Achieving Zero-Discharge NORM Waste Disposal Using Slurry Fracture Injection (SFI) Technology

NORM-IX Symposium:
9th International Symposium on Naturally Occurring Radioactive Material

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September 25, 2019
TTI’s Slurry Fracture Injection (SFI) is an Environmentally Sustainable HF technology. SFI is used as an advanced deep well disposal process:

- Large volume of waste disposal (10,000+ m$^3$/month ~ 63,000+ bbl/month)
- Disposal of multiple wastes: contaminated soil, oily sludge, NORM, E&P waste
- Fast implementation allowing for rapid deployment and start-up
- Environmentally sustainable disposal process- Zero Discharge waste management
- Life-cycle cost effectiveness

Significant environmental advantages for SFI as a waste management strategy:

- Process Control systems to mitigate risks (OOZI, loss of wellbore integrity, groundwater impact, maintain optimal formation response, max. storage capacity)
- Permanent disposal: no risk future environmental liabilities
- Zero Discharge: no interaction of disposed waste with the surface biosphere
- No ground water contamination, protects soil and air quality
- Disposal operations do not impair surface lands & water resources
- Cost effective and time effective waste disposal.
- Safeguard public health by reducing & removing pollution
Surface Disposal of Waste

SFI solves this problem
Advanced deep well disposal: granular / fines or viscous fluid waste streams
- Produced solids, granular fines, and oily sludge
- These waste streams are slurried into a pumpable slurry
- Waste water (produced water) used as carrying fluid
- Multiple waste streams (including NORM/TENORM)

Heavy slurry – Different ‘slurry design’ for different waste types
- 15-25% by volume waste concentration
- 1.15-1.3 SG & FV < 60 sec

Long-term, continuous, hydraulic fracturing in ‘soft rock’
- Different injection strategies for different waste types
- Injection rates and pressures; cycle design

Injection of large waste volumes (3,000-17,000 m³/month)

Deep geological sequestration (350-2000 m / 1150-6500 ft)
- Thick friable sand formations: optimum fluid-flow and geomechanics

Process control for operational & environmental assurance

**Excellent long-term security & Environmental Advantages**
TTI’s proprietary SFI technology provides Zero Discharge solutions with ‘Process Control’:

1. **Formation Containment**
   - Ensures the integrity of containment of the disposed slurry.

2. **Optimization Formation Response**
   - Ensures optimum sustainable pressures and rates of injection.
   - Dissipation of stress/pressure gradients.

3. **Maximization of Storage Capacity**
   - With strong backgrounds in geomechanics & reservoir engineering, TTI maximizes formation storage capacity.

4. **Maintenance of Wellbore Integrity**
   - Ensures mechanical and hydraulic integrity of the wellbore.

**TTI applies the science of geomechanics in providing customized, long-term & permanent waste disposal solutions to E&P companies** (“Bottoms Up vs. Pump & Pray”).
• **Ensures wellbore integrity**
  - Mechanical & hydraulic

• **No surface and groundwater contamination**
  - Multiple barriers to USDW
  - Wellbore & geologic barriers

• **Allows for wellbore monitoring & control**
Project Development Workflow – Best Practices

TTI SFI Project Development

Phase 1 – Technical Feasibility Study (TFS)
- Geological Assessment
- Waste Material Audit
- Slurry Fracture Mechanics
- Operating Strategy
- Disposal Well Design
- Prelim SFI Project Design & Recommendations
- Prelim SFI Project Estimates

Phase 2 – SFI Front End Engineering & Design (FEED)
- Field Site Assessment & Location Selection
- Formation Testing
- SFI Start-up, Operating Strategies & Contingency Procedures
- SFI Process Control Monitoring Program
- Final Process Design Specifications
- Final SFI Facility Design
- CAPEX & OPEX Cost Structure
- Comprehensive SFI Project Implementation Schedule

Phase 3 – Regulatory Approval
- Identify Relevant Government Regulatory Agency
- Comprehensive SFI Project Application
- Liaison with Regulatory Agency & Address Concerns
- Letter of Approval / Project Permit

Phase 4 – SFI Field Operations
- Entire SDU Equipment System
- Field Operating Personnel
- SFI Engineering Personnel & Technical Support
- SFI Project Management Personnel & Project Management Support
Total 5,000 m³ of NORM disposed

*NORM was not pre-treated prior to injection*

30+ pCi/gm Radium 226/228 (1.5 Bq/gm)
SFI Field Case #1: NORM Project Site
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Louisiana, Chevron Port Fourchon Project
(Summary from SPE 71434, 53821)

• Port Fourchon, Bay Marchand terminal facility
• Processed oil from nearby offshore platforms since 1949
• Facility cleaned up 1997-2000:
  o NORM: Naturally occurring radioactive material
  o NOW: Non-hazardous oilfield waste
  o Processing pits: Contained drill cuttings, drilling mud, produced sand, pipe scale (barium/calcium precipitate), oily wastes
  o Canal: Sediments were contaminated by overflows from processing pits
Location of Port Fourchon

Fourchon Site Map

Bay Marchand Terminal Pits
SFI Pumping Equipment
California Canal
Retaining Wall (for drainage of canal)
Dead End Canal
Chevron Pipeline Co. Facility

Fourchon Pits (material disposed in landfill)

Slurry Barge
SFI Well
SFI Field Case #2: NORM

NORM:

Contamination level
- Maximum ~ 110 pCi/gm Radium 226 (4.1 Bq/gm)
- Average ~ 40 pCi/gm Radium 226 (1.5 Bq/gm)
- U238 and Th 234/Ra 228

Area
- Bay Marchand Terminal: Pits #1, #2, #3 and some land area
- Storage pits for drill cuttings, spent drilling fluids, oily waste, pipe scale, etc

Depth of contamination
- Maximum ~ 12 ft (3.6 meters)
- Average ~ 8 ft (2.4 meters)
SFI Field Case #2: NORM

- **VETCO GRAY TREE**
  - 5000 PSI
  - 6” OD (4.5” ID) INJECTION LINE TO TREE
  - all surface lines are 4.5” ID

- **10 3/4” SURFACE CSG 40 SR**
  - SET AT 1005 FT

- **TOP OF PERMITTED ZONE 2000 FT**

- **LAMINATED SAND/SHALE SEQUENCE**

- **CONFINING SHALE ZONE**

- **LAMINATED SAND/SHALE SEQUENCE**

- **INJECTION ZONE 4500 - 6000 FT**

- **7 5/8” CSG, 29.7K, P110**
  - 0 - 5000 FT CEMENTED TO SURFACE

- **4 1/2” TBG, 12.75#, N80**
  - 0 - 4515 FT

- **Casing cemented to surface**

- **Panex Electronic Quartz Gauge at 4321 FT with 1/4” encapsulated TBG to surface non-retrievable**

- **Packer at 4406 FT**

- **Perforations at 4 SPF**
  - DDEG Phasing 4520-4560 FT

- **Damaged casing at 4514’**
  - Top of fish at 4786’
SFI Field Case #2: NORM

SFI Project – Site Remediation

….Before

….During

….After

Final closure criteria:
• upper 15cm soil < 7 pCi/g Ra$^{226/228}$
• below 15cm soil ~17pCi/g Ra$^{226/228}$
• unrestricted land use permitted
<table>
<thead>
<tr>
<th>Location</th>
<th>Waste Volume (bbls)</th>
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<tbody>
<tr>
<td>Bay Marchand Pits (Oct 1997 – Sept 1998)</td>
<td>371,600 (59,080 m³)</td>
</tr>
<tr>
<td>Dead End Canal (Feb 1999 – Mar 2000)</td>
<td>623,100 (99,065 m³)</td>
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<tr>
<td>Other NOW Solids</td>
<td>6,120 (973 m³)</td>
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<tr>
<td>Total</td>
<td>1,000,800 (~160,000 m³)</td>
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The most common risks/problems effecting overall performance of SFI projects are:

- **Loss of wellbore integrity during injection operations.**
  - Typically related to poor cementing of the disposal-injection well above the disposal zone.
    - loss of hydraulic integrity
  - Injection well collapse/shear above injection formation
    - loss of mechanical integrity

- **Inter-well communication**
  - Hydraulic communication between injection well and offset well(s)
    - containment breach due to intersecting nearby poorly cemented wells
  - Potential for OOZI

- Poor well design wrt the waste type, waste volumes to be injected and disposal zone geology.
  - This factor can result in wellbore plugging and poor formation injectivity.
  - Potential for wellbore integrity problems & OOZI
  - DON’T ‘Save’ money on the well…..!!!

- Poor geological characterization of the injection zone and target zones.

- Poor (or no) integration of geological assessment, well design, slurry design & injection strategy

  **Poor integration = poor performance…guaranteed !!!**

2. Key Process Monitoring Tools:
   - BHP monitoring at injection well
     - Pump Pressure and WHP are NOT enough
     - Assess formation response to injection operations
   - Formation Testing Program
     - Evaluate formation flow behavior and in-situ stress:
       - SRT to assess stress state & FEP/FER
       - Pressure Fall-off Analyses
   - Tracer & Temperature Logs
     - Evaluate near-well fluid flow & wellbore integrity
     - Fracture geometry
   - Tiltmeters (surface movements)
     - Evaluate fracture geometry at shallow depths (<1000 m)

3. Process Control Analyses:
   - Analyses & Integration of process monitoring data
   - Assessment of injected material in situ & formation response – ‘Smart Injection’
   - Wellbore integrity
Environmental Benefits of SFI

• SFI achieves ‘Zero Discharge’ of wastes
  o No negative biosphere interaction
  o Protection of USDW, soil quality, air quality
  o Prevents surface water and ground water contamination

• Does not impair future land use
  o Protects environmentally sensitive areas
  o Allows for land re-use/development

• Acceptable to society & community
  o Reduces pollution to safeguard human health

• Safe and secure disposal approach
  o Wastes are safely sequestered
  o Multiple waste stream disposal

• Efficient & economical waste management strategy

• Permanent & secure disposal is best!
  o Long-term liability and cost to operator/generator is greatly reduced

To help Clients achieve Zero Discharge Operations...

…Greater environmental security with SFI
Thank-you for your attention...

Questions?

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