METSIM INTERNATIONAL

Mantoverde Heap Leach Operation: Using Dynamic Talent to Understand Copper/Cobalt Chemistry

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74th Annual Colorado MPD Conference
May 2025

AGENDA

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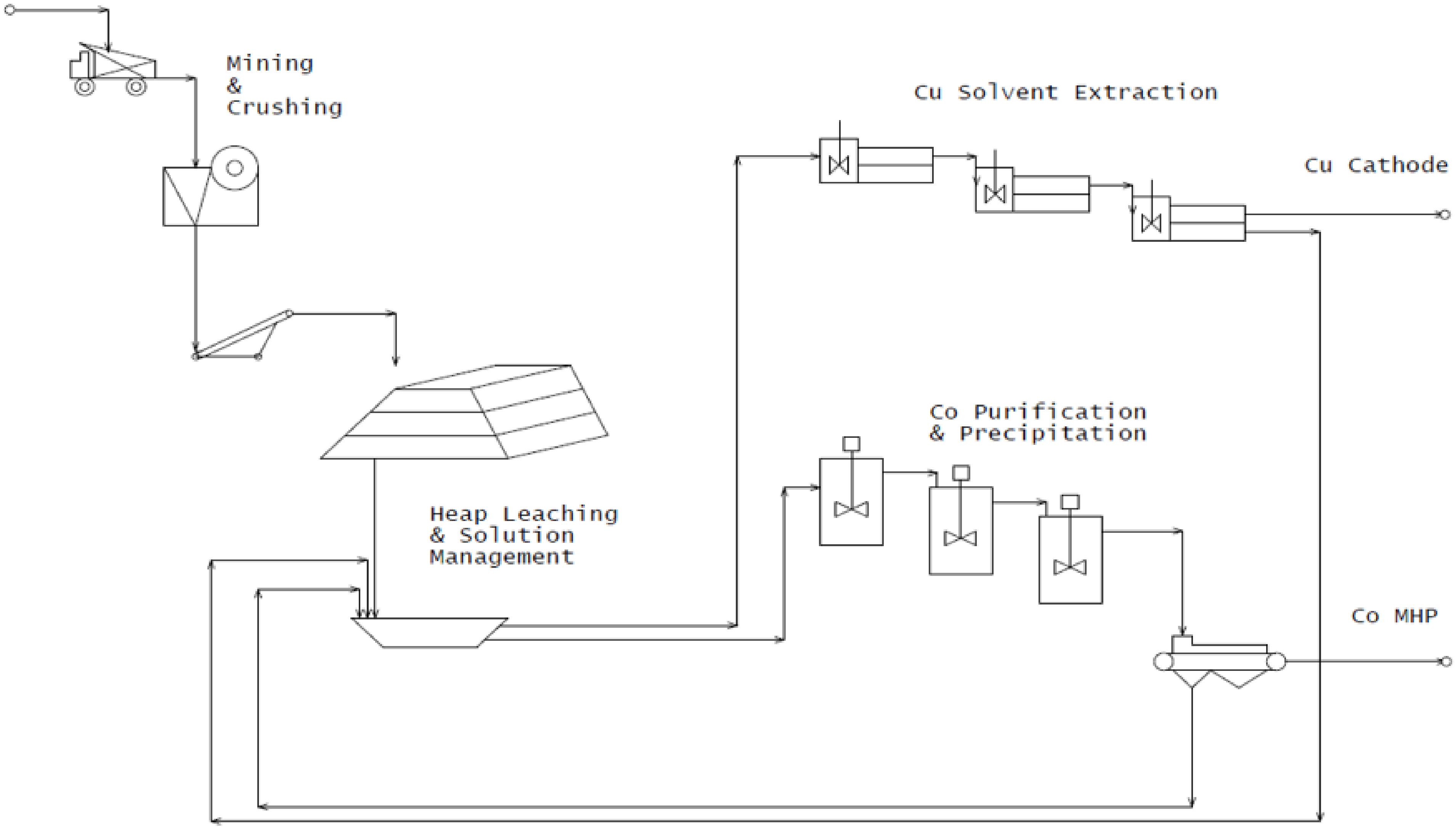
- Mantoverde Project Overview
- Heap Leaching using METSIM®
  - Base Case Model
    - Inclusion of all site equipment into model.
    - Constructing the heap, solution management, and adding processing circuits into the model
    - Model calibration from operational data
  - Chemistry
    - Reaction kinetics, solubilities, species formation
- Scenario testing to increase copper production and reduce acid requirements
- Using the OLI API within METSIM® to validate test work and predict chemistry
- Cobalt purification results and summary
- Final Scenario – optimize Cu and Co Recovery.

Mantoverde Project Introduction

- Located in Chile
- 4 total Leach Pads
  - 3 Permanent Pads
  - 1 Dynamic On/Off Pad
- Downstream processing facilities
  - Common raffinate pond
  - ILS ponds for each pad
  - Common PLS pond
  - SXEW Circuit

Mantoverde Simplified Flowsheet

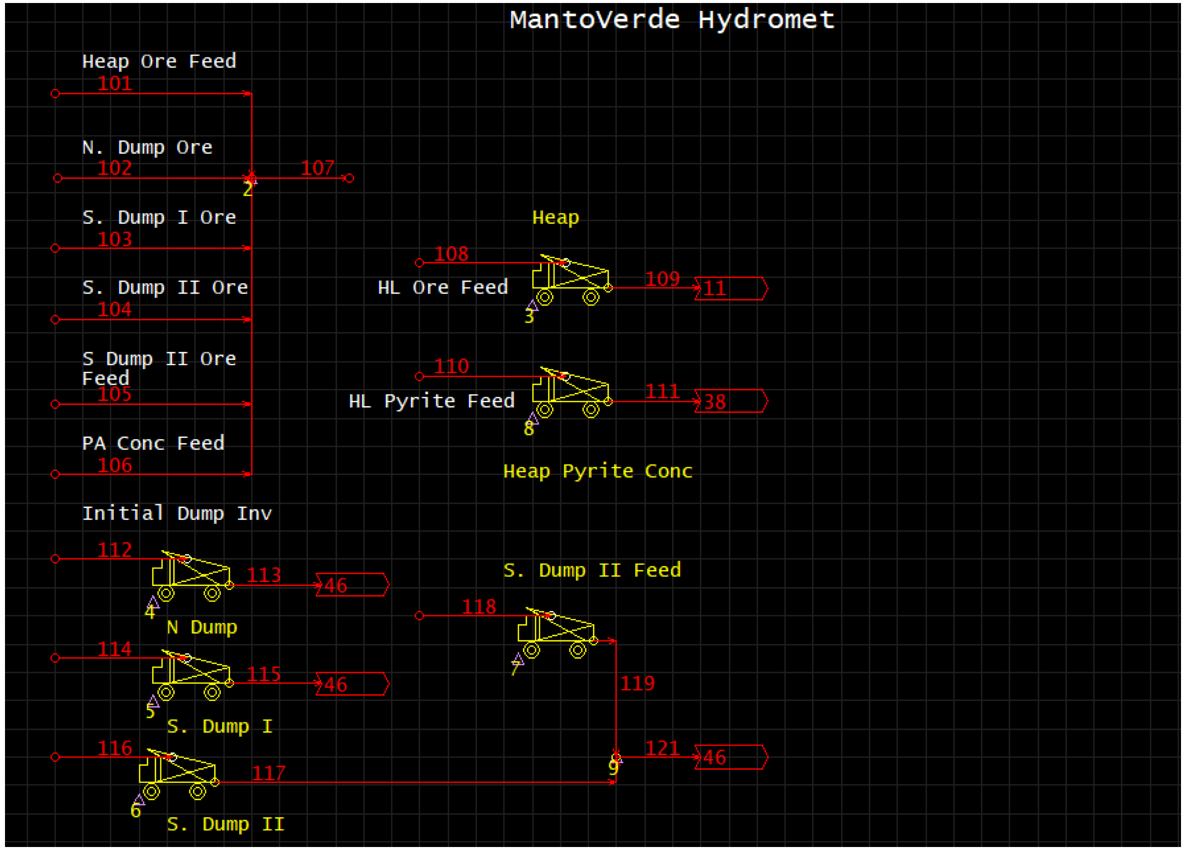


Modelling Overview

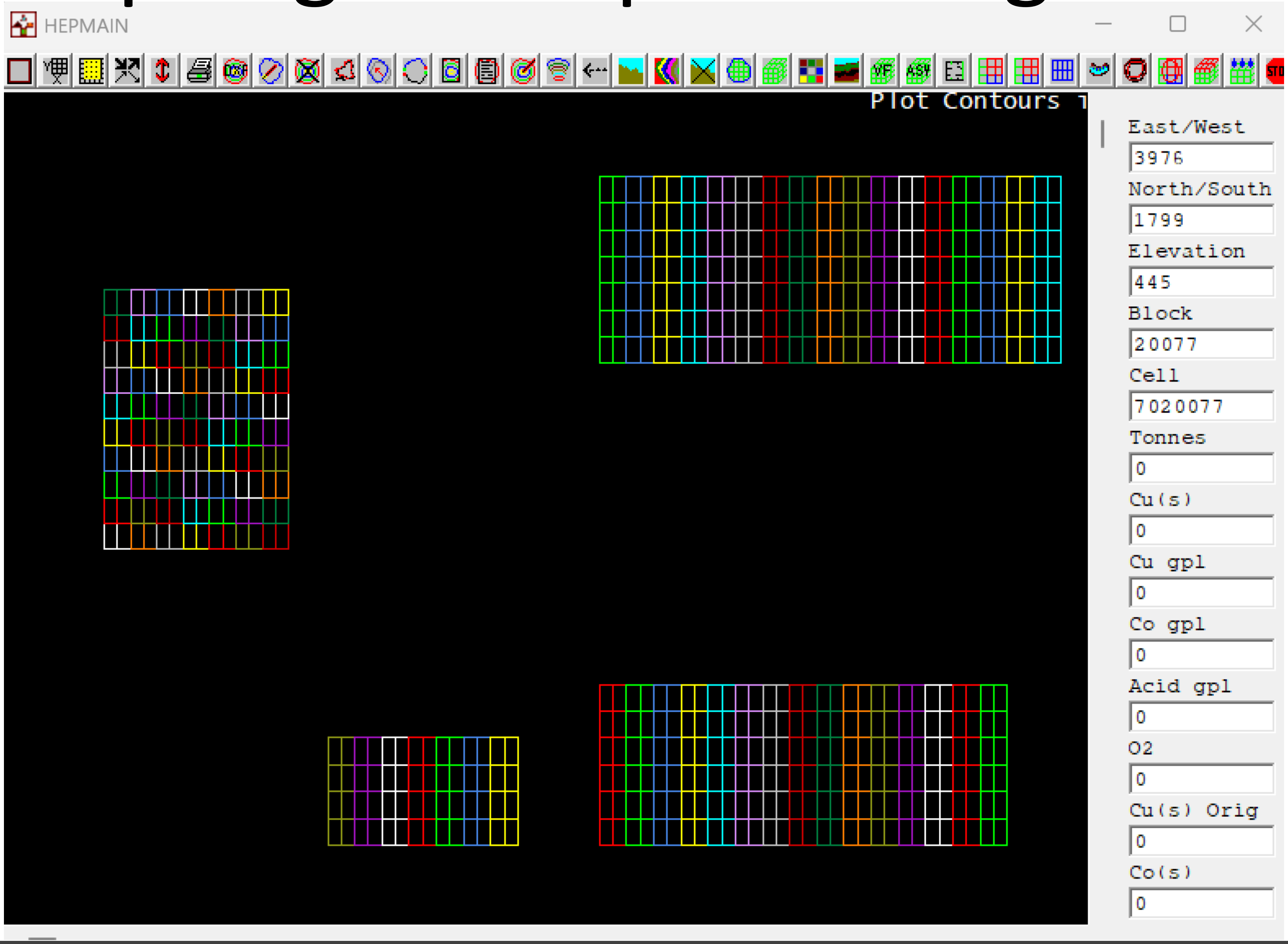
- METSIM® used to evaluate Base Case Model including:
  - All equipment associated with the operation
  - Past and forecasted ore tons and grade schedule for stacked ore
  - Dynamic water balancing and solution management
  - Copper and Cobalt production forecast
- Two Main Scenarios were evaluated
  - Conversion to a bioleach via air and bacteria addition
  - New pyrite concentrate feed stream (30% w/w moisture) added to the dynamic heap leach pad with a cobalt bleed circuit for mixed hydroxide precipitate (MHP) production

Heap Leach Model Parameters

- Ore tons and metal/mineral grades stacked on heap leach according to mine plan
- Column test results – extraction kinetics
- Complete flowsheet from ore handling through product precipitation, water balancing
- Three-dimensional block structure of heap leach
- Heap leach operational parameters, eg leach cycle, drainage rates, bulk density, etc
- Process chemistry for heap and processing plant
  - Reaction chemistry
  - Fe2+/Fe3+ Solubility
  - SX Isotherms - Operational Data
- Pond Solution Inventory (PLS, ILS, Raff, Event, and Emergency Ponds)

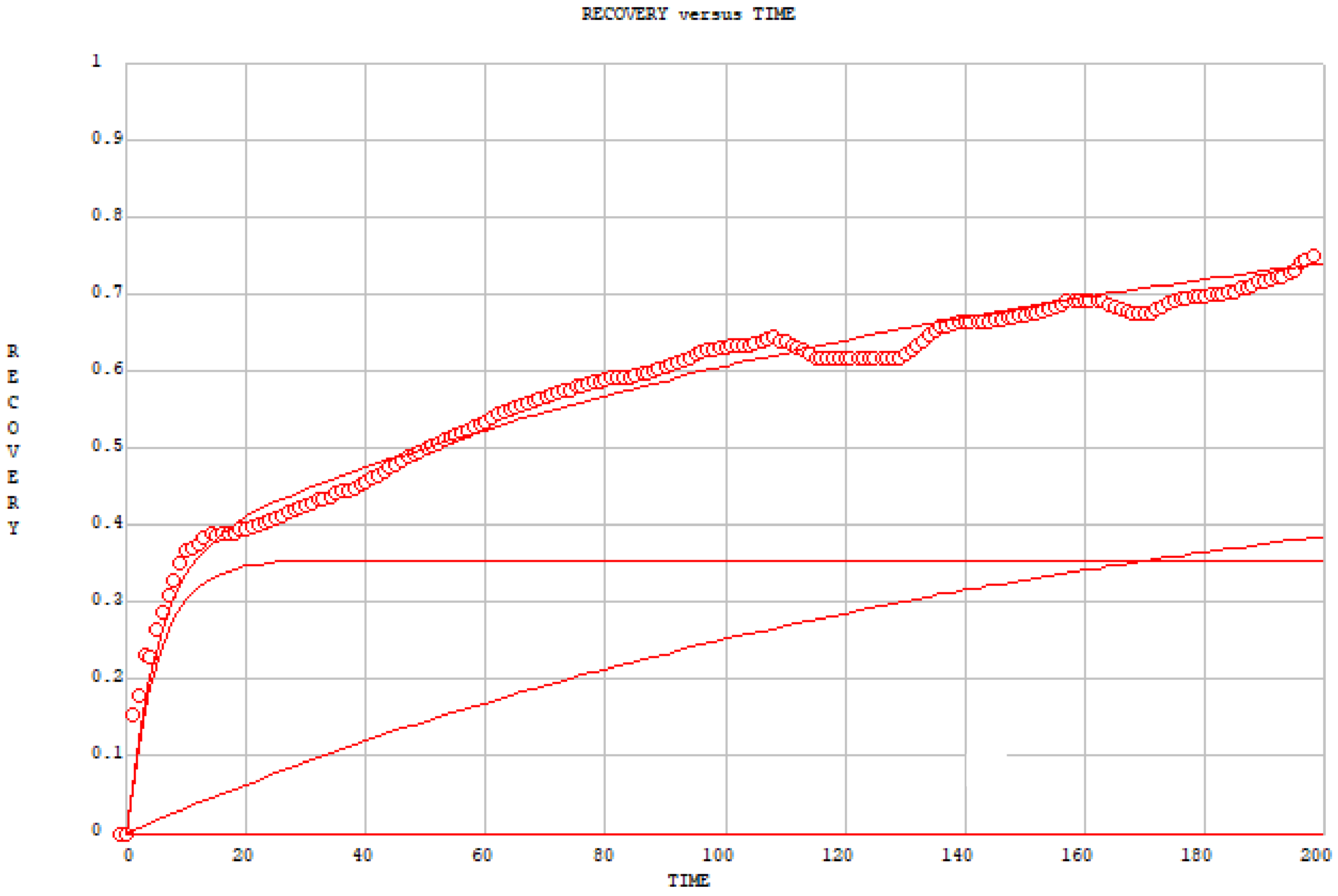


Stockpiling & Heap Leaching



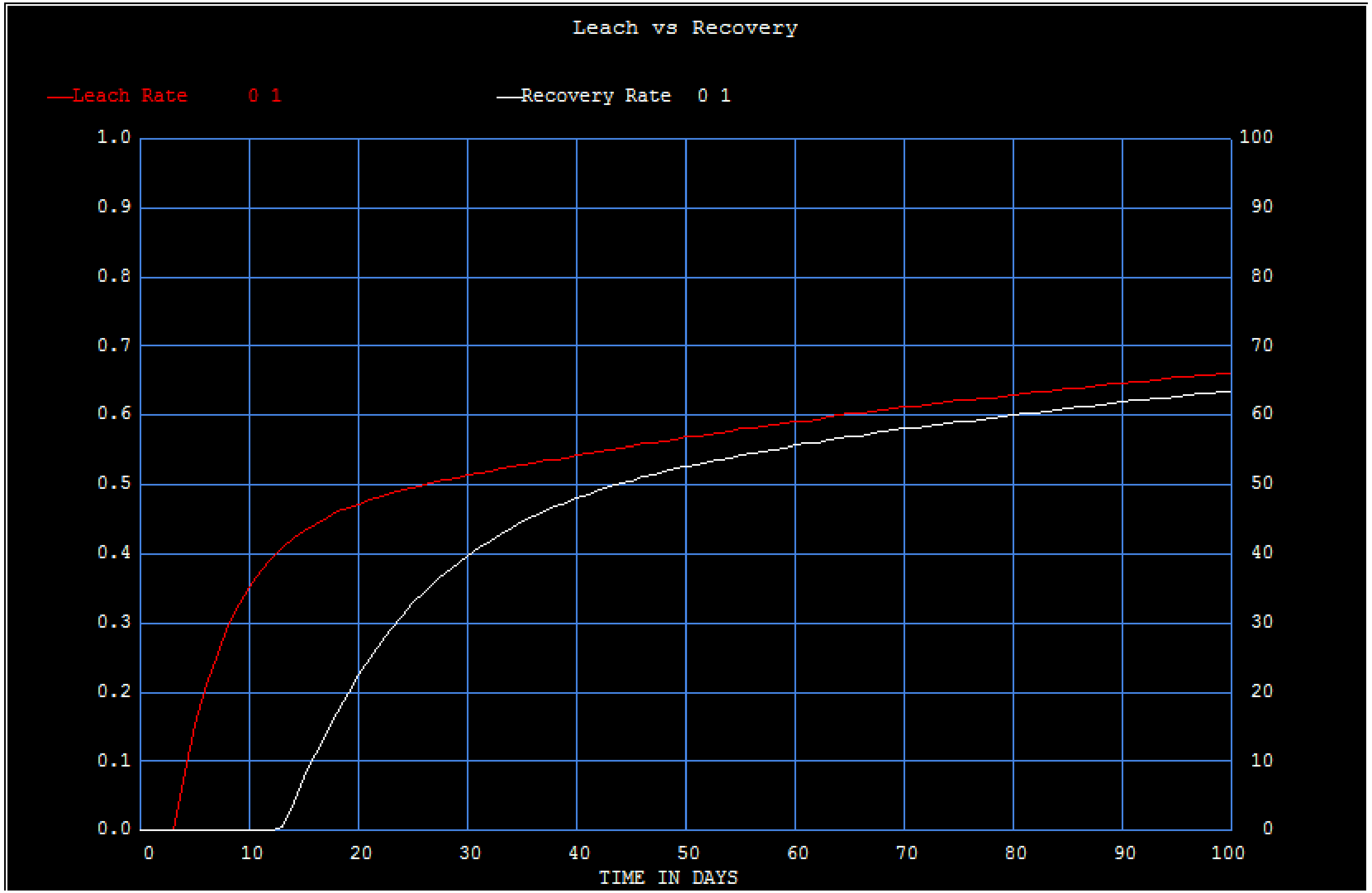
3-dimensional block model for material tracking

Heap Leach Chemistry



Fast (chemical) and slow (diffusion) leaching components for a single mineral/metal at their respective leach rates comprise the overall leach/recovery curve

Heap Leach Chemistry



The Recovery or production curve gives a more accurate financial model due to following factors:

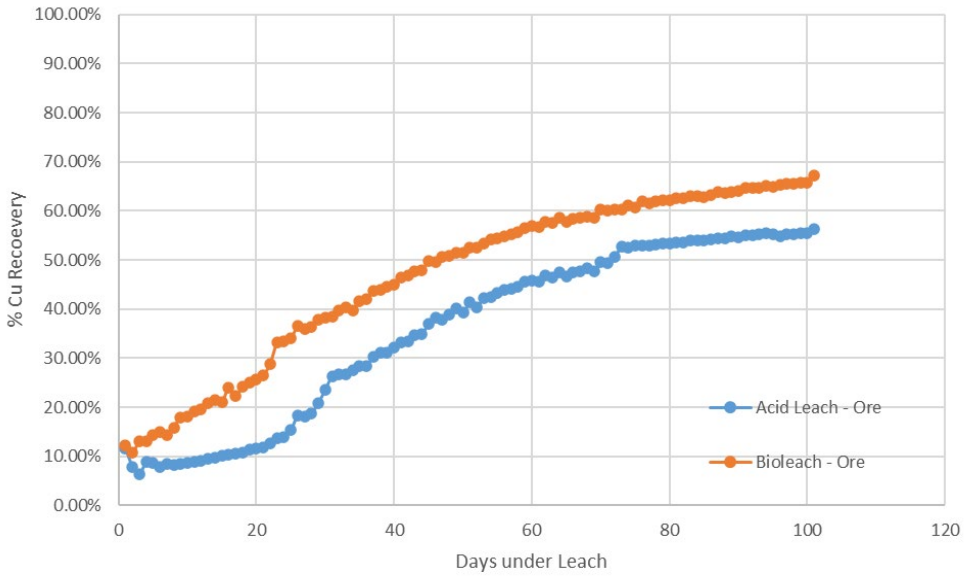
- Drainage times/inventory
- Solution recycles with dissolved metals
- Agglomeration effect
- Rainfall/evaporation

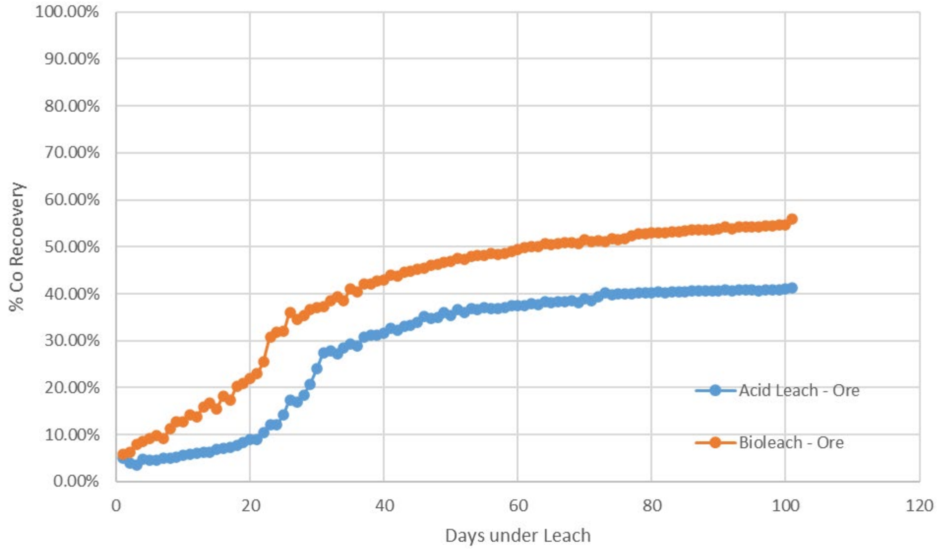
Base Case Findings

- Calibration of the model to existing plant using 26 years of data
- Base Case Results
  - Dynamic Pad – 80% CuAS Recovery (50% Cu Recovery total)
  - Permanent Pad – 40% CuAS Recovery (25% Cu Recovery total)
- Significant amount of primary and secondary sulfides are not being leached.
- Base Case Optimization
  - Scenario testing necessary to improve economics
    - Conversion to Bioleach
    - Pyrite feed addition
  - Ore management strategy – transferring ore from the static pad to the dynamic pad.

Scenario 1

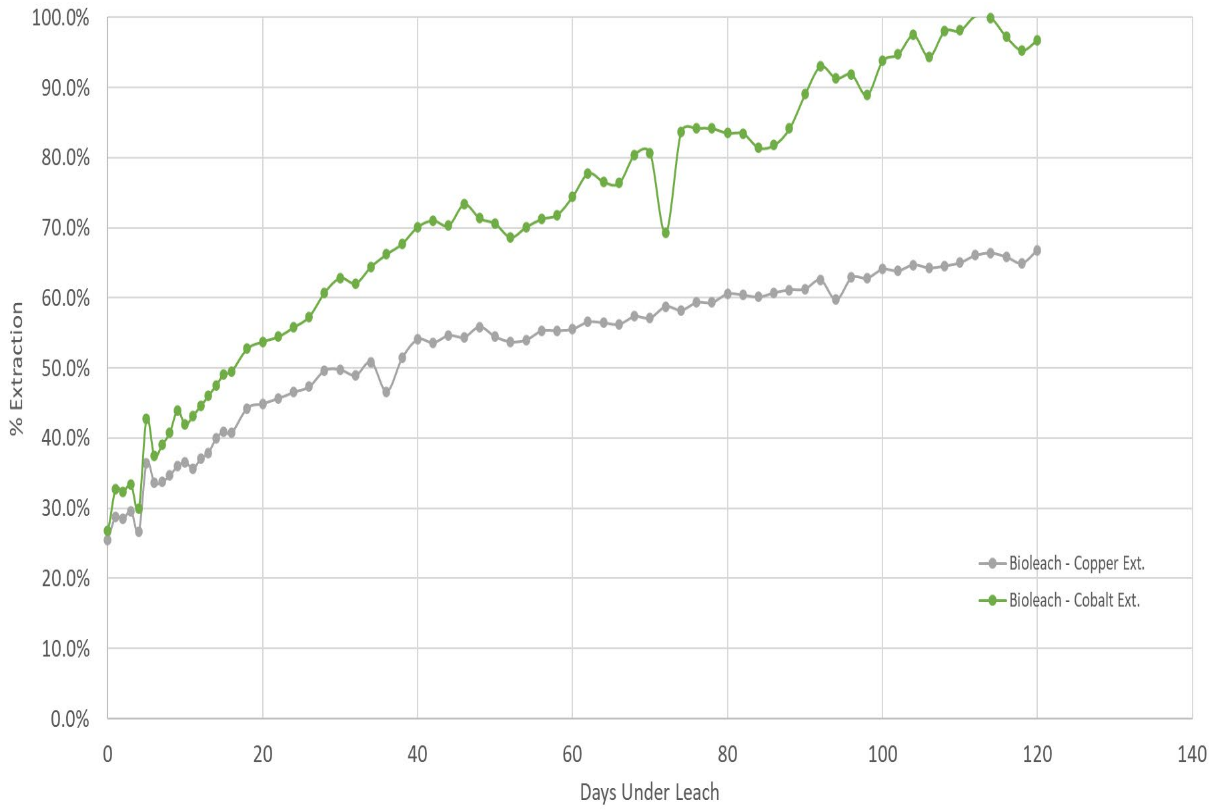
- Conversion to Bioleach
  - Column tests to determine sulfide ore leach kinetics under bioleach conditions.
  - Copper Recovery Curve (top)
  - Cobalt Recovery Curve (bottom)
  - Aeration of heap required – blower throughput decreased greatly by controlling air injected to panels under active leach only





Scenario 2

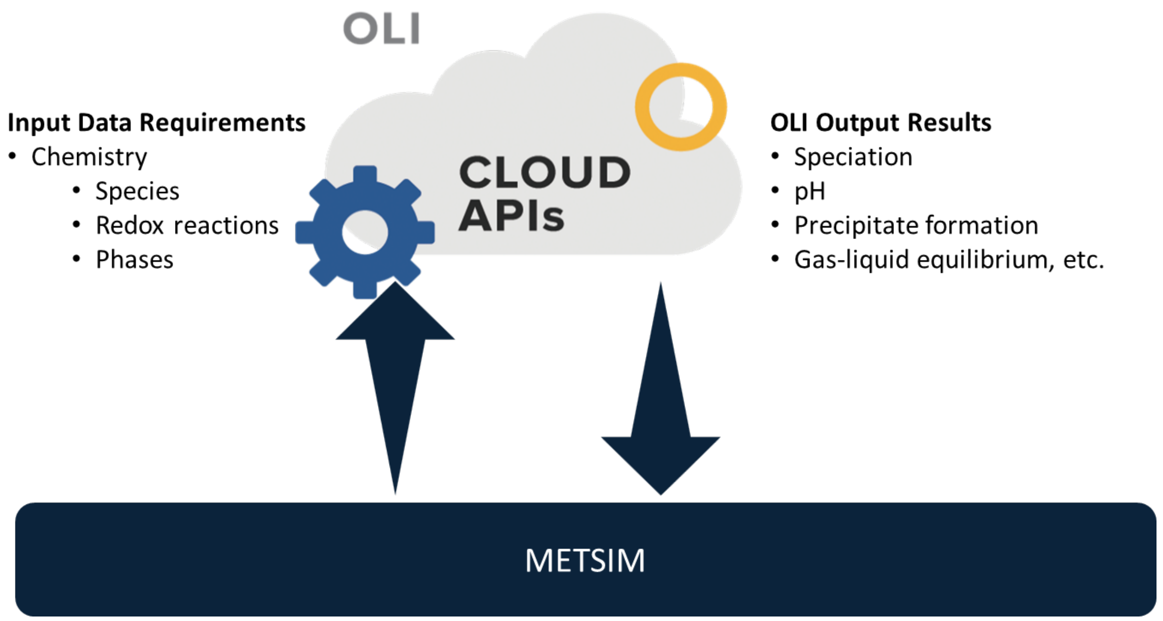
- Pyrite Concentrate Feed added to Dynamic Heap Leach Pad
  - Pyrite contains high Cobalt concentrations
  - Column tests to determine Copper and Cobalt leach kinetics
  - OLI software used to determine metal solubility and reaction products for iron and sulfuric acid.
  - Pyrite addition drastically reduced acid demand and is main source of Cobalt.
  - SX separated into 2 units: dynamic heap PLS & static heap PLS
    - Allows Cobalt to be concentrated in dynamic PLS.



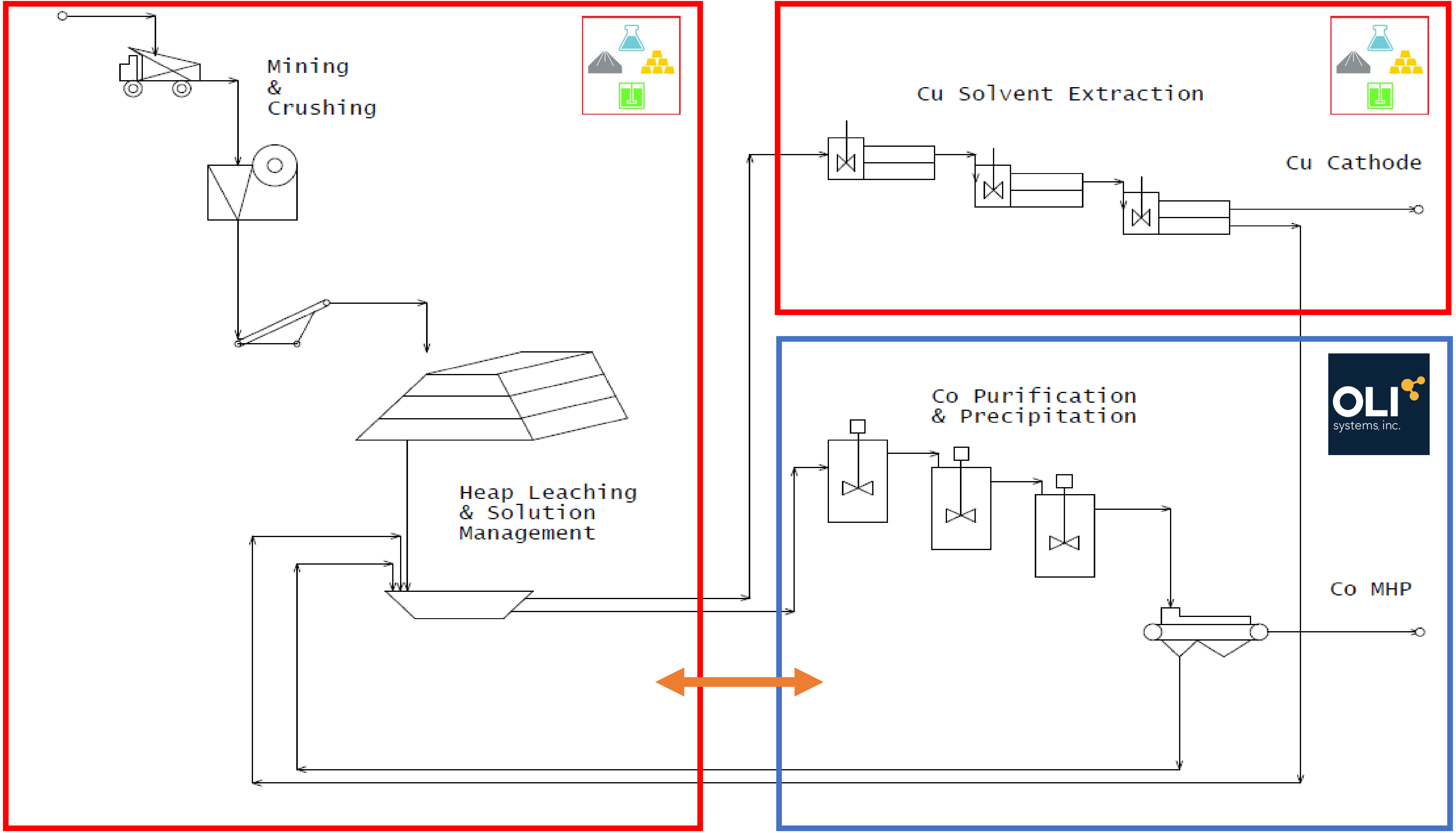
OLI Systems APIs*

- Benefits to a METSIM® Model
  - Extensive Database
  - Improves model accuracy with unknown chemistry or limited test work data
  - Equipment Design
  - Model Calibration/Verification

- Limitations
  - Assumes equilibrium – infinite time, perfect mixing

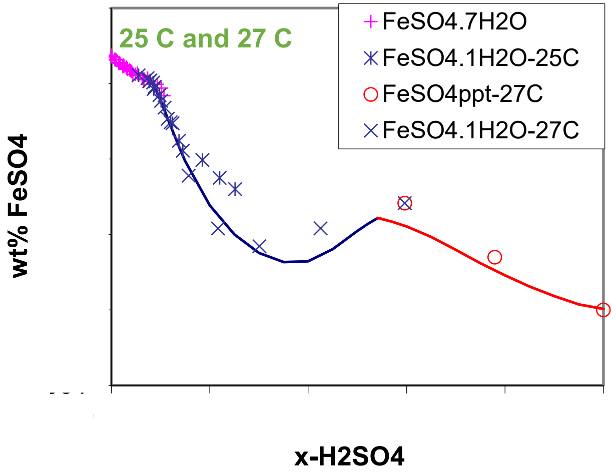


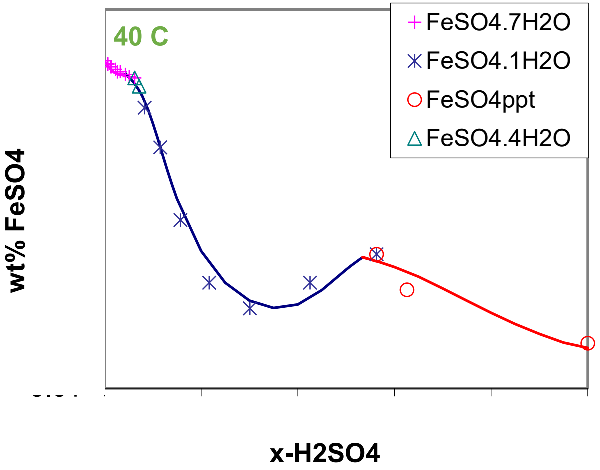
*Application Programming Interface

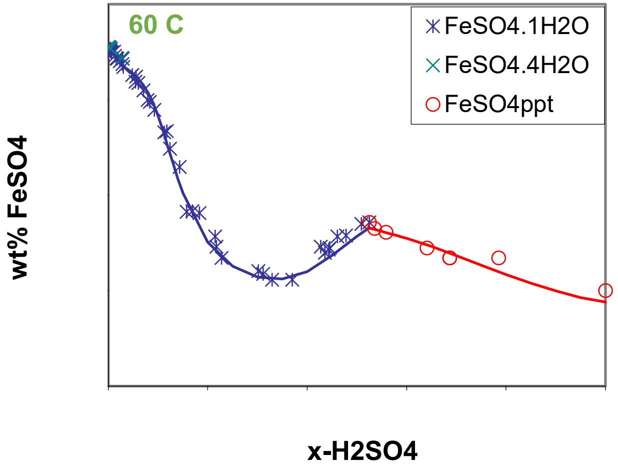

Mining
&
Crushing
Heap Leaching
& Solution
Management
Cu Solvent Extraction
Cu Cathode
Co Purification
& Precipitation
Co MHP

OLI vs Test Work Verification

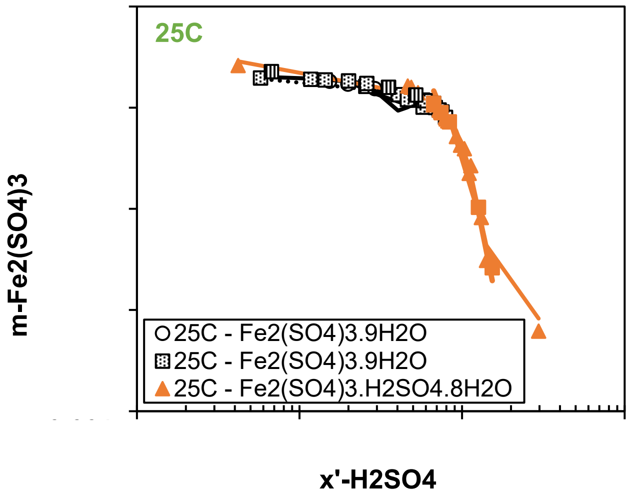
Ferrous Sulfate Solubility in Sulfuric Acid

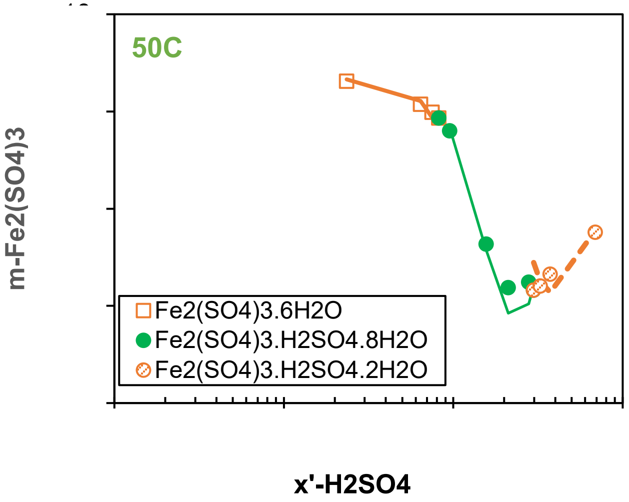






Ferric Sulfate Solubility in Sulfuric Acid

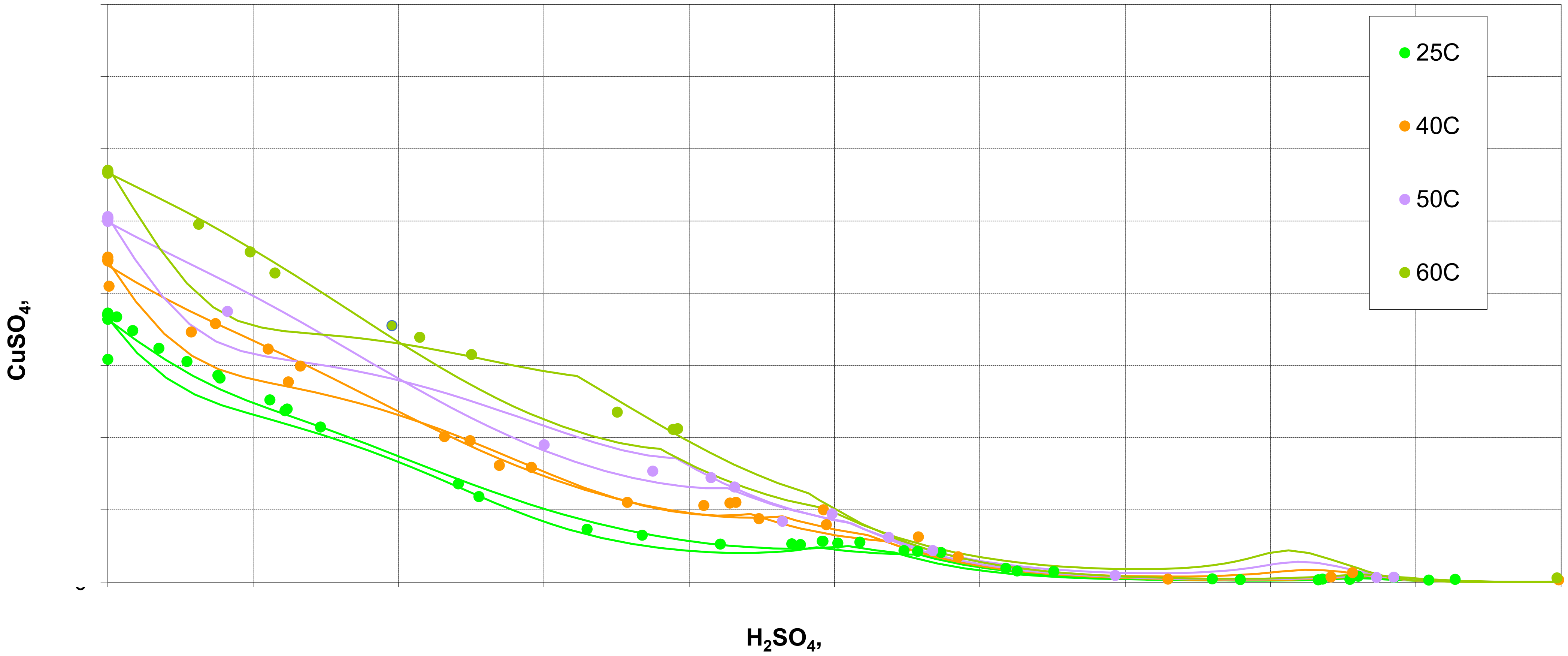




***Symbols** are experimental points*
***curves** are OLI predictions*

OLI vs Test Work Verification

Copper Sulfate Solubility in Sulfuric Acid



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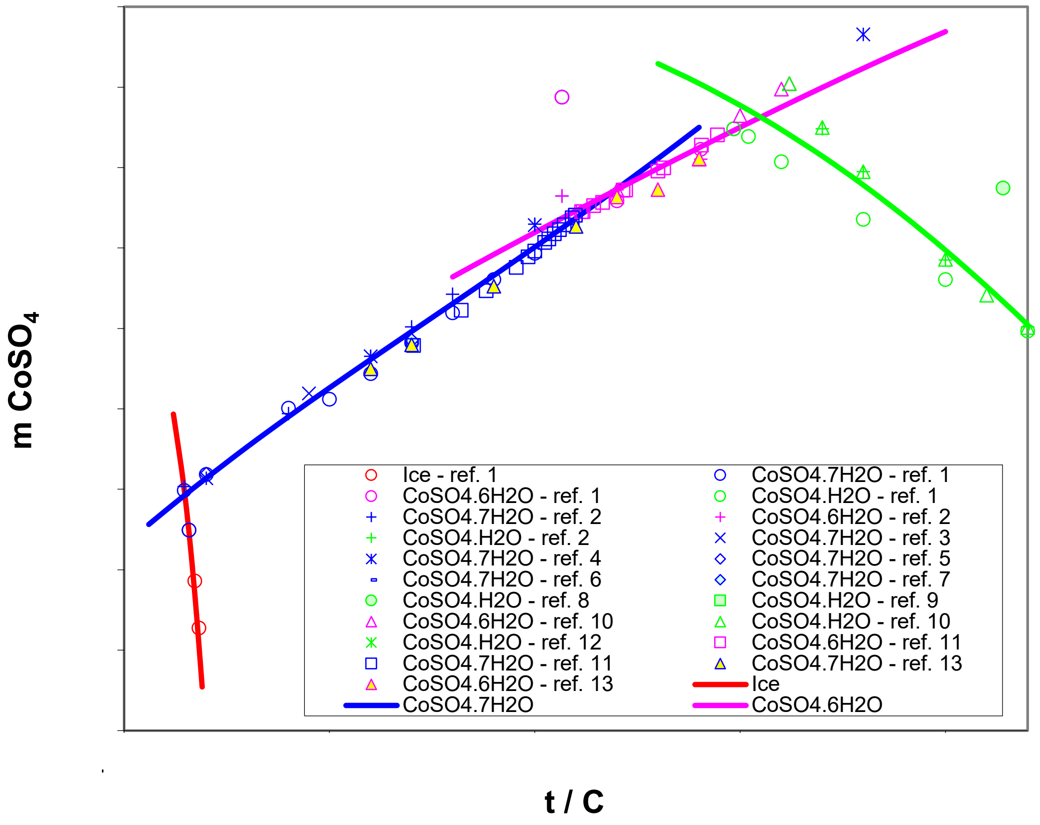
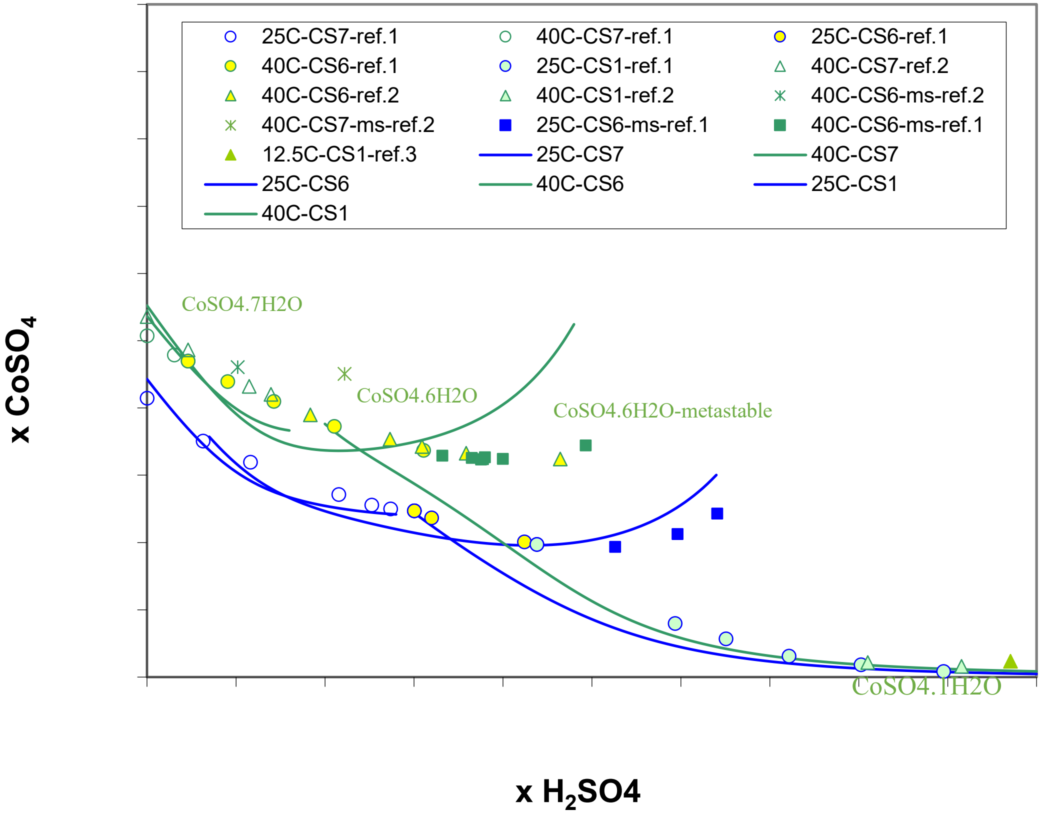
OLI vs Test Work Verification

Cobalt Sulfate Solubility vs Temperature



Cobalt Sulfate Solubility in Sulfuric Acid



Symbols are experimental points, curves are OLI predications

Cobalt Purification and Precipitation - Test Work

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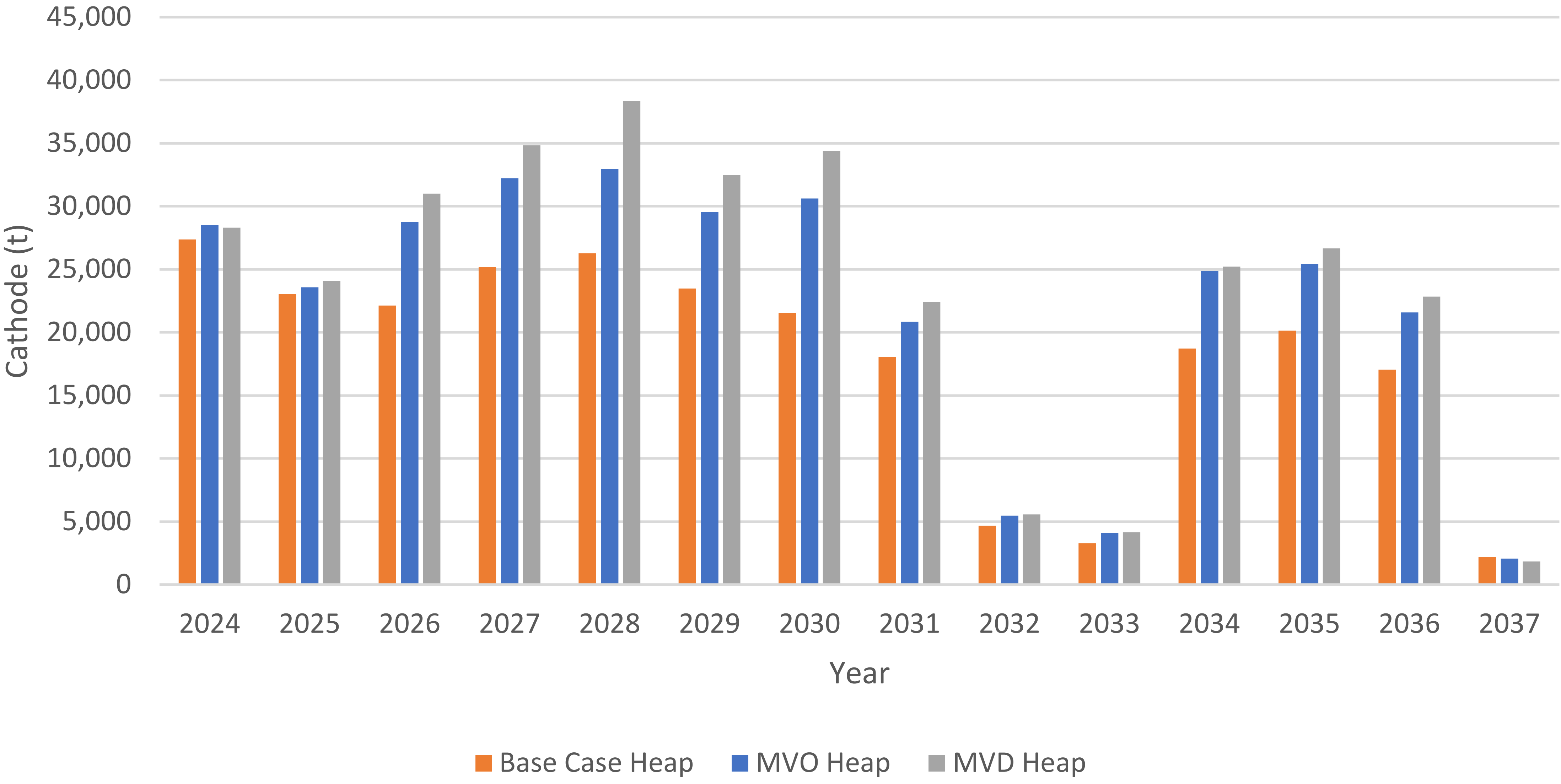
Feed Solution								
Co gpl	Cu ppm	Ni ppm	Mg ppm	Fe ppm	Mn ppm	Ca ppm	Al ppm	Zn ppm
2.5-3.0	<1	40	222	565	222	<50	236	69.3

Test	Pretreatment		Temp (°C)/ Time (hrs)	Precip. Reagent		MHP Product Assay								
Description	Fe/Al Removal	Zn Removal		MgO Addition	NaOH Addition	Co, %	Cu, %	Ni, %	Mg, %	Fe, %	Mn, %	Ca, %	Al, %	Zn, %
1. No Pretreatment	No	No	Ambient/2	3:1	No	20.20%	<0.0025%	0.35%	13.00%	4.32%	0.07%	0.14%	1.95%	0.66%
2. No Pretreatment	No	No	40/2	3:1	No	21.40%	<0.0025%	0.33%	12.00%	4.66%	0.20%	0.18%	1.81%	0.61%
3. Fe precipitated at pH 4, pH 5 required for full removal of Al	Fe Only	No	Ambient/2	3:1	No	20.20%	<0.0025%	0.33%	26.10%	0.05%	0.35%	0.53%	0.71%	0.51%
4. Lower stoichiometric dosage of MgO	Yes	Yes	40/2	1.5:1	No	32.30%	<0.0025%	0.58%	15.70%	<0.005%	0.44%	0.92%	0.07%	0.21%
5. Reaction time was 24 hours, allowing all MgO to dissolve/react.	Yes	Yes	40/24	1.5:1	No	47.2%	<0.0025%	0.8%	1.0%	<0.005%	0.73%	2.02%	0.04%	0.1%
6. MgO added as an acid consumer only, NaOH for Co precipitation	Yes	Yes	40/0.25	Low	1.5:1	40.90%	<0.0025%	0.74%	5.96%	<0.005%	0.68%	0.10%	0.05%	0.21%
7. MgO added as an acid consumer, Zn IX dialed in. Process currently selected for design	Yes	Yes	40/0.25	Low	1:1	46.7%	<0.0025%	<0.0025%	<0.0025%	<0.005%	0.22%	0.30%	0.02%	<0.001%

MHP Impurities Summary

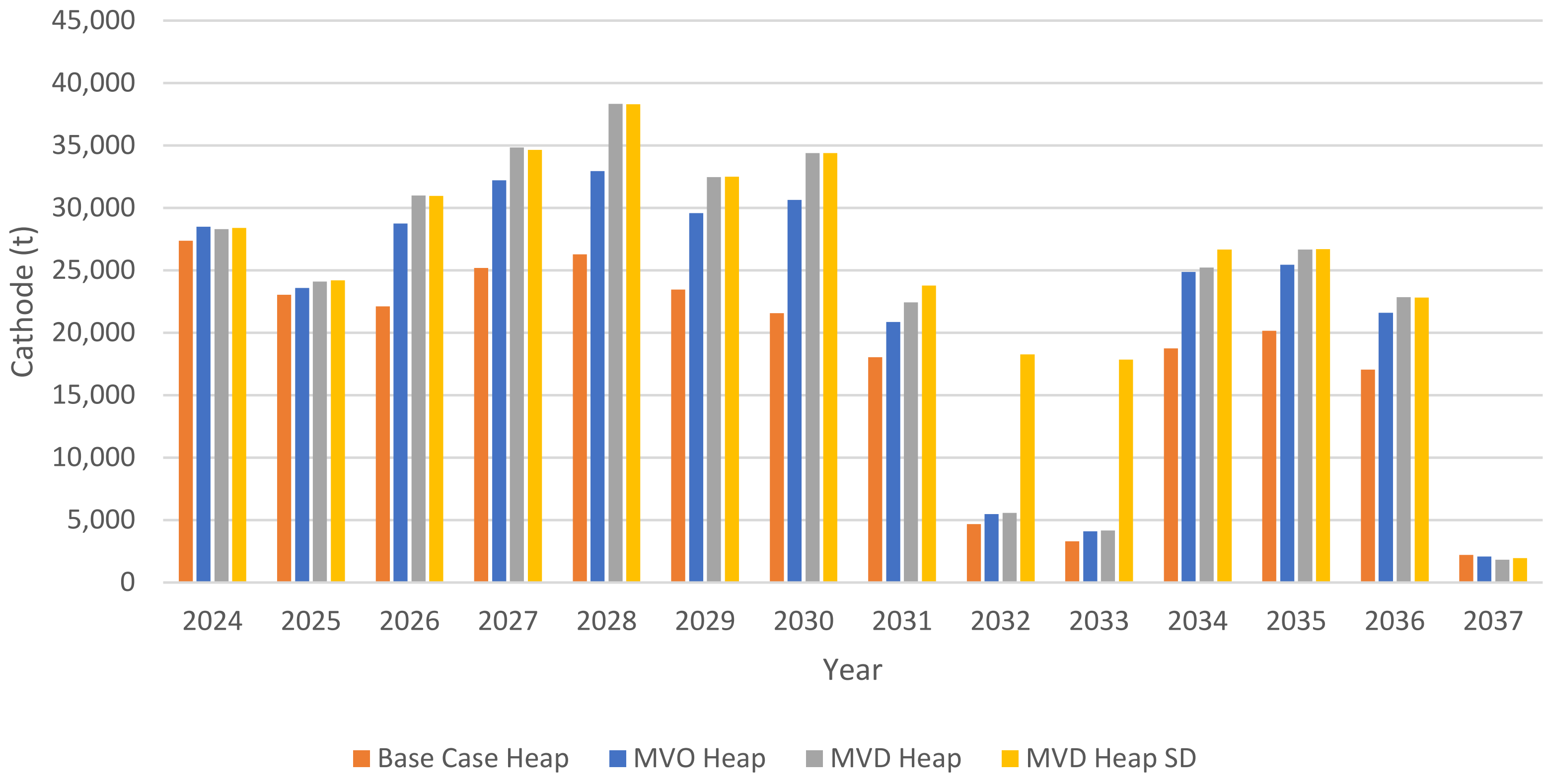
- OLI identified potential MHP impurities – confirmed by testing
- Impurities led to lower Co grade in MHP (~30%)
- Iron and aluminum entrainment in the cobalt IX PLS mitigated by higher rinse flows
- Zinc IX stage was added to accommodate Zn concentrations
- Fe/Al precipitation circuit introduced by adding MgO
- Using a combination of NaOH and MgO improved purity
- Co Grade in MHP increased to >45% with these modifications

Copper Production for Each Scenario



Final Scenario

- Updating material handling scheme
  - New scheme made it possible to increase carbonate cutoff grade allowing ore from the dump pad to be placed on the dynamic pad to fill the 2032-2033 production gap
  - Net copper production increased by 17,700 tonnes per annum
    - 60% - increased recovery from ore
    - 25% - capturing Cu in the pyrite concentrate
    - 15% – production/process improvement



Conclusion

- METSIM® was used to build a simulation of the Mantoverde heaps calibrated to operational data. Scenarios were then run to optimize the operation and maximize Copper and Cobalt recovery.
- Separation of the SX circuit into two individual units for dynamic and static pad PLS treatment could be achieved and is critical for high cobalt recovery
- Solution chemistry modeling identified areas where process adjustments needed to be made
  - Iron and acid balance in the dynamic heap was modified by adjusting reactions to reflect metal solubility and reaction products from OLI models
  - MHP purity was improved by identifying sources of impurity metals with the assistance of OLI models
- Laboratory experiments on the cobalt circuit were validated in the model
- Project Value increased by hundreds of millions of dollars
- Together, OLI and METSIM® provide a comprehensive approach to complex chemistry analysis and can be incorporated into a single detailed dynamic (and steady-state) process model.

Thank You!

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Acknowledgements

Thank you to the teams at Capstone Copper and GRE for all their efforts and including us in this work.