Injection Leach Technical Guidance

Geotechnical Criteria and Flow

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Standardization – Prescriptive approach

› Standardizing an ad-hoc approach will allow the functional area of SXEW to work better with the technical arms of leaching
  – g/l of copper is more meaningful when prescriptive measures define the boundaries of the flow regime
  › Water balance will only work if operations keep careful records
    – Once discipline is created within operational staff function, the technical nuances of unsaturated phenomena and dispersion are meaningful
      › The three more meaningful kpi’s are the geotechnical factor of safety and degree of dispersion with increased ROI
      › Tools and techniques involve geophysics snapshots and correlation to dispersion
      › As dump understanding evolves, a prescriptive approach will precede the investigations to lower costs and improve operational efficiency, as long as material characterization is dialed in correctly
First generation of technical support is to install simple applications – then develop further understanding through more sophisticated methods

Tools to systematize leach operations
- Flowmeters
- Pressure gauges, piping networks, and discharge assemblies in correct sequence and hydraulic function
- Piezometers – open standpipe or hydraulic
- Reconstruction of dump cross-sections and method of placement
- Historical research, especially on an older site
- Limit equilibrium slope-stability and seepage analyses, with sensitivity to pressures applied
- Review and proper project documentation of pre-construction, construction, and as-built phases of project, with field engineer oversight and geological interpretation
- Foundation, and flow directions to collection pools
- Good flow records from raffinate, cure, rinse cycles for both surface and injection, and correlation with geotechnical instrumentation
- Continuous integration of day to day SXEW operations with technical staff
- Base water balance approaches to define hydrologic basins at original ground level – i.e. topographic divides and basin boundaries
- Development of standard operating procedures with an eye on generating a full OMS manual
- Application of observational method and engineering judgement to deformation controls (prisms) well spacings, application rates
Dividing any installation into pre-construction, construction, and as-built sequence enables better adherence to schedules, and accommodation to unforeseen conditions.

A thin zone of 100% saturation at a depth of about 65 feet is a candidate weak layer. Higher resistivity zones (> 10 ohm-m) above and below indicate free drainage of fluid. Low permeability in the thin zone is assumed to contribute to 100% saturation there.

- Free draining: Res > 10 ohm-m - high fraction of air in porosity
- Saturation < 100% - air in porosity
- Low Strength: Res > 5 ohm-m - good solution drainage
- Saturation 100% - high times / low permeability
- S-wave < 1,500 ft/s lower modulus

Moderate / High Strength:
- Res < 10 ohm-m - good solution distribution
- Saturation < 100% - fair / good drainage
- S-wave > 2,000 ft/s - moderate / high modulus

Rock Deposition Area Stability
ASARCO RAY Operations

Conceptual Geophysical Interpretation

FIGURE B4

Project ID: 1521404
15-MC-07, 15-MC-08
Date: 15082001
Scale: 1:1000
Engineer the process - Size trunk line feeders bigger, protect backslope, install flowmeters

Cheap hydraulic barrier
40 mil hdpe
Top of new lift

It pays off!
Observational approach and engineering judgement

- Are dump leaches heterogenous, can bridging of fines encourage erosive piping and blank off lower portions of dump to leach dispersion?
Dumps are heterogeneous, widely varying material properties – do materials weather faster under leachate? Are we overstating?

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Moist Unit Weight (lb/ft³)</th>
<th>Cohesion (lb/ft²)</th>
<th>Friction Angle (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Rock</td>
<td>120</td>
<td>0</td>
<td>33</td>
</tr>
<tr>
<td>Slime</td>
<td>110</td>
<td>300</td>
<td>18</td>
</tr>
<tr>
<td>Foundation</td>
<td>120</td>
<td>5000</td>
<td>30</td>
</tr>
</tbody>
</table>

Accurate?
Layout in accordance with geotechnical criteria with geophysics
Moisture sensors at depth don’t track – or take time to track

Volumetric Water Content
8C-M-03

Volumetric Water Content
8C-20-10R

8-26-2017 12:00 AM  9-2-2017 12:00 AM  9-9-2017 12:00 AM  9-16-2017 12:00 AM  9-23-2017 12:00 AM  9-30-2017 12:00 AM

VWC (m³/m³)

60 feet  180 feet  210 feet

9/30/2017 12:00 AM  10/7/2017 12:00 AM  10/14/2017 12:00 AM  10/21/2017 12:00 AM  10/28/2017 12:00 AM  11/4/2017 12:00 AM  11/11/2017 12:00 AM
Challenge - Development of unsaturated soils criteria as predictive tool

- Can soil water characteristic curve be used for predictive measure?
- What are the effects of matric suction, especially in arid climate?
- Can deep injection and surface sprinkling be alternated or performed simultaneously to maximize productivity?
Bathymetry at collection pools will allow a stage-capacity relationship.
Remote imaging – INSAR holds promise, but still vague results, still relying on surface prisms
Geotechnical Criteria as part of SOP – hard and fast

- geodetic prisms spacing at 150 ft edge of bench – max 3 cm movement threshold
Plumbing layout – must comply with SOP – Geotechnical criteria – any injection well discharge riser should be at least 135 ft back from crest.

<table>
<thead>
<tr>
<th>Estimated flow per injection well (gpm)</th>
<th>max psi**</th>
<th>minimum depth to first screened interval (ft bgs)</th>
<th>bench setback distance from crest (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>25</td>
<td>75</td>
<td>175</td>
</tr>
</tbody>
</table>
"An instrument too often overlooked in our technical world is a human eye connected to the brain of an intelligent human being."
Observation and Instrumentation (Ralph Peck, 1972)

Ramp up slowly, use SOP
Assemble lessons learned and continue

› Geophysics pays off - moisture sensors haven’t replaced yet
Ongoing Research

› Withdrawal wells especially using geological or manmade features

› Experimentation with horizontal headers, so wells can continue to be used subsequent to next lift placement

› Careful consideration of fluffing (pulse blasts), hydraulic fracture, or air injection cycle

› Lysimeter tests for geochemistry and material behavior

Withdrawal well may aid stability
Thank you! It takes a team!

 › Thanks to:
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