# Leaching beyond Metallurgy

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# Contents

# Classical Hydromet Process Engineering

Orebody Characterization

- ❑ Drilling core extraction
- ❑ Geological model
- ❑ Geotechnical model
- ❑ Geomet model
- ❑ Block model development and its population (variability testing)

Metallurgical Survey

- ❑ Sample characterization: Grades, mineralogy, PSD
- ❑ Column trials: Metallurgical testing
- ❑ Scale up factors
- ❑ Process design parameter estimation
- ❑ Reinforce algorithms for the block model

# How Safe is the Current Approach?

The current Hydrometallurgy, either practical or theoretical, is centered in “copper extraction” instead of “copper recovery”, which strongly depends on transport phenomena. Related relevant lacks are:

- ❑ Selection of heap height
- ❑ Selection of irrigation rates and irrigation calendar
- ❑ Design of wetting ramp
- ❑ Dependence between irrigation and aeration
- ❑ Coupling between mass transfer and heat transfer
- ❑ Relationship between fluid dynamics and metallurgical performance
- ❑ Knowledge of static liquefaction, channeling, ponding, decrepitation, suffosion and suffusion transient phenomena
- ❑ Comprehension of the theoretical frame inside the heap

# Irrigation: Variables/Responses

| PHYSICAL ORE CONDITIONS |
| --- |
| High fines content |
| High ore plasticity |
| PSD wideness or uniformity index |

| OPERATIONAL MODES |
| --- |
| Uneven agglomeration |
| Aggresive irrigation |
| Uneven irrigation |
| Defective solution exit net |
| Excessive heap height |

| HYDRODYNAMIC EFFECTS |
| --- |
| Bed consolidation |
| Bed channeling |
| Pore oversaturation |
| Reduced permeability |
| Random capillary barriers |
| Decrepitation |
| Suffusion and suffosion |
| Porosity clogging |
| Erosion tunnels/sinkholes |

| METALLURGICAL IMPACTS |
| --- |
| Reduced copper recovery |
| Higher net acid consumption |
| Higher water consumption |
| Complex material handling |

| GEOTECHNICAL IMPACTS |
| --- |
| Surface ponding |
| Surface run off |
| Pad slope slide |
| Pad collapse |

# Going beyond Metallurgy...

Orebody Characterization (same as before)

Hydro-Metallurgical Survey

- ❑ Sample characterization: Grades, mineralogy and PSD
- ❑ Edometric consolidation test and permeability
- ❑ SWCC Curve test
- ❑ Atterberg limits test
- ❑ Optimum moisture test. The agglomeration limit
- ❑ Column trials: Hydrodynamic and pneumatic testing
- ❑ Column trials: Hydro-metallurgical testing
- ❑ Phenomenological scale up procedure
- ❑ Mine plan dynamic leach simulation
- ❑ Process design parameter estimation
- ❑ Reinforce algorithm for the block model

Much more reliable production program forecast compared to the block model

# Going beyond Metallurgy...

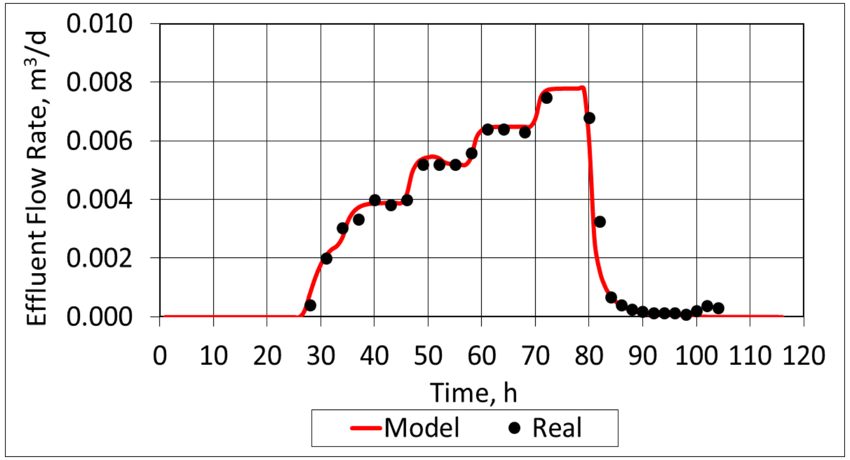
Hydro-Metallurgical Survey (Special testing)

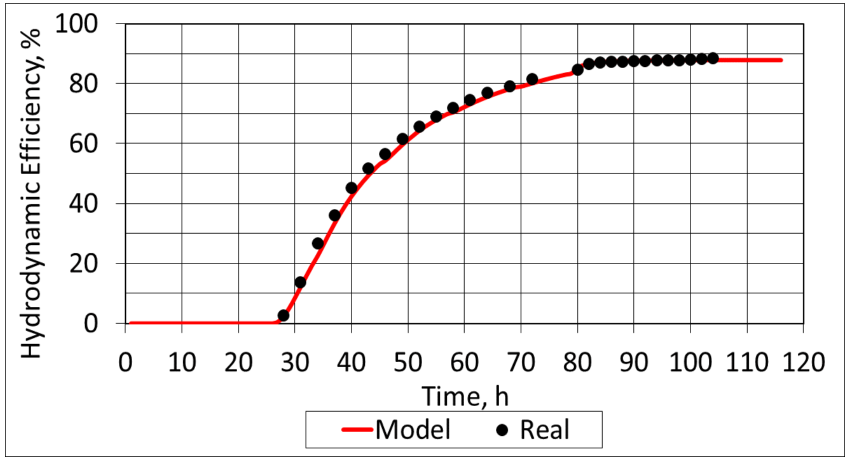
- ❑ Wetting ramp simulation
- ❑ Channeling occurrence
- ❑ Liquid exit delay occurrence
- ❑ Static liquefaction threshold
- ❑ Decrepitation yield
- ❑ Suffusion/suffosion occurrence

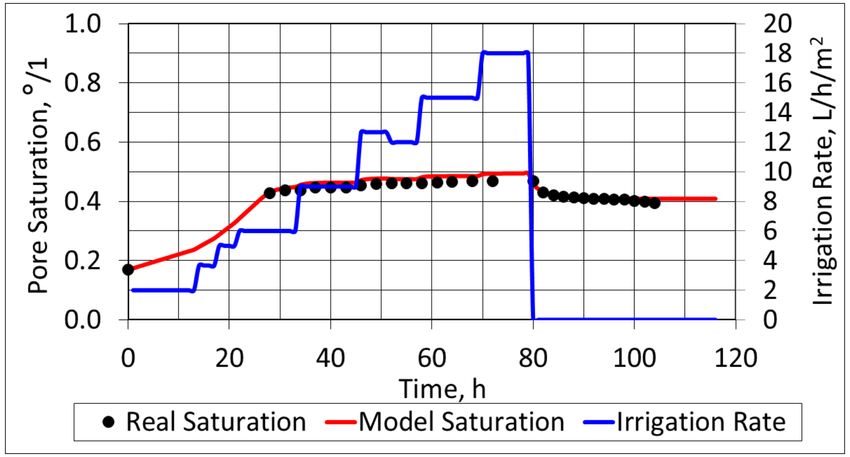
Relevant Leaching Analytica Tools

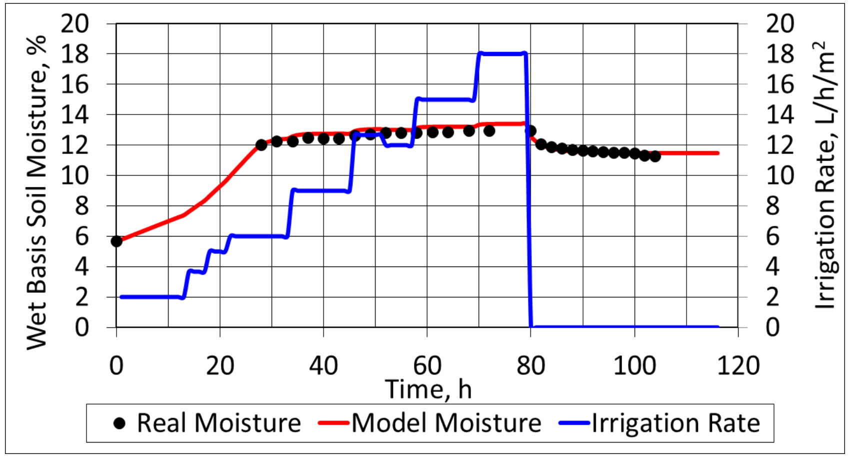
- ❑ Flux code
- ❑ Leach dynamic simulator
- ❑ Hydrus code
- ❑ Pedotransfer function simulator
- ❑ Rock science, limit equilibrium method and numerical deformation codes

# Case Study I:
# Hydrodynamic and Pneumatic Heap Leach Design



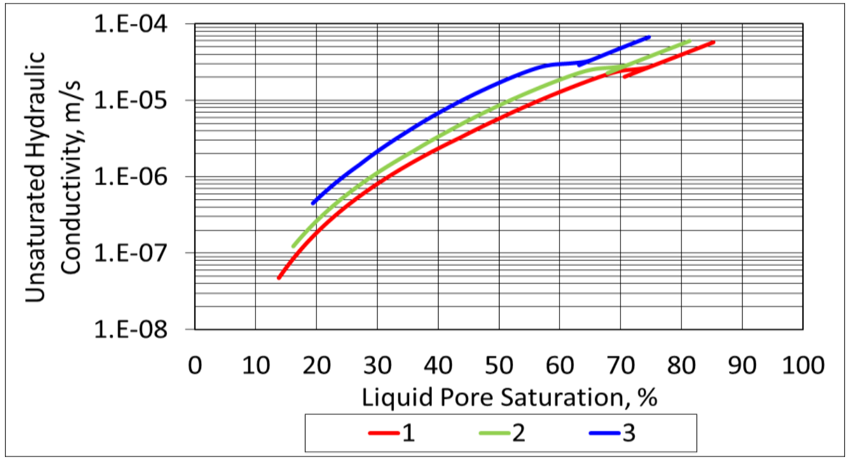



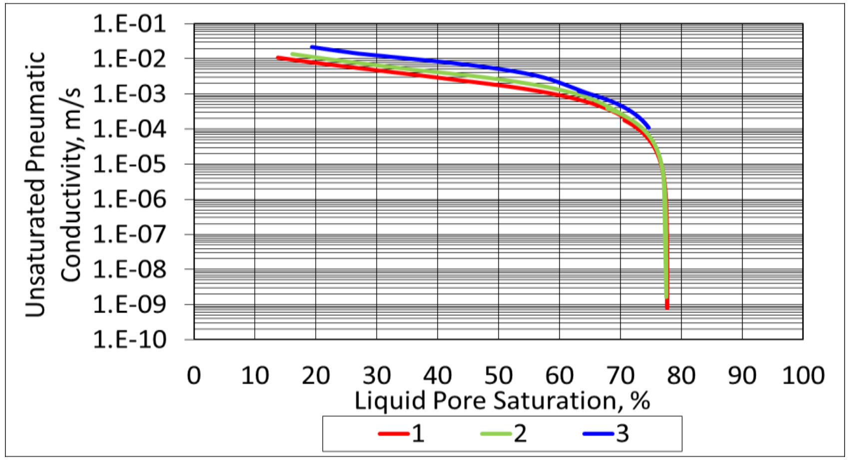



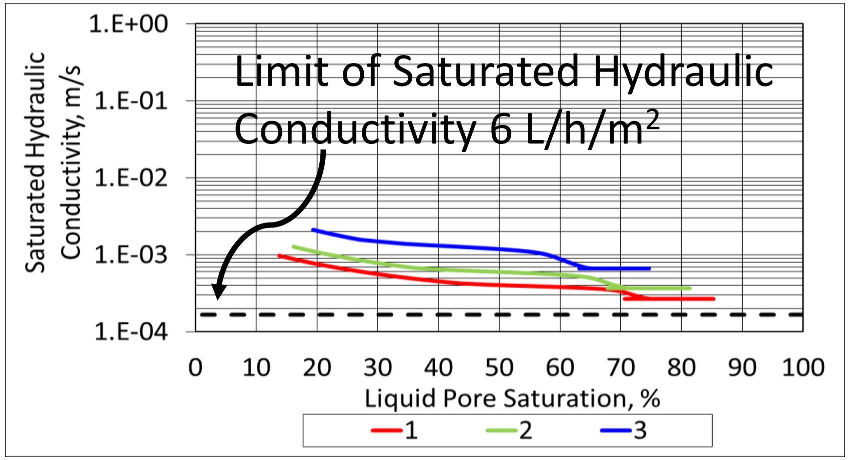

# Case Study I:
# Hydrodynamic and Pneumatic Heap Leach Design

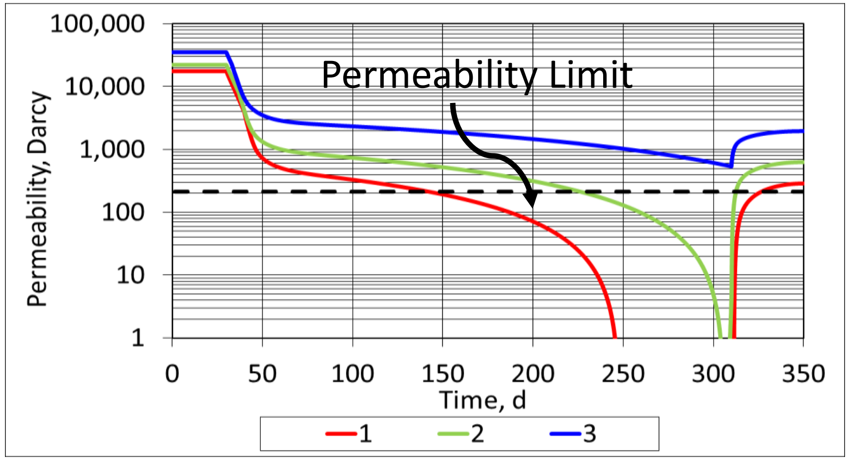
DESIGN RULES:

- The CHS or saturated hydraulic conductivity is ≥ 100 x design rate of irrigation.
- The pore saturation is ≤ 75% to avoid geo technical risks.
- The free pore volume is ≥ 40% for proper aeration.
- The gas permeability of the porous bed is ≥ the planned aeration rate, estimated from the stoichiometry.



# Case Study I:
# Hydrodynamic and Pneumatic Heap Leach Design

| Design Condition 1 | Fine | Average | Coarse | Limit |
|---|---|---|---|---|
| Minimum CHS, m/s | 3.E-04 | 4.E-04 | 7.E-04 | Min. 1.7E-4 m/s |
| Max. Saturation for Geotechnics, % | 84.9 | 81.0 | 74.3 | Max. 75.0% |
| Max. Saturation for Aeration, % | 84.9 | 81.0 | 74.3 | Max. 60.0% |
| Minimum Gas Permeability, Darcy | 0 | 0 | 209.6 | Min. 214 Darcy |

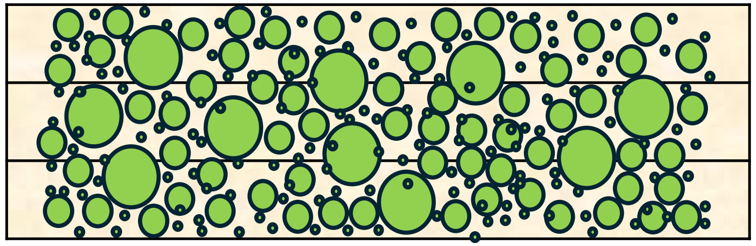
| Design Condition 2 | Fine | Average | Coarse | Limit |
|---|---|---|---|---|
| Minimum CHS, m/s | 5.E-04 | 8.E-04 | 2.E-03 | Min. 1.7E-4 m/s |
| Max. Saturation for Geotechnics, % | 73.0 | 68.2 | 60.0 | Max. 75.0% |
| Max. Saturation for Aeration, % | 73.0 | 68.2 | 60.0 | Max. 60.0% |
| Minimum Gas Permeability, Darcy | 207.3 | 1,021.8 | 6,801.4 | Min. 214 Darcy |

COMMENTS:

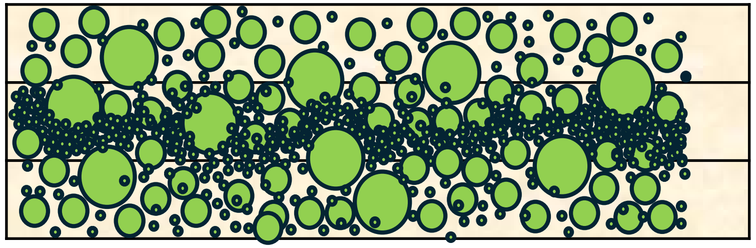
- Condition 2 is the best option, with some care to assure aeration.
- Condition 1 is discarded from this feasibility analysis. It has too many potential failures.
- Note that the weakest aspect in all cases is the aeration assurance.

# Case Study II: The Suffusion Phenomena

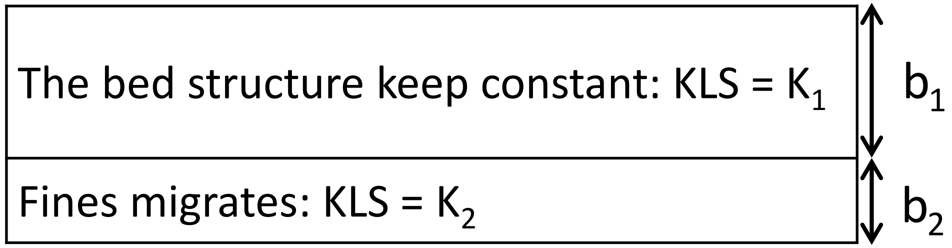
Initial Condition



Final Condition

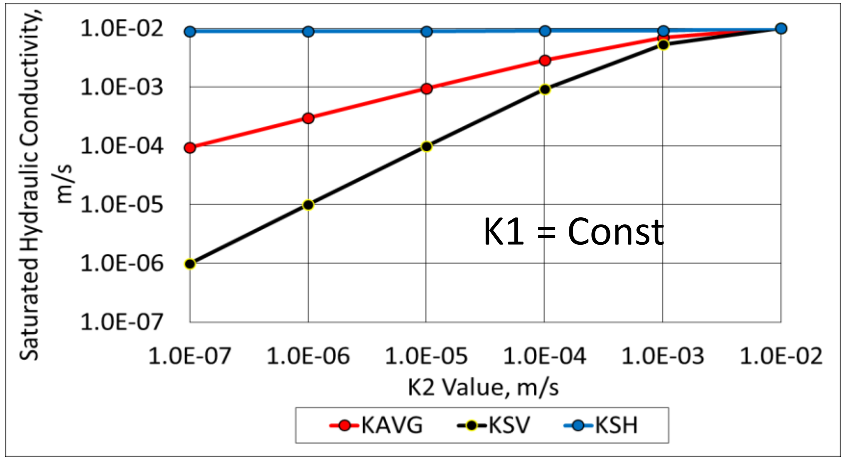


Migration of Fines



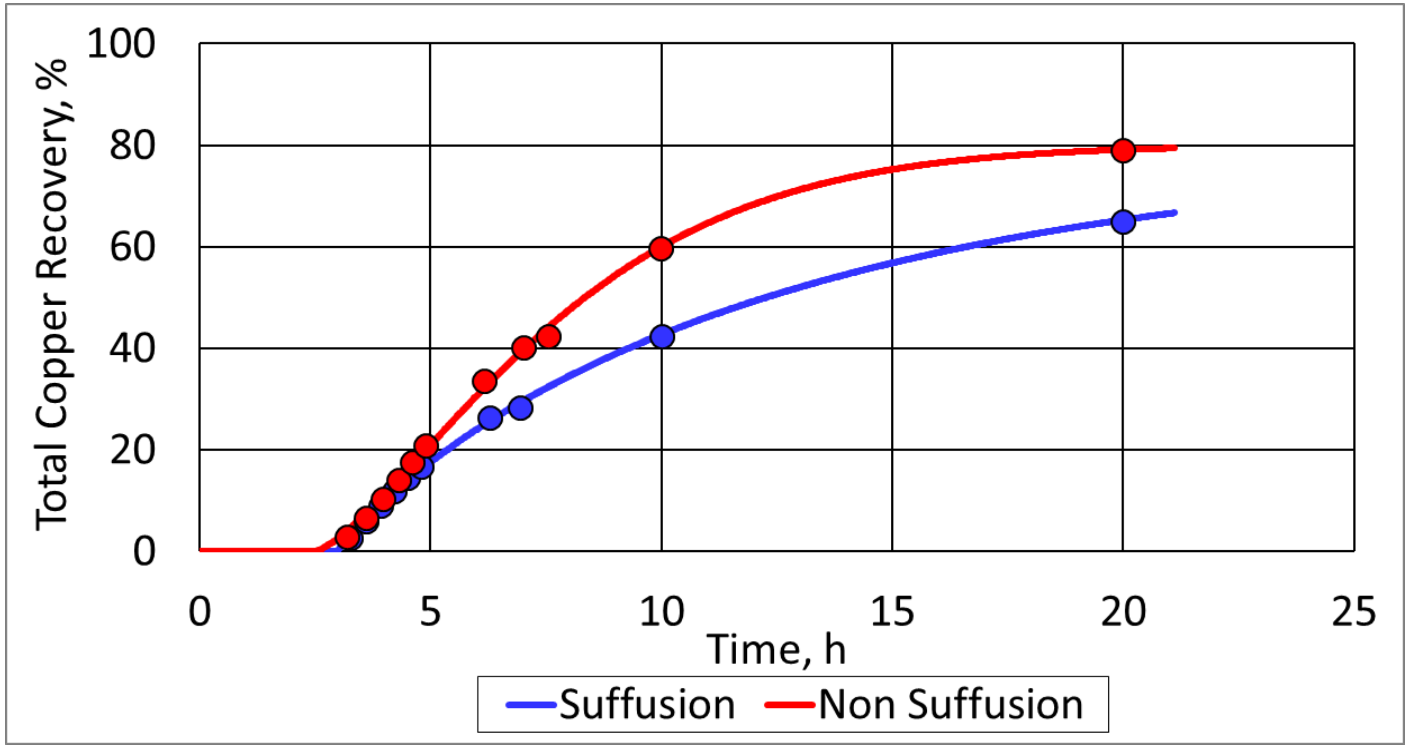

Horizontal Sat. hydraulic conductivity: $K_{LSH} = \frac{\sum_i b_i K_i}{\sum_i b_i}$

Vertical Sat. hydraulic conductivity: $K_{LSV} = \frac{\sum_i b_i}{\sum_i \frac{b_i}{K_i}}$

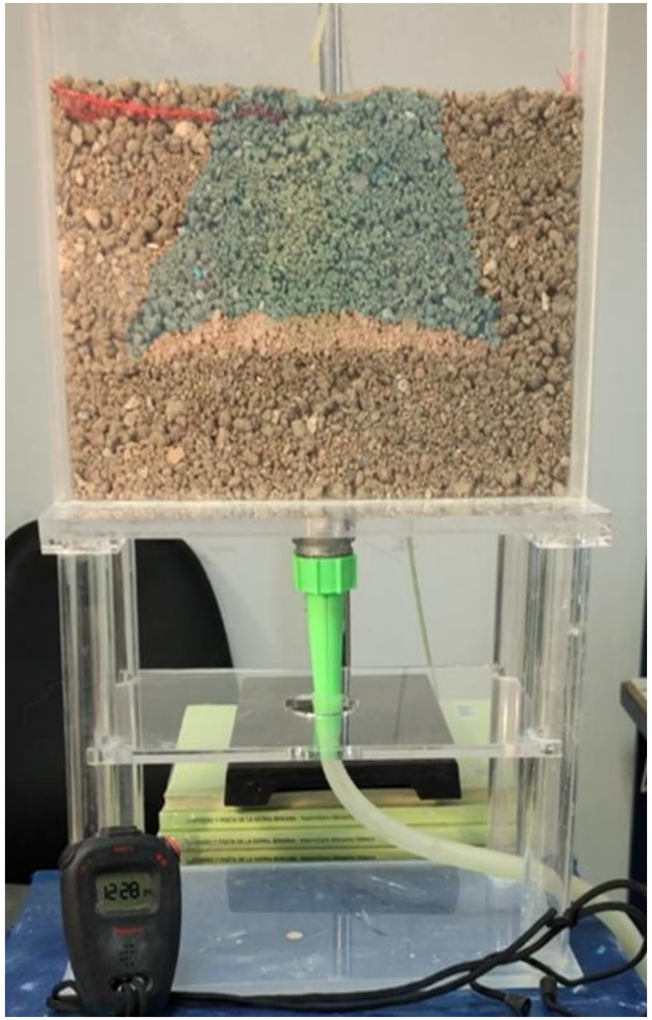



Average Sat. hydraulic conductivity: $K_{AVG} = \sqrt{K_{SH} K_{SV}} = \sqrt{K_1 K_2 \left(b_1 K_1 + b_2 K_2\right) / \left(b_1 K_2 + b_2 K_1\right)}$

# Case Study II: Suffusion and Lack of Recovery




Under irrigation, fines migrate and accumulate in certain positions within the bed and this reduces the infiltration uniformity and hence the copper dissolution rate.



# Case Study II: Suffusion and Fines Production

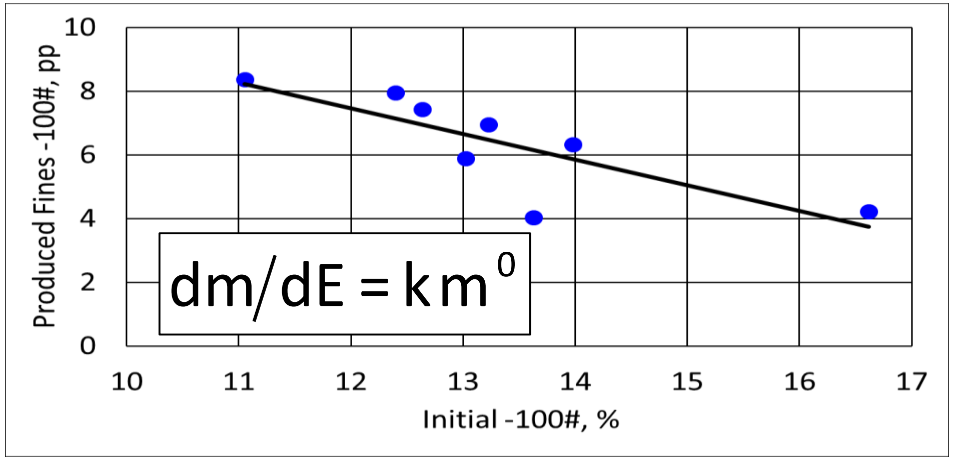
## Ore 1: High-order fines production

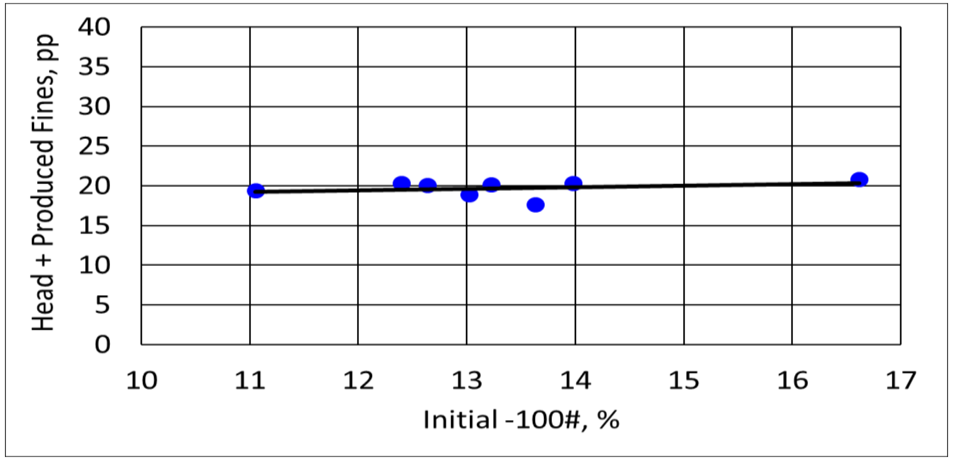
| Head -100#, pp | | | | | | |
|---|---|---|---|---|---|---|
| UGM | 1 | 2 | 3 | 4 | 5 | 6 |
| P100: 64 mm | 1.0 | 2.2 | 6.7 | 1.8 | 2.6 | 4.3 |
| P100: 19 mm | 1.9 | 2.7 | 6.9 | 2.6 | 3.3 | 4.7 |
| P100: 12 mm | 3.5 | 3.5 | 8.1 | 3.9 | 4.7 | 6.1 |

| Ripios -100#, pp | | | | | | |
|---|---|---|---|---|---|---|
| UGM | 1 | 2 | 3 | 4 | 5 | 6 |
| P100: 64 mm | 8.1 | 11.8 | 22.9 | 22.8 | 30.3 | 39.5 |
| P100: 19 mm | 10.7 | 13.7 | 25.5 | 21.7 | 27.7 | 46.8 |
| P100: 12 mm | 14.6 | 15.5 | 23.5 | 27.3 | 29.5 | 46.7 |
| Average | 11.1 | 13.7 | 24.0 | 23.9 | 29.2 | 44.3 |

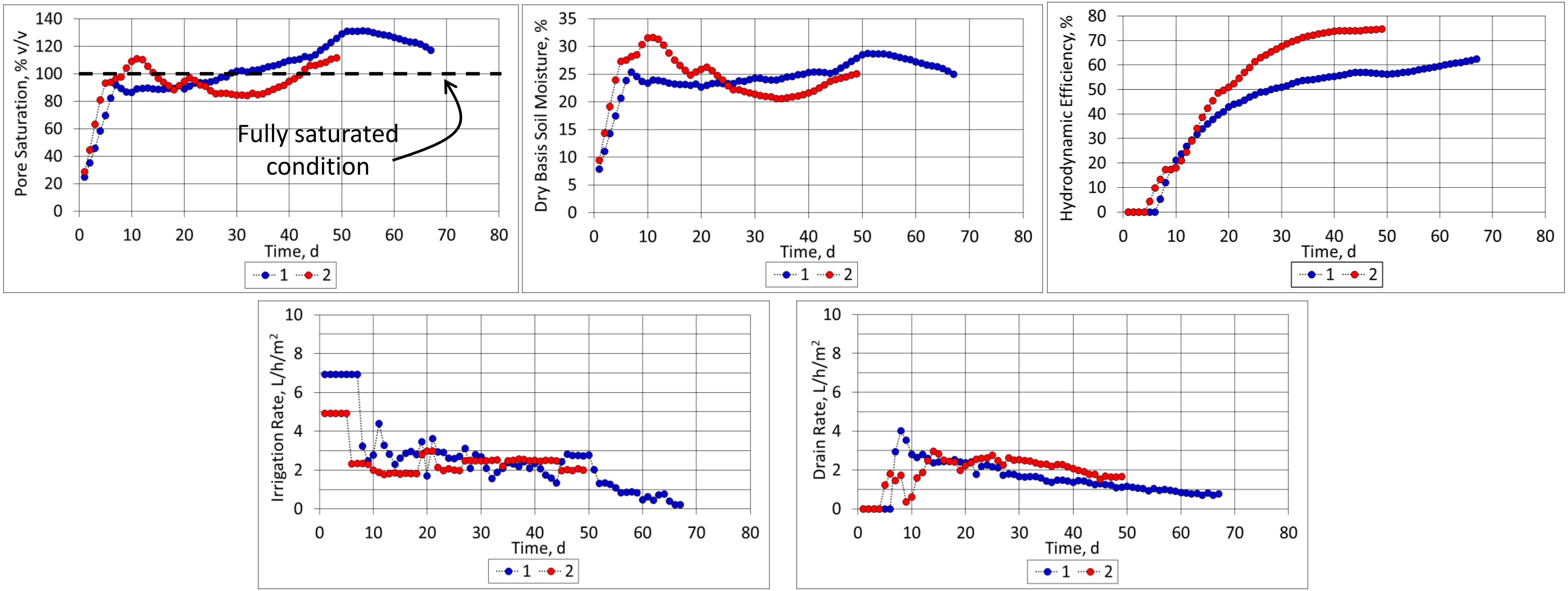
$$dm/dE = k m^n, \quad n \neq 0$$

## Ore 2: Zero-order fines production

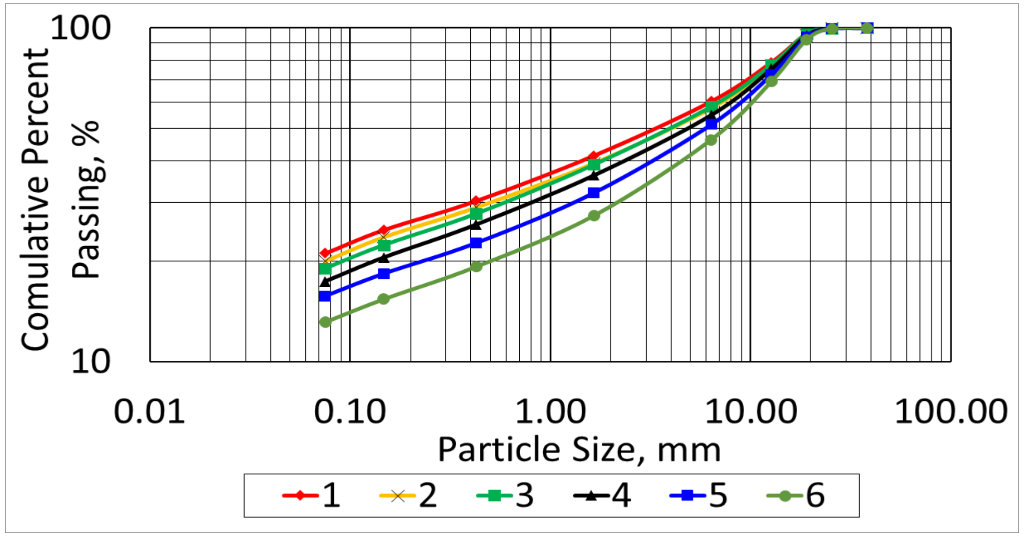


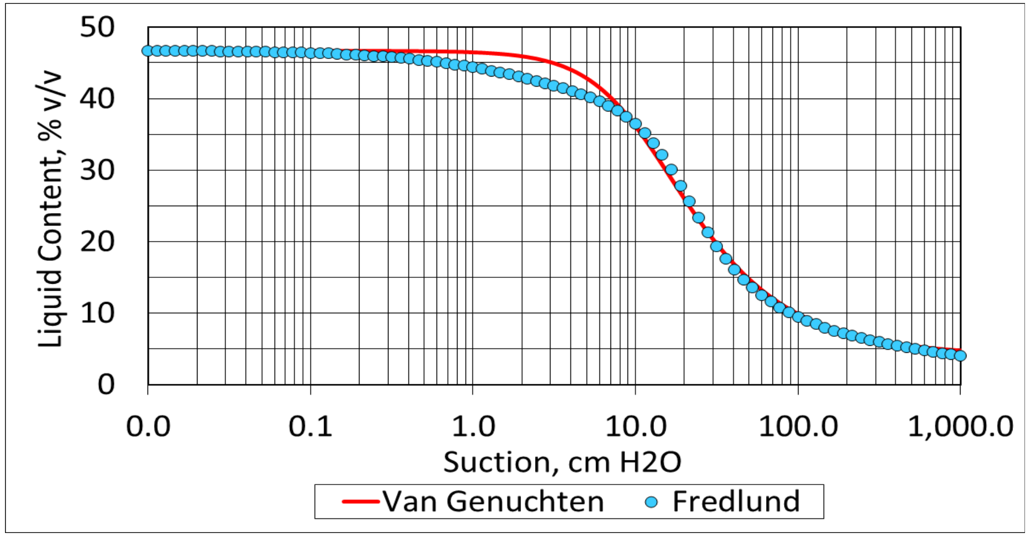



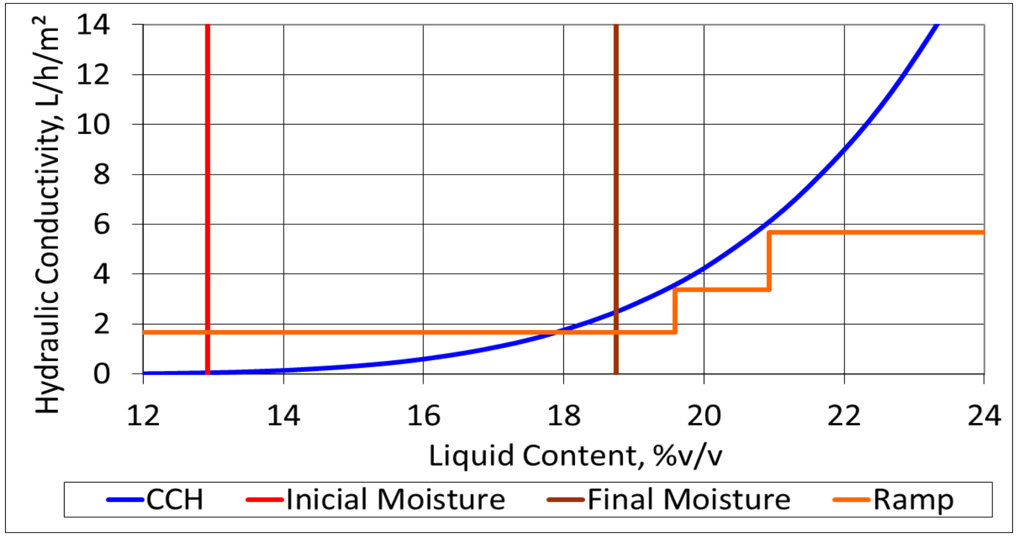
# Case Study II: Suffusion and Lack of Permeability

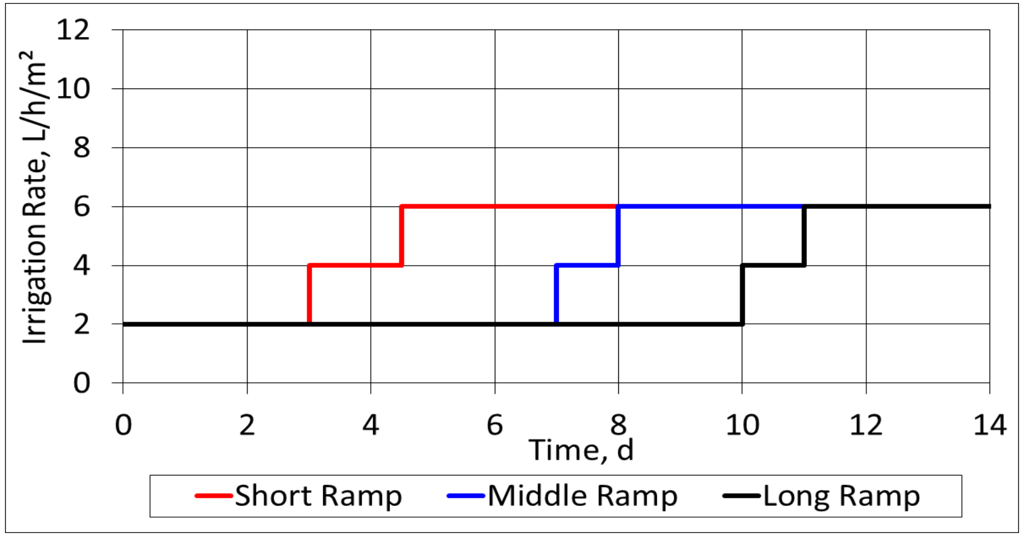


# Case Study III: Wetting Ramp Design

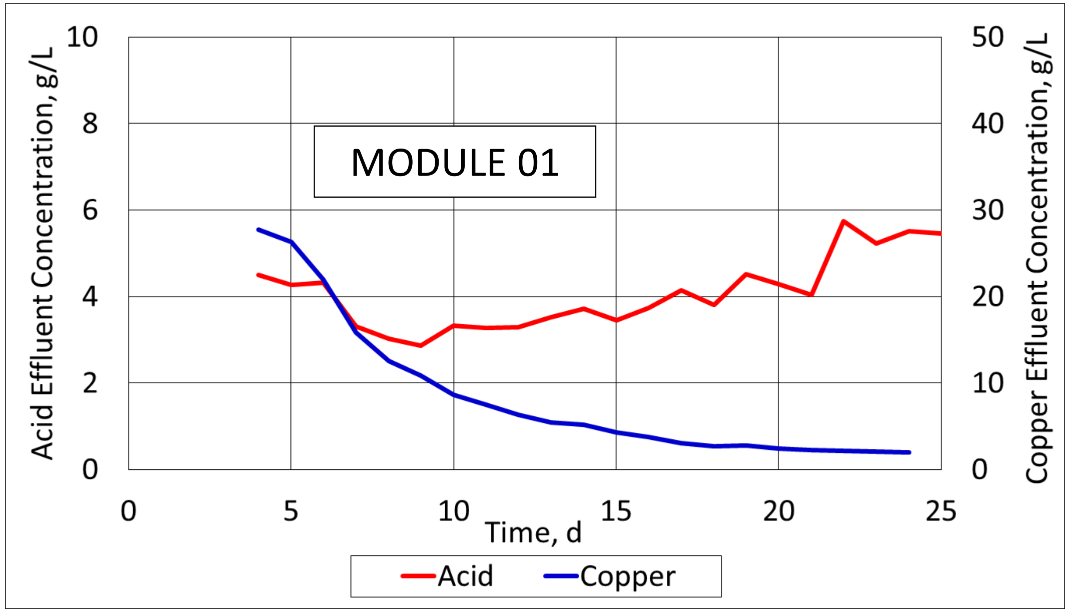


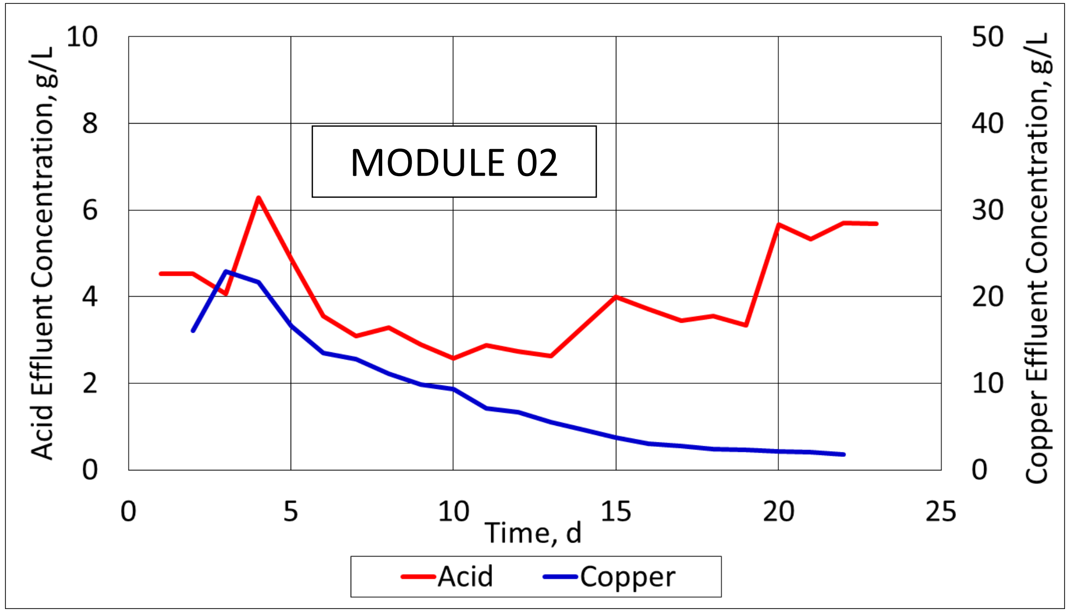



# Case Study IV: Liquid Channeling at Plant Level




- ✓ Improper irrigation ramp
- ✓ Excessive irrigation rate
- ✓ Lack of agglomeration
- ✓ Too broad PSD
- ✓ Too much fines
- ✓ Clayish material

Channeling →

- ✓ Early effluent appearance
- ✓ Low initial copper concentration
- ✓ High initial acid concentration

# Conclusions

- We must go further "recovery" and "acid consumption" to get reliable heap leach design and efficient operation.
- Scale up factors, based only on experience are not objective. Instead, we should employ phenomenological scale up procedure.
- Heap leaching is a reactive transport phenomena system, highly non linear, then well settled phenomenological hydrodynamic/pneumatic models complementing the metallurgical kinetic approach are needed.
- There is a thin but strong thread connecting metallurgy with geotechnics, geomechanics, soil mechanics, hydrodynamics, pneumatics and heat transport, among others, interactions are hard to predict if phenomena are not enough understood.