Fractured Injection Design and Monitoring

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Fractured Injection: A Primer

Fractured injection is standard practice

- Fractured injection is a standard practice for managing solid wastes in environmentally sensitive regions including offshore, tundra, marsh, and remote areas
- Injected waste would otherwise be discharged to ocean, left in reserve pits, or land-farmed
- Injection of slurry relies on hydraulic fracturing science to create subsurface voids in which solids are stored

Best practices are critical to success

- Proper feasibility studies, well construction, and zonal selection are all critical to achievement of waste disposal objectives

Safe operations require real-time monitoring

- Best practice uses well surveillance and control to continually monitor both surface pressure and subsurface fracture behavior to assure containment at all times
Injection can solve many current acute waste issues
Historical and Current Applications

Nuclear Waste (1960’s-1987)
- First applied at Oak Ridge National Laboratory from the 1960’s – 1987, low level radioactive water was used to make a cement which would set in the subsurface, binding the radioactive isotopes in place.

Oil and Gas Wastes (1987-Present)
- First large scale project was in Alaska North Slope. Widespread adoption in offshore followed along with some major onshore facilities.

BioSolids (~2009-Present)
- Recent Class V project in Los Angeles (biosolids)
- Obviates land-farming + long distance hauls and sequesters CO₂ and CH₄

Other Applicable Wastes
- Technique can solve many other urgent waste issues (NORM, organics, mining and power, superfund, gypsum stacks, petrochem, barge / bilge / dredge...)

From a 1998 EPA report: “The deep injection of waste [enabled by slurry injection] is the only disposal option that effectively removes waste from the biosphere.”

The Terminal Island Renewable Energy (“TIRE”) project is the USA’s first full scale facility to dispose biosolids, brine effluent and tertiary effluent by deep well injection and geothermal biodegradation

- Initiated operations in July 2008 as an EPA demonstration project

- New EPA permit approved December 2013 (allowing construction of 4th well, deepening of wells to 7,500 feet, alternating injection into two wells, and construction of replacement wells as needed)

- Site now manages 100% of the biosolids from the City of Los Angeles Terminal Island Plant and about 20% of the residuals output from the Hyperion Treatment Plant
We are sequestering large amounts of greenhouse gas and reducing risk

Deep well sequestration eliminates environmental impacts from landfarming, reduces operational risks, and provides significant GHG emission reductions

<table>
<thead>
<tr>
<th>Advantek’s TIRE facility in LA</th>
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<tbody>
<tr>
<td>1. Biosolids blending pit</td>
</tr>
<tr>
<td>2. Screen system</td>
</tr>
<tr>
<td>3. Mixing Tank</td>
</tr>
<tr>
<td>4. Electric Pumps</td>
</tr>
<tr>
<td>5. Injection Well</td>
</tr>
<tr>
<td>6. Monitoring Well</td>
</tr>
<tr>
<td>7. Office</td>
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<table>
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<tr>
<th>12 mos at current rates (projection)</th>
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<tbody>
<tr>
<td>% of City Biosolids Diverted</td>
</tr>
<tr>
<td>Biosolids Injected (gals)</td>
</tr>
<tr>
<td>GHGs avoided or sequestered</td>
</tr>
<tr>
<td>Road miles eliminated</td>
</tr>
<tr>
<td>Injuries and Fatalities avoided</td>
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Technology Overview: Slurry vs Water Injection

Salt Water Disposal Wells:
• Typically inject water directly into the disposal zone’s rock matrix
• Total capacity is determined by the volume of the disposal reservoir
• Disposal zones are selected based on isolation from freshwater sources

Fractured Injection Wells:
• Inject solids by grinding them with water to create slurry and injecting the slurry into naturally occurring hydraulic fractures or those created during the injection process
• Capacity determined by the volume of the fractures accessed during injection
• Disposal zones are selected based on isolation from freshwater sources and stress barriers which prevent fracture propagation beyond the permit zone
Achieving best practice requires attention to three key activities

Feasibility, site selection, and permitting
Establishing that a target zone provides a safe operating window considering geological, geomechanical, and seismicity data requires sophisticated analysis.

Well logging, testing and process design review
Initial analysis using offset well data must be reviewed once the well has been drilled to target and the true formation properties tested.

Ongoing, real-time operational monitoring
Monitoring is crucial for the long term assurance of waste containment and well integrity, as well as the safe maximization of disposed volumes.

Successful operations must focus on all three areas
Establishing feasibility & designing a well requires sophisticated analysis

Feasibility and safe well capacity are determined using a workflow based on well logs, offset well performance, geomechanics and fracture simulation & optimization.
Simulations using real field data allow strong assurance of containment

Fracture behaviors are predicted by geomechanical modeling and verified using periodic well tests

Safe margins are built into operating procedures

- Log analyses + breakdown and fall-off tests determine properties of both the injection zone and overlying formations (cap rocks and intermediate zones)
- Fracture and flow simulations are used to predict and confirm containment within the injection zone

Identifying barrier zone and mechanism is critical

- **Stress**: Fracture energy insufficient to crack zone
- **Stiffness**: Fracs become very narrow causing high friction losses and plugging which arrest propagation
- **Permeability**: High perm syphons off fluid energy
# Best Practices in Well Construction for Cyclic + Abrasive Injection

<table>
<thead>
<tr>
<th>Element</th>
<th>Practice</th>
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<tbody>
<tr>
<td>Well head</td>
<td>Typically inspected bi annually for erosion and corrosion, and is replaced as needed</td>
</tr>
<tr>
<td>Tubing</td>
<td>Coated tubing aids in minimizing erosion and corrosion issues due to the abrasive nature of the slurry. The annulus pressure will be monitored to detect any pressure communication between the annulus and the tubing which would signify a possible need to change tubing</td>
</tr>
<tr>
<td>Packer</td>
<td>Packer settings (tension, compression, neutral) are chosen carefully such that the net force is always from one side whether during injection, fall off, or resting. This aids in minimizing the risk of a packer being unseated due to cyclic forces</td>
</tr>
<tr>
<td>Cement</td>
<td>Cement is set through the containment layer (Queenston, Reedsville, Utica, and Pleasant shales) to prevent fluid migration out of zone behind the casing. A cement bond long is studied to assure the quality of the cement before injection</td>
</tr>
<tr>
<td>Particle Size</td>
<td>The maximum particle size of the solids in the injected slurry is controlled (usually below 300 microns) to minimize the tubing erosions and solid settlings issues</td>
</tr>
<tr>
<td>Flushing</td>
<td>After each batch injection, the wellbore and surface piping are flushed with clear fluid to prevent settling of solids in the wellbore which could cover the perforations. Larger flushing events are done periodically to help sweep solids away from the near wellbore to help minimize injection pressure rise</td>
</tr>
<tr>
<td>Geometry</td>
<td>Eliminate / reduce use of 90 degree turns to reduce the erosion wear issues</td>
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Once the well is drilled, initial design parameters must be remodeled

1. Feasibility assessment and option identification
2. Preliminary design
3. HazId/HazOp and permit support
4. Injection test and process redesign
Ongoing, real-time operational monitoring requires close collaboration

Field operators and subsurface engineers must work together to monitor and control the well

- **Well performance**
  - Well-head pressure
  - Injection rate
- **Operational procedures**
  - Correct batch times and rates
  - Correct flushing volume
- **Slurry rheology**
  - Correct slurry viscosity & density
  - Correct particle sizes

**Safe operations must be the highest priority**
- Both surface and subsurface risks must be constantly evaluated using real-time surveillance to ensure that surface pressures and subsurface behaviors are within bounds
Correctly gathered data provide deep insights into subsurface dynamics

**Fall-Off Test**

Injection fall off data can be analyzed for information on fracture containment in-zone, near-well damage, and reservoir properties

**Step Rate Test**

Fracture closure and propagation pressures are interpreted through the step rate test to confirm fracture geometry and injection zone

Too often, operators of injection (including water) facilities gather data only to the extent minimum required by regulation, rendering proper analysis and diagnostics impossible. Real-time monitoring and data archiving should be mandatory.
Fall-off data can be used to provide deep understanding of the fracture behavior

**Standard fall off test analyses:**
- Formation properties such as: permeability, reservoir model, near wellbore skin
- Fracture properties such as: Geometry (L, W, H), conductivity, skin, closure pressure
- Trends in closure pressure can forecast zonal capacity

**Advanced fall off test analyses:**
- Fracture properties: out of zone propagation, cross flow, interference with another well / fault, fracture shrinkage during closure, extent of inner / outer domain (plume), storage volume, stress contrast with confining layer

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Temperature logs can also identify fracture height / containment

Temperature gradient logs can correlate fluid plume / fracture height to rock temperature changes induced by the injected fluid.

Can also illuminate flow behind casing or tubing, such as channeling.

Can identify casing, tubing, or packer leaks.

Injection horizon has lower temperature than the overlying formation since injecting fluids tends to cool down the formation.

Top of the injection horizon. No water migration above this depth.
USGS data enables ongoing seismic monitoring to underpin “traffic light” systems

Seismicity monitoring can be enabled using USGS systems, private monitors, or both.

In-well seismic monitors can complement the data, but are mechanically unreliable.

Careful thought must go into the method of monitoring to minimize well interventions while providing data needed to enable “traffic light” programs which curtail injection wells near established epicenters.
Best practice in regulation raises the bar for all and reduces risks

Tighten injection regulations generally

Strong models of regulation exist currently within the UIC. These should be applied broadly, including to Class II injectors:

- Class I/II Fractured Injection in Alaska’s “Grind-and-Inject” facilities
- Class V Fractured Injection of biosolids at Los Angeles Terminal Island Waste Water Treatment Plant

These models generally require technically rigorous demonstration of safe operations using a combination of scientific and physical observation techniques along with muscular reporting requirements

Broaden application of fractured injection

Encourage state level regulators to establish guidelines for Class II fractured injection potentially alongside no pit rules (i.e., as in New Mexico, Alaska)

Expand use of fractured injection for other sludge / semi-solid waste streams which present challenges to traditional infrastructure:

- Non-Hazardous (i.e., food)
- Haz (i.e., biosolids, mining, refinery, pipeline, chemical plant wastes)

These wastes continue to present significant challenges to their safe disposal which can be addressed under the UIC with appropriate consideration to safe injection best practices
Final thoughts

Fractured injection provides high value use of UIC wells

1. Addresses serious disposal needs in specialized environments
2. Some state UIC permit rules provide insufficient operating windows for fractured injection techniques
3. Users hesitant to advance “experimental” projects mistakenly believing that they provide insufficient certainty for long term operations
4. Balanced monitoring and reporting requirements are in place for some injected solids projects and can serve as a model for future installations
   • Class I/II solids injection in Alaska's "grind-and-inject" facilities
   • Class V biosolids injection in Los Angeles

Clarification within UIC local rules could assist in unlocking the potential of solids injection to address several challenging waste types, including biosolids
Thank You