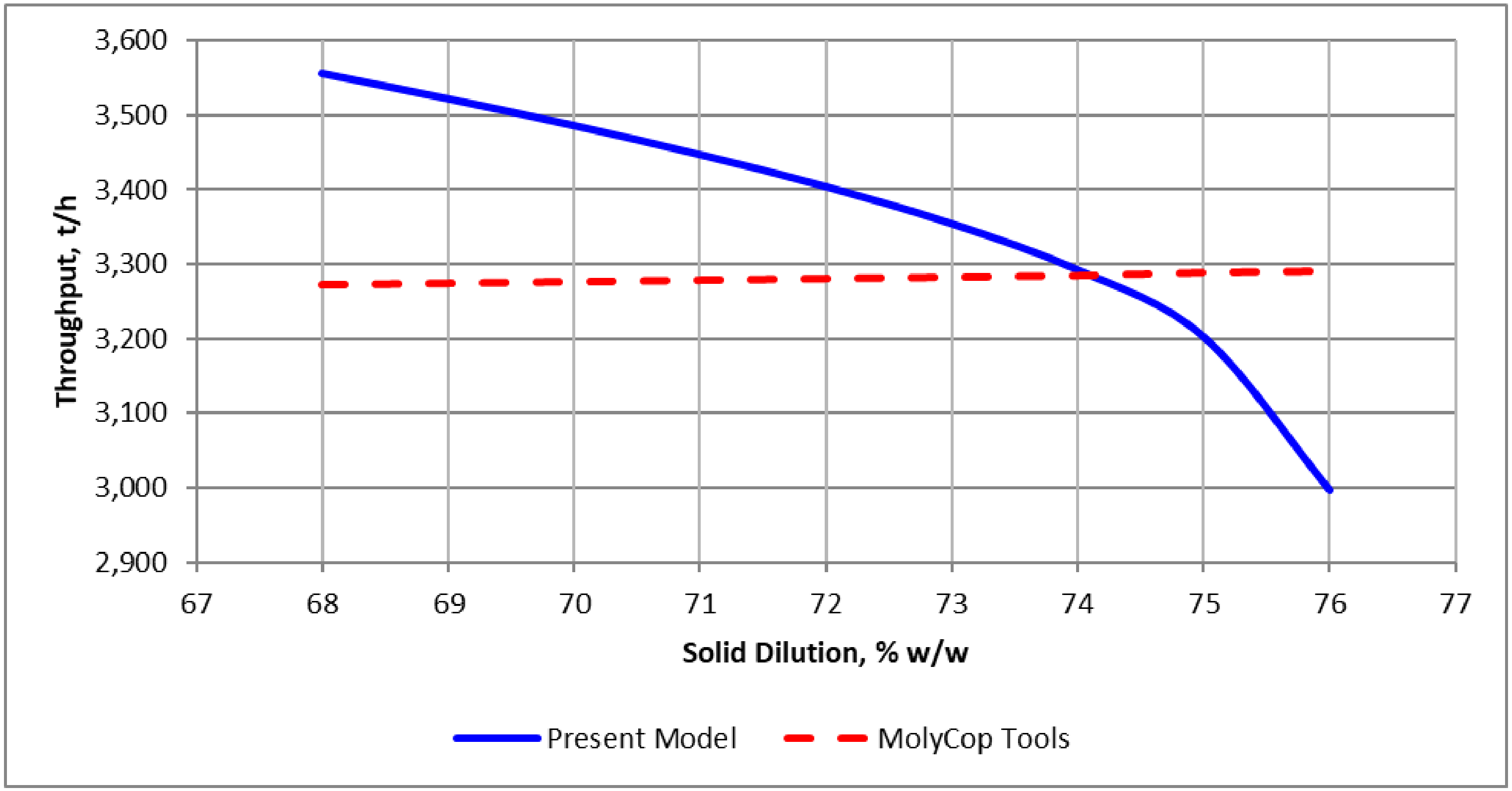
This Model

Marchand!!

$$W_P \simeq \overbrace{f\left(\tau_0, \rho_L, \phi, \varepsilon, d_{32}, D_M, V_M, Q, J_B, N_c\right)} \simeq kQ^m$$

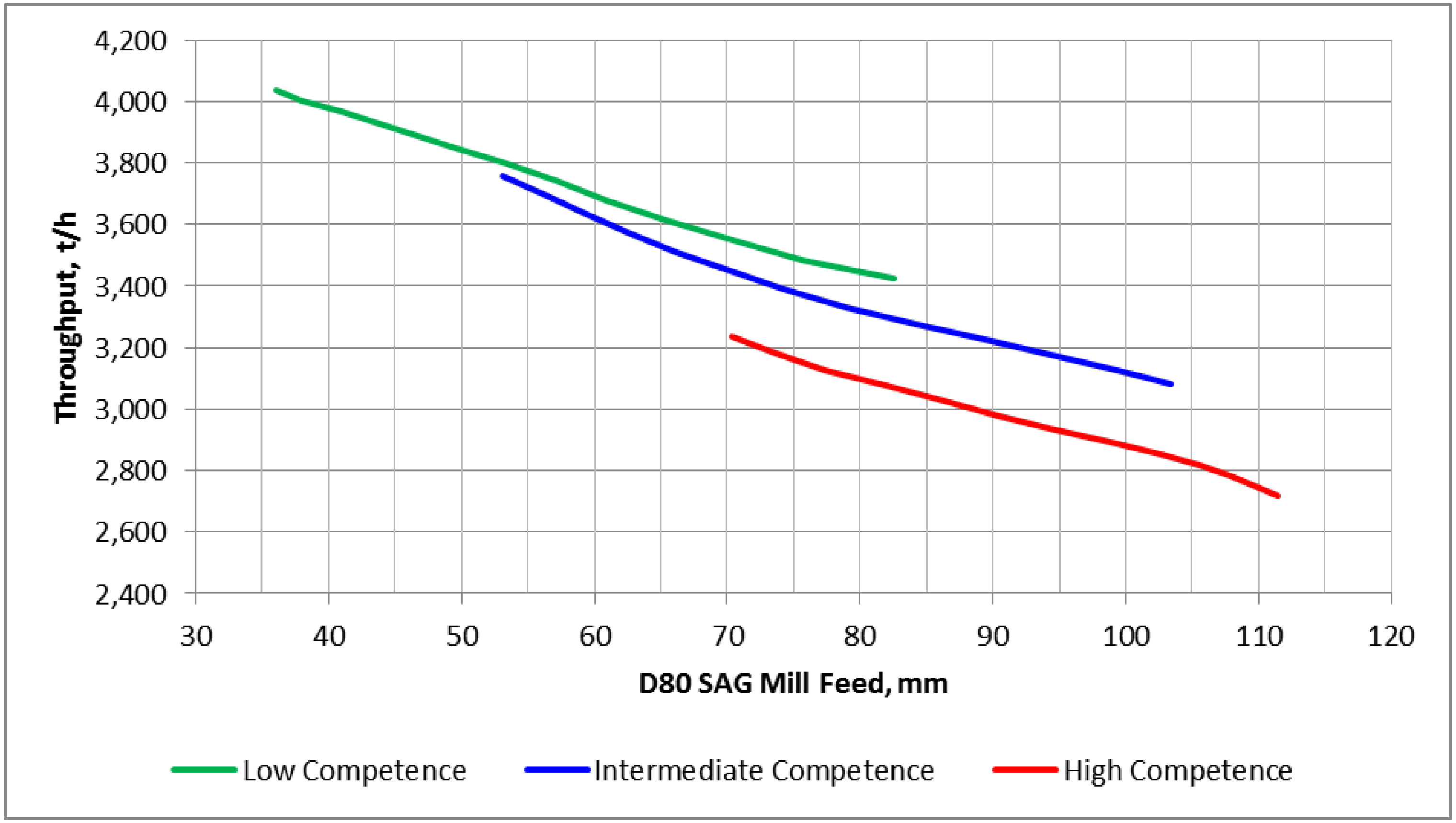
Mill Overfilling

- ✓ Lump accumulation due to insufficient rate of breakage
- ✓ Low evacuation rate due to increased yield stress



Impact of Feed Particle Size

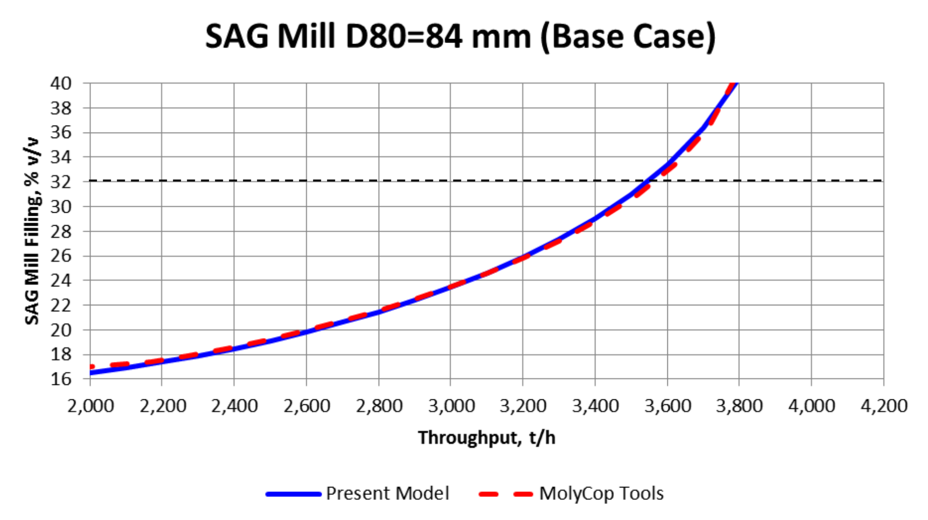
The rate of increase in throughput per mm in feed is lower for low competence ores compared to higher competence due to increasing rheology effect.

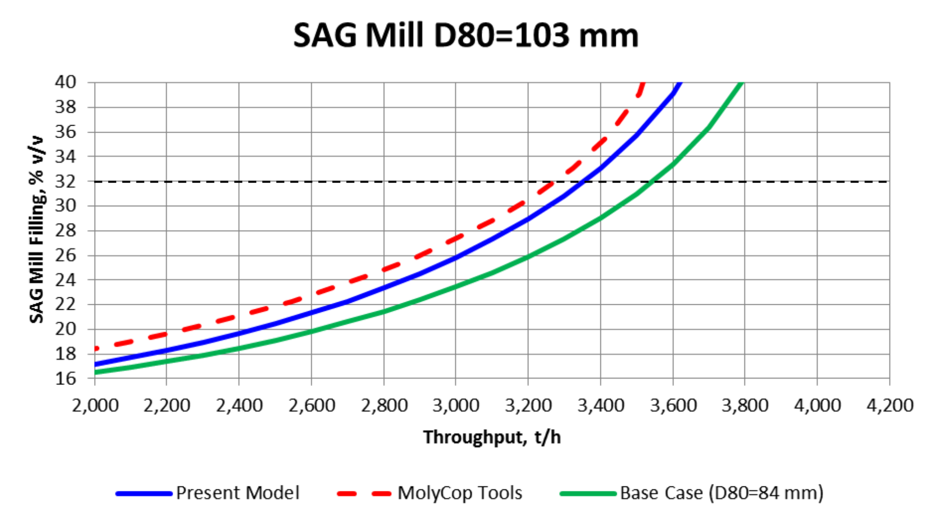


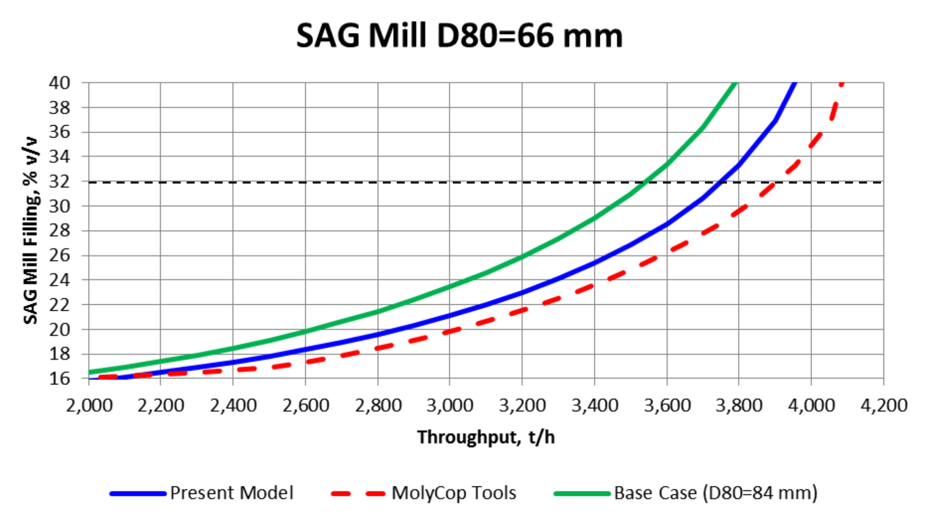
Maximum SAG Mill Capacity

Early overfilling is predicted by this model when coarser ore is feed to the SAG mil, but its higher permeability attenuate the higher grinding task.

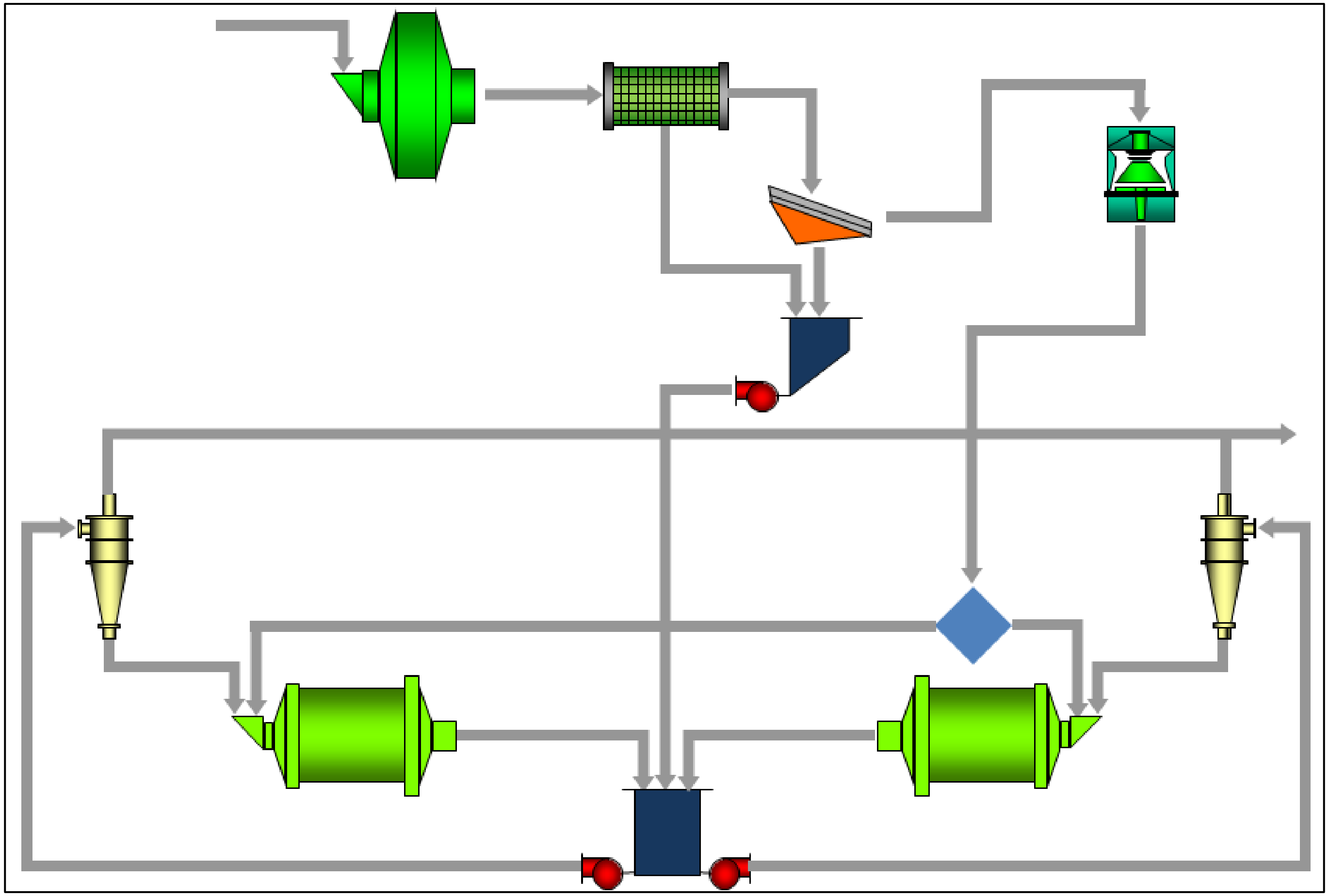
Early overfilling is also predicted by this model when the feed size is reduced due to higher rheology constraint.







Study Case:
Plant Optimization vs. Mine-to-Plant Optimization



General Characteristics

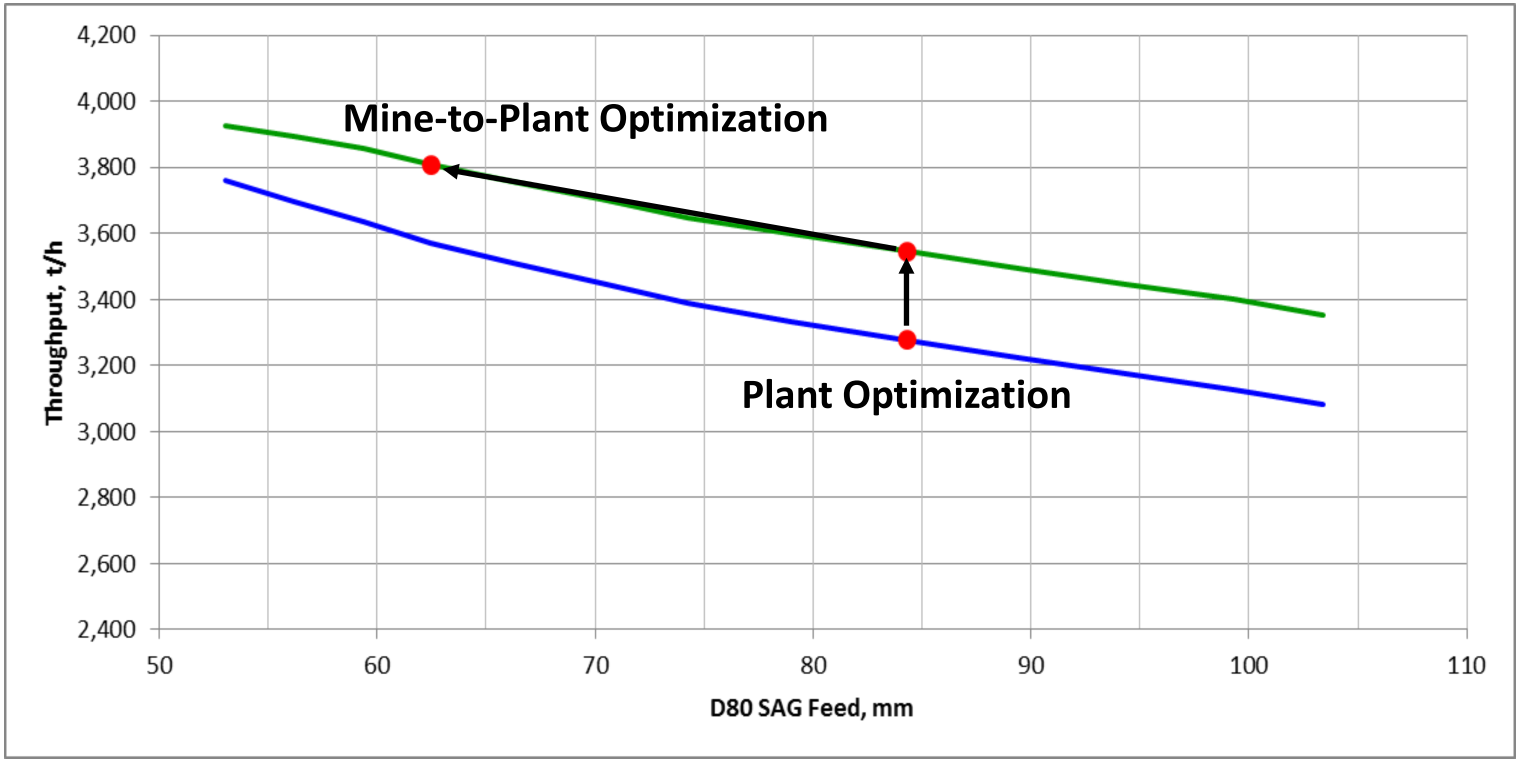
SABC-2 configuration, 3,277 t/h throughput, 0.80 %Cu. Some characteristics of the main equipment are listed below:

Design Parameter	SAG Mill	Ball Mill X 2
Diameter, m (ft)	11.48 (37.7)	8.025 (26.3)
Length, m (ft)	6.99 (23.0)	13.56 (44.5)
Grate openings, mm	88	Overflow
Grate open area, %	12.8	Overflow
Position relative to grate openings	0.88	Overflow
Critical velocity fraction, %	71.7	75.0
Ball load (J_B), % v/v	14.7	32
Power demand, kW	22,000	17,900

Design parameter	Value
Hydrocyclone diameter, m (in)	0.800 (31.5)
Inlet diameter, m (in)	0.350 (13.8)
Vortex diameter, m (in)	0.345 (13.6)
Spigot diameter, Battery 1, m (in)	0.230 (9.0)
Spigot diameter, Battery 2, m (in)	0.250 (9.8)
Length of the cylinder, m (in)	1.097 (43.2)
Cone angle, degree	20

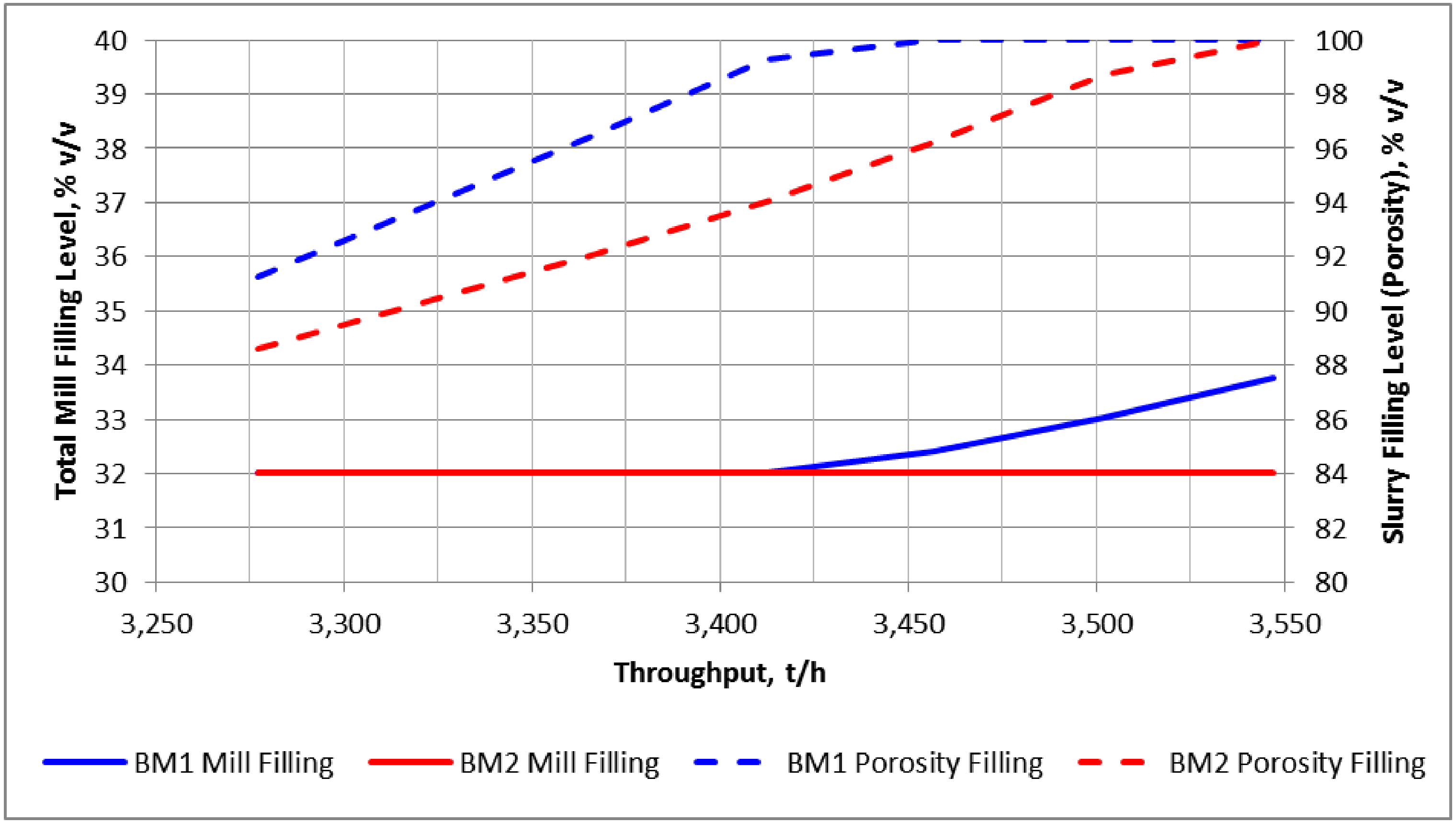
Throughput Optimization

Optimization proceeds in two stages, the grinding circuit is first improved and then the blasting, such that the new tonnage and granulometry are effectively captured.



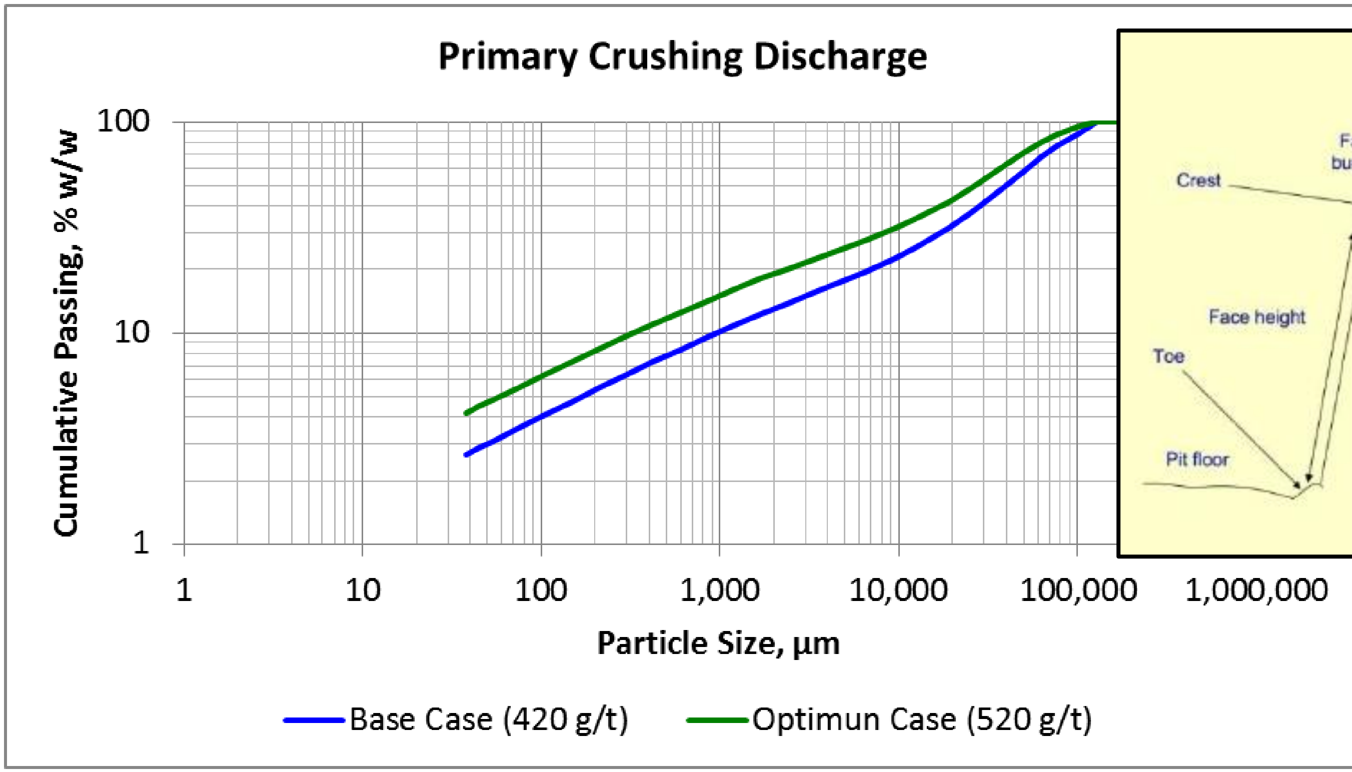
Overfilling in Ball Mill

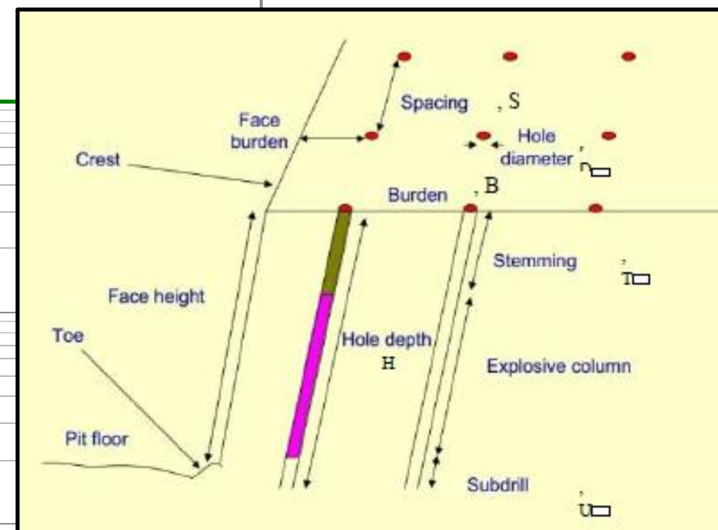
The rate of increase in throughput per mm in feed is lower for low competence ores compared to high competence due to increasing rheology effect. The high circulating load in Ball Mill 1 makes it working quite forced.



Blasting Optimization

The blasting technology offers many options to improve results. The more simple is to increase the amount of explosive per tonne of ore (powder factor), which maximum value is limited by stability conditions and dilution at the mine[(1)].





V.M. Bowa, Optimization of blasting design parameters on open pit bench. A Case study of Nchanga open pits, Int. J. Sci & Tech. Res., Vol. 4 (09), Sept. 2015, pp 45-51.

Summary of Results

The integral optimization is limited by boundary conditions, such as the maximum powder factor depends on bench stability rather tan benefit at the SAG mil. Main results and conditions are listed below:

Variable	Base Case	Plant Optimization	Mine-to-Plant Optimization
Throughput, t/h	3,277	3,545	3,808
Head Cu grade, %	0.80	0.80	0.80
D80 to Flotation, µm	152	161	163
Flotation recovery, %	90.1	89.9	89.8
Powder factor, g/t	420	420	520
D80 blasted ore, mm	98.5	98.5	71.2
D80 SAG feed, mm	84.3	84.3	62.5
J_{Total} SAG mill, %	27	32	32
J_B SAG	14.7	14.7	14.7
J_B BM1	32	32	33
J_B BM2	32	32	33

Final Remarks

- ✓ A formal SAG milling model is here presented, which explicitly includes the slurry transport throughout the grinding chamber.
- ✓ Transport is modelled by using the Bernoulli energy equation coupled with the Ergun equation within the frame of turbulent transport through a dynamic porous media formed by the balls and the lumps larger than the effective grate openings.
- ✓ Rheology is described by the Krieger and Dougherty model, properly adapted to the present application. Breakage is represented by the PBM approach assuming valid the compensation condition. An special shape for the selection function is adopted.
- ✓ The transport model is extended to ball milling, a relevant issue as the size of the machines as well as the grinding task have been significantly enlarged along the time, thus also giving origin to a new ball mill model.

Final Remarks

- ✓ Two overfilling phenomena clearly appear in the model: (i) Coarse fraction accumulation due to insufficient grinding rate and (ii) Accumulation related to increasing shear resistance of the slurry.
- ✓ Consistency of the new model was proved by modelling and simulating an industrial set of data belonging to an operation from the Big Chilean Copper Mining. Reasonable fit to the experimental data was obtained.
- ✓ The new SAG and ball mill models have been coupled with previously developed phenomenological models for blasting, crushing and flotation, such that a robust integrated mine-to-plant simulator is available to explore different optimizing scenarios particularly useful for production planning tasks.